Received: 29 September 2021 | Revised: 10 January 2022 | Accepted: 27 January 2022

DOI: 10.1111/joss.12739

ORIGINAL ARTICLE

Journal of Sensory Studies | WILEY

Role of body weight and sex in the olfactory and gustatory pleasantness, intensity, and familiarity of a lipid-rich food

Antonella Rosa | Ilenia Pinna | Carla Masala

Department of Biomedical Sciences, University of Cagliari, Cittadella Universitaria, Cagliari, Italy

Correspondence
Carla Masala, Department of Biomedical Sciences, University of Cagliari, SP 8 Cittadella Universitaria, 09042 Monserrato, Italy.
Email: cmasala@unica.it

Abstract

In this study, the role of sex and body weight in the olfactory and gustatory dimensions (pleasantness, intensity, and familiarity) of mullet cured roes, a marine rich-fat food with peculiar sensory attributes, was evaluated. One hundred seventy-seven participants were enrolled. Positive correlations were observed between all food taste and odor dimensions. Women reported a significantly higher odor and taste intensity ratings than men. Multivariate linear regression analyses evidenced that body weight in women was negatively correlated to the food odor and taste pleasantness and positively correlated to odor intensity. These negative correlations were due to different women gustatory performance in relation to body weight. A significantly lower perception of salty and bitter taste was observed in women with a body weight >60 kg compared to those with a body weight ≤60 kg. Our results underline the important role of sex and body weight in the food products sensory evaluation.

Practical applications

This study evidenced higher intensity ratings in women than men for the evaluation of olfactory and gustatory dimensions (pleasantness, intensity, and familiarity) of the salted and dried mullet roes, a lipid-rich food, and the role of body weight in women sensory perception. Therefore, our data highlight the importance of taking into consideration sex and body weight when consumers panels are selected and constituted for the evaluation of sensory properties and acceptance of lipid-rich foods, but also applicable to other types of foods.

1 | INTRODUCTION

Olfactory and gustatory systems provide animals the opportunity to distinguish smells and to find food sources (Loy, Solari, Isola, Crnjar, & Masala, 2016; Masala, Solari, Sollai, Crnjar, & Liscia, 2008; Solari et al., 2017). In humans, olfactory and gustatory information may share common pathways involving orbitofrontal cortex, amygdala, insular, and anterior cingulate cortex (de Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003; Rolls, 2004). In particular, olfaction plays a key role in eating behavior, in emotional responses (such as pleasantness), and social life (Hoskison, 2013; Mahmut & Croy, 2019; Stevenson, Mahmut, Horstmann, & Hummel, 2020). The decision to eat or reject a specific food usually depends on the multisensory information induced not only by taste but also by smell and nutritive value (de Araujo & Simon, 2009). The flavor is considered a multimodal experience detected by different components such as odor, taste, and touch of food in the oral cavity (Green, 2003; Prescott, 1999). About 80% of the flavor information is modulated through olfactory information (Murphy, Cain, & Bartoshuk, 1977). In particular, smells of foods are acquired by two different routes such as orthonasal and retronasal

olfaction (Heilmann & Hummel, 2004; Hummel et al., 2006; Small & Green, 2012). However, the perception and pleasantness of a food-related odor may change in relation to hormonal influences and is usually significantly lower in participants with a state of satiety compared to those with the hungry condition (Albrecht et al., 2009).

In addition, it is well known that olfactory dysfunction may be linked to a change in dietary habits (Aschenbrenner et al., 2008; Ferris & Duffy, 1989; Stevenson et al., 2020; Walliczek-Dworschak & Hummel, 2017). The change in dietary habits may induce weight gain (Ferris & Duffy, 1989) or weight loss (Deems et al., 1991).

The ability to perceive odors usually decreases in relation to age especially in people over 65 years (Doty, 2009; Doty & Kamath, 2014; Masala, Saba, Cecchini, Solla, & Loy, 2018), and elderly subjects reported an increased body mass index in relation to the age (Reas, Nygård, Svensson, Sørensen, & Sandanger, 2007; Yi, Ohrr, Shin, & Yi, 2015). The studies that evaluated correlations between body weight and olfactory function are very contradictory. For example, a significant correlation only between body weight versus odor threshold was reported by Skrandies and Zschieschang (2015), while another study (Simchen, Koebnick, Hoyer, Issanchou, & Zunft, 2006) indicated a lower odor identification score in patients with high body mass index (BMI). Moreover, Patel, DelGaudio, and Wise (2015) indicated that a BMI is associated with olfactory dysfunction. However, interactions between body weight and olfactory function are complicated due to many different parameters, regardless of chemosensory functions, such as sex, age, orexigenic molecules (e.g., ghrelin, neuropeptide Y, somatostatin, and orexins) (Palouzier-Paulignan et al., 2012), intestinal, microbiota, physical activity level, cultural factors, etc.

In terms of sex differences on olfactory function, previous studies showed superior women olfactory performance in odor perception compared to men due to the hormonal influence on olfactory function, not only in healthy subjects with an age range from 16 to 55 years (Doty & Cameron, 2009; Hummel, Kobal, Gudziol, & Mackay-Sim, 2007; Sorokowski et al., 2019) but also in patients with neurodegenerative disorders (Melis et al., 2019; Solla et al., 2020).

Taste is usually perceived by five specific sensations such as sweet, sour, salty, bitter, and umami (Bartoshuk, 1991; Chandrashekar, Hoon, Ryba, & Zuker, 2006). In addition, the fat sensation, which is considered the ability to detect free fatty acids (FFA), is still under discussion (Gilbertson, 1998). However, humans and animals both show an attraction for foods with a high concentration of FFA (Besnard, Passilly-Degrace, & Khan, 2016). In particular, previous studies (Fukuwatari et al., 1997; Laugerette et al., 2005) identified in rat circumvallate and foliate papillae a specific transporter (CD36) with a high affinity for long-chain FFA.

The potential mechanism involved in the transduction for long-chain FFA may inhibit delayed rectifying K^+ channels in taste receptor cells (Gilbertson, Fontenot, Liu, Zhang, & Monroe, 1997).

In addition, previous studies (Bai et al., 2007; Hu et al., 2009; Vasconcelos, Souza, Pinheiro, & Silva, 2016) indicated that obesity is considered a multifactorial disease associated with genetic determinants such as the expression of ion channels and metabolic diseases.

On the contrary, Sauer et al. (2017), suggested that high body weight is associated with low gustatory function. In line with these data, there is an evidence that subjects with low gustatory function are more prone to obesity because adipokines may change the perception and pleasantness of olfactory stimuli (Fernandez-Garcia et al., 2017).

In our study, the attention was focused on the salted and dried mullet ovary product, a marine fat-rich food with nutritional and nutraceutical properties, produced in numerous world countries with different names, in Italy, is called "bottarga" (Scano et al., 2008), in Greece, "avgotaracho" (Kalogeropoulos, Nomikos, Chiou, Fragopoulou, & Antonopoulou, 2008), and in Japan, "karasumi" (Bledsoe, Bledsoe, & Rasco, 2003). Our previous studies analyzed bottarga chemical composition (Rosa et al., 2009, 2011; Scano et al., 2008), stability to the oxidative degradation (Rosa et al., 2009, 2011), non-enzymatic browning process (Rosa et al., 2009, 2011), the effect on viability and lipid profile in normal and cancer cells (Rosa et al., 2011, 2016; Rosa, Scano, Atzeri, Deiana, & Falchi, 2013), and bioavailability in cell systems and rat model (Rosa et al., 2011, 2013, 2016). Bottarga is considered a naturally rich source of n-3 polyunsaturated fatty acids (n-3 PUFA or ω-3 PUFA), such as eicosapentaenoic acid (EPA, 20:5 n-3) and docosahexaenoic acid (DHA, 22:6 n-3) with beneficial health effects (Rosa et al., 2009, 2016). Previous studies (Chang, Ke, & Chen, 2009; Salem Jr. et al., 2001) in the animal model showed that the n-3 long-chain fatty acid such as DHA plays an important role neuronal growth and in the synaptic connection among brain areas. In addition, in humans, the increased ingestion of n-3 PUFA may reduce body weight in obese subjects (Buckley & Howe, 2010). Bottarga is a complex food matrix characterized by peculiar sensory attributes and several nutritive components such as salt, fatty acids, and proteins, which elicited intense odor and taste qualities (Rosa et al., 2009; Rosa, Isola, Nieddu, & Masala, 2020). In particular, this food is characterized by a strong odor and an intense pleasant salty taste, balanced with a slightly bitter aftertaste. Moreover, we have recently demonstrated a clear contribution of FFA amount in the pleasantness and familiarity dimensions of the taste of bottarga (Rosa et al., 2020).

The aim of this study was to evaluate the role of body weight and sex in the olfactory and gustatory pleasantness (P), intensity (I), and familiarity (F) of this food product rich in n-3 PUFA. First, were evaluated olfactory and gustatory P, I, and F for the bottarga, and then, we analyzed the olfactory and gustatory perception in relation to sex and body weight.

2 | MATERIALS AND METHODS

2.1 | Chemicals

Standards of saturated and unsaturated fatty acids (see Table 1 for the complete list), Desferal (deferoxamine mesylate salt), ascorbic acid, and high purity solvents (chloroform, methanol, ethanol, n-hexane, and acetonitrile) were obtained from Sigma–Aldrich (Milan, Italy). The ultrapure water was obtained by distillation and filtration through the

TABLE 1 Compositional mean value (obtained for 100 g of product, as reported in the label*) and fatty acid (FA) composition expressed as mg/g of edible portion and % of total FA in the grated bottarga sample used for sensory evaluations

Composition for 100 g of product			
Parameter			**Mean value ± SD**
Fat (%)			26.83 ± 3.91
Protein (%)			42.17 ± 2.25
Carbohydrates (%)			0.00 ± 0.00
Salt (%)			4.00 ± 0.50
FA composition			
FA common name	**CA:DB**	**Mg/g edible portion**	**% Total FA**
Lauric acid	12:0	Trace	Trace
Myristic acid	14:0	4.66 ± 0.46	3.13 ± 0.24
Palmitic acid	16:0	16.32 ± 2.49	10.81 ± 0.97
Palmitoleic acid	16:1 n-7	22.40 ± 3.69	14.83 ± 1.30
Hexadecadienoic acid	16:2	2.15 ± 0.30	1.47 ± 0.16
Hexadecatrienoic acid	16:3	1.10 ± 0.16	0.74 ± 0.09
Hexadecatetranoic acid	16:4	0.31 ± 0.14	0.22 ± 0.09
Stearic acid	18:0	7.63 ± 0.79	5.18 ± 0.86
Oleic acid	18:1 n-9	18.87 ± 2.55	12.84 ± 1.91
Cis-Vaccenic acid	18:1 n-7	8.56 ± 1.48	5.70 ± 0.60
Linoleic acid	18:2 n-6	7.63 ± 1.01	5.02 ± 0.60
γ-Linolenic acid	18:3 n-6	0.99 ± 0.51	0.60 ± 0.28
α-Linolenic acid	18:3 n-3	1.64 ± 0.38	1.06 ± 0.17
Stearidonic acid	18:4 n-3	2.56 ± 0.24	1.71 ± 0.06
Eicosatrienoic acid	20:3 n-6	4.00 ± 0.65	2.62 ± 0.27
Arachidonic acid	20:4 n-6	2.49 ± 0.66	1.48 ± 0.94
Eicosapentaenoic acid	20:5 n-3	17.99 ± 1.69	12.10 ± 1.27
Docosapentaenoic acid	22:5 n-3	7.38 ± 0.89	4.90 ± 0.30
Docosahexaenoic acid	22:6 n-3	23.75 ± 2.84	15.59 ± 0.58
Saturated fatty acids	SFA	28.48 ± 2.26	19.12 ± 0.58
Monounsaturated fatty acids	MUFA	49.82 ± 5.53	33.36 ± 0.61
Polyunsaturated fatty acids	PUFA	70.88 ± 7.03	47.51 ± 0.62

Notes: Carbon Atoms: Double Bonds (CA:DB); FA analysis was performed in quadruplicate and all data are expressed as mean values ± standard deviations (SD).
*Food product used for sensory assessment was obtained after pooling three different commercial samples of mullet grated bottarga.

Milli-Q water purification system ZFMQ23004 (Millipore, Milan, Italy). All chemicals used were of analytical grade.

2.2 | Participants

One hundred seventy-seven participants were enrolled in this study, 72 men and 105 women, with an age range of 19–64 years and a mean age ± standard deviation of 37.3 ± 14.2. In our data, 22.8% of women were in the menstrual phase, while 60.1% were in the luteal phase and 17.1% were in the menopausal phase. Inclusion criteria were the absence of chronic/acute rhinosinusitis and systemic diseases related to smell disorders, and neurodegenerative diseases as reported in previous studies (Masala, Käehling, Fall, & Hummel, 2019; Masala, Saba, et al., 2018). None of the participants was taking medications for allergies or other medical illnesses 5 days before the test. These conditions were checked by the examiner before the beginning of the procedure. In all participants were collected age (years), weight (kg), and height (m), and were assessed olfactory and gustatory dimensions (pleasantness, intensity, and familiarity) of mullet cured roes.

2.3 | Food product

Commercial samples of mullet grated bottarga ("bottarga di muggine" in Italian) were provided by Sardinian manufacturers ("Mediterranea Conserve Alimentari" S.r.l., Quartucciu, CA; "Sud Ovest Bottarga", Iglesias, CA, Italy) and were produced according to the Sardinian traditional procedures. Ingredients reported in the labels were: mullet roes and salt. Three commercial samples of grated bottarga (in 70 g jars), different for the provenance of raw roes, Mugil species, and manufacturing procedures (Rosa et al., 2020), were mixed in order to obtain an adequate amount of bottarga and a representative, uniform sample of this food product for olfactory and gustatory assessment. The chemical composition (fat %, protein %, and salt %) of the grated bottarga sample used in this study was determined as mean ± standard deviation (SD) of values indicated in the respective labels of mixed commercial products (Table 1). The prepared sample was analyzed for free (FFA), and total fatty acid (TFA) profile. All participants were familiar with the bottarga, and its consumption may range between subjects who do not use it to those who consume it 1 or 2 times a week.

2.4 | Procedures to assess pleasantness, intensity, and familiarity in odor and taste for the food product bottarga

The pleasantness, intensity, and familiarity were assessed for odor and taste of the mullet bottarga sample using a 7-points Likert-type scale ranging from 0-not at all to 6: such as 0 = very unpleasant and 6 = very pleasant; 0 = not intense at all and 6 = very intense; 0 = not familiar at all and 6 = very familiar (Lim, 2011; Rosa et al., 2020). Olfactory and gustatory stimuli were presented for approximately 2–3 s and at 20 s intervals by the experimenter. A grated bottarga sample (approximately a portion of 60 mg at room temperature) was administered to participants using a minitaster spoon. Participants first evaluated the bottarga olfactory properties and then gustatory dimensions. Before each experiment participants rinsed their mouths with water.

All participants were asked to evaluate the pleasantness, intensity, and familiarity of the odor and taste qualities in the grated

bottarga samples. All participants may drink only water 1 h before the experiment and did not wear any scented products on the day of testing (Masala et al., 2018; Masala, Saba, et al., 2018).

2.5 | Assessment of olfactory function

The olfactory performance of each participant was evaluated using the Sniffin' Sticks test (Burghart Messtechnik, Wedel, Germany), which consists of three olfactory tasks: odor threshold (OT), odor discrimination (Odis), and odor identification (OId) (Hummel et al., 2007; Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997).

The Sniffin' Sticks test are pen-like odor-dispensing devices, each pen, with a length of 14 cm and an inner diameter of 1.3 cm, was positioned at approximately 2 cm in front of both participants' nostrils for a few seconds. All subjects were blindfolded during the OT and Odis task. First, OT was evaluated using n-butanol with 16 stepwise dilutions (Fadda, Piras, Doneddu, Saba, & Masala, 2018; Masala et al., 2019, 2020). OT was evaluated using a three-alternative forced-choice task (3AFC) and the single-staircase technique (Fadda et al., 2018; Masala et al., 2019, 2020). Scores of OT may range from 16 for a participant who was able to detect the lowest concentration of n-butanol to 1 for subjects who were unable to detect the highest concentration.

Second, Odis was assessed using the 3AFC task over 16 trials by means of three different pens, two containing the same odor, and the third containing the target odorant. The Odis score is considered as the sum of the correct responses and ranges from 0 to 16 points (Oleszkiewicz, Schriver, Croy, Hähner, & Hummel, 2019). Third, OId was measured by means of 16 common odors presented in a multiple forced-choice format with four verbal descriptors (three distractors and one target).

The total score of odor threshold, discrimination, identification is the TDI. A value of TDI score between 30.75 and 41.25 points is considered normosmia, between 16.25 and 30.5 points hyposmia, and a score ≤16 points is indicated functional anosmia (Hummel et al., 2007; Oleszkiewicz et al., 2019).

2.6 | Gustatory function

The gustatory function was evaluated using the taste strips test (Burghart Messtechnik, Wedel, Germany) with four concentrations for each modality: sweet, bitter, sour, and salty (Landis et al., 2009; Masala et al., 2020). Before the test, the mouths of the participants were rinsed with water. The score ranged from 0 to 16 and a score <9 was considered hypogeusia.

2.7 | Analysis of fatty acid composition in bottarga sample

Total lipids were extracted from aliquots (40 mg) of the grated bottarga sample by the addition of 12 ml of chloroform/methanol (2/1, v/v) solution for 1 h at room temperature in the dark (Rosa et al., 2016, 2020). After the addition of 4 ml H_2O and centrifugation at 900×*g* for 1 h, the lower chloroform phase (total lipid extract) was separated. Dried aliquots of the chloroform fraction were dissolved in ethanol and subjected to mild saponification by the addition of 50 μl of Desferal solution (25 mg/ml of water), 0.5 ml of a water solution of ascorbic acid (25%, w/v), and 0.25 ml of 10 N KOH, as previously reported (Rosa et al., 2016, 2020). After saponification, the n-hexane fraction with total fatty acids (TFA) was collected, the solvent evaporated, and the dried residue was dissolved in acetonitrile (Rosa et al., 2016, 2020). Analyses of bottarga TFA, representing the sum of fatty acids present in the food product in their free form (FFA) and fatty acids liberated from lipid molecules after saponification, were carried out with an Agilent Technologies 1100 HPLC (Palo Alto, CA) equipped with a DAD and an Infinity 1260 ELSD detector (HPLC-DAD/ELSD) as previously reported (Rosa et al., 2016, 2020). Recording and integration of the chromatogram data were carried out through an Agilent OpenLAB Chromatography data system. Calibration curves were performed using standards as reported in a previous study (Rosa et al., 2020). An aliquot of dried chloroform fractions, dissolved in methanol, was directly analyzed without saponification by HPLC-DAD/ELSD with the same chromatographic conditions for the quantification of FFA in the bottarga sample.

2.8 | Statistical analyses

Statistical analysis was performed by the SPSS software version 23 for Windows (IBM, Armonk, N.Y., USA). The normal distribution of the data was assessed using the Shapiro–Wilk test. Comparison between different olfactory and gustatory bottarga dimensions was assessed by Student's unpaired *t*-test with Welch's correction, which does not require the assumption of equal variance between populations. Bivariate correlations were calculated between body weight versus odor and taste ratings of pleasantness (P), intensity (I), and familiarity (F) dimensions of the food bottarga product using Pearson's coefficient (r).

Moreover, multivariate linear regression analyses were evaluated in order to assess the effect of olfactory and gustatory pleasantness (P), intensity (I), and familiarity (F) of bottarga on body weight. In the multivariate linear regression analysis body weight was a dependent variable, while pleasantness (P), intensity (I), and familiarity (F) for bottarga odor and taste were independent variables. The values with $p < .05$ were considered significant.

3 | RESULTS

3.1 | Chemical composition of bottarga

The chemical composition (% of fat, protein, and salt) of the grated bottarga sample used for olfactory and gustatory assessment is reported in Table 1, as mean ± standard deviation (SD) of values

indicated in the labels. The tasted sample was characterized by 27% of fats, 42% of proteins, and 4% of salt. Values of the main saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) FA measured in bottarga sample by HPLC-DAD/ELSD analysis after saponification of lipid compounds are shown in Table 1, expressed as mg/g of edible portion and % of total FA (TFA). Bottarga sample showed 19% of SFA, mostly palmitic acid (11%), MUFA (approximately 33%), mainly palmitoleic acid (15%) and oleic acid (13%), and PUFA (48%), largely constituted by the highly unsaturated n-3 FA, in particular docosahexaenoic acid (DHA, 16%) and eicosapentaenoic acid (EPA, 12%). In particular, total n-3 PUFA accounted for 53.31 ± 4.87 mg/g of edible portion. The direct analysis of the chloroform fractions obtained from the bottarga sample extraction without saponification allowed the determination of the amount of free fatty acids (FFA) in the food matrix, which accounted for 27.1 ± 6.1 mg/g of an edible portion (18% of TFA). The FFA profile resembled that of TFA.

3.2 | Olfactory and gustatory pleasantness (P), intensity (I), and familiarity (F) of the bottarga

Mean values ± standard deviation of age, height, weight, olfactory, and gustatory function for all subjects were indicated in Table 2. In the evaluation of pleasantness (P), intensity (I), and familiarity (F) dimensions mean values ± standard deviation were 4.08 ± 1.60, 3.99 ± 1.40 and 4.33 ± 1.79 for bottarga odor and 4.14 ± 1.65, 3.98 ± 1.45 and 4.07 ± 1.88 for bottarga taste, respectively, (Figure 1) considering all participants together. No significant differences ($p > .05$) were observed between odor and taste ratings of pleasantness (P), intensity (I), and familiarity (F) dimensions in the bottarga product. However, the following significant positive correlations were observed among bottarga odor dimensions: between pleasantness versus intensity ($r = 0.377$, $p < .01$) and versus familiarity ($r = 0.452$, $p < .01$), and also between familiarity versus intensity ($r = 0.446$, $p < .01$) (Table 3a). Whereas, the following positive correlations were found among bottarga gustatory dimensions: between familiarity versus intensity ($r = 0.348$, $p < .01$), between pleasantness versus intensity ($r = 0.346$, $p < .01$) and versus familiarity ($r = 0.709$, $p < .01$; Table 3b). Significant positive correlations were also found between bottarga odor and taste dimensions, in particular, between odor pleasantness versus taste pleasantness ($r = 0.555$, $p < .01$), between odor intensity versus taste intensity ($r = 0.308$, $p < .01$) and versus taste familiarity ($r = 0.308$, $p < .01$) (Table 3c).

3.3 | Relation between bottarga sensory dimensions with the body weight and sex

Then, scores of olfactory and gustatory functions were evaluated in relation to body weight. The Figure 2a showed the olfactory function (odor threshold = OT, odor discrimination = Odis, and odor identification = OId) in subjects with body weight ≤60 and >60 kg. No significant differences were observed in olfactory function for OT, Odis, and OId between the two body weight groups. Although, significant differences were shown in gustatory function only in salty and bitter perception between subjects with a body weight > 60 and ≤ 60 kg (Figure 2b). In particular, subjects with a body weight > 60 kg rated the stimuli as being significantly less salty ($p < .05$) and bitter ($p < .01$). Mean values ± standard deviations for salty perception were 3.7 ± 0.5 in participants with a body weight ≤ 60 kg and 3.2 ± 0.6 in subjects with a body weight > 60 kg. While mean values ± standard deviations for bitter perception were 3.4 ± 0.7 and 2.4 ± 1.3 in subjects with a body weight ≤ 60 kg and with a body weight > 60 kg, respectively.

No significant correlations were found between odor/taste functions and perceived olfactory and gustatory bottarga intensities.

TABLE 2 Mean values ± standard deviation of age, height, weight, olfactory, and gustatory function in all participants ($n = 177$)

Parameters	Mean ± standard deviation	Men ($n = 72$)	Women ($n = 105$)
Age (years)	37.3 ± 14.2	38.7 ± 14.7	37.2 ± 14.3
Height (m)	1.67 ± 0.08	1.9 ± 0.2	1.6 ± 0.07
Weight (kg)	64.6 ± 16.1	74.8 ± 15.6	57.5 ± 12.6
BMI (kg/m^2)	24.8 ± 11	29 ± 16.2	20.4 ± 2.9
Olfactory function			
Odor threshold	6.13 ± 3.7	6.9 ± 5.1	5.9 ± 2.5
Odor discrimination	12.3 ± 2.1	11.9 ± 1.9	12.4 ± 1.8
Odor identification	13.7 ± 1.1	13.8 ± 1.3	13.5 ± 1.1
TDI score	32.1 ± 4.2	32.4 ± 5.9	31.8 ± 2.9
Gustatory function			
Sweet taste	3.5 ± 0.6	3.5 ± 0.6	3.5 ± 0.7
Salty taste	3.3 ± 0.8	2.9 ± 0.9	3.6 ± 0.6
Sour taste	2.3 ± 0.7	2.3 ± 0.7	3.1 ± 0.8
Bitter taste	3.1 ± 1.0	2.8 ± 1.3	3.1 ± 0.9
Total taste	12.2 ± 1.7	11.6 ± 1.6	12.5 ± 1.7

However, a significant sex-related effect was observed in olfactory and gustatory ratings for the intensity of bottarga samples (Figure 3a,b). In particular, women showed significant higher scores in odor ($p < .01$) and taste ($p < .001$) intensity compared to men. In the odor intensity perception mean values ± standard deviation were 3.6 ± 1.5 in men and 4.3 ± 1.3 in women. Whereas as regards familiarity, women exhibited a high significant ($p < .001$) scores only in odor and not in taste perception. In olfactory and gustatory performance, men did not show any significant differences in relation to body weight (kg) (data not shown). Also, women did not show any significant differences for OT, Odis, and Old in relation to body weight (Figure 4a). Whereas considering taste performance (Figure 4b), women with a body weight > 60 kg rated the stimuli as being significantly less salty ($p < .05$) and bitter ($p < .01$) compared to those with a body weight ≤ 60 kg.

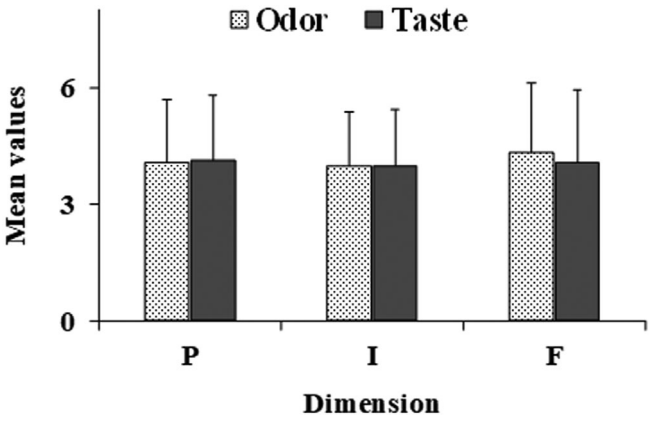

FIGURE 1 Ratings of pleasantness (P), intensity (I), and familiarity (F) dimensions determined for odor and taste of the food product bottarga ($n = 177$). Data are presented as mean values ± standard deviations (SD)

In order to evaluate the potential role of the body weight on bottarga olfactory and gustatory dimensions (pleasantness, intensity, and familiarity) bivariate correlations and multiple linear regression analyses were performed. In bivariate correlations, negative significant correlations were found between body weight versus pleasantness for olfactory and gustatory dimensions ($r = -0.272$, $p < .01$ in bottarga odor; $r = -0.268$, $p < .01$ in bottarga taste). Furthermore, a low significant negative correlation was found between body weight and familiarity ($r = -0.199$, $p < .05$ for bottarga odor; $r = -0.160$, $p < .05$ for bottarga taste) (Table 4a,b). In addition, we calculated the bivariate correlations between age and the sensory perception of odor/taste intensity, pleasantness, and familiarity. A significant positive correlation ($r = 0.198$, $p < .01$) was observed only for age and taste familiarity of the bottarga, while no other correlations emerged for olfactory and taste dimensions. Consequently, our attention was focused on body weight and sex.

In order to confirm these correlations multivariate linear regression analyses were performed using body weight as a dependent variable. Negative significant correlations emerged between body weight versus bottarga odor ($F_{[3,176]} = 5.564$, $p \leq .001$, Table 5a) and taste pleasantness ($F_{[3,176]} = 5.543$, $p \leq .001$, Tables 5b), while no contributions were found for odor intensity and familiarity. These models explained 8% of variance ($R^2 = 0.088$) in odor and taste dimensions (Table 5a,b).

TABLE 3 (a–c) Bivariate correlations between olfactory and gustatory dimensions in the bottarga sample

	Pleasantness	Intensity	Familiarity
(a) *Odor dimensions of the bottarga*			
Pleasantness	1 –	$r = 0.377$ $p < .01$	$r = 0.452$ $p < .01$
Intensity	$r = 0.377$ $p < .01$	1 –	$r = 0.446$ $p < .01$
Familiarity	$r = 0.452$ $p < .01$	$r = 0.446$ $p < .01$	1 –
(b) *Taste dimensions of the bottarga*			
Pleasantness	1 –	$r = 0.346$ $p < .01$	$r = 0.709$ $p < .01$
Intensity	$r = 0.346$ $p < .01$	1 –	$r = 0.348$ $p < .01$
Familiarity	$r = 0.709$ $p < .01$	$r = 0.348$ $p < .01$	1 –
(c) *Odor and taste dimensions of the bottarga*			
	Taste pleasantness	Taste intensity	Taste familiarity
Odor pleasantness	$r = 0.555$ $p < .01$	$r = 0.138$ $p > .05$	$r = 0.415$ $p < .01$
Odor intensity	$r = 0.118$ $p > .05$	$r = 0.308$ $p < .01$	$r = 0.188$ $p < .05$
Odor familiarity	$r = 0.336$ $p < .01$	$r = 0.152$ $p < .05$	$r = 0.465$ $p < .01$

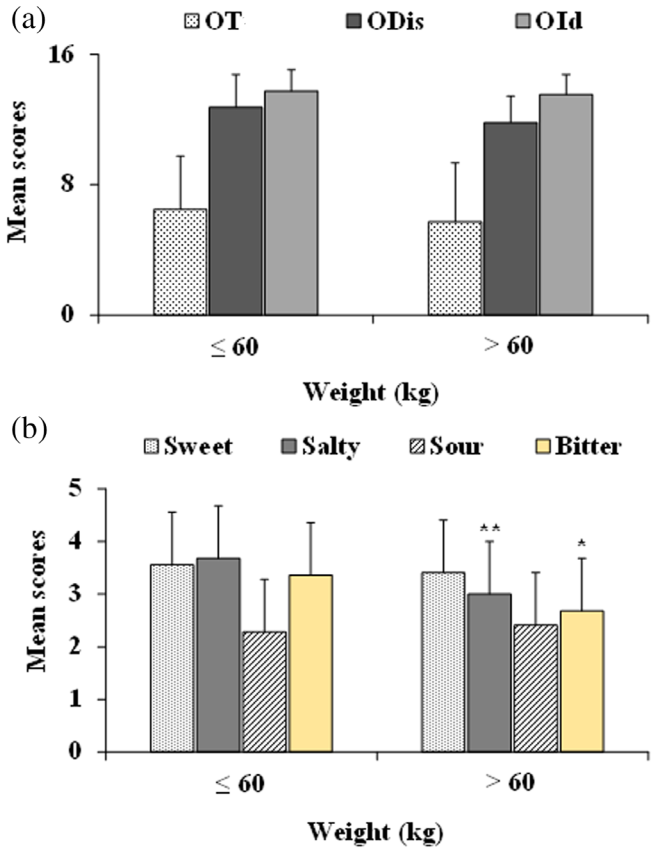

FIGURE 2 Scores of olfactory functions (OT, odor threshold; ODis, odor discrimination; OId, odor identification) (a) and gustatory function (sweet, salty, sour, and bitter) (b) in subjects with a body weight ≤ 60 kg ($n = 98$) and > 60 kg ($n = 79$). Data are presented as mean values ± standard deviations (SD). $^{**}p < .01$, $^{*}p < .05$ (Student's unpaired t-test with Welch's correction) in subjects >60 and ≤ 60 kg

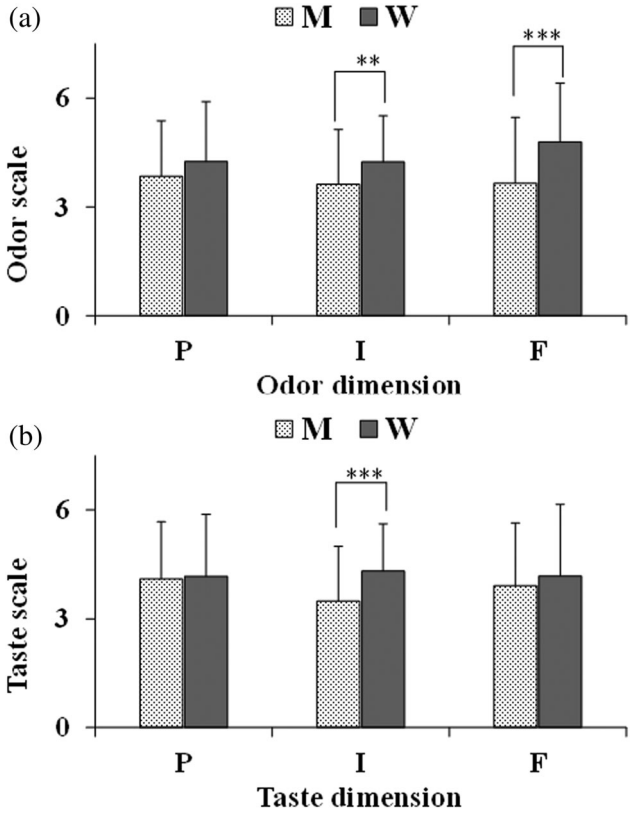

FIGURE 3 Ratings of odor pleasantness, intensity, and familiarity determined for odor (a) and taste (b) of the food product bottarga in relation to the sex of participants (72 men and 105 women). Data are presented as mean values ± standard deviations (SD). $^{***}p < .001$, $^{**}p < .01$ (Student's unpaired t-test with Welch's correction) for women (W) and men (M)

With the purpose of evaluating possible sex-related differences in bottarga olfactory and gustatory perception, we performed multivariate linear regression analyses in men and women using body weight as a dependent variable. In women emerged the following significant correlations: body weight was negatively correlated to odor ($F_{[3,104]} = 9.371$, $p \leq .0005$) and taste pleasantness ($F_{[3,104]} = 7.284$, $p \leq .0005$) (Table 6a,b) and positively correlated to odor intensity ($F_{[3,104]} = 9.371$, $p \leq .001$). These models explained 22% of variance ($R^2 = 0.218$) in odor dimensions and 17% ($R^2 = 0.178$) in taste dimensions. Instead, no significant correlations were observed in men between body weight versus bottarga odor and taste dimensions.

4 | DISCUSSION

4.1 | Chemical composition of bottarga

Our study evaluated the role of body weight and sex-related differences in the olfactory and gustatory pleasantness (P), intensity (I), and familiarity (F) of bottarga, a lipid-rich food product. The marine food bottarga, a salted and dried mullet ovary product, is a rich source of health beneficial long-chain n-3 PUFA (mainly EPA and DHA) (13%–25% of total fatty acids), mostly in the form of wax esters (that represent about 50%–65% of total lipids) (Rosa et al., 2009, 2016, 2020). It is considered a highly nutritive food for its richness in vitamins and well-balanced proteins with essential amino acids (Bledsoe et al., 2003; Rosa et al., 2009, 2016, 2020). Commercial whole and grated bottarga samples are generally characterized by a high content of free fatty acids (FFA) due to hydrolytic processes on lipid components induced on the raw matrix by the manufacturing/storage procedures and conditions (Rosa et al., 2009, 2016, 2020). Therefore, the quality and sensory properties of this product may change according to the provenance and quality of raw materials, and differences in manufacturing/storage conditions may affect bottarga physicochemical characteristics (Rosa et al., 2009, 2016, 2020). According to literature data, the main components of the bottarga sample used for sensory assessment were salt, proteins, and lipids, with high levels of n-3 PUFA (EPA + DHA, 28% of TFA). Moreover, a high amount of FFA (18% of TFA) was also detected in the tested sample.

Humans showed an attraction for palatable fat-rich foods (Besnard et al., 2016) and a taste component is implicated in the orosensory detection of dietary lipids (especially long-chain FA).

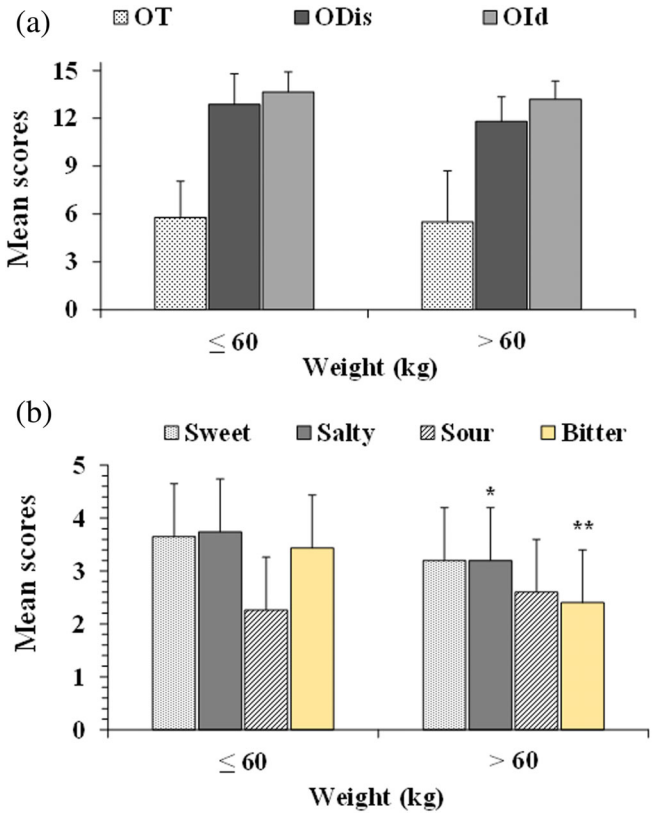

FIGURE 4 Scores of olfactory functions (OT, odor threshold; ODis; OId, odor identification) (a) and gustatory function (sweet, salty, sour, and bitter) (b) in women with a body weight ≤ 60 kg ($n = 73$) and > 60 kg ($n = 32$). Data are presented as mean values ± standard deviations (SD). $^{**}p < .01$, $^{*}p < .05$ (Student's unpaired *t*-test with Welch's correction) in subjects >60 and ≤ 60 kg

TABLE 4 (a and b) Bivariate correlations between body weight versus olfactory (a) and gustatory dimensions (b) of bottarga sample (pleasantness, intensity, and familiarity)

Parameters	Pearson's correlation (r)	Significance (*p* value)
Body weight	1.000	–
(a) Olfactory dimensions		
Pleasantness	−0.272	0.01
Intensity	−0.056	0.458
Familiarity	−0.199	0.01
(b) Gustatory dimensions		
Pleasantness	−0.268	0.01
Intensity	−0.197	0.01
Familiarity	−0.160	0.05

Particularly, the FFA level seems to be involved in fatty food recognition (Besnard et al., 2016). In the murine model, chemoreception of FFA appears to depend on their carbon chain length and unsaturation, with a high licking response to unsaturated long-chain FA (like palmitic acid, oleic acid, linoleic acid, linolenic acid, stearidonic acid, arachidonic acid, and DHA) (Adachi et al., 2014) and requires a free carboxylic group (Besnard et al., 2016). The assessment of fat taste in humans is complex, as some researchers believe FFA does not elicit perceptual taste qualities (such as sweet, umami, bitter, salty, and sour tastes) (Liu, Archer, Duesing, Hannan, & Keast, 2016). In a previous study on the human model, we investigated differences in the sensory properties (taste and odor) and acceptance of different grated mullet bottarga samples in relation to their lipid composition (Rosa et al., 2020). We observed a potential contribution of the FFA amount in the taste pleasantness and familiarity dimensions of bottarga samples, while the FFA contribution to bottarga odor dimensions was inconsistent (Rosa et al., 2020).

4.2 | Relation between bottarga olfactory and gustatory pleasantness, intensity, and familiarity

First, the relation between olfactory and gustatory pleasantness (P), intensity (I), and familiarity (F) dimensions of the bottarga was evaluated. All participants enrolled in this study showed normal olfactory and gustatory function. In general, values of olfactory and gustatory function determined in men and women are in line with those reported in previous studies (Masala et al., 2020; Solla et al., 2020). According to the literature (Distel et al., 1999), our results showed positive correlations between bottarga olfactory pleasantness versus intensity, and versus familiarity. In literature is well-known that pleasantness, familiarity, and intensity are considered standard dimensions used to describe odor and food qualities (Delplanque et al., 2008). These dimensions are not independent since previous studies showed significant positive correlations between the pleasantness and familiarity of an odor (Bensafi et al., 2002; Distel et al., 1999). In particular, in line with a previous study (Distel & Hudson, 2001), our data suggest that a more familiar food odor is judged more pleasant. Moreover, a previous study (Moss, Miles, Elsley, & Johnson, 2016) suggested that odor familiarity was related to pleasantness, and a non-linear relationship was observed between odor pleasantness and intensity.

However, these dimensions are not specific only for the olfaction, but also for taste (Amsellem & Ohla, 2016). In fact, in our data for bottarga gustatory dimensions, positive correlations were found between familiarity versus intensity, between pleasantness versus intensity, and versus familiarity. Our results, according to a previous study (Amsellem & Ohla, 2016) suggest that pleasantness and familiarity could be considered a common subjective dimension in the evaluation of odor and taste stimuli. In particular, odor familiarity involves cognitive processes such as the activation of the orbitofrontal cortex involving attention and working memory (Royet et al., 1999). Instead, the mere odor threshold is related to the morphology of the nasal cavity (Masala et al., 2019).

4.3 | Relation between bottarga sensory dimensions with the body weight and sex

Then, we analyzed the bottarga olfactory and gustatory perception in relation to the sex and body weight of the participants. Interestingly,

TABLE 5 (a and b) Multivariate linear regression analyses for bottarga odor (a) and taste (b) dimensions

Model	Unstandardized coefficients		Standard coefficients		Significance
	B	Std error	β	t	
Body weight as a dependent variable					
(a) Odor dimensions of the bottarga					
Odor pleasantness	−2.534	0.847	−0.250	−2.991	0.003
Odor intensity	1.104	0.966	0.095	1.143	0.255
Odor familiarity	−1.168	0.786	−0.128	−1.486	0.139
(b) Taste dimensions of the bottarga					
Taste pleasantness	−2.797	1.025	−0.284	−2.729	0.007
Taste intensity	−1.454	0.883	−0.129	−1.647	0.101
Taste familiarity	0.747	0.904	0.086	0.827	0.410

TABLE 6 (a and b) Multivariate linear regression analyses for bottarga odor and taste dimensions in women

Model	Unstandardized coefficients		Standard coefficients		Significance
	B	Std error	β	t	
Body weight as a dependent variable					
(a) Odor dimensions of the bottarga					
Odor pleasantness	−3.248	0.740	−0.423	−4.387	0.0005
Odor intensity	3.429	0.955	0.345	3.589	0.001
Odor familiarity	0.102	0.783	0.013	0.131	0.896
(b) Taste dimensions of the bottarga					
Taste pleasantness	−3.431	1.109	−0.464	−3.093	0.003
Taste intensity	1.532	0.926	0.158	1.655	0.101
Taste familiarity	0.235	0.976	0.037	0.240	0.810

our results showed negative significant correlations between body weight versus pleasantness in olfactory and gustatory dimensions. These data according to a previous study (Fernandez-Garcia et al., 2017), indicated a significantly lower olfactory and gustatory pleasantness in relation to the increased body weight. This result could be explained considering a decrease in taste and olfactory bottarga perception in relation to an increase in body weight. In addition, our data are in line with the previous study (Fernandez-Garcia et al., 2017) that reported negative associations between taste function and body mass index.

The interactions between body weight, gustatory, and olfactory functions are complicated due to lots of different physiological parameters that may influence chemosensory functions such as hormonal influences, hunger, and satiety states (Fernandez-Garcia et al., 2017). Recently, a previous study (Chen et al., 2022) indicated a nonlinear association between olfactory and gustatory dysfunctions versus body mass index.

In general, our results showed sex differences in the olfactory and gustatory function of the participants. Our data, in line with previous studies (Doty, 1994; Schiffman & Warwick, 1993; Simchen et al., 2006), indicated that olfactory and gustatory dimensions were correlated to sex and women showed higher scores than men. The cause of the higher olfactory perception in women could be related to complex interactions between the olfactory system versus hormones and neuroendocrine agents (Doty & Cameron, 2009; Sorokowski et al., 2019). In women, the higher sensitivity to specific odors could be also associated with menstrual cycle-related fluctuations (Nováková, Havlíček, & Roberts, 2014). Moreover, a previous study (Oliveira-Pinto et al., 2014) indicated that females showed a higher average number of cells in the olfactory bulb and an increased cell density compared to males. Sex-related differences in olfactory function were also observed in children (Schriever et al., 2018) and patients with Parkinson's disease (Melis et al., 2019; Solla et al., 2020) reporting that women had significantly higher scores in olfactory function than men. A sex-related effect of bottarga was observed in our previous study not only in the human model but also in the animal model (Rosa et al., 2020).

In addition, our data suggested complex relationships between sex-related differences, olfactory and gustatory bottarga chemosensory dimensions, and body weight. In fact, women exhibited significant negative correlations between body weight versus odor and taste bottarga pleasantness, and positive correlations between body weight versus odor intensity. This result indicated that in women an increase in body weight was associated with a rise in the bottarga odor intensity perception. Instead, in men, no significant correlations were observed between body weight versus bottarga odor and taste dimensions.

In taste performance, only women with a body weight > 60 kg exhibited a significant decrease in salty and bitter perception compared to those with a body weight ≤ 60 kg.

As regards bitter perception, our data in line with a previous study (Simchen et al., 2006) indicated that obesity was associated with lower bitter taste perception, and it may induce a change in gustatory bottarga pleasantness and intensity. Moreover, patients with an impairment in bitter perception showed higher body mass index and low olfactory function as reported by Chen and Colleagues (2022). It is important to consider that in humans there are about 30% of subjects who could not identify bitter taste (Bartoshuk & Duffy, 1994; Tepper et al., 2009). In addition, a previous study (Skrandies & Zschieschang, 2015) reported that an increased BMI was associated with a decreased sensitivity to salt taste.

Few studies to date investigated the correlation between body weight and salty taste in obese subjects. However, Vignini and Colleagues (2019)) reported a general low taste sensitivity in relation to an increase of body mass index (BMI), while Bartoshuk, Duffy, Hayes, Moskowitz, and Snyder (2006) showed that BMI increases in relation to an increase in sweet taste perception.

Finally, a positive correlation between body weight versus bottarga odor intensity was observed only in women and not men. This positive correlation may be explained considering that the relationship between odor intensity and food acceptability (pleasantness) is a complex multifactorial mechanism involving different aspects such as satiety and cultural experience. In particular, the hedonic perception of an odor is usually explained considering a mechanism of associative learning through experience as described in a previous study (Herz, 2005).

5 | CONCLUSIONS

Our results showed a strong effect of the sex in olfactory and gustatory dimensions of the bottarga, a marine food rich in health-beneficial n-3 PUFA. Taken together, our results showed in women a significant negative correlation between body weight versus bottarga odor and taste pleasantness. The pleasantness of the bottarga flavor is associated with its salty taste coupled with a lightly bitter and spicy aftertaste. The significantly lower salty and bitter perception observed for women with a body weight > 60 kg compared to those with ≤60 kg could justify the negative correlation between body weight versus bottarga odor and taste pleasantness. Moreover, our data confirmed sex-related differences in the evaluation of pleasantness (P), intensity (I), and familiarity (F) dimensions of bottarga and women exhibited significantly higher scores in odor and taste dimensions compared to men. Our data highlight the important role of sex and body weight in the sensory evaluation of food products.

ACKNOWLEDGMENTS

The authors sincerely thank the companies "Mediterranea Conserve Alimentari S.r.l.," Quartucciu, CA (Sardinia, Italy) and "Sud Ovest Bottarga," Iglesias, CA, for samples supplies.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

This study was approved by the local Ethics Committee (Prot. PG/2018/10157) and was performed according to the Declaration of Helsinki.

INFORMED CONSENT

All participants received an explanatory statement and gave their written informed consent to participate in the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Antonella Rosa https://orcid.org/0000-0003-0939-9364
Carla Masala https://orcid.org/0000-0001-5272-8421

REFERENCES

Adachi, S., Eguchi, A., Sakamoto, K., Asano, H., Manabe, Y., Matsumura, S., … Fushiki, T. (2014). Behavioral palatability of dietary fatty acids correlates with the intracellular calcium ion levels induced by the fatty acids in GPR120-expressing cells. *Biomedical Research*, *35*, 357–367.

Albrecht, J., Schreder, T., Kleemann, A. M., Schöpf, V., Kopietz, R., Anzinger, A., … Wiesmann, M. (2009). Olfactory detection thresholds and pleasantness of a food-related and a non-food odour in hunger and satiety. *Rhinology*, *47*(2), 160–165.

Amsellem, S., & Ohla, K. (2016). Perceived odor–taste congruence influences intensity and pleasantness differently. *Chemical Senses*, *41*, 677–684.

Aschenbrenner, K., Hummel, C., Teszmer, K., Krone, F., Ishimaru, T., Seo, H. S., & Hummel, T. (2008). The influence of olfactory loss on dietary behaviors. *Laryngoscope*, *118*(1), 135–144.

Bai, X., Ma, J., Pan, Z., Song, Y. H., Freyberg, S., Yan, Y., … Alt, E. (2007). Electrophysiological properties of human adipose tissue-derived stem cells. *American Journal of Physiology-Cell Physiology*, *293*, C1539–C1550.

Bartoshuk, L. M. (1991). Taste, smell, and pleasure. In R. C. Bolles (Ed.), *The hedonics of taste and smell* (pp. 15–28). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bartoshuk, L. M., & Duffy, V. B. (1994). PTC/PROP tasting: Anatomy, psychophysics, and sex effects. *Physiology & Behavior*, *56*(6), 1165–1171.

Bartoshuk, L. M., Duffy, V. B., Hayes, J. E., Moskowitz, H. R., & Snyder, D. J. (2006). Psychophysics of sweet and fat perception in obesity: Problems, solutions and new perspectives. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *361*(1471), 1137–1148.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., & Holley, A. (2002). Autonomic nervous system responses to odours: The role of pleasantness and arousal. *Chemical Senses*, *27*, 703–709.

Besnard, P., Passilly-Degrace, P., & Khan, N. A. (2016). Taste of fat: A sixth taste modality? *Physiological Reviews*, *96*, 151–176.

Bledsoe, G., Bledsoe, C., & Rasco, B. A. (2003). Caviars and fish roe products. *Critical Reviews in Food Science and Nutrition*, *43*, 317–356.

Buckley, J. D., & Howe, P. R. C. (2010). Long-chain Omega-3 polyunsaturated fatty acids may be beneficial for reducing obesity—A review. *Nutrients*, *2*, 1212–1230.

Chandrashekar, J., Hoon, M. A., Ryba, N. J., & Zuker, C. S. (2006). The receptors and cells for mammalian taste. *Nature*, *444*(7117), 288–294.

Chang, C.-Y., Ke, D.-S., & Chen, J.-Y. (2009). Essential fatty acids and human brain. *Acta Neurologica. Taiwan*, *18*, 231–241.

Chen, B., Masala, C., Oleszkiewicz, A., Englmaier, V., Gunder, N., Menzel, A., … Hummel, T. (2022). Nonlinear association between chemosensory dysfunction and body mass index. *Journal of Sensory Studies*, *37*(1), e12715. https://doi.org/10.1111/joss.12715

de Araujo, I. E., & Simon, S. A. (2009). The gustatory cortex and multisensory integration. *International Journal of Obesity*, *33*(Suppl 2), S34–S43. https://doi.org/10.1038/ijo.2009.70

de Araujo, I. E., Rolls, E. T., Kringelbach, M. L., McGlone, F., & Phillips, N. (2003). Taste-olfactory convergence, and the representation of the pleasantness of flavour, in the human brain. *European Journal of Neuroscience*, *18*, 2059–2068.

Deems, D. A., Doty, R. L., Settle, R. G., Moore-Gillon, V., Shaman, P., Mester, A. F., … Snow, J. B., Jr. (1991). Smell and taste disorders, a study of 750 patients from the University of Pennsylvania Smell and taste center. *Archives of Otolaryngology-Head & Neck Surgery*, *117*(5), 519–528.

Delplanque, S., Grandjean, D., Chrea, C., Aymard, L., Cayeux, I., Le Calve´, B., … Sander, D. (2008). Emotional processing of odors: Evidence for a nonlinear relation between pleasantness and familiarity evaluations. *Chemical Senses*, *33*, 469–479.

Distel, H., Ayabe-Kanamura, S., Martínez-Gómez, M., Schicker, I., Kobayakawa, T., Saito, S., & Hudson, R. (1999). Perception of everyday odors—correlation between intensity, familiarity and strength of hedonic judgement. *Chemical Senses*, *24*(2), 191–199.

Distel, H., & Hudson, R. (2001). Judgement of odor intensity is influenced by subjects' knowledge of the odor source. *Chemical Senses*, *26*(3), 247–251.

Doty, R. L. (1994). Olfaction and multiple chemical sensitivity. *Toxicology & Industrial Health*, *10*, 359–368.

Doty, R. L. (2009). The olfactory system and its disorders. *Seminars in Neurology*, *29*(1), 74–81.

Doty, R. L., & Cameron, E. L. (2009). Sex differences and reproductive hormone influences on human odor perception. *Physiology & Behavior*, *97*(2), 213–228.

Doty, R. L., & Kamath, V. (2014). The influence of age on olfaction: A review. *Frontiers in Phycology*, *5*(20), 1–20.

Fadda, R., Piras, F., Doneddu, G., Saba, L., & Masala, C. (2018). Olfactory function assessment in Italian subjects with autism spectrum disorder. *Chemosensory Perception*, *11*, 51–58.

Fernandez-Garcia, J. C., Alcaide, J., Santiago Fernandez, C., Roca-Rodriguez, M., Aguera, Z., Baños, R., … Garrido-Sanchez, L. (2017). An increase in visceral fat is associated with a decrease in the taste and olfactory capacity. *PLoS One*, *12*(2), e0171204.

Ferris, A., & Duffy, V. (1989). Effect of olfactory deficits on nutritional status. *Annals of the New York Academy of Sciences*, *561*, 113–123.

Fukuwatari, T., Kawada, T., Tsuruta, M., Hiraoka, T., Iwanaga, T., Sugimoto, E., & Fushiki, T. (1997). Expression of the putative membrane fatty acid transporter (FAT) in taste buds of the circumvallate papillae in rats. *FEBS Letters*, *414*, 461–464.

Gilbertson, T. A., Fontenot, D. T., Liu, L., Zhang, H., & Monroe, W. T. (1997). Fatty acid modulation of K^+ channels in taste receptor cells: Gustatory cues for dietary fat. *American Journal of Physiology*, *272*, C1203–C1210.

Gilbertson, T. A. (1998). Role of the taste system in ingestive behavior: Studies in NaCl and fatty acid transduction. *Annals of the New York Academy of Sciences*, *30*(855), 860–867.

Green, B. G. (2003). Studying taste as a cutaneous sense. *Food Quality and Preference*, *14*, 99–109.

Heilmann, S., & Hummel, T. (2004). A new method for comparing orthonasal and retronasal olfaction. *Behavioral Neuroscience*, *118*, 412–419.

Herz, R. S. (2005). Odor-associative learning and emotion: Effects on perception and behavior. *Chemical Senses*, *30*(1), i250–i251.

Hoskison, E. E. (2013). Olfaction, pheromones and life. *The Journal of Laryngology & Otology*, *127*, 1156–1159.

Hu, H., He, M. L., Tao, R., Sun, H. Y., Hu, R., Zang, W. J., … Li, G. R. (2009). Characterization of ion channels in human preadipocytes. *Journal of Cellular Physiology*, *218*, 427–435.

Hummel, T., Heilmann, S., Landis, B. N., Reden, J., Frasnelli, J., Small, D. M., & Gerber, J. (2006). Perceptual differences between chemical stimuli presented through the ortho- or retronasal route. *Flavour and Fragrance Journal*, *21*, 42–47.

Hummel, T., Kobal, G., Gudziol, H., & Mackay-Sim, A. (2007). Normative data for the "Sniffin' sticks" including tests of odor identification, odor discrimination, and olfactory thresholds: An upgrade based on a group of more than 3000 subjects. *European Archives of Oto-Rhino-Laryngology*, *264*, 237–243.

Hummel, T., Sekinger, B., Wolf, S. R., Pauli, E., & Kobal, G. (1997). Sniffin' sticks' olfactory performances assessed by the combined testing of odor identification, odor discrimination and olfactory threshold. *Chemical Senses*, *22*, 39–52.

Kalogeropoulos, N., Nomikos, T., Chiou, A., Fragopoulou, E., & Antonopoulou, S. (2008). Chemical composition of Greek Avgotaracho prepared from mullet (*Mugil cephalus*): Nutritional and health benefits. *Journal of Agricultural and Food Chemistry*, *56*, 5916–5925.

Landis, B. N., Welge-Luessen, A., Brämerson, A., Bende, M., Mueller, C. A., Nordin, S., & Hummel, T. (2009). "Taste strips"—A rapid, lateralized, gustatory bedside identification test based on impregnated filter papers. *Journal of Neurology*, *256*, 242–248.

Laugerette, F., Passilly-Degrace, P., Patris, B., Niot, I., Febbraio, M., Montmayeur, J. P., & Besnard, P. (2005). CD36 involvement in orosensory detection of dietary lipids, spontaneous fat preference, and digestive secretions. *Journal of Clinical Investigation*, *115*, 3177–3184.

Lim, J. (2011). Hedonic scaling: A review of methods and theory. *Food Quality and Preference*, *22*, 733–747.

Liu, D., Archer, N., Duesing, K., Hannan, G., & Keast, R. (2016). Mechanism of fat taste perception: Association with diet and obesity. *Progress in Lipid Research*, *63*, 41–49.

Loy, F., Solari, P., Isola, M., Crnjar, R., & Masala, C. (2016). Morphological and electrophysiological analysis of tarsal sensilla in the medfly *Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae). *Italian Journal of Zoology*, *83*(4), 456–468.

Mahmut, M. K., & Croy, I. (2019). The role of body odors and olfactory ability in the initiation, maintenance and breakdown of romantic relationships—A review. *Physiology & Behavior*, *207*, 179–184.

Masala, C., Käehling, C., Fall, F., & Hummel, T. (2019). Correlation between olfactory function, trigeminal sensitivity, and nasal anatomy in healthy subjects. *European Archives of Oto-Rhino-Laryngology*, *276*, 1649–1654.

Masala, C., Loy, F., Piras, R., Liscia, A., Fadda, L., Moat, A., … Defazio, G. (2020). Olfactory and gustatory dysfunction and motor symptoms on body weight in patients with Parkinson's disease. *Brain Sciences*, *10*, 218. https://doi.org/10.3390/brainsci10040218

Masala, C., Saba, L., Cecchini, M. P., Solla, P., & Loy, F. (2018). Olfactory function and age: A Sniffin' sticks extended test study performed in Sardinia. *Chemosensory Perception*, *11*, 19–26.

Masala, C., Solla, P., Liscia, A., Defazio, G., Saba, L., Cannas, A., … Haehner, A. (2018). Correlation among olfactory function, motors' symptoms, cognitive impairment, apathy, and fatigue in patients with Parkinson's disease. *Journal of Neurology*, *265*, 1764–1771.

Masala, C., Solari, P., Sollai, G., Crnjar, R., & Liscia, A. (2008). Clonidine effects on protein and carbohydrate electrophysiological responses of labellar and tarsal sensilla in *Phormia regina*. *Journal of Insect Physiology*, *54*, 1193–1199.

Melis, M., Sollai, G., Masala, C., Pisanu, C., Cossu, G., Melis, M., … Tomassini Barbarossa, I. (2019). Odor identification performance in idiopathic Parkinson's disease is associated with gender and the genetic variability of the olfactory binding protein. *Chemical Senses*, *44*, 311–318.

Moss, A. G., Miles, C., Elsley, J. V., & Johnson, A. J. (2016). Odorant normative data for use in olfactory memory experiments: Dimension selection and analysis of individual differences. *Frontiers in Psychology*, *7*, 1267.

Murphy, C., Cain, W. S., & Bartoshuk, L. M. (1977). Mutual action of taste and olfaction. *Sensory Processes*, *1*(3), 204–211.

Nováková, L. M., Havlíček, J., & Roberts, S. C. (2014). Olfactory processing and odor specificity: A meta-analysis of menstrual cycle variation in olfactory sensitivity. *Annual Review of Anthropology*, *77*, 331–345. https://doi.org/10.2478/anre-2014-0024

Oleszkiewicz, A., Schriver, V. A., Croy, I., Hähner, A., & Hummel, T. (2019). Updated Sniffin' stick normative data based on an extended sample of 9139 subjects. *European Archives of Oto-Rhino-Laryngology*, *276*, 719–728.

Oliveira-Pinto, A. V., Santos, R. M., Coutinho, R. A., Oliveira, L. M., Santos, G. B., Alho, A. T., … Lent, R. (2014). Sexual dimorphism in the human olfactory bulb: Females have more neurons and glial cells than males. *PLoS One*, *9*(11), e111733. https://doi.org/10.1371/journal.pone.0111733

Palouzier-Paulignan, B., Lacroix, M. C., Aimé, P., Baly, C., Caillol, M., Congar, P., … Fadool, D. A. (2012). Olfaction under metabolic influences. *Chemical Senses*, *37*(9), 769–797.

Patel, Z. M., DelGaudio, J. M., & Wise, S. K. (2015). Higher body mass index is associated with subjective olfactory dysfunction. *Behavioural Neurology*, *2015*, 675635.

Prescott, J. (1999). Flavour as a psychological construct: Implications for perceiving and measuring the sensory qualities of foods. *Food Quality and Preference*, *10*, 349–356.

Reas, D. L., Nygård, J. F., Svensson, E., Sørensen, T., & Sandanger, I. (2007). Changes in body mass index by age, gender, and socio-economic status among a cohort of Norwegian men and women (1990–2001). *BMC Public Health*, *7*, 269.

Rolls, E. T. (2004). The functions of the orbitofrontal cortex. *Brain Cognition*, *55*, 11–29.

Rosa, A., Isola, R., Nieddu, M., & Masala, C. (2020). The role of lipid composition in the sensory attributes and acceptability of the salted and dried mullet roes (bottarga): A study in human and animal models. *Nutrients*, *12*, 3454.

Rosa, A., Piras, A., Nieddu, M., Putzu, D., Marincola, F. C., & Falchi, A. M. (2016). *Mugil cephalus* roe oil obtained by supercritical fluid extraction affects the lipid profile and viability in cancer HeLa and B16F10 cells. *Food & Function*, *7*, 4092–4103.

Rosa, A., Scano, P., Atzeri, A., Deiana, M., & Falchi, A. M. (2013). Potential anti-tumor effects of *Mugil cephalus* processed roe extracts on colon cancer cells. *Food and Chemical Toxicology*, *60*, 471–478.

Rosa, A., Scano, P., Atzeri, A., Deiana, M., Mereu, S., & Dessi, M. A. (2011). Effect of storage conditions on lipid components and color of *Mugil cephalus* processed roes. *Journal of Food Science*, *77*, C107–C114.

Rosa, A., Scano, P., Melis, M. P., Deiana, M., Atzeri, A., & Dessì, M. A. (2009). Oxidative stability of lipid components of mullet (*Mugil cephalus*) roe and its product "bottarga". *Food Chemistry*, *115*, 891–896.

Royet, J. P., Koenig, O., Gregoire, M. C., Cinotti, L., Lavenne, F., Le Bars, D., … Froment, J. C. (1999). Functional anatomy of perceptual and semantic processing for odors. *Journal of Cognitive Neuroscience*, *11*(1), 94–109.

Salem, N., Jr., Moriguchi, T., Greiner, R. S., Mcbride, K., Ahmad, A., Catalan, J. N., & Slotnick, B. (2001). Alterations in brain function after loss of docosa hexaenoate due to dietary restriction of n-3fatty acids. *Journal of Molecular Neuroscience*, *16*, 299–307.

Sauer, H., Ohla, K., Dammann, D., Teufel, M., Zipfel, S., Enck, P., & Mack, I. (2017). Changes in gustatory function and taste preference following weight loss. *Journal of Pediatrics*, *182*, 120–126.

Scano, P., Rosa, A., Marincola, F. C., Locci, E., Melis, M., Dessì, M., & Lai, A. (2008). 13C NMR, GC and HPLC characterization of lipid components of the salted and dried mullet (*Mugil cephalus*) roe "bottarga". *Chemistry and Physics of Lipids*, *151*, 69–76.

Schiffman, S. S., & Warwick, Z. S. (1993). Effect of flavor enhancement of foods for the elderly on nutritional status: Food intake, biochemical indices, and anthropometric measures. *Physiology & Behavior*, *53*, 395–402.

Schriever, V. A., Agosin, E., Altundag, A., Avni, H., Van, H. C., Cornejo, C., … Hummel, T. (2018). Development of an international odor identification test for children: The universal sniff test. *Journal of Pediatrics*, *198*, 265–272.

Simchen, U., Koebnick, C., Hoyer, S., Issanchou, S., & Zunft, H. J. (2006). Odour and taste sensitivity is associated with body weight and extent of misreporting of body weight. *European Journal of Clinical Nutrition*, *60*(6), 698–705.

Skrandies, W., & Zschieschang, R. (2015). Olfactory and gustatory functions and its relation to body weight. *Physiology & Behavior*, *142*, 1–4.

Small, D. M., & Green, B. G. (2012). A proposed model of a flavor modality. In M. M. Murray & M. T. Wallace (Eds.), *The neural bases of multisensory processes* (Chapter 36). Boca Raton, FL: CRC Press/Taylor & Francis.

Solari, P., Sollai, G., Masala, C., Loy, F., Palmas, F., Sabatini, A., & Crnjar, R. (2017). Antennular morphology and contribution of Aesthetascs in the detection of food-related compounds in the shrimp *Palaemon adspersus* Rathke, 1837 (Decapoda: Palaemonidae). *Biological Bulletin*, *232*, 110–122.

Solla, P., Masala, C., Liscia, A., Piras, R., Ercoli, T., Fadda, L., … Defazio, G. (2020). Sex-related differences in olfactory function and evaluation of possible confounding factor among patients with Parkinson's disease. *Journal of Neurology*, *267*, 57–63.

Sorokowski, P., Karwowski, M., Misiak, M., Konstancja Marczak, M., Dziekan, M., Hummel, H., & Sorokowska, A. (2019). Sex differences in human olfaction: A meta-analysis. *Frontiers in Psychology*, *10*, 242.

Stevenson, R. J., Mahmut, M. K., Horstmann, A., & Hummel, T. (2020). The aetiology of olfactory dysfunction and its relationship to diet quality. *Brain Sciences*, *10*(11), 769.

Tepper, B. J., White, E. A., Koelliker, Y., Lanzara, C., d'Adamo, P., & Gasparini, P. (2009). Genetic variation in taste sensitivity to 6-n-propylthiouracil and its relationship to taste perception and food selection. *Annals of the new York Academy of Sciences*, *1170*, 126–139.

Vasconcelos, L. H. C., Souza, I. L. L., Pinheiro, L. S., & Silva, B. A. (2016). Ion channels in obesity: Pathophysiology and potential therapeutic targets. *Frontiers in Pharmacology*, *7*, 58.

Vignini, A., Borroni, F., Sabbatinelli, J., Pugnaloni, S., Alia, S., Taus, M., Ferrante, L., Mazzanti, L., Fabri, M. (2019). General Decrease of Taste Sensitivity Is Related to Increase of BMI: A Simple Method to Monitor Eating Behavior. *Dis Markers*. *2019*, 2978026. https://doi.org/10.1155/2019/2978026. PMID: 31089392; PMCID: PMC6476129.

Walliczek-Dworschak, U., & Hummel, T. (2017). The human sense of olfaction. *Facial Plastic Surgery*, *33*, 396–404.

Yi, S. W., Ohrr, H., Shin, S. A., & Yi, J. J. (2015). Sex-age-specific association of body mass index with all-cause mortality among 12.8 million Korean adults: A prospective cohort study. *International Journal of Epidemiology*, *44*, 1696–1705.

How to cite this article: Rosa, A., Pinna, I., & Masala, C. (2022). Role of body weight and sex in the olfactory and gustatory pleasantness, intensity, and familiarity of a lipid-rich food. *Journal of Sensory Studies*, e12739. https://doi.org/10.1111/joss.12739