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Responsiveness to warning sensations and anxiety-related psychological traits modulate individual differences in preference for vegetable foods with varied sensory properties

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A R T I C L E I N F O

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A B S T R A C T

The innate aversion to warning sensations is an important barrier to the acceptance of vegetable food often characterized by bitter and sour tastes, and astringency. Large individual variations exist in preference for this food category. The present study aimed at exploring differences in demographics, anthropometrics, taste responsiveness, personality traits and attitudes in consumers differing in their preference for vegetable food with varied levels of warning sensations. A panel of Italian consumers (n = 718; 53.6% women, age 18–74 years) self-reported familiarity with, preference for and choice of vegetables with high and low levels of warning sensations. Two clusters were identified: High Warning-Vegetable Consumers (HWVC, n = 464) and Low-Warning Vegetable Consumers (LWVC, n = 254). HWVC showed higher familiarity with and preference for vegetables as a whole and higher choice of vegetables characterized by warning sensations than LWVC. HWVC were more represented by older and normal weight individuals as compared to LWVC. Differences among clusters in liking for and perception of a phenol-enriched plant-based food model specifically developed to induce different levels of bitterness, sourness and astringency were found. HWVC rated bitterness, sourness, and astringency lower and liking higher than LWVC. Scores in anxiety-related psychological traits were lower while attitudes to healthy and high-quality food choice were higher in HWVC than in LWVC. The results of the present study depicted a coherent interplay among several person-related dimensions in modulating preference for vegetable foods. Higher responsiveness to warning sensations, higher level of anxiety-related traits, lower importance assigned to food healthy/quality aspects and younger age all acted as barriers to exposure and acceptance of vegetable food and call for a multidimensional approach to promote the consumption of this food category.

1. Introduction

The health benefits of vegetable-rich diets are widely recognized and the general interest in consuming vegetable foods is further increased by the sustainability and environmental concerns of the animal-based diet. Despite this, the intake of vegetables remains lower than what is recommended by The World Health Organization (WHO) (Appleton et al., 2017; Vereecken et al., 2015), thus contributing to the increase of the risk of obesity and related chronic diseases (Astrup et al., 2008). The understanding of how people perceive plant-based food and the barriers they face in increasing their consumption is thus a matter of wide interest (Brown et al., 2011; Nekitsing et al., 2018; Nørnberg et al., 2016; Schreinemachers et al., 2018; Wallace et al., 2020).

Unappealing sensory characteristics, including bitterness, sourness and astringency represent one of the most important barriers to the consumption of vegetables (Hoppu et al., 2021). These sensations represent warning sensory cues discouraging the consumption of potentially noxious food, thus the innate rejection for bitterness, sourness and astringency is an adaptative behavior to avoid the ingestion of toxic or unripe plant compounds. Large differences exist among consumers with individuals that are much more inclined than others to prefer and consume foods characterized by those sensory properties. However, not all vegetables are characterized by unappealing sensory characteristics with many considered more sweet-tasting than bitter-tasting (Cox et al., 2012) and different motives were found to be associated with the regular consumption and liking of vegetables with varied

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sensory profile (Appleton et al., 2017, 2019).

Responsiveness to oral sensations widely varies across individuals mainly due to genetic predispositions (Feeney et al., 2021). 6-n-propylthiouracil (PROP) bitterness perception is a very investigated taste phenotype associated to the intensity of oral sensations including other tastes and somatosensory sensations (Tepper et al., 2017). Significant negative associations have been reported between responsiveness to solution of bitter, sour and astringent compounds and vegetable preference and intake (Louro et al., 2021; Pagliarini et al., 2021). Individuals more responsive to PROP also perceived greater bitterness and reported lower liking and intake for vegetables characterized by warning sensations and objectionable flavors (Dinehart et al., 2006; Duffy et al., 2020; Shen et al., 2016). Intricate interrelationships were found between bitterness and *retro*-nasal flavor sensations which negatively affect liking for green vegetables (Duffy et al., 2020) pointing out the complexity of real food perception. The real food experience is the result of interaction across multiple senses which impact both sensation ratings and affective response to a given food context (Delwiche, 2004; Small & Prescott, 2005). Thus, the extent to which individual variation in responsiveness to oral sensation may actually impact on hedonic responses to vegetable food connoted by less or more appealing sensory properties with downstream influences on diet and food-related health outcomes (i.e., Body Mass Index) is far to be elucidated (Cox et al., 2016).

Recent studies have shown that personality has an important role in preferences and choices and, in some cases, in determining sensory responses to foods. Several studies have shown that food neophobia, originally defined as the reluctance to consume unfamiliar foods, is one of the most reliable predictors of food preferences. The association between food neophobia and reduced preference and intake of many food products (including vegetables) has been demonstrated both in adults (Jaeger et al., 2017; Knaapila et al., 2011; Törnwall et al., 2014) and children (Kral, 2018). Individuals higher in food neophobia (neophobics) are reported to like fewer vegetables, beverages, fruits, and spicy foods than those low in food neophobia (neophilics) especially if these foods are high in warning sensations such as bitterness, astringency, sourness, and pungency (De Toffoli et al., 2019a; Laureati et al., 2018; Törnwall et al., 2014; Spinelli et al 2018). Furthermore, heightened sensory sensitivity was observed in neophobic individuals (Spinelli et al 2018, Laureati et al., 2018, Prescott et al., 2022).

Two other personality traits, sensitivity to punishment and sensitivity to reward have been found to be associated with the consumption of healthy/unhealthy foods. These traits are salient because they reflect reactivity and responsivity to behavioral inhibition and activation systems that underlie learning (Gray, 1982). Recent studies have highlighted a positive association between sensitivity to reward and unhealthier food behaviors (Davis et al., 2007; Tapper et al., 2015). Furthermore, negative associations between sensitivity to reward/ sensitivity to punishment, and liking for bitter and pungent vegetables were also reported in a large Italian cohort (Monteleone et al., 2017; De Toffoli et al., 2019b).

Other personality traits have also been linked to lower preferences for, and consumption of, vegetables. Individuals highly sensitive to visceral disgust (disgust related to rotten food, vermin, and body fluids) showed significantly lower preferences and consumption of vegetables that were characterized by bitterness and astringency (De Toffoli et al., 2019b). Furthermore, a positive association was found between PROP responsiveness and sensitivity to visceral disgust (Herz, 2011, 2014). Sensitivity to disgust may also be associated with more generalised anxiety, resultant physiological responses (i.e. increased heart rate, stress hormone secretion, vigilance), and fear of potentially dangerous environments (Cisler et al., 2007), which can be viewed as an adaptive reaction from an evolutionary perspective, but that can lead to food avoidance (Randler et al., 2017). High anxiety individuals might be more sensitive to intense 'warning sensations' like sourness bitterness, and astringency and this can lead to a decreased acceptability of vegetables.

The tendency to pursue new and different sensations, feelings, and experiences – that is, sensation seeking (Zuckerman, 1971) – was also found to be linked to preference for pungent food (Rozin & Schiller, 1980) and the intake of foods characterized by bitterness and astringency, including coffee, tea, or chocolate (Evans, 2005). However, the role of this personality trait in influencing the consumption of vegetables has been less studied.

Systematic investigations of differences in sensory perception among individuals were also related to the disposition to focus on internal bodily sensations (awareness of internal sensations) measured with the construct of private body consciousness (PBC, Miller et al., 1981). Stevens (1990) and Stevens et al. (1989) reported differences in the perception of sensory attributes and hedonic responses among high and low PBC individuals. Solheim & Lawless (1996) observed that high PBC individuals were more aware of food sensory characteristics and more able to discriminate between products based on sensory attributes than low PBC individuals. Thus, it is possible that sensory characteristics may be more important determinants of food acceptability to high PBC than low PBC individuals.

Food-related knowledge and attitudes are also crucial in explaining preferences for vegetables. Thus, enhanced vegetable consumption in adults has been associated with greater nutritional knowledge (Brown et al., 2011; McMahon et al., 2013), a greater appreciation of health and the value of a healthy diet (Brown et al., 2011), greater culinary knowledge and culinary confidence (Brown et al., 2011; Izumi et al., 2011; McMahon et al., 2013), and increased time and willingness to prepare and cook home-made meals (Darian & Tucci, 2013; Glasson et al., 2011; McMahon et al., 2013). Finally, also attitudes linked more broadly to a person's life-world such as the meaning of food in life made explicit in many cultures as "you are what you eat" has been associated with higher consumption of fruit and vegetables (Arbit et al., 2017).

An extant body of evidence depicts a complex frame of several personal dimensions modulating individual differences in vegetable food preference which have been rarely investigated together on representative population samples. The present study aimed at exploring differences in demographics, anthropometrics, taste responsiveness (measured through responsiveness to PROP and other tastants in aqueous solutions and a model food), personality traits and attitudes in consumers differing in their preference for vegetables with varied level of warning sensations. To investigate these aspects a large cohort of Italian adults ($n = 718$; 53.6% women, age 18–74) was considered and self-reported measures of preference (stated liking, familiarity, and choice) for vegetables with varied levels of warning sensations (bitterness, sourness and astringency) were collected.

2. Materials and methods

2.1. Participants

Participants ($n = 718$; 53.6% women, age 18–74 years) were recruited in eight cities in north, centre and south of Italy by means of announcements published on websites and newspapers, emails, pamphlet distribution and by word of mouth. Inclusion criteria were not to be pregnant or breastfeeding at the time of testing, being born in Italy or having lived at least 20 years in Italy. The successful response to the sensory evaluation training procedure and the capacity of correctly run the software guided procedure for sensory data acquisition were considered as further inclusion criteria. Their demographic characteristics are reported in Table 1.

The study was conducted in agreement with the Italian ethical requirements on research activities and personal data protection (D.L. 30.6.03n. 196). The study protocol was approved by the Ethics Committee of Florence University. The respondents gave their written informed consent at the beginning of the test according to the principles of the Declaration of Helsinki.

Table 1
Socio-demographic and anthropometric characteristics of participants.

	Women (n = 385) %	Men (n = 333) %	Total (n = 718) %
Gender	53.6	46.4	100
Age (years)			
18–30	40	36.3	38.3
31–45	28.3	30.3	29.2
46–74 (89% under 61)	31.7	33.3	32.5
Body mass index (kg/m^2)[a]			
Underweight (<18.50)	6	0.9	3.6
Normal range (18.50–24.99)	70.1	56.7	63.9
Overweight (25.00–29.99)	18.2	34.8	25.9
Obese (≥30.00)	5.7	7.6	6.6

[a] Classification according to World Health Organization (WHO).

2.2. Procedure and overview of data collection

Self-reported measures of preference (stated liking, familiarity, and choice) for vegetables with varied levels of warning sensations (bitterness, sourness and astringency) were collected. Then, differences among consumers varying in their preference for vegetables were investigated. Oral responsiveness to prototypical stimuli was assessed in water solutions of caffeine and PROP for bitter taste and aluminum sulphate for astringency. Aluminum sulphate was selected as the prototypical astringent stimulus due to its purity (98%) and to its sensory profile characterized more by astringency descriptors (drying, puckering and roughing) than side taste qualities (such as bitterness) in respect to other astringent compounds (e.g., polyphenols) (Fleming et al., 2015). Furthermore, responsiveness to bitterness, sourness and astringency was assessed in a plant-based model food (bean purée) specifically developed to induce different levels of these sensations by adding different concentrations of a phenol extract.

A comprehensive set of measures of personality traits and attitudes that have been shown to be relevant to vegetable preference and intake were measured. Demographics (age and gender) and anthropometric measures (Body Mass Index) were also collected.

The study consisted in an online and a laboratory session. Participants first completed an online questionnaire including socio-demographic information (self-reported gender and age), anthropometrics, psychological traits (Food Neophobia scale, Sensitivity to Punishment and Reward, Disgust sensitivity, Private Body Consciousness questionnaires) attitudes toward food (Health and Taste Attitude scale and the Food Related Lifestyles Questionnaire), stated liking for, familiarity with, and choice of various vegetables. In the laboratory session, participants were asked to express their liking and to evaluate the intensity of sensory properties of four bean purée samples at four phenol concentrations. Participants also rated the intensity of two series of astringent and bitter solutions. During this lab session, data on personality traits (State and Trait anxiety, Sensation Seeking scale) and food attitudes (Meaning of Food in Life questionnaire) were collected. PROP bitterness ratings were collected at the end of the session. A scheme of data collection is reported in Fig. 1.

2.3. Questionnaires

2.3.1. Familiarity with, stated liking for and choice of vegetables

Familiarity with, and stated liking for vegetables (presented by names) were measured using a selection of the IT-Food Preference, Familiarity and Choice Questionnaire (IT-FPQ; FFQ and FCQ) developed within the Italian Taste project (Monteleone et al., 2017). The selection included eleven vegetables with varied levels of warning sensations (low bitterness/sourness/astringency: carrots salad, zucchini, lettuce and valerian salad, chard, and cucumbers; high bitterness/sourness/astringency: broccoli, asparagus, radish, chicory, radicchio, and rocket salad, and cauliflower salad) based on the results of a previous sensory Check-All-That-Apply (CATA) study (De Toffoli et al., 2019b). Choice questionnaire included two vegetable pairs, taken as representative of the low and high expected level of warning sensation vegetable groups, arranged so that the options in each pair significantly differed in bitterness, sourness, and astringency (chard vs chicory; lettuce and valerian salad vs radicchio and rocket salad) (De Toffoli et al., 2019b) (see Table 2). For each pair in the choice questionnaire, participants were asked to indicate which item they would ideally choose in a main meal context, pointing out that the answer should describe not what they usually choose but rather what they would like to choose in a situation of absence of restrictions (e.g., due to health or weight concerns). Options within the pairs were coded as "0" and "1" according, respectively, to the lower and higher level of warning sensations (De Toffoli et al., 2019b).

Familiarity was measured using a 5-point labeled scale (1 = I do not recognize it; 2 = I recognize it, but I have never tasted it; 3 = I have tasted it, but I don't eat it; 4 = I occasionally eat it; 5 = I regularly eat it; Tuorila et al., 2001) while stated liking was assessed using the 9-point hedonic scale (1 = extremely disliked; 9 = extremely liked, Peryam & Pilgrim, 1957). An "I have never tasted it" option was included and liking data for this option were not collected (Monteleone et al. 2017).

Table 2
Vegetable items selected for familiarity, stated liking and choice assessment (items in bold).

Low expected bitterness, sourness and astringency	High expected bitterness, sourness and astringency
Carrot salad	Broccoli
Zucchini	Asparagus
Cucumbers	Radish
Chard	**Chicory**
Lettuce and valerian salad	**Radicchio and rocket salad**
	Cauliflower salad

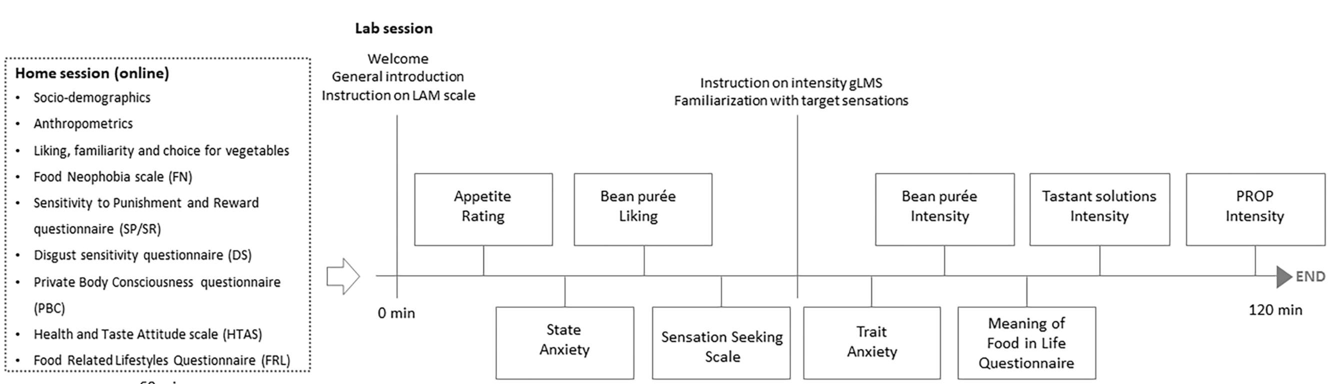

Fig. 1. Overview of data collection.

The presentation order of the items and pairs was randomized across participants.

2.3.2. Psychological traits

Food neophobia (FN), which denotes the apprehension or reluctance to consume new or unfamiliar foods, was assessed using the 10-statement scale developed by Pliner and Hobden (1992) and validated in Italian by Laureati et al. (2018). The individual food neophobia scores were obtained by summing up the ratings given to the 10 statements, with the neophilic items being reversed. The scale utilized a seven-point Likert system, ranging from "disagree strongly" to "agree strongly." The computed scores ranged from 10 to 70, where higher scores were indicative of greater levels of food neophobia.

Sensitivity to punishment (SP) and sensitivity to reward (SR) were quantified using the questionnaire (SPSRQ) developed by Torrubia et al. (2001) and validated in Italian by Spinelli et al. (2018). The scales used to measure sensitivity to punishment and reward were scored using a binary format (yes/no). The scores for each participant were calculated by adding up the number of affirmative responses, with a possible SP score range of 0–23 and an SR score range of 0–18. Higher scores corresponded to a greater sensitivity to punishment or reward.

Sensitivity to disgust (SD), also known as sensitivity to core-visceral disgust was mesured using an 8-item scale created by Inbar et al. (2009) and validated in Italian by Spinelli et al. (2018). The scale comprises two subscales, each utilizing a distinct rating system, ranging from 1 (strongly disagree/very untrue about me) to 5 (strongly agree/very true about me) for subscale 1, and 1 (not at all disgusting) to 5 (extremely disgusting) for subscale 2. Individual scores fell within a range of 8 to 40, with higher scores indicating a greater degree of sensitivity to disgust.

Anxiety defined as "an emotion characterized by feelings of tension, worried thoughts, and physical changes like increased blood pressure" (American Psychiatric Association, 2013) was quantified using the State-Trait Anxiety Inventory form Y (STAI-Y) presented in the validated Italian translation of Pedrabissi & Santinello, 1989. STAI-Y includes two scales: State Anxiety Scale (SA), which measures current anxiety, and the Trait Anxiety Scale (TA), which measures anxiety level as a personal characteristic. SA instructions ask the participant to respond based on how they feel at that precise moment, whereas TA instructions ask the participant to respond, based on how they usually feel. Each scale is composed of 20 items on a 4-point Likert scale (1 = not at all; 4 = very much). For each participant, state and trait anxiety scores are computed by adding all the scores of each question on each respective scale after reversing low anxiety items. Higher scores indicate higher levels of anxiety.

Private Body Consciousness (PBC), defined as the degree of focus on internal bodily sensations, referred to as, we used a five-item questionnaire created by Miller et al. (1981) and validated in Italian by Spinelli et al. (2018). Each statement was rated on a five-point scale ranging from "extremely uncharacteristic" to "extremely characteristic". The individual score was calculated by adding the scores of the five items, with a possible range from 5 to 25. Higher scores indicate a higher level of private body consciousness.

Sensation seeking defined as the tendency to pursue new and different sensations, feelings, and experiences was measured with the Sensation Seeking Scale (SSS) revised in the Zuckerman-Kuhlman-Aluja Personality Questionnaire (ZKA-PQ, Aluja, et al., 2010) validated in Italian by Rossier et al. (2016). The SSS consists of 40 questions. For each participant a global score was computed by adding all the scores of each question measured on a 4-point Likert scale (1 = strongly disagree;4 = completely agree) after reversing the low sensation seeking item. Higher scores indicate higher levels sensation seeking.

2.3.3. Attitudes toward foods

The Food-Related Lifestyles (FRL) questionnaire (Grunert et al., 2001) was employed to measure lifestyle, which refers to the cognitive categories, scripts, and associations linking a set of food products to a set of values. This questionnaire, validated in Italian by Saba et al. (2019), consists of 69 items, 7 of which require reverse scoring. It is organized into 5 domains, with each domain having 23 subscales, covering various food-related topics including shopping behaviors (6 subscales), the importance of quality aspects (6 subscales), cooking methods (6 subscales), consumption situations (2 subscales), and purchasing motives (3 subscales). Respondents used a 7-point Likert scale, where 1 indicated strong disagreement and 7 indicated strong agreement, to evaluate each item. The mean scores provided by respondents were calculated to determine the total score for each subscale.

The Health and Taste Attitudes Scale (HTAS) questionnaire was utilized to assess an individual's food preferences based on health and taste. The questionnaire was originally developed by Roininen et al. in 1999 and later validated in Italian by Saba et al. in 2019. The HTAS contains six domains, three related to health (general health interest-GHI, interest in consuming reduced-fat foods-light product interest-LPI, and interest in eating unprocessed foods without additives-natural product interest-NPI) and three related to taste (craving for sweet foods-CSF, food as a reward-FR, and pleasure-P). Respondents rated 38 items on a 7-point Likert scale ranging from 1 (strong disagreement) to 7 (strong agreement). The mean rating for each domain of the HTAS was calculated.

The Meaning of Food in Life Questionnaire (MFLQ) developed by Arbit et al. (2017) was used to measure the meaning of food in life construct which has been shown to exert influence on food choice. The MFLQ is organized into five different domains: moral, sacred, health, social, and aesthetic. The MFLQ included a total of 22 items, rated on a 7-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. The MFLQ for each domain was calculated as the mean of the ratings. The items of the questionnaire were translated into Italian by two different bilingual Italian native speakers and then back translated into the source language by an English native speaker. Back translations were reviewed by an expert in semantics and adjustments were made when necessary to select the most appropriate translation.

2.4. Sensory evaluations

2.4.1. Sensory stimuli

2.4.1.1. Food model. Bean purée samples (BP) were prepared by blending canned beans (Valfrutta - Conserve Italia Soc. Coop. Agricola) as described in De Toffoli et al. (2019a). The BP samples had three levels of phenol extract from olive mill wastewater added: 0.44, 1.00, and 2.25 g/kg. A further sample consisting of the BP without phenol extract added and indicated as 0.00 g/kg, was considered. In total, four levels of phenol concentration were considered for evaluation. Samples were evaluated within 15 min of extract addition.

2.4.1.2. Tastant solutions. Caffeine and aluminum sulfate (European Pharmacopoeia Reference Standard, Sigma Aldrich, Milano, Italy) were used to elicit bitterness and astringency. Two solution series were prepared at five tastant concentration levels: caffeine (bitterness) – 0, 0.75, 1.50, 3.00, 6.00 g/kg; aluminium potassium sulphate (astringency) – 0, 0.40, 0.80, 1.60, 3.20 g/kg, selected to induce intensity from weak to strong (Monteleone et al., 2017). PROP taster status was assessed using a 3.2 mM PROP solution, prepared by dissolving 0.545 g/L of 6-n-propyl-2-thiouracil (European Pharmacopoeia Reference Standard, Sigma Aldrich, Milano, Italy) in deionized water (Prescott et al., 2004).

2.4.2. Procedures

All samples were presented in disposable white cups (6 g bean puree samples; 10 ml tastant solutions) identified by a 3-digit random code. Presentation order was randomized across participants. After each sample, participants rinsed their mouths with water for 30 s, had some plain crackers for 30 s, and finally rinsed their mouths with water for a further 30 s. Evaluations were performed in individual booths under white lights. Data were collected with the software Fizz (ver.2.51., Biosystèmes, Couternon, France).

2.4.2.1. Liking for bean purée samples. Before starting the hedonic evaluation of food samples, participants were introduced to the use of the Labelled Affective Magnitude scale (LAM; Cardello & Schutz, 2004; Schutz & Cardello, 2001) and familiarized with it. The scale anchors were spaced according to the values of Cardello and Schutz (2004), from "greatest imaginable dislike" (0) to "greatest imaginable like" (1 0 0), with "neither liked nor disliked" set at 50. Numerical labels were not reported on the scale. To control for alliesthesia (Cabanac, 1971), participants were asked to rate their appetite using a 0–100 visual analog scale ("How hungry are you?"; range: "Not at all/Very much") before tasting the samples. Then participants were instructed to take a spoonful of the sample and express their liking on the LAM scale.

2.4.2.2. Intensity evaluations: model food and solutions. Participants were instructed on how to use the gLMS, a scale ranging from 0 to 100 that measures intensity of sensations (Bartoshuk et al., 2004), before conducting the evaluations. The established procedures for using the scale were followed (Bartoshuk, 2000; Green et al., 1993). Participants recalled various sensations from different modalities and then rated the intensity of the brightest light they had ever seen on a paper ballot (Bajec & Pickering, 2008; Kalva et al., 2014; Webb et al., 2015). Their ratings had to fall between "very strong" and "the strongest imaginable sensation of any kind" to ensure correct use of the scale. If not, clarification was given to each participant individually (Dinnella et al., 2018).

Then, participants were trained to recognize and rate the perceived intensity of target sensations. The following tastant concentrations were selected to induce moderate/strong intensity on the gLMS: citric acid, 4 g/kg (sourness); caffeine, 3 g/kg (bitterness); sucrose, 200 g/kg (sweetness); and aluminium sulphate, 0.8 g/kg (astringency). Furthermore, for each sensation, appropriate food and beverages examples were recalled and discussed (table sugar was used as an example of sweetness; chicory, black coffee, and tonic water were used to recall bitter taste; fresh lemon juice was used as an example of sourness; artichokes and unripe persimmon was used to recall astringency). Participants were encouraged to join the discussion by giving their examples of food and beverages characterized by the target sensations and the appropriateness of their examples was collectively discussed. This part of the training session ended with a verbal agreement on the meaning of the target sensations.

Participants were instructed to take a spoonful of the BP sample, wait for 10 s, then swallow and evaluate the intensity of bitterness, sourness, and astringency on the gLMS. The order of evaluation of the sensations was randomized for bitterness and sourness, while astringency was always evaluated in the last position to consider its slower development.

Participants evaluated first the caffeine solution set and then the aluminum sulfate solution set both presented at five concentration levels. Participants were instructed to hold the whole tastant solution in their mouth for 3 s, then spit, wait a few seconds, and evaluate the intensity on the gLMS.

2.4.2.3. PROP phenotyping. Participants were presented with two identical 10 ml samples, each coded with a three-digit code, and instructed to hold each sample in their mouth for 10 s, then to spit, wait for 20 s, and evaluate the intensity of bitterness using the gLMS. Participants had a 90 s break to control for carry-over effects after the first sample evaluation (Monteleone et al., 2004). The average bitterness score across the 2 replicates was used for each participant. Participants were classified as non tasters - NT (PROP bitterness < 17, moderate, $n = 99$), medium tasters - MT (PROP bitterness ≥ 17, moderate and ≤ 53, very strong, $n = 234$) and super tasters - ST (PROP bitterness on gLMS $>$ very strong, 53, $n = 385$) (Fischer et al., 2013; Hayes et al., 2010).

2.5. Data analysis

2.5.1. Questionnaires

Reliability of personality and psycho-attitudinal scales was assessed by calculating Cronbach's α (Cronbach, 1951) as a measure of internal consistency. The value of 0.60 was set as the lowest acceptable limit for the satisfactory internal consistency of the measure (Bagozzi & Yi, 1988; Mohamad et al., 2015).

2.5.2. Indices for consumer clustering

Five indices to be used as input for cluster analysis were calculated for each participant considering the individual response to the two vegetable pairs taken as representative of the low and high level of recalled warning sensation vegetable groups: 1) choice index, calculated as the sum of the choices for the most bitter/sour/astringent vegetable option (range 0–2); 2) familiarity index for the most bitter/sour/astringent vegetables, calculated as the sum of the familiarity scores for radicchio and rocket salad and chicory (range 2–10); 3) familiarity index for the least bitter/sour/astringent vegetables, calculated as the sum of the familiarity scores for lettuce and valerian salad and chard (range 2–10); 4) stated liking index for the most bitter/sour/astringent vegetables, calculated as the sum of the liking scores for radicchio and rocket salad and chicory (range 2–18) and 5) stated liking index for the least bitter/sour/astringent vegetables, calculated as the sum of the liking scores for lettuce and valerian salad and chard (range 2–18).

2.5.3. Consumer clustering

A preliminary hierarchical clustering was performed using Ward's method (Ward, 1963) on the five indices of familiarity, liking, and choice for vegetables with different sensory properties. A two-cluster solution was selected based on the agglomeration schedule and dendrogram visual inspection. A K-means cluster analysis was performed with 2 clusters. The K-means clustering partition method was selected as recommended by Wajrock et al. (2008). To confirm that the derived consumer clusters had different patterns of preference and choice for vegetables with varied sensory properties, analysis of variance was performed on indices scores considering cluster as a factor. When significant effects were established, Fisher (LSD) multiple comparison tests ($\alpha = 0.05$) were carried out to determine significant differences between clusters.

2.5.4. Cluster characterization

Participants were grouped in three age classes (18–30; 31–45 and 46–74). The vast majority of participants grouped in the 46–74 class were below the age of 61 (89%). The association between cluster and, respectively, gender, age class (18–30; 31–45 and 46–74), BMI class (underweight <18.50; normal range 18.50–24.99; overweight 25.00–29.99; obese ≥ 30.00), and PROP status (NT, MT and ST) was investigated using chi-square tests. One-way analysis of variance (ANOVA) models were applied to test the effect of cluster on personality traits (FNS, SR, SP, SD, PBC, SSS, SA, TA, and SSS), PROP responsiveness, attitudes (HTAS: general health interest, light product interest, natural product interest, craving for sweet foods, food as a reward, pleasure; FRL: ways of shopping, importance of quality aspects, cooking methods, consumption situation, purchasing motives; MFLQ: moral, sacred, health, social, and aesthetic) and appetite.

Two-way ANOVA models were applied to test the effect of cluster and concentration on liking and sensory responses to bean purée samples as well as on the perceived intensity of bitterness, and astringency in aqueous solutions. When significant effects were established ($p \leq 0.05$), Fisher's LSD test was used for post hoc comparison of means.

Explanatory variables that significantly discriminated among clusters were used to perform a Partial Least Squares discriminant analysis (PLS-DA) regression model. Liking data for BP and mean intensity data on BP target sensations (bitterness, sourness, astringency) were expressed as mean values across all phenol concentrations. PLS regression models were run on standardized mean-centered input variables, using cross-validation on 20 random segments and performing a jack-knife uncertainty test with a 95% confidence interval for the detection of significant variables (Martens & Martens, 2001). The model development involved the use of 718 calibration samples. Initially, the model considered 7 factors for factor analysis. However, based on optimization criteria, it was determined that a 2 factor solution was the most suitable. To improve the model's predictive abilities, an uncertainty test was conducted using 2 factors. Due to the large amount of information collected, a two-step procedure was used (Asioli et al., 2016). In the first step, all the individual attributes were included in the model. Then, in a further step, a new model was run only including as active variables those that were found to be significant according to the uncertainty test. The other variables were included in the model as downweighed. This resulted in a better suited and more parsimonious model. All data were analyzed using XLSTAT 2021.2.2, except for the PLS-DA, which was computed using Unscrambler® 11.0.

3. Results

3.1. Consumer clusterization

Two consumer clusters were identified based on the five indices of familiarity, liking, and choice for vegetables with different sensory properties: Cluster 1 ($n = 464$, 64.6%) and Cluster 2 ($n = 254$, 35.4%). Familiarity and liking indices independently from the level of warning sensations, as well as the choice index for vegetables higher in bitterness, sourness and astringency, were always higher in Cluster 1 than in Cluster 2 (Table 3). Due to these differences, clusters were hereafter named as High Warning Vegetables Consumers (HWVC, Cl1) and Low Warning Vegetables Consumers (LWVC, Cl2). No differences in appetite before participating in the session were found among the clusters: appetite scale mean value was 32.8 for HWVC and 30.26 for LWVC ($p = 0.091$).

3.2. Differences among clusters

3.2.1. Demographics and anthropometrics

Cluster composition was compared by gender, age classes and BMI (Table 4). Gender distribution did not significantly differ between clusters. Age classes distribution differed between clusters; the proportion of individuals with older age was higher in HWVC than in LWVC while the proportion of the younger individuals was higher in LWVC than in HWVC. Significant differences were found for BMI classes distribution, with a higher proportion of normal weight individuals and lower proportion of overweight individuals that was found in HWVC compared to LWVC.

3.2.2. Differences in the perception of tastant solutions

Clusters did not differ for PROP status distribution ($p = 0.298$). A main effect of increasing caffeine concentration on bitterness ($F_{4,\ 3589} = 584.32$, $p > 0.0001$) and increasing aluminum sulfate concentration on astringency ($F_{4,\ 3589} = 549.76$, $p = 0.0001$) was found (Fig. 2). HWVC perceived bitterness as less intense as compared with LWVC ($F_{1,\ 3589} = 11.19$, $p = 0.001$), while no differences between clusters in astringency ratings were found (Fig. 3). There were no significant interactions between cluster and concentration for either sensation.

3.2.3. Cluster differences in liking for and sensory perception of bean purée samples

Liking for the bean purée samples steeply decreased with the concentration of phenols ($F_{3,\ 2871} = 517.67$, $p < 0.0001$). Mean liking scores for the BP samples were higher in HWVC (46.4) than in LWVC (44.3) ($F_{1,\ 2871} = 10.63$, $p < 0.001$). No significant cluster*concentration interactions were found. However, HWVC tended to like more the bean purée added with 1.00 g/kg of phenol extract as compared to LWVC (Fig. 4).

Bitterness ($F_{3,\ 2871} = 670.21$, $p < 0.001$), astringency ($F_{3,\ 2871} = 123.76$, $p < 0.001$) and sourness ($F_{3,\ 2871} = 516.67$, $p < 0.001$) increased with phenol concentration. Main effects of cluster were found on bitterness, $F(_{1,\ 2871}) = 15.02$, $p < 0.0001$, sourness ($F_{1,\ 2871}) = 25.72$, $p < 0.0001$) and astringency ($F_{1,\ 2871} = 23.10$, $p < 0.0001$) ratings, always rated lower for HWVC than LWVC. A significant cluster*phenol concentration was found for sourness ($F_{3,\ 2871} = 2.72$, $p = 0.043$) with LWVC rating sourness higher than HWVC only at the higher phenol concentration levels. A similar trend was observed also for bitterness and astringency even if the interaction cluster*phenol concentration was not significant (Fig. 5).

3.2.4. Cluster differences in psychographics

The computed Cronbach's alpha on the psychographics measures showed a good internal consistency of most questionnaires. The "Pleasure" subscale of the Health and Taste Attitudes Scale as well as the "Cooking methods"and "Consumption situation" subscales of the Food-Related Lifestyles and the "Moral" and "Social" subscales of the Meaning of food in life questionnaire were not considered due to low internal reliability (Cronbach's alpha below 0.60). Several differences were found between the two clusters in terms of personality traits and food attitudes (Table 5).

HWVC showed scores significantly lower than LWVC for traits that have been associated with arousal or anxiety, namely Food Neophobia, Sensitivity to Punishment, Sensitivity to Reward, State Anxiety and Trait Anxiety. In contrast, HWVC had higher ratings than LWVC of Private

Table 4
Cluster characteristics expressed in percentages for High-Warning Vegetable Consumers (HWVC) and Low-Warning Vegetable Consumers (LWVC). Significant differences among clusters are in bold ($p \leq 0.05$).

Variables (%)	HWVC	LWVC	Chi-Square/F	*p*-Value
Gender				
Women	55.4	50.4	3.84	0.199
Men	44.6	49.6		
Age class				
18–30	**27.2 <**	**58.7 >**	5.99	**0.050**
31–45	**33.4 >**	**21.7 <**		
46–74	**39.4 >**	**19.7 <**		
BMI				
Underweight	2.8	5.2	7.81	**0.034**
Normal weight	**67.5 >**	**57.1 <**		
Overweight	**23.4 <**	**30.6 >**		
Obese	6.3	7.1		

Table 3
Differences by cluster: High-Warning Vegetable Consumers (HWVC) and Low-Warning Vegetable Consumers (LWVC) in choice, familiarity and liking for vegetables with varied sensory properties. Different letters indicate a significant difference ($p < 0.05$).

Variables	Range	Cluster 1 HWVC	Cluster 2 LWVC	F-value	*p*-Value
Choice index for vegetables higher in bitterness, sourness and astringency	0–2	0.91^a	0.76^b	8.16	0.012
Familiarity index for vegetables higher in bitterness, sourness and astringency	2–10	8.46^a	6.32^b	359.48	<0.0001
Familiarity index for vegetables lower in bitterness, sourness and astringency	2–10	8.88^a	7.00^b	277.88	<0.0001
Stated liking index for vegetable higher in bitterness, sourness and astringency	2–18	14.56^a	7.45^b	1023.25	<0.0001
Stated liking index for vegetable lower in bitterness, sourness and astringency	2–18	15.07^a	9.27^b	631.97	<0.0001

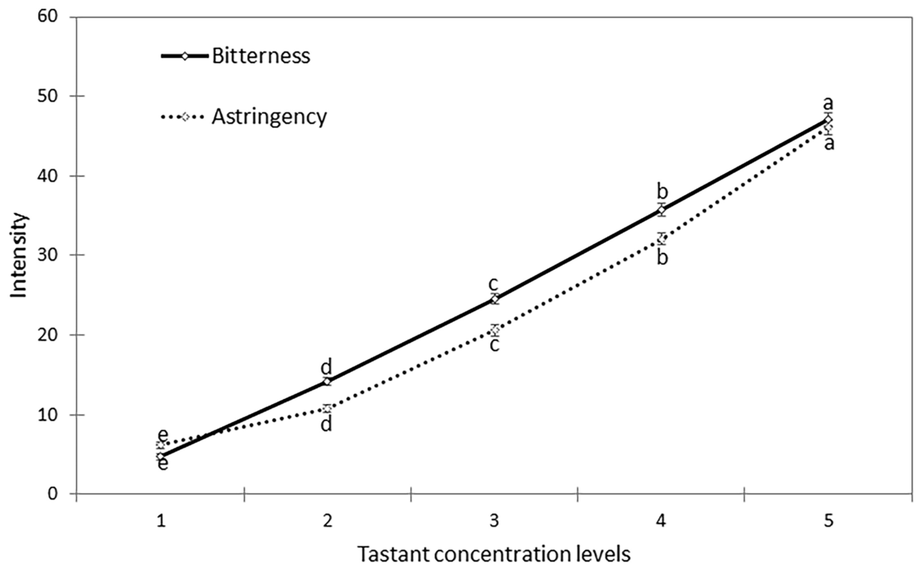

Fig. 2. Mean intensity ratings of bitterness and astringency in water solutions as a function of tastant concentration. For each series separately, different letters indicate a significant difference in the Fisher's LSD post hoc test (p<0.05).

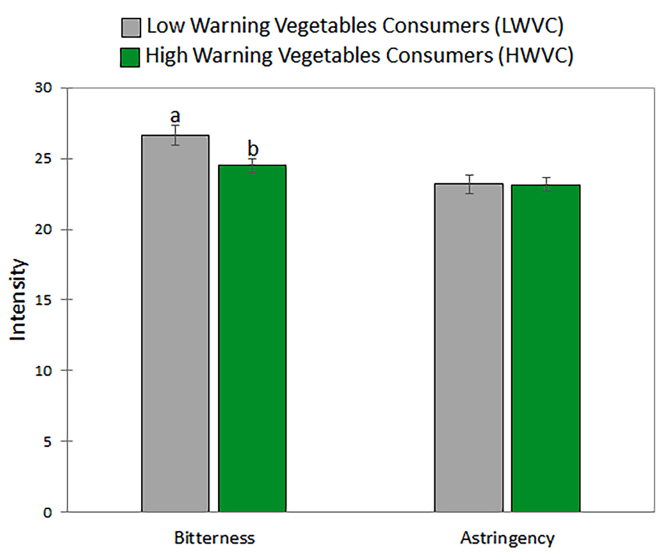

Fig. 3. Bitterness and astringency mean intensity ratings in water solutions for Low Warning Vegetables Consumer (LWVC) and High Warning Vegetables Consumer (HWVC) clusters. Different letters indicate a significant difference in the Fisher's LSD post hoc test (p<0.05).

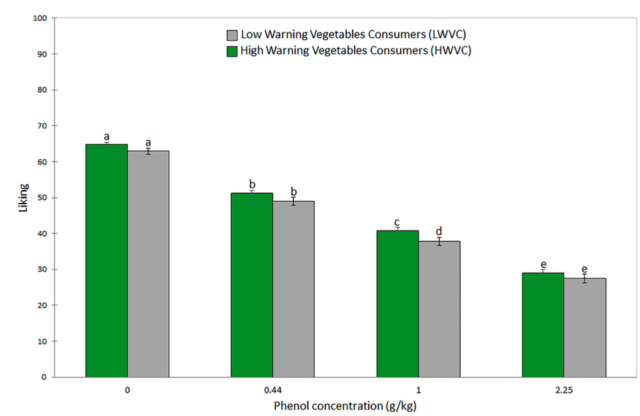

Fig. 4. Mean liking ratings for the bean purée samples (0.44, 1.00, and 2.25 g/kg of phenol extract from olive mill wastewater added) for Low Warning Vegetables Consumers (LWVC) and High Warning Vegetables Consumers (HWVC) clusters as a function of phenol concentration. Different letters indicate a significant difference in the Fisher's LSD post hoc test.

Body Consciousness. No significant cluster differences were found for Sensitivity to Disgust, and Sensation Seeking Scale.

A main effect of cluster was found also for several food attitudes that have been associated with the adoption of healthier diets: natural product interest (HTAS subscale), ways of shopping, importance of quality aspects, cooking methods and purchasing motives (FRL subscales), moral, social, sacred, health, and aesthetic (MLFQ subscales). HWVC showed scores for all the significant food attitudes higher than LWVC.

3.2.5. Associations between variables and cluster membership

The PLS-DA regression model was used to summarize the variables that mainly predict cluster membership. In the PLS-DA, the cross-validation indicated that one factor had a significant prediction ability and was used in the jack-knife test for estimating the uncertainty of the model parameters. The explained variance for the first two components was 13% and 8% for X and 17% and 2% for Y. On the first component, age classes 31–45 and 46–74, normal weight, sacred subscale of MFLQ as well as the importance of quality aspects subscale of the FRL were positively associated with HWVC, while age class 18–30, overweight, sensitivity to reward, and food neophobia were negatively associated with HWVC and positively associated with LWVC (Fig. 6).

4. Discussion

4.1. Consumer segmentation based on vegetable preference and sensory properties

A consumer segmentation approach based on the self-reported preference for vegetables with varied sensory properties was applied to a large population sample. Two consumer clusters HWVC and LWVC were identified, representing different patterns in terms of liking for, familiarity with, and choice of vegetables with different intensity of warning sensations, i.e. bitterness, astringency, and sourness. A cluster (HWVC) was found to like, consume and be more familiar with all vegetables, independently from their sensory characteristics, compared

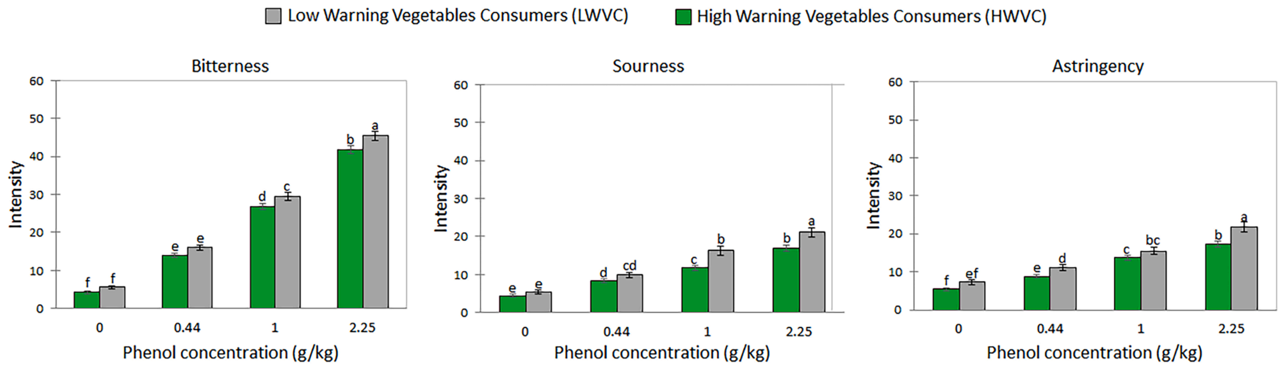

Fig. 5. Bitterness, sourness and astringency mean intensity ratings in bean purée (0.44, 1.00, and 2.25 g/kg of phenol extract from olive mill wastewater added) for Low Warning Vegetables Consumers (LWVC) and High Warning Vegetables Consumers (HWVC) clusters as a function of phenol concentration. Different letters indicate a significant difference in the Fisher's LSD post hoc test.

Table 5
Differences between Low Warning Vegetables Consumers (LWVC) and High Warning Vegetables Consumers (HWVC) in personality traits and food attitudes. For each trait, Cronbach's α, mean scores by cluster, F- and p-values are reported. Significant differences are in bold. Only domains with satisfactory internal consistency are reported (Cronbach's α >0.6). Different letters indicate a significant difference ($p < 0.05$).

Variables	Cronbach's α	HWVC	LWVC	F	*p*-Value
Personality measures					
Food Neophobia (FN)	**0.88**	**26.35**^{b}	**30.23** ^{a}	**18.46**	**< 0.0001**
Sensitivity to Punishment (SP)	**0.84**	**8.58**^{b}	**9.93** ^{a}	**11.96**	**< 0.001**
Sensitivity to Reward (SR)	**0.78**	**5.30**^{b}	**6.33** ^{a}	**13.2**	**< 0.0001**
Sensitivity to Disgust (SD)	**0.67**	29.04	29.87	3.48	0.063
Private Body Consciousness (PBC)	**0.74**	**17.57** ^{a}	**16.80**^{b}	**4.88**	**0.027**
State Anxiety (SA)	**0.89**	**30.91**^{b}	**32.66** ^{a}	**10.60**	**< 0.001**
Trait Anxiety (TA)	**0.91**	**39.91**^{b}	**41.80** ^{a}	**7.55**	**0.006**
Sensation Seeking Scale (SSS)	**0.89**	95.40	95.14	0.044	0.835
Food attitudes					
Health and Taste Attitudes Scale (HTAS)					
General Health Interest (GHI)	**0.79**	4.07	4.04	0.34	0.528
Light Product Interest (LPI)	**0.81**	3.93	3.89	0.49	0.483
Natural Product Interest (NPI)	**0.74**	**3.87** ^{a}	**3.76**^{b}	**5.28**	**0.022**
Craving for Sweet Foods (CSF)	**0.82**	3.42	3.53	1.95	0.163
Food as a Reward (FR)	**0.78**	4.22	4.29	1.67	0.196
Food-Related Lifestyles (FRL)					
Ways of shopping	**0.75**	**4.63** ^{a}	**4.51**^{b}	**4.60**	**0.032**
Importance of quality aspects	**0.75**	**5.31** ^{a}	**5.01**^{b}	**33.80**	**< 0.0001**
Purchasing motives	**0.63**	**5.08** ^{a}	**4.95**^{b}	**5.28**	**0.022**
Meaning of Food in Life Questionnaire (MFLQ)					
Sacred	**0.64**	**3.62** ^{a}	**3.23**^{b}	**11.77**	**< 0.001**
Health	**0.64**	**5.72** ^{a}	**5.53**^{b}	**6.70**	**0.008**
Aesthetic	**0.60**	**5.72** ^{a}	**5.49**^{b}	**11.30**	**< 0.001**

to another cluster of participants (LWVC). These patterns derived from self-reported vegetable preference correspond to differences in liking for and perception of model food developed to elicit varied intensity of the same warning sensations. Participants showing higher self-reported preferences for vegetable characterized by warning sensations (HWVC) also showed higher liking for been puree cream enriched with phenols and characterized by bitterness, astringency, and sourness and lower responsiveness to these sensations. This, in turn associates to a lower expression of traits associated with arousal and anxiety, higher attitudes toward healthy eating and natural products and higher attention to food purchase and to its quality aspects. Thus, these data depict a coherent interplay among perception and acceptance of food connoted by warning sensations in association with individual variation in psycho-attitudinal traits.

4.2. Oral responsiveness and vegetable food acceptance

Data from the present study show the clear association between oral responsiveness and vegetable food acceptance. LWVC individuals were more responsive to critical sensations (bitterness, sourness, and astringency) and showed lower familiarity with vegetables and lower liking for both vegetables and phenol-enriched food model. Thus, the heightened perception of warning sensations not only reduces the acceptance of vegetable food characterized by those sensations but seems to act as a barrier to liking and consumption of the food category. Exposure is a key determinant of preference learning mechanism (Yeomans, 2006); it appears that the negative affective reactions induced by the perception of intense and generally disliked sensations discourages the consumption of the specific food items inducing such sensations and this expands to the food category with a kind of negative feedback loop (low exposure-low preference-low consumption). Taken together these data confirms that individual variation in responsiveness to warning sensations has an important role in determining barriers to vegetable consumption (Tepper, 2008; Duffy et al., 2010; Dinnella et al., 2011; Puputti et al., 2019).

Differences in perception of the target sensations in the food model were more discriminant among clusters than differences perceived in water solutions. HWVC were less responsive than LWVC to all the target sensations in food model while differed only for perception of bitterness from caffeine solutions. The lack of significant differences among clusters for astringency perception in solution might be due to difficulties in recognizing this sensation in a non-food context and to the bitter, sour,

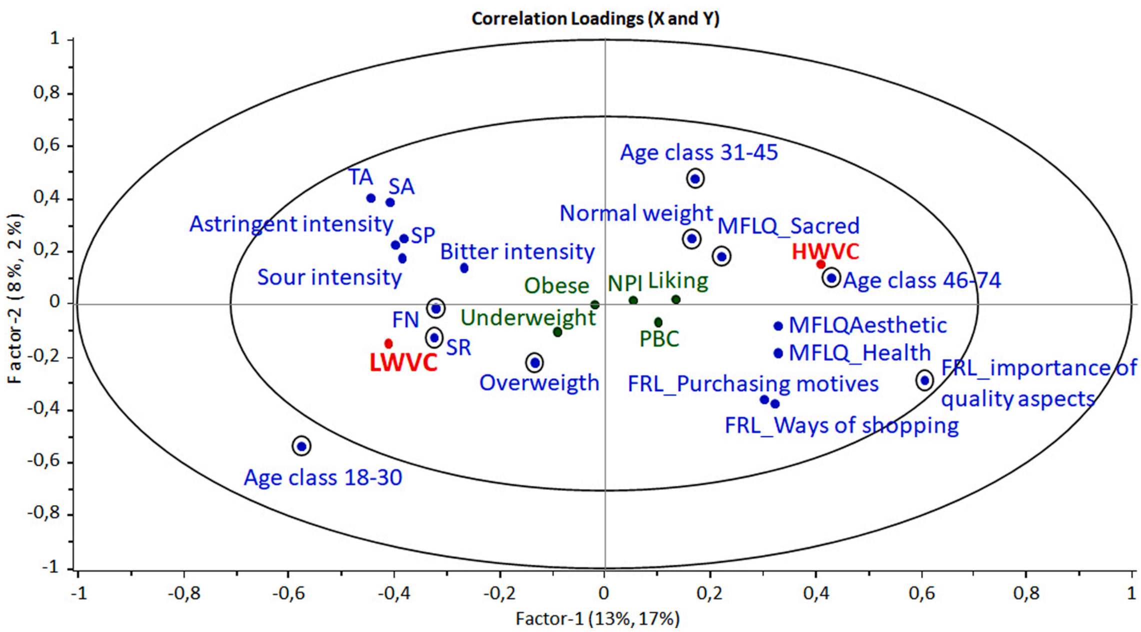

Fig. 6. Correlation loadings from PLS-DA model. Variance accounted for X and Y for PC 1 and PC2 are reported in brackets. Important variables (based on the uncertainty test) are circled. In green are the downweighted variables.

and sweet side taste qualities of the stimulus (Fleming et al., 2015). No difference in PROP bitterness perception was found among clusters. Results on associations between responsiveness to PROP and vegetable preference and consumption are conflicting, with some recent studies showing a lack of association of bitter vegetable preference with responsiveness to PROP (Gajari et al., 2022; De Toffoli et al., 2019b; Laureati et al., 2018) while other providing evidence of such a relationship (Duffy et al., 2020; Mezzavilla et al., 2019). The relatively low correlation between the perception of PROP and the perception of the other oral sensations (Dinnella et al., 2018; Nolden et al., 2020) might at least in part account for the inconsistency of the results on association between responsiveness to PROP and perception and intake of bitter vegetables. In general, the results of the present work indicate that responsiveness to sensations in water solutions do not necessarily reflect sensory and hedonic responses to food. The adoption of food models specifically developed to induce varied levels of the target sensations allow to collect intensity measures and related liking responses in a food context and appears a more precise and ecological approach for interpretative purpose of food behaviors.

4.3. The role of psychological traits in relation to vegetable preference

Differences in liking could be also mediated by higher levels of arousal when eating food and/or drinking beverages that are perceived as unpleasant and potentially dangerous as suggested by Laureati et al., (2018) for neophobics. In general, the proposed clustering methodology indicated the relevant role of psychological traits in determining barriers to the consumption of vegetables characterized by warning sensations.

Anxiety, food neophobia, sensitivity to reward and to punishment were higher in LWVC as compared to HWVC. The effect of anxiety is in line with previous findings, which showed that low-anxious individuals consume more fruit and vegetables (Ocean et al., 2019). The higher food neophobia score found among LWVC as compared to HWVC is coherent with previous research that highlighted a negative relationship between food neophobia and intake, particularly of vegetables, fruits, and protein foods (Costa et al., 2020; Hazley et al., 2022; Jaeger et al., 2017; Knaapila et al., 2011; Rabadán & Bernabéu, 2021). Furthermore neophobia has been associated with lower liking for vegetables both in adults (Jaeger et al., 2021; Laureati et al., 2018) and adolescents (Appleton et al., 2019) as well as lower familiarity for vegetables which are characterized by higher levels of alarm stimuli (i.e. bitterness, sourness, astringency) (De Toffoli et al., 2019). Furthermore, higher reward and punishment sensitivity were both found to be associated with a lower appreciation of vegetables, in line with previous studies reporting an association between these traits and a greater intake of unhealthy foods (Tapper et al., 2015) and lower liking of vegetables with bitter and pungent taste (Monteleone et al., 2017).

Vegetables characterized by strong bitterness, sourness, and astringency could elicit higher levels of arousal due to the perceived dangerousness and high intensity of these sensations (Berlyne, 1970; Giacalone et al., 2014). According to Galloway et al. (2003) and Pliner & Melo, (1997), individuals who are high sensation seekers, meaning those who need a lot of stimulation to achieve the right level of excitement, are more receptive to new food experiences and less neophobic. Given the links with these traits, it is surprising that the clusters did not differ in sensation seeking. This suggests perhaps the fact that the variation of sensory properties found in vegetables could not be enough to constitute a factor capable of influencing the perception and the appreciation of vegetables of high and low sensation seekers. This lack of results is also in line with Terasaki & Imada, (1988) that found sensation seeking to be not related to the preference for vegetables but for spicy foods, meats, and alcoholic beverages.

Other than psychological traits linked to arousal activation, also aspects of sensory sensitivity such as private body consciousness characterized HWVC. PBC theory predicts that this trait is positively correlated with the sensitivity to changes in bodily states and that this is linked to an enhanced awareness of sensory characteristics in food products consumed, and a higher ability to discriminate between products based on sensory attributes (Jaeger et al., 1998). The association between PBC and food preferences is however not completely clear. For instance, while pungent sensations from piperine and capsaicin were found to be greater among high PBC individuals (Stevens, 1990), a more recent study failed to show any link between PBC and pungency (Byrnes & Hayes, 2013) or liking of spicy meals (Byrnes & Hayes, 2013, Spinelli et al 2018). Nevertheless, in the present study, PBC was positively correlated with preference for vegetables connoted by the “warning” sensations of bitterness and astringency. We can hypothesize that high PBC individuals may be able to detect the finer nuances of different sensory properties while low PBC individuals may not be able to detect other than the most prominent sensory properties present in vegetables. This effect could result in an enhanced perception of the intensity of unappealing sensations that could contribute to product disliking in LWVC group.

4.4. The influence of age and lifestyle on vegetable food choices

HWVC rated the natural/organic product interest subscale of HTAS higher than LWVC thus indicating that this aspect highlights different motivations in food choice between the two clusters. This observation is supported by previous findings showing that natural product interest was associated with familiarity with plant-based dishes and higher interest in health (Cliceri et al., 2019; Roininen et al., 1999; Saba et al., 2019) as well as with interest in products enriched with pro-health compounds (Caracciolo et al., 2019). Consumers belonging to HWVC showed higher scores also in the FRL subscales ways of shopping, importance of quality aspects, and purchasing motives, as compared to LWVC. HWVC cluster was composed by consumers whose way of shopping was more characterized by attention to product information and price as well as a higher motivation to do the shopping list and buy food in specialty stores as compared to LWVC. Time dedicated to preparing meals and seeking novelty in food preparation coupled with the preference for organic, fresh and healthy products were also aspects that characterized more HWVC as compared to LWVC. In general, HWBC group appears to assign higher importance to the food dimension as a whole than LWVC group.

Gender was not found to affect vegetable food preferences and consumption, while increased preference and consumption of vegetables was associated with age, consistently with previous data indicating that healthy eating motivations become stronger with increasing age (Hearty et al., 2007; Kearney et al., 1998; Roininen et al., 1999; Saba et al., 2019) and also that older Italians have greater adherence to culinary traditions, particularly the strongly vegetable-focused Mediterranean diet (Dinu et al., 2021; Predieri et al., 2020; Sofi et al., 2010). Thus, the traditional lifestyle of older Italians includes the common practice to grow vegetables or buying them in local shops associated with the availability of a wide variety of vegetables that represent the cheapest and most convenient options according to the season (Appleton et al., 2017). These observations pointed out that the HWVC cluster was composed of consumers that were more focused on food quality and that includes a variety of vegetables in their way of eating. Conversely, younger participants may pay less attention to product information and could be more interested in price. These observations are further substantiated by a large-scale study on a subsample ($n = 1224$) within the Italian Taste project (Saba et al., 2019) in which it was observed that people more convenience-oriented and less interested in product information and food quality had a higher probability to have a lower interest in food-related health. Furthermore, a negative association between vegetable preferences and consumption and BMI was found in line with previous studies (Azagba & Sharaf, 2012; Rolls et al., 2004; Tohill et al., 2004).

Higher scores in MFLQ subscales sacred, health, and aesthetic were found in HWVC as compared to LWVC. Even in this case, the observations were coherent with previous findings that highlighted that the sacred, health and moral factors of the MFLQ were significantly and positively associated with daily servings of vegetable intake (Arbit et al., 2017), although in the present study only a comparison of three out of five domains of MFLQ among cluster was possible due to a lack of internal consistency of the moral and social subscales.

4.5. Exploring key factors influencing vegetable acceptance: Personality traits, age, and BMI

An important consideration in the measurement of a wide variety of different variables in determining responses to foods is the ability to identify the 'key' factors that influence acceptance. The PLS regression models allowed the examination of the main factors that acted as barriers or facilitators of the consumption of vegetables. Our findings indicate that personality traits, age and BMI significantly associated with different preference and familiarity for vegetables as a whole and as groups with varied level of warning sensations. Furthermore, these factors associate with the acceptance and perception of plant-based model foods prepared to induce different level of bitterness, astringency, and sourness thus highlighting the importance of the responsiveness to warning sensations in determining vegetable acceptance. The dimension of anxiety appears to act as a barrier for a wider adoption of vegetables for the alerting effect of their sensory properties but also for vegetables that are less characterized by unappealing sensory properties. On the other hand, the adoption of a diet rich in vegetables could be fostered by attitudes related to the importance of health dimension and quality aspects of food related lifestyle. Taken together these results suggest also that anxiety-related personality traits and higher taste responsiveness together with younger age may act as barriers to the acceptance of enriched foods functionalized with phenols.

4.6. Practical implications

This study provides valuable insights into consumer preferences and sensory properties that influence the acceptance of vegetables. This information can be utilized by food companies to develop new vegetable-based products that cater to different types of consumers. By modulating the perception of unpleasant sensations like bitterness, astringency, and sourness, companies can enhance the appeal of vegetable dishes and increase their acceptance among individuals who are more sensitive to these sensations.

The study also identifies distinct consumer clusters, which can guide targeted marketing and communication strategies. Food companies can customize their messaging and advertising to specific segments based on their preferences and psychological characteristics. For instance, for individuals who already have a preference for vegetables, emphasizing the health benefits and natural aspects of vegetable products may be effective. On the other hand, for individuals who are hesitant to try new foods and have higher levels of anxiety, it would be more effective to address their concerns, provide information about the safety and quality of vegetable products, and offer recipes and tips for gradually incorporating vegetables into their diets.

Furthermore, the findings of this study can inform educational interventions aimed at raising awareness about the health outcomes associated with dietary choices and strategies to manage anxiety and reduce reluctance of trying new foods. By providing targeted educational materials, individuals can gain knowledge about the nutritional value of vegetables and the benefits of a healthy diet, while also learning techniques to overcome anxiety and neophobia related to food. These interventions may include information on the nutritional content of vegetables, cooking demonstrations and suggested recipes, and resources that help individuals build confidence in trying new foods.

5. Conclusions

The proposed clustering approach based on sensory-driven preference was applied to a large population sample and appeared effective for elucidating key factors of vegetable food acceptance and consumption. The results depict a coherent interplay among several personal dimensions in modulating preference for vegetable foods. Higher responsiveness to warning sensations, higher level of reward and anxiety-related traits, lower importance assigned to food healthy/quality aspects all act as barriers to exposure and acceptance of vegetable food and call for multidimensional approach to promote the consumption of this food category. This opens the possibility to take action to promote healthier eating behaviors in targeted consumer groups by designing interventions based on the development of vegetable-based recipes masking unappealing sensations, educational intervention to promote awareness on health-related diet outcomes and strategies to manage anxiety and reduce food neophobia.

CRediT authorship contribution statement

L. Pierguidi: Validation, Formal analysis, Data curation, Writing – original draft, Visualization. **S. Spinelli:** Conceptualization, Methodology, Writing – review & editing. **J. Prescott:** Conceptualization, Methodology, Writing – review & editing. **E. Monteleone:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition. **C. Dinnella:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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