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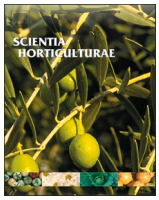

Research Paper

European fresh-market tomato sensory ideotypes based on consumer preferences

Joan Casals [a,*], Roser Romero del Castillo [a], Clara Pons [b,c], Andrea Mazzucato [d], Ivanka Tringovska [e], Gancho Pasev [e], Amalia Barone [f], Salvador Soler [c], Ludovica Fumelli [d], Stanislava Grozeva [e], Daniela Ganeva [e], Jaime Prohens [c], Maria José Díez [c], Antonio Granell [b,**]

[a] Department of Agri-Food Engineering and Biotechnology/Miquel Agustí Foundation, Universitat Politècnica de Catalunya, Campus Baix Llobregat, Castelldefels, Spain
[b] Instituto de Biología Molecular y Celular de Plantas (IBMCP), Consejo Superior de Investigaciones Científicas (CSIC), Universitat Politècnica de València, València, Spain
[c] Instituto de Conservación y Mejora de la Agrodiversidad Valenciana (COMAV), Universitat Politècnica de València, València, Spain
[d] Department of Agriculture and Forest Sciences (DAFNE), Università degli Studi della Tuscia, Viterbo, Italy
[e] Maritsa Vegetable Crops Research Institute, Agricultural Academy, Plovdiv, Bulgaria
[f] Department of Agricultural Sciences, University of Naples Federico II, Portici, Italy

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ABSTRACT

Tomato consumer liking results from the interaction between the fruit's characteristics and human senses, shaped by diversity among consumers regarding physiology, culture and past consumption experiences. Rather than a unique preference, consumers can be segmented into different sensory clusters (sensoclusters). This study investigates European consumer preferences for general-supermarket tomatoes and compares them with preferences for renowned landraces in local markets. Based on the results of two focus groups, online surveys were designed to collect consumer preferences related to fruit external and internal appearance, ripening stage, odor, flavor and texture attributes. Preferences obtained from 2333 consumers revealed the existence of different sensoclusters. For the General Survey five sensoclusters were identified, and according to the sensory attributes enriched in each the profiles "tasty tomato" (22.9% of the surveyed population), "cherry-sweet tomato" (11.3%), "light-flavor tomato" (21.6%), "beefsteak-tomato" (31.2%), and "unripen tomato" (12.0%) were described. The most discriminant sensory attributes were the ripening stage, taste intensity, sweetness, typical tomato odor, hollowness, juiciness, and skin perception. General consumer preferences were also identified, such as the preference for fruits with calyx (75.4%), uniform green shoulder (73.1%), and medium sweetness (64.9%). For Bulgarian Oxheart and Valenciano landraces we identified three and two sensoclusters, respectively, indicating the need to diversify breeding efforts to meet consumers' expectations. By contrast, Montserrat landrace consumers are mostly included in a single sensocluster. Sensoclusters presented in this work can be translated in sensory ideotypes for plant breeding programs, with the aim of targeting specific consumer segments.

1. Introduction

Tomato is one of the most consumed vegetables around the world, with a mean supply of 20.9 kg/year per capita, reaching in some Mediterranean countries >50 kg/year per capita (FAO, 2020). Tomato has shown a general growing trend for yield and global production over the last decades, increasing its contribution to the human diet (Fernie and Yan, 2019). In developed countries such as Spain, it is one of the vegetables preferred by young people (Pérez-Rodrigo et al., 2003). It is a species in which sensory attributes exert a substantial influence on consumers' perception of quality (Bruhn et al., 1991; Jürkenbeck and Spiller, 2021). Since the 1980s, consumers have been complaining about the sensory quality of tomatoes, as evidenced by publications such as Kramer's "The ruination of the tomato" (1980), and Hobson's "How the tomato lost its taste" (1988), or the popular surname "water bombs" that was used in German media (Schouten et al., 2019). The lack of flavor in

* Corresponding author at: Department of Agri-Food Engineering and Biotechnology/Miquel Agustí Foundation, Esteve Terrades 8, 08860 Castelldefels, Spain.
** Corresponding author at: Instituto de Biología Molecular y Celular de Plantas (IBMCP), Enginyer Fausto Elio, 46011 València, Spain.
E-mail addresses: joan.casals-missio@upc.edu (J. Casals), agranell@ibmcp.upv.es (A. Granell).

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modern tomatoes has been described as a sensory sacrifice resulting from 50 years of breeding efforts to meet the high-yield, pest resistance, immaculate appearance, and long storage ideotype of the supply chain (Folta and Klee, 2016). Other factors such as inadvertent selection for genes that negatively affect quality, either during domestication (Tieman et al., 2017b) or recent breeding (Powell et al., 2012; Zhu et al., 2018), have also caused negative sensory tradeoffs. In this context, some landraces, which have not gone through this commercial breeding process, have emerged as cultural icons representing the taste of the tomato ("the flavor of the past" belief) (Jordan, 2007).

The overall sensory sensation of tomatoes is the result of integrating the different sensory stimuli generated by taste and smell (flavor, odor), sight (fruit appearance), touch, and hearing (texture and firmness) in the brain (Goff and Klee, 2006). Tomato flavor and odor are generated from both primary and secondary metabolites, mainly sugars, acids, and volatile compounds (Baldwin et al., 2000; Buttery et al., 1987; Colantonio et al., 2022; Tieman et al., 2017a). Genomic studies have deciphered the genetic architecture of tomato flavor (Zhao et al., 2019; Zhu et al., 2018), appearance (Monforte et al., 2013), and texture-related attributes (Causse et al., 2003). These advances, coupled with the progress in the knowledge of the pre-harvest factors that affect quality (Bertin and Génard, 2018), may allow increase tomato consumer acceptance. Focused on fruit flavor since the 1990s, breeding programs have incorporated new genetic variability into modern varieties, which is reflected in an increase in the diversity of aroma volatiles (Schouten et al., 2019). Studies comparing consumer liking of modern and landrace varieties start to yield comparable appreciation results (Sinesio et al., 2021; Tieman et al., 2017a), which may reflect an improvement in quality of modern varieties. This is coupled with the diversity of sensory profiles found in landraces, which comprise both flavorful and less flavorful genotypes (Casals et al., 2011; Casañas et al., 2017).

Several studies have successfully used genomic or metabolomic data to create models for predicting consumer overall liking (Colantonio et al., 2022; Tieman et al., 2017a). These promising outcomes suggest the potential integration of these screening tools into breeding programs. Metabolomic prediction for flavor, sourness, or sweetness yields high accuracy, but much lower accuracy is obtained for overall liking (Colantonio et al., 2022), which is the most important character for the consumer. Consumer overall liking is not a deterministic result of the fruit's chemical composition but is rather shaped by individual physiology, psychology, past experience, tradition, and by the culinary preparation in which the tomato is consumed (Bartoshuk and Klee, 2013; Goff and Klee, 2006). Rather than a universal "tomato overall liking", the cultural and biological diversity among consumers, and also the diversity of varietal types that exist within the fresh-market tomato, are translated into different consumer preferences. For instance, consumer sensory expectations for salad and cherry tomato types present important differences (Casals et al., 2018; Hobson and Bedford, 1989). Previous reports have described the existence of different tomato consumer segments, either using sensory analysis combining the results of consumer and trained panels (Berna et al., 2005; Causse et al., 2010; Pagliarini et al., 2001; Rocha et al., 2013; Sinesio et al., 2010), or online simulated choice-experiments (Jürkenbeck et al., 2020; Jürkenbeck and Meyerding, 2019; Oltman et al., 2014). These reports focused on specific varietal types (fresh-market or cherry), regions, or in dissecting the effect of label quality signals on consumers' responses. A broader view is now needed to identify tomato fresh-market sensory preference groups, which will allow aligning tomato plant breeding programs to consumer preferences, and to improve the accuracy of molecular phenotyping to predict overall liking (Klee and Tieman, 2018). In this paper, we conducted and analyzed an extensive online survey that allowed us to define sensory clusters for the European fresh-market tomato. To get further insights into the consumer expectations of tomato fruit quality, we also explored consumer preferences behind specific European landraces that consumers recognize for their 'superior' quality.

2. Methods

2.1. Experimental overview

Two focus groups were conducted to define a list of sensory attributes relevant for consumers and subsequently refine the list to target the local characteristics of each landrace/group of consumers. We conducted the focus groups to scan the maximum width of the tomato sensory landscape, taking advantage of hidden information that can appear in open discussions with specialists. This exercise was necessary to decide lists of attributes related to purchase intention, sensory profile and socio-demographic membership, necessary to characterize European tomato consumers. Following the guidelines developed by the two focus groups, five surveys were designed, one general and four for specific selected tomato landraces (Montserrat, Valenciano, Bulgarian Oxheart and San Marzano). The primary objective of these surveys was to delineate the principal sensory clusters within the European fresh tomato market (General Survey) and to juxtapose them with tomato landraces, thereby facilitating an understanding of the sensory expectations held by consumers who are currently consuming these varieties. These landraces were selected to represent different states of in situ conservation: varieties with very local distribution and consumed by a small group of citizens (Montserrat, Valenciano) on the one hand, and varieties with international fame and consumed at the country level (San Marzano, Bulgarian Oxheart) on the other. The five online surveys were conducted in parallel, the general open to any European consumer, and the four devoted to local landraces open only to consumers from the areas of origin of each variety. Each survey data was analyzed independently, using different multivariate procedures to classify consumers in sensory clusters.

2.2. Survey design using a focus group discussion methodology

Two focus group sessions (FG) were conducted, each moderated by one facilitator, to formulate the foundation for the development of the five surveys. The initial focus group (FG1) comprised two farmers, two tomato breeders, and a chef. The primary objective of FG1 was to generate an extensive inventory of sensory attributes essential for the consumer survey. The moderator guided discussions using a predefined framework (Table S1), in line with recommendations from previous research (Chung et al., 2011; Lawless and Heymann, 2010). To address appearance attributes, fruit photographs were used. The second focus group (FG2) comprised 11 tomato researchers representing Spain (3), Bulgaria (4), and Italy (4). These researchers were selected based on their understanding of the designated tomato landraces. Initially, all participants proposed intensity levels for the sensory attributes chosen in FG1, forming the basis for the General Survey. Subsequently, each participant refined attribute lists and corresponding scales, drawing from their familiarity with natural variability in their respective landraces. FG sessions were conducted online and recorded for future reference. Subsequently, three researchers reviewed independently the recordings, cataloging attributes and scales for survey integration. Attributes cited by two-thirds or more of the FG participants were generally chosen for inclusion.

2.3. Survey description

Surveys were implemented on-line using the SurveySparrow® platform. The surveys included 29 common questions related to the socio-demographic profile of the participant (age, gender, socio-professional group, level of education, country of residence), consumption habits (shopping place, frequency of consumption, preparations in which the tomato is consumed), and preferred sensory attributes (Table S2). We examined the comprehensive sensory profile (*sensu lato*), encompassing all attributes perceptible by the human senses. Sensory attributes were related to fruit external (fruit size, fruit color, fruit shape, fruit ribbing,

fruit shoulder shape, green shoulder, presence of calyx), and internal appearance (hollowness, proportion of flesh and pericarp), ripening stage at consumption, odor (presence/absence of odor descriptors tomato ID, herbaceous, fruity, floral, earthy), flavor (sweetness, acidity, tomato ID taste intensity), and texture (juiciness, mealiness, and skin perception). We defined "tomato ID" as the aromatics and flavors associated with ripen tomato (Hongsoongnern and Chambers, 2008). Participants were also asked to express their consumption beliefs: (a) rating different management factors according to their importance in the final fruit quality (levels: fruits recently harvested, organic farming, ancient varieties, local production), (b) answering if they agree with the statement that "tomato has no longer taste", using a four-point scale (0 (disagree) to 3 (totally agree)). For all questions we randomized the order of items within a question, to avoid any order bias effects, unless there was a logical order to the items (e.g. fruit size). A single choice answer was allowed in all the questions, except for the variables "shopping place", "preparations in which the tomato is consumed", and "odor descriptors", for which different answers were allowed to be selected. The levels of these variables were treated as independent variables (presence/absence). Appearance attributes were illustrated using drawings made specifically for each survey, to facilitate respondents' understanding of the attribute (Fig. 1). The survey was designed in English, and translated into the languages of the main regions where it was disseminated (Bulgarian, Catalan, Dutch, French, and Spanish).

2.4. Data collection

The surveys were open from 01th December 2021 to 30th June 2022 and disseminated via multiple streams: personal contacts, local media, farmer cooperatives, chefs' associations, the European Citizen Science platform, and social media. Surveys were considered valid if the respondent answered a minimum of 80% of the questions, with no missing values for the sensory attributes. Surveys with less than 100 respondents were not considered in further analyses.

2.5. Ethics declaration

In order to comply with ethical standards and current legislation to collect personal data (General Data Protection Regulation (EU Regulation 2016/679)), participants were asked to agree with an informed consent at the beginning of the survey. The informed consent detailed that participation was voluntary and free and that data would be collected and treated anonymously and used solely for research purposes. Participants were informed of the name and contact details of the researchers who would analyze the data. Participants were informed that they could withdraw from the survey at any time without giving any reason. Ethical approval for the involvement of human subjects in this study was granted by the Research Ethics Committee of the Polytechnic University of Valencia (Reference number P10_16_11_20).

2.6. Statistical analysis

All the analyses were performed with R (R Core Team, 2020). For categorical variables, we performed descriptive analysis and calculated frequencies and contingency tables. To detect enriched attributes, deviation from equal distribution was calculated with the chi-square test (function "goodnessOfFitTest" of the *lsr* package).

A Multiple Correspondence Analysis (MCA) was then performed on each survey, with sensory attributes as active variables, and sociodemographic and consumption habit as supplementary variables (which do not contribute to the principal coordinates (PCo)) with package *FactoMineR* (Lê et al., 2008). Variable contribution to each PCo was assessed using the 'fviz_contrib' function, considering only significant correlations (chi-square test). Hierarchical cluster of principal components (HCPC) was performed in *FactoMineR* (Lê et al., 2008) using Euclidean distances and the Ward's minimum variance method with the first 40 MCA PCo components (>80% of the total variance). For each survey, the optimal number of clusters was determined using the *NbClust* package. Twenty-six indices were computed (KL, CH, Hartigan, CCC, Scott, Marriot, TrCovW, TraceW, Friedman, Rubin, Cindex, DB, Silhouette, Duda, PseudoT2, Beale, Ratkowsky, Ball, PtBiserial, Frey, McClain, Dunn, Hubert, SDindex, Dindex, SDbw), with the retention of

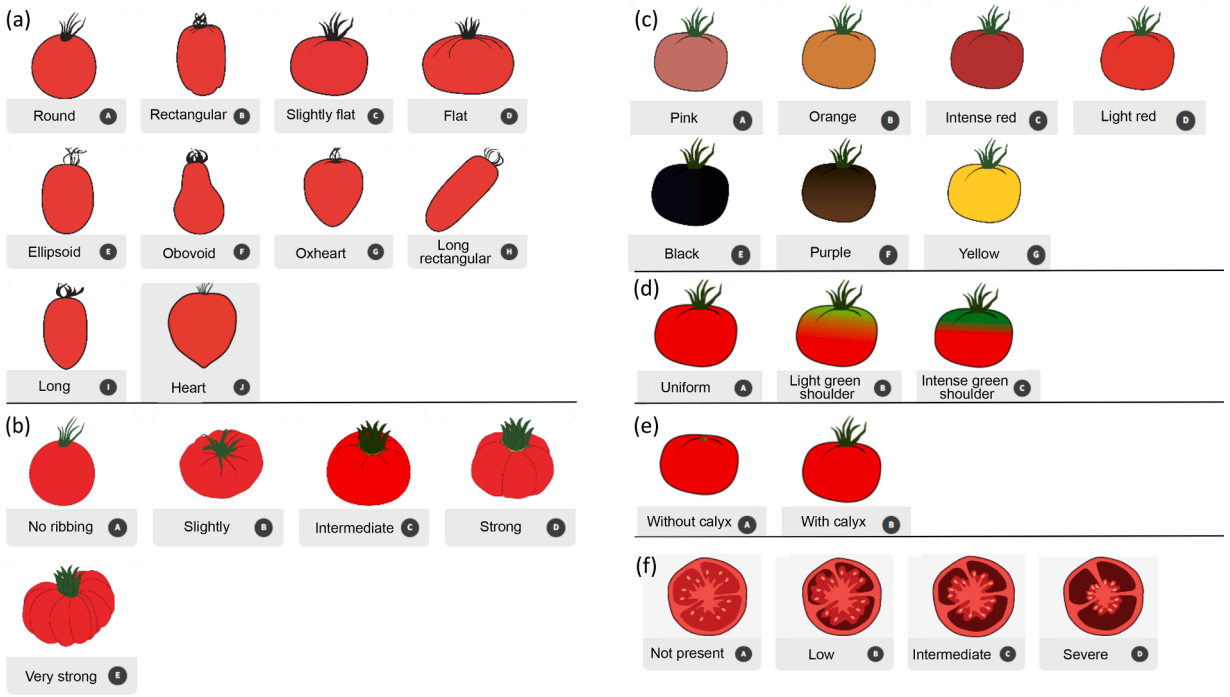

Fig. 1. Drawings used to illustrate the fruit appearance sensory attributes: (a) fruit shape, (b) fruit ribbing, (c) fruit color, (d) green shoulder, (e) presence of calyx, (f) hollowness degree.

the number of clusters that exhibited the best values in the various indices (Figure S1, Table S3). A detailed description of the indices and their interpretation can be found in Charrad et al. (2014). Sensory attributes defining each sensocluster (i.e. clusters obtained from the HCPC analysis based on sensory attributes) were calculated using the v.test, which compares the proportion of participants within a cluster that has selected a specific level of a given attribute with the proportion in the whole survey. Profiling of each sensocluster was carried out by considering sensory attributes that displayed significant enrichment ($p < 0.05$, $|v.test|>2$) and a within-cluster membership (Mod/Cla, i.e., the percentage of respondents within a cluster selecting a particular attribute category) >60% (indicating overrepresentation) or <40% (indicating underrepresentation). Results were plotted in a heatmap using the "heatmap.2″ function of the *gplots* package (Warnes et al., 2022). Heatmaps were constructed based on the scores of the v.test. Ideotypes were defined using representative sensoclusters. A sensocluster was considered representative of the population when it contained more than 10% of participants. Finally, sensoclusters where characterized by their consumption habits and beliefs. Similarity/dissimilarity relationships among sensoclusters were computed by performing a Principal Component Analysis (PCA) and HCPC on a dataset containing the percentage of consumers that selected each attribute category in each sensocluster. The results were plotted using a dendrogram and a heatmap with *gplots* package. To identify consumption habits and beliefs enriched in each sensocluster, standardized Pearson's residuals (d_{ij}) were calculated to analyze the departure of each category from the expected values. The results were presented using mosaic plots with the "vcd" R package (Friendly et al., 2015).

3. Results

3.1. Focus groups discussions

Five surveys were designed, including one General Survey and four surveys specific for Montserrat, Valenciano, Bulgarian Oxheart, and San Marzano landraces. Surveys were built upon the results of focus groups. To swiftly discern tomato consumer preferences, a discussion guide containing 18 statements, drawn from a literature search of prior studies, was prepared by the moderator. The list of these items is accessible in Table S1. These statements were categorized into five themes relevant to tomato acceptance, encompassing purchase habits and sensory attributes such as appearance, odor, taste, and texture. An open-ended question about the "ideal tomato" was then presented to participants. The discussion guide was subsequently introduced to FG1, aimed at selecting a subset of questions that maximized sensory diversity. FG1 enumerated 18 sensory attributes as the most pertinent for a tomato sensory ideotype, four needed to characterize participants' consumption habits, and 2 to understand consumer beliefs about tomato quality (Table S2). Furthermore, they opted to depict attributes related to fruit appearance through drawings in the survey, due to the unavailability of photographs showcasing fruits differing solely in the targeted phenotypic trait. Following this, the 24 attributes chosen from FG1 were presented to FG2, experts specialized in the breeding of the studied tomato landraces. FG2 refined the FG1 selection and outlined potential levels of sensory attributes found in each landrace. Careful consideration was given to prevent the depiction of unattainable ideotypes, with particular attention to attribute levels. For the General Survey the objective was to encompass the whole sensory diversity that can be found within the tomato fresh-market genetic pool. Conversely, in the case of landrace surveys, the focus was placed on capturing the essential attributes distinct to each landrace type and their associated variability. Finally, an additional section was appended to collect information on participants' age, gender, job, educational background, and country of residence. A comprehensive account of the questions and their selected levels, endorsed by FG2 for integration into the final survey, is provided in Table S2.

3.2. Response rates to european tomato online surveys

Out of a total 8649 views, 3123 questionnaires were completed (36.11% survey response rate). Following filtering criteria, 2333 complete questionnaires with average answered questions 94.6% and no missing values for the sensory attributes remained. After filtering, 1795 questionnaires were considered valid for the General Survey, while 139, 116, 229 and 54 for the Montserrat, Valenciano, Bulgarian Oxheart and San Marzano landraces surveys, respectively (Fig. 2.a). These landraces represent a low market share and are marketed in very small areas. For this reason, the number of responses was much lower, compared to the General Survey. San Marzano landrace survey, with less than 100 responses ($n = 54$), was removed from further analyses.

3.3. Sociodemographic profile of participants

Considering all the surveys, participants were enriched in females (female, 58.9%; male, 40.0%; non-binary, 1.1%) (Fig. 2.b, Table S4), and a majority identified as students (33.3%), followed by employees (24.7%) or workers (10.7%) (Fig. 2.c). Regarding age, enriched groups were very young (<18 years, 23.3%), and middle-aged (35–49 years, 22.8%; 50–64 years, 23.4%) (Fig. 2.d). Participants were characterized to consume tomatoes very often (51.4%), or often (34.1%) (Fig. 2.e), and to have attained a high school degree (upper secondary school, 30.2%; university, 64.6%) (Fig. 2.f). Most of participants declared to consume fresh-market tomatoes raw in a salad (80.2%), or/and cooked as a second ingredient (56.3%) (Table S4). Besides these common trends, significant differences were identified in the sociodemographic profile of respondents when surveys were compared. In the General Survey, there was a significantly higher participation of young individuals (<18 years, 27.9%) which declared to be students (38.8%) and lower participation of individuals of 50–64 years (19.8%). Most of the respondents where from Spain (63.5%), Italy (15.4%), and Bulgaria (10.6%). In the Montserrat survey, significantly enriched categories were aged persons (>65 years, 12.9%), the socio-professional groups retired (12.9%), shopkeeper (2.9%), and worker (18.7%), and low frequency of consumption (from time to time, 14.5%), while high frequency of consumption (very often, 35.5%) was negatively enriched. In the Bulgarian Oxheart survey, middle-aged individuals (35–49 years, 39.7%; 50–64 years, 30.6%), employees (48.9%) and farmers (8.7%), those with a high consumption frequency (very often, 77.9%), and individuals with a high school degree (85.2%) showed positive enrichment. On the other hand, males (31.4%), students (8.7%), very young (<18 years, 0.4%), those with low and intermediate consumption frequencies (hardly ever, 0.9%; often, 6.2%), and those with lower (0.0%) or upper secondary school levels (14.8%) were negatively enriched groups. In the Valenciano survey, individuals of 50–64 years (54.3%), with intermediate (18.9%), high-level positions (17.2%) or workers (10.7%) were positively enriched, whereas very young participants (<18 years, 4.3%), students (6.9%), and those with an upper secondary school education (16.4%) were groups that showed a negative enrichment. Most of the participants of specific landraces' surveys had a good knowledge of the varieties, indicating that they have been consuming it since they were young (Montserrat, 61.1%; Oxheart, 69.6%; Valenciano, 79.0%), or for more than 10–15 years (Montserrat, 22.9%; Oxheart, 24.7%; Valenciano, 17.0%) (Table S4). In the case of the Montserrat survey, 14.7% of the participants declared to have discovered the landrace during the last 2 years, indicating that the landrace is experiencing a recovery in the market.

3.4. Current trends in tomato consumer preferences

To investigate the tomato sensory attributes most appreciated by European consumers, distributions and enrichment of the categories of the sensory attributes were analyzed. Fig. 3 depicts the distribution of the most selected levels by participants in each survey. Significant

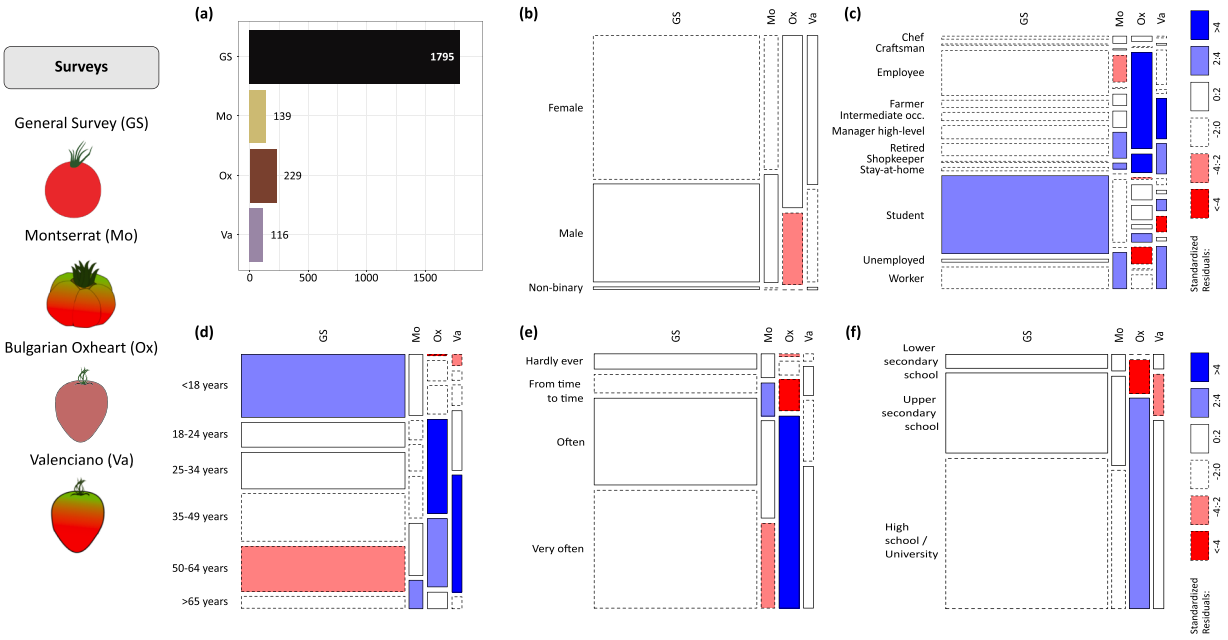

Fig. 2. Sociodemographic respondents' profile of General Survey (GS), and landraces surveys (Montserrat (Mo), Bulgarian Oxheart (Ox), Valenciano (Va)). (a) number of respondents per survey, (b) gender, (c) socio-professional group, (d) age, (e) frequency of consumption, (f) education level. In panels b-f, enrichment was evaluated by departure of residuals from the expected value. Residuals with $|dij| > 4$ have an approximate P-value < 0.001, and $|dij| > 2$ have an approximate P-value < 0.05.

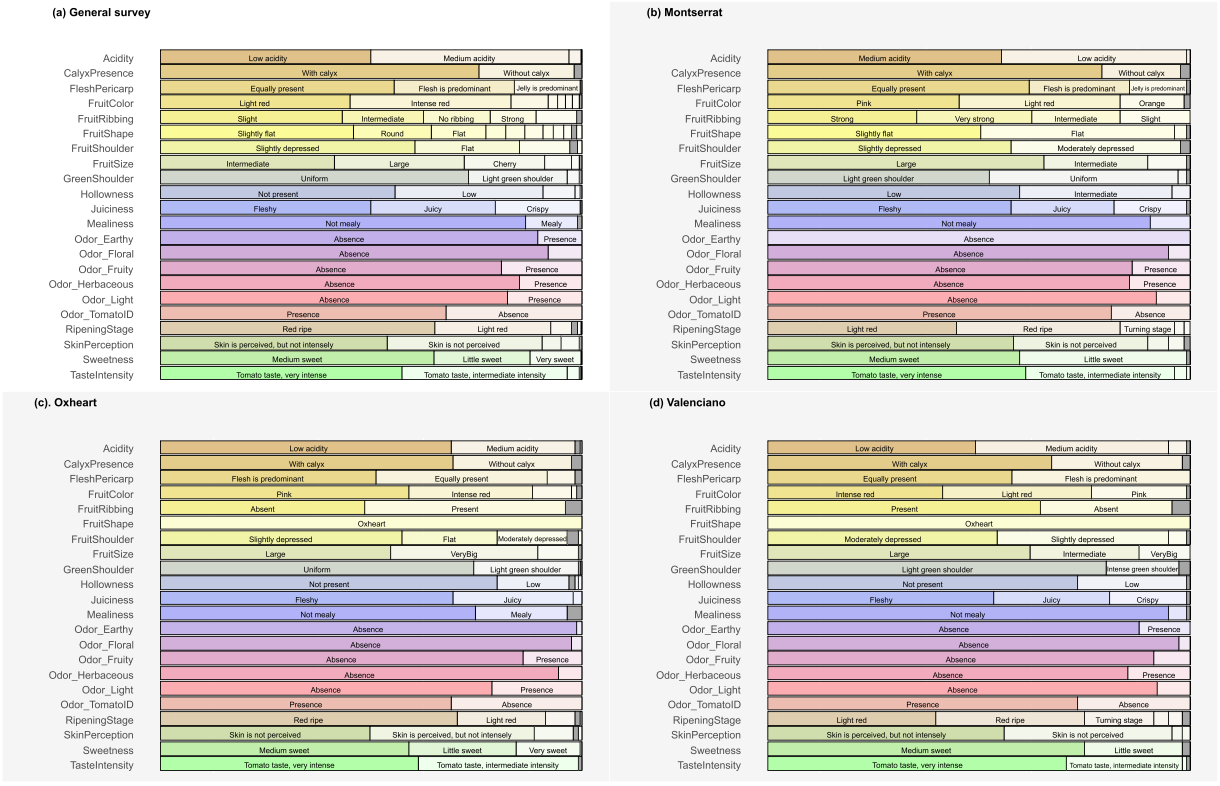

Fig. 3. Tomato sensory attributes appreciated by consumers in the General Survey, and landraces. Mosaic plot showing the frequencies for each variable in the (a) General Survey, (b) Montserrat, (c) Oxheart and (d) Valenciano. Significant differences from equal distribution were obtained for all the variables (chi-square test, $p < 0.001$), except for commercial presentation on the General Survey (detached tomatoes, 53.3%; tomato on the branch, 44.8%; this attribute was not studied in the surveys of the landraces, and is therefore not presented to facilitate comparison between surveys). For each sensory attribute, the levels are sorted in order of importance from left to right. Colors are for ease of reading only. Missing values are represented with a gray color.

enrichment (p value<0.05) was identified in the General Survey for at least one of the selected levels of all the attributes (Fig. 3.a), except for the commercial presentation attribute (detached tomatoes, 53.3%; tomato on the branch, 44.8%). As seen in Fig. 3.a, fruit external appearance attributes such as fruit with calyx present (75.4%), uniform green shoulder (73.1%), slightly depressed fruit shoulder (60.4%), slightly flat fruit shape (45.8%), light red fruit color (45.0%), slight fruit ribbing (43.1%) and intermediate fruit size (41.3%) are the most preferred for the General Survey participants. In addition, participants preferred fruits that internally do not present hollowness (55.7%) and have pericarp and flesh tissues equally present (55.4%). Regarding to the odor, consumers in the General Survey liked fruits with a tomato ID odor (67.6%), but with absence of floral (92.0%), earthy (89.5%), herbaceous (85.2%) and fruity (80.8%) notes. With respect to the taste attributes, participants preferred a very intense tomato taste intensity (57.3%), a low acidity (49.9%) and medium sweetness (64.9%). Further, consumers preferred to consume fruits in red ripe stage (65.1%), with skin perceived, but not intensely (53.8%), and with a not mealy (86.5%) and fleshy (49.8%) texture.

Participants in landrace surveys (Fig. 3.b-d) also preferred absence of floral, earthy, herbaceous and fruity odors, not mealy texture, calyx present, tomato ID odor present, medium sweetness, very intense tomato taste intensity, and a fleshy texture. However, landrace participants appreciate other tomato attributes. Enrichment analysis indicated that the Montserrat landrace survey participants (Fig. 3.b) preferred tomatoes with low or intermediate hollowness (59.7% and 36.0%, respectively), having large fruit size (61.9%), strong or very strong fruit ribbing (35.3% and 27.3%, respectively), medium acidity (52.5%), light green shoulders (49.6%), pink fruit color (44.6%), and consumed at the light red ripening stage (42.4%). In the case of the Bulgarian Oxheart landrace (Fig. 3.c), enrichment analysis indicated that participants preferred fruits having an oxheart fruit shape (100%), pink color (52.0%), large size (46.7%), no skin perception (45.4%), and no fruit ribbing (42.8%). With regard to the Valenciano landrace (Fig. 3.d), preferred attributes were oxheart fruit shape (100%), light green shoulders (71.5%), slight presence of fruit ribbing (56.9%), large size

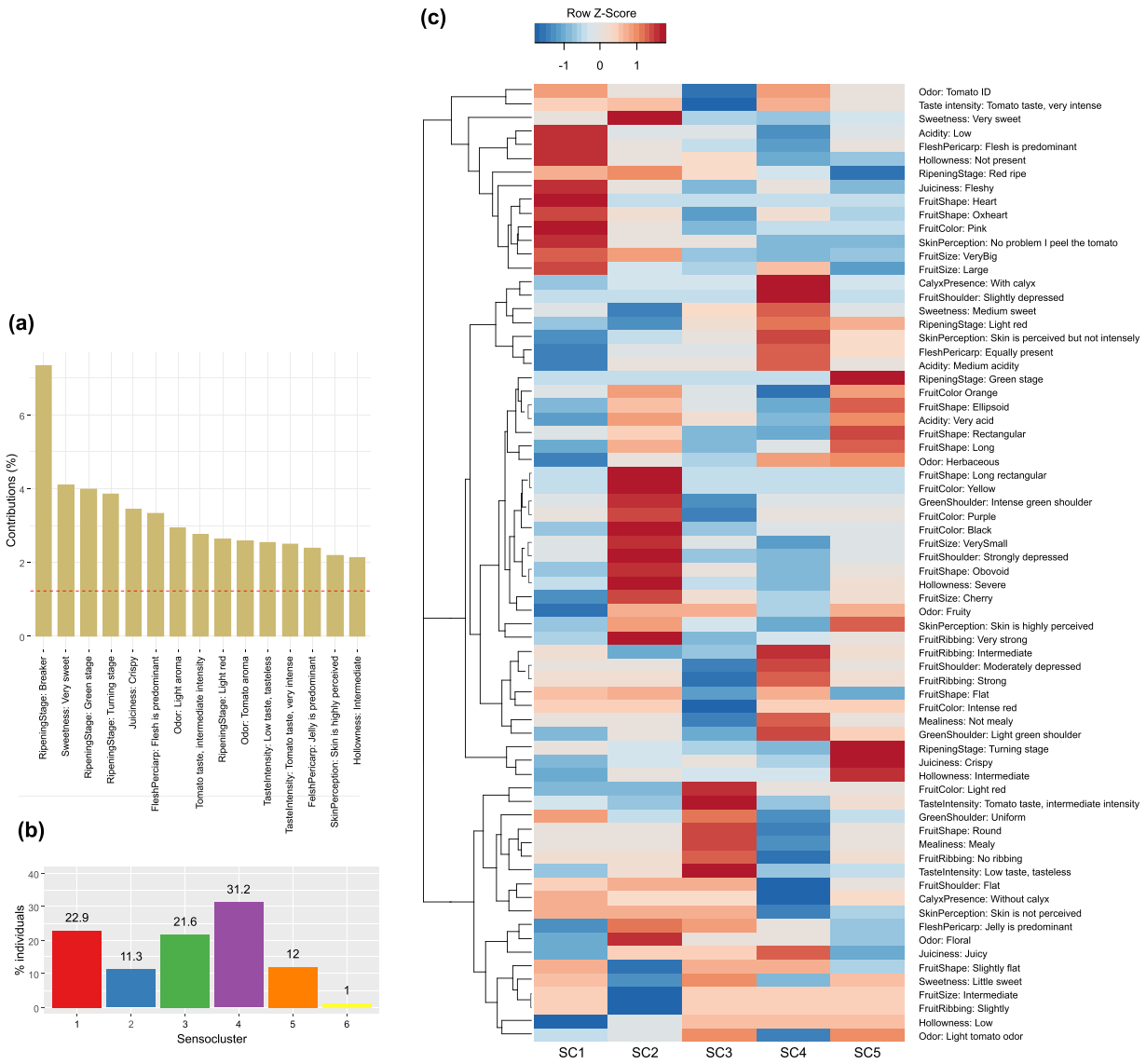

Fig. 4. General survey consumer segmentation based on sensory attributes. (a) Attributes that contribute most to dimensions 1–5 of the Multiple Correspondence Analysis (MCA). The red dotted line represents the contribution threshold. (b) Percentage of participants from the total population ($n = 1795$) in each sensocluster. (c) Heatmap showing the enrichment (v.test) of different categories in each sensocluster. Only significantly enriched categories (chi-square test, $p < 0.05$; |v.test|>2) and representing >60% or <40% of the sensocluster population are shown. Red indicates positively enriched categories; blue indicates negatively enriched attributes. Abbreviations: SC1-SC5, sensoclusters 1 to 5.

(52.6%), intense red color (36.2%), and the light red ripening stage at consumption (34.5%).

3.5. Definition of sensoclusters: tomato sensory ideotypes

MCA followed by HCPC was used to identify the General Survey participant's profiles on the basis of the sensory attributes that were important to them for an ideal tomato. MCA analysis indicated that the most discriminant variables were ripening stage, taste intensity, sweetness, presence of a light tomato odor, hollowness, juiciness, and skin perception (p values $< 10^{-79}$ in the chi-square test) (Table S5). Concretely the levels of these attributes that most contribute to differentiate participants (threshold value $p < 0.001$) were ripening stage breaker, very sweet fruit, green and turning ripening stages, crispy texture, flesh predominant over jelly, presence of a light tomato odor, and intermediate tomato taste intensity (Fig. 4.a).

Next, we conducted HCPC on the 40 first PCo MCA components (explaining >80% of the total variance). HCPC analysis segmented General Survey participants into six sensoclusters (Fig. 4.b, Figure S2) based on response similarities. Out of the 1795 participants, 22.9% were in sensocluster1 (SC1), 11.3% in sensocluster2 (SC2), 21.6% in sensocluster3 (SC3), 31.2% in sensocluster4 (SC4), 12.0% in sensocluster5 (SC5), and 1.0% in sensocluster6 (SC6) (Fig. 4.b). We excluded SC6 from the analysis since it comprised only 1% of participants and was not considered representative of the population. Variable attribute enrichment analysis (Fig. 4.c, Table S6) was then performed to assess the preferences of individuals in each sensocluster and to define their respective ideotypes.

Enrichment analysis indicated that SC1 was mainly characterized by preference for non-hollow fruits with a fleshy texture (flesh predominant over jelly), a tomato ID odor, and very high taste intensity, as well as low acidity. Concerning skin perception, participants did not find this attribute problematic, as the skin can be peeled. SC1 consumers prefered large-fruited varieties (large, very big) with a pink color and heart or oxheart fruit shapes. They also prefer a fleshy texture and fruit consumption at the red ripe stage. Considering these preferences, SC1 consumers seemed more focused on flavor-related attributes than on fruit appearance ones. Accordingly, SC1 was defined as the "tasty tomato consumer".

SC2 mainly consisted of consumers who like tomatoes with high sweetness and a fruity or floral odor. They also prefer a very intense tomato taste, a jelly-like appearance when cut, and fruits consumed at the red ripe stage. This cluster grouped consumers who like small-sized fruits (very small, cherry) with an intense green shoulder. They also appreciate a wide diversity of shapes (long rectangular, obovoid, ellipsoid, long, rectangular) and colors (yellow, purple, black, orange). Other attributes judged positively by these consumers included a strongly depressed shoulder and very pronounced fruit ribbing. Therefore, SC2 was characterized by a preference for high sweetness and small fruit size and can be referred to as the "cherry-sweet tomato consumer".

SC3 was mainly characterized by consumers who prefer fruits with low taste intensity (low taste or intermediate taste), a light tomato odor, and low sweetness. These consumers like a mealy texture. Other attributes that define SC3 were the preference for fruits of intermediate size, light red color, round or slightly flat shape, without ribbing, and a uniform green shoulder. Accordingly, SC3 was defined as the "light-flavor tomato consumer".

SC4 was the most abundant (31.2%) and was characterized by fruit-appearance attributes: in this cluster, consumers prefer large fruits at the light red stage, a flat or slightly flat shape with intermediate or strong ribbing, a light green shoulder, a slight or moderately depressed shoulder shape, and the calyx present. Concerning taste-related attributes, SC4 consumers prefer fruits with a strong tomato taste and an herbaceous plus tomato ID odor, medium sweetness and acidity. Regarding texture, they prefer fruits with flesh and jelly equally present, slight skin perception, and not mealy or juicy. SC4 consumers can be defined as the "beefsteak-tomato consumer".

Finally, SC5 consumers like unripe fruits, specifically fruits at the green or turning stage – very acidic, crispy, and with an herbaceous, fruity, or light tomato odor. High skin perception was a positive sensory attribute for these consumers. They also appreciated fruits of different shapes (ellipsoid, long, rectangular) with an orange color and accepted some level of hollowness. SC5 consumers can be designated as the "unripe tomato consumer".

3.6. Sensory ideotypes of selected european tomato landraces

To study whether each landrace is represented by a single or different sensory ideotypes, the same statistical procedure used for the General Survey was applied to landrace surveys. The analyses were performed separately for each landrace. MCA and HCPC analysis on the Montserrat data revealed that consumers optimally split into two sensoclusters (Table S3). Nonetheless, one cluster was formed by solely 6.8% of the Montserrat consumers and was excluded from ideotype definition. As a result, we retained the primary sensocluster for defining the Montserrat ideotype, representing 93.2% of the respondents. The sensory ideotype of Montserrat is defined in Fig. 3.

For the Bulgarian Oxheart landrace, the optimal number of clusters was five (Table S3). Two clusters were removed from the analysis because each represented less than 10% of the responses. Sensory ideotypes Oxheart1, Oxheart2, and Oxheart3 represented 29.4%, 22.1%, and 45.4% of the respondents, respectively. The main attributes segmenting Bulgarian Oxheart consumers into different sensory ideotypes were: ripening stage, green shoulder, presence of earthy odor, skin perception, fruit shoulder, internal appearance (flesh vs. pericarp), hollowness, and fruit ribbing (Table S7). Consumers from Oxheart1 prefer medium-sized fruits, slightly ribbed, with a light red color, the shoulder slightly depressed, the calyx present, a light green shoulder, low hollowness, and the flesh and pericarp equally present. Concerning taste-related attributes, Oxheart1 consumers prefer to consume fruits at the light red ripening stage, with medium-acidity, intermediate taste intensity and some degree of skin perception (skin is perceived but not intensely) (Fig. 5.a, Table S8). Consumers from Oxheart2 like large and pink-colored fruits, at the turning stage, medium sweet and with a light tomato odor. These consumers also preferred a crispy texture. Consumers from Oxheart3 like fruits at the red ripe stage, with high tomato taste intensity, very sweet, and with low acidity. They like a fleshy texture, where flesh is predominant over jelly and without hollowness. Skin should not be perceived. Concerning fruit appearance, Oxheart3 consumers like fruits with an intense red color, a uniform green shoulder, without the calyx, with a flat shape, and no ribbing.

For the Valenciano landrace, the optimal number of clusters was five (Table S3). Three clusters were removed because each represented less than 10% of the responses. Sensoclusters Valenciano1 and Valenciano2 represented 50% and 37% of the individuals, respectively. The main sensory attributes that differentiated the two Valenciano ideotypes were the ripening stage, taste intensity, skin perception, mealiness, fruit shoulder appearance, and acidity (Table S7). Valenciano1 consumers were characterized by preferring fruits at the red ripe stage, with a tomato odor and very intense taste. They like a fleshy texture, with a light green shoulder (Fig. 5.a, Table S8). Valenciano2 consumers had preferences considerably different from Valenciano1, liking fruits characterized mainly by an herbaceous odor and the fruit shoulder moderately depressed. They prefer fruits at the light red or turning stage, with low hollowness, and intermediate taste intensity. In contrast to Valenciano1, Valenciano2 consumers liked earthy odor, high acidity, and an intense green shoulder.

The comparison among the sensoclusters identified in the General Survey and in landrace surveys revealed three main groups (Fig. 5.b). Oxheart consumers (Oxheart1–3) showed similarities with Valenciano1 and SC1 from the General Survey (i.e., the "tasty tomato consumer"). Oxheart1, Oxheart2, and Valenciano1 presented high similarity,

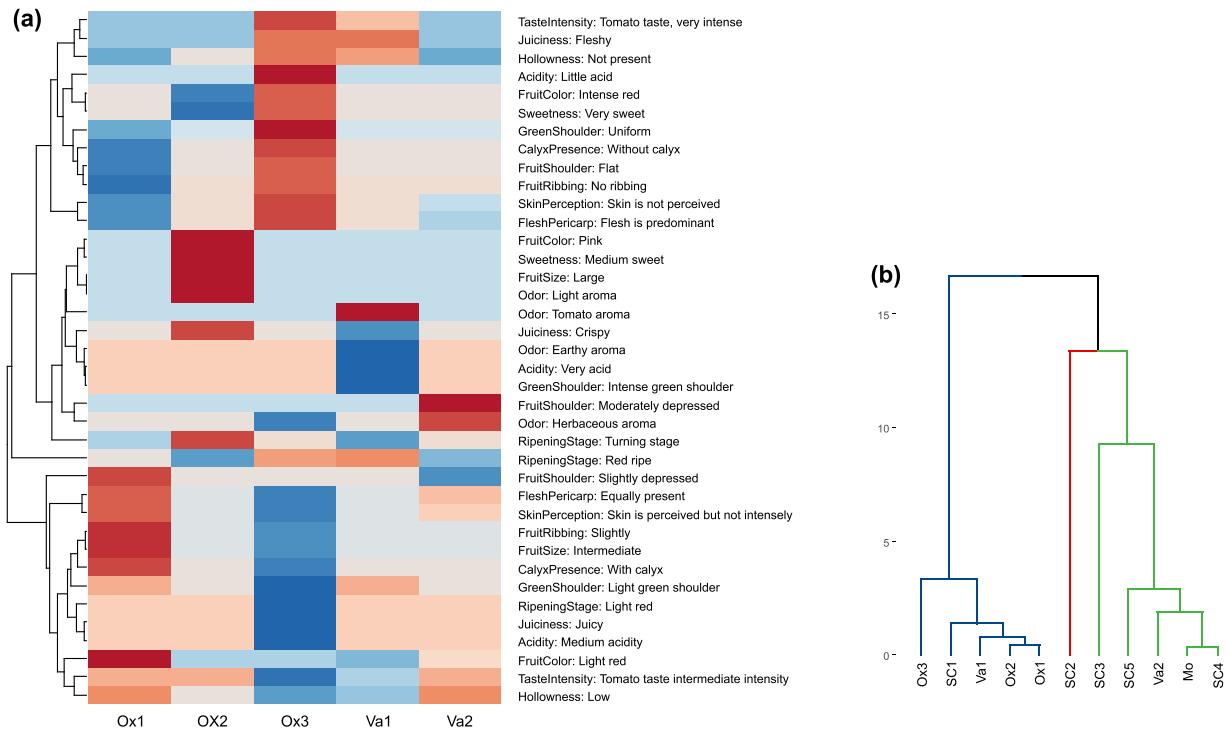

Fig. 5. Sensoclusters within the Valenciano, and Oxheart landraces. (a) Consumer segmentation of each landrace based on sensory attributes. Heatmap showing the enrichment (v.test) of different categories in each sensocluster. Only significantly enriched categories (chi-square test, $p < 0.05$; |v.test|>2) and representing >60% or <40% of the sensocluster population are shown. Red indicates positively enriched categories; blue indicates negatively enriched attributes. (b) Dissimilarity dendrogram showing the sensory relationships between the sensoclusters identified in the General Survey and the sensory ideotypes drawn from the landraces' surveys. The dendrogram was generated by a Hierarchical Cluster of Principal Components (HCPC) based on the relative abundance of each category in each sensocluster. Color indicates the grouping of sensoclusters ($k = 3$). Abbreviations: SC1-SC5, sensoclusters 1 to 5; Mo, Montserrat; Ox1-Ox3, sensoclusters Oxheart1 to Oxheart3; Va1-Va2, sensoclusters Valenciano1 and Valenciano2.

whereas Oxheart3 presented more differences from them. SC2 (i.e., the "cherry-sweet tomato consumer") showed no similarity to any of the other sensoclusters defined in this work. Montserrat and Valenciano2 presented high similitude with SC4 (i.e., the "beefsteak-tomato consumer"), and were located close to SC5 (i.e., the "unripe tomato consumer") and SC3 (i.e., the "light-flavor tomato consumer").

3.7. Consumption habits and beliefs among sensoclusters

We further investigated the consumption habits (shopping place, frequency of consumption, preparations in which the tomato is consumed) and beliefs (sorting of important factors in tomato quality, agreement with the statement "tomato has no longer taste") of the individuals that constitute each sensocluster. The HCPC analysis performed on these variables revealed the existence of 3 main groups (Fig. 6.a, Figure S3) that corresponded to the different surveys designed in this work: that is, Oxheart1–3 sensoclusters grouped together; Montserrat and Valenciano1 and 2 sensoclusters also (both are landraces from the Mediterranean coastal area of the Iberian Peninsula); and SC1–5 emerging from the General Survey also clustered together. Thus, it seems that consumers of the different landraces were also shaped by different consumption habits and beliefs, in comparison with regular tomato consumers (SC1–5).

Regarding the shopping place (Fig. 6.b), Valenciano landrace respondents were enriched in consumers who buy the tomatoes in the supermarket or in a hard discount shop; Bulgarian Oxheart and Montserrat participants were enriched in consumers who grow the tomatoes themselves or buy them directly from the grower. Concerning the sensoclusters from the General Survey, the main difference was the enrichment in consumers buying the tomatoes at the supermarket and not directly from the grower or growing themselves in SC3. Regarding the frequency of consumption (Fig. 6.c), Bulgarian Oxheart sensoclusters were enriched in consumers who eat the landrace very often, while Montserrat consumers in consuming the landrace often. Enrichment analysis in the General Survey revealed that SC3 ("light-flavor tomato consumer") was enriched in consumers who consume tomatoes hardly ever, and negatively enriched in consumers who eat tomatoes very often. SC4 ("beefsteak-tomato consumer") and SC5 ("unripe tomato consumer") were enriched in consumers who eat tomatoes often. Concerning preparations in which the tomato is consumed (Fig. 6.d), significant differences were found between sensoclusters. Participants in the landrace's surveys were enriched in consumers who prefer to eat the tomatoes raw and unprepared (Oxheart2 and 3) or raw in a salad (Montserrat, Oxheart3, and Valenciano1 and 2). In contrast, consumers from SC2 ("cherry-sweet tomato consumer"), SC3, and SC4 tend to consume less raw tomatoes but use them more cooked as a second ingredient.

In relation to consumer beliefs, consumers' opinions regarding the statement "the tomato has lost its taste" revealed that on average, about half of the consumers (46.0%) totally agree or agree with this affirmation, 21.6% totally disagree or disagree, while 32.4% remain neutral. Significant differences among sensoclusters were found for this variable, with Oxheart1 and 2 and Valenciano2 sensoclusters enriched in consumers who did not agree with this sentence, Montserrat enriched in consumers who agree with the sentence, and consumers from SC3 who are neutral (Fig. 6.e). Finally, participants sorted different production factors according to their importance for tomato quality (Fig. 6.f). Organic farming was the most important production factor for consumers in all the sensoclusters (on average, 42.5%), particularly for Valenciano1 and 2, Oxheart1 and 2, and SC2. Meanwhile, the recent harvest of the fruits was deemed the least important factor (on average, 12.0%). Importance scoring for local production and the cultivation of

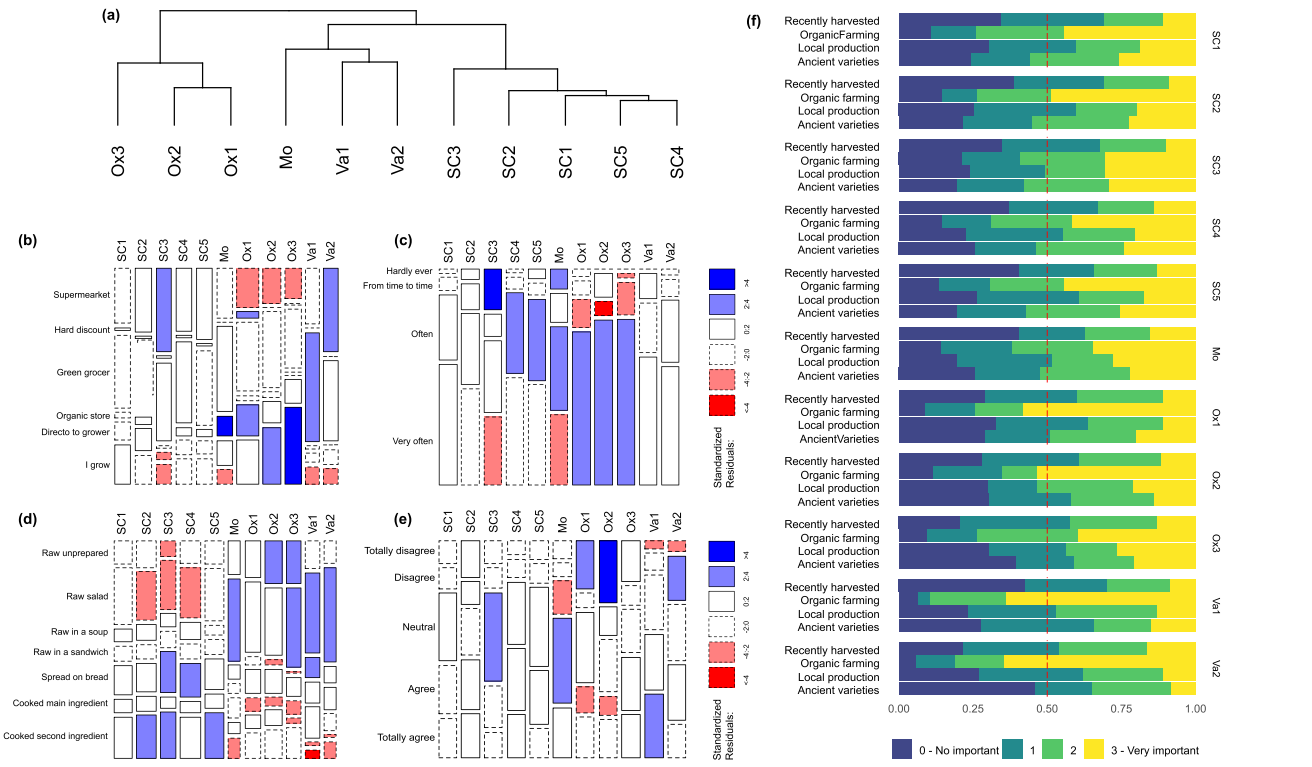

Fig. 6. Purchase preferences and consumer beliefs of the different sensoclusters. Variables included in the analyses are related to consumption habits (shopping place, frequency of consumption, preparations in which the tomato is consumed) and consumer beliefs (sorting of important factors in tomato quality, agreement with the statement "tomato has no longer taste"). (a) Dendrogram showing the relationship between sensoclusters calculated from the relative abundance of each category. The corresponding heatmap with the enrichment of each attribute can be found in Figure S3. (b-e) Mosaic plots showing the enrichment in each sensocluster for variables shopping place (b), frequency of consumption (c), preparations in which the tomato is consumed (d), and agreement with the statement "tomato has no longer taste" (e). Enrichment was evaluated by departure of residuals from the expected value. Residuals with $|dij| > 4$ have an approximate P-value < 0.001 and $|dij| > 2$ have an approximate P-value < 0.05. (f) Average sorting in each sensocluster of the management factors that drive a tasty tomato (factors: recently harvested, organic farming, old varieties, local production). Abbreviations: SC1-SC5, sensoclusters 1 to 5; Mo, Montserrat; Ox1-Ox3, sensoclusters Oxheart1 to Oxheart3; Va1-Va2, sensoclusters Valenciano1 and Valenciano2.

ancient varieties (i.e., landraces) was generally evenly distributed. However, the cultivation of ancient varieties was not considered important for consumers in Valenciano1 and 2, and Oxheart3 sensoclusters. We finally assessed differences in consumer beliefs between the different age groups (Figure S4) to unveil consumer patterns across the various age categories. This analysis revealed distinct behavioral patterns among the youngest (<18 years), who expressed less agreement with the statement "tomato has no longer taste" (responses "neutral" and "totally agree" were positively and negatively enriched, respectively). They also considered "local production" and the cultivation of "ancient varieties" as more important factors determining tomato quality (the response "very important" was significantly enriched in these factors), while "organic farming" was less important to them compared to other age groups. Few differences were identified among the remaining age groups concerning these variables.

4. Discussion

Sensory attributes are essential quality attributes that determine consumer preferences for vegetables, such as tomatoes (Folta and Klee, 2016). Instead of existing a single consumer preference, the wide variation among humans in their sensory perception (Hasin-Brumshtein et al., 2009), coupled with the diversity of culinary forms in which tomatoes are consumed, lead to the existence of more than one sensory ideotype in tomato. The objective of this work was to explore the diversity of European consumer preferences for fresh-market tomatoes, based on their preferences for sensory attributes related to fruit external and internal appearance, taste, odor, and texture-related attributes.

Our online questionnaire allowed us to explore tomato consumer sensory preferences of 2333 European individuals, achieving a response rate of 36.11%. However, our approach utilizing a snowball distribution strategy may introduce deviations from population representativeness (Chang and Krosnick, 2009; Couper, 2011), particularly evident in basic demographic variables such as age, and education level, with an overrepresentation of younger age groups (<18 years: survey, 23.3%; EU27, 18.9%) and individuals with higher education levels (University degree: survey, 30.2%; EU27, 12.3%) (Table S4). This bias has been described as usual in online surveys using non-probability models (e.g. snowball sampling) (Szolnoki and Hoffmann, 2013), which tends to result in an over-participation of individuals interested in the survey topic. Additionally, the participants' household income, which was not surveyed in the questionnaire, may introduce bias in consumer expectations for tomato sensory quality, as reported elsewhere (Jürkenbeck et al., 2020). Despite these limitations, our large sample size may offer a more comprehensive representation of consumer diversity compared to traditional sensory analysis studies, typically limited to around 100 panelists with minimal quota representation (Causse et al., 2010; Sinesio et al., 2021). Additionally, sensory studies are constrained by panelists' capacity and the inherent influence of sample selection on the studied sensory space, i.e. tomato samples are pre-specified by researchers, consumers not having the opportunity to choose which tomatoes they would like to taste (Jürkenbeck et al., 2020). Importantly, our innovative approach utilizing drawings (Fig. 1) to define sensory attributes has fostered a common understanding of attribute meanings among participants and minimized discrepancies in terminology commonly encountered in consumer panels (Lawless and Heymann, 2010). Overall, our

results pave the way for refining the design of sensory studies aimed at delineating the sensory clusters relevant to European tomato consumers.

The questionnaire included many questions commonly addressed in tasting sessions, such as tomato taste intensity, odor, sweetness, acidity or skin perception. The results indicated average sensory attributes that positively impact consumer acceptance, including the presence of an intense tomato ID taste and odor, medium-to-high sweetness, low or medium acidity, and low skin perception. These findings align with the results widely reported in studies based on sensory analysis (Baldwin et al., 1998; Casals et al., 2018; Hobson, 1988; Tieman et al., 2017a). Noteworthy, our approach enabled us to explore other sensory attributes that have been scarcely addressed in consumer surveys. For instance, the presence of green shoulders. Surprisingly, our results indicated that most of consumers preferred uniform fruits (73.1%), i.e. no green shoulders, despite this phenotype has been associated with a diminution in sugar content, and therefore to the fruit sweetness that consumers appreciate (Powell et al., 2012). The preference for fruits that present the flesh and pericarp tissues equally present in the transversal section (55.4%) or the calyx attached (75.4%), as well as the nearly equal percentages of consumers preferring tomatoes presented on the branch (44.8%) and those who preferred detached fruits (53.3%) are other general trends that emerged from the survey.

The large number of participants has allowed to classify the general fresh-market tomato consumers in five robust groups based on preferences. Sensory attributes characterizing these consumer groups (i.e. sensoclusters) can be translated into sensory ideotypes for plant breeding programs, taking advantage of the increased knowledge of the chemical and genetic basis of the different tomato sensory attributes (Klee and Tieman, 2018; Tieman et al., 2017b). Although most of the previous preference-mapping experiments investigated separately cherry and salad fresh-market tomatoes, altogether our survey yielded similar results. For the salad group, previous works reported that consumers can be segmented into three or four main sensoclusters (Berna et al., 2005; Causse et al., 2010; Oltman et al., 2014; Serrano-Megías and López-Nicolás, 2005; Sinesio et al., 2010), while cherry consumers into two or three sensoclusters (Pagliarini et al., 2001; Rocha et al., 2013). Similarly, Jürkenbeck et al. (2020) also reported the existence of six different tomato consumer groups using a choice experiment that included also labeling and other characteristics of the product. The significance of our study lies in our exclusive utilization of sensory attributes to delineate consumer groups, deliberately omitting the influence of other factors that contribute to preference, such as product information or pricing. As a result, our findings offer a comprehensive insight into the intricate tapestry of consumer preferences, centered solely around the sensory profile.

Our findings unveil that the five distinct sensoclusters are primarily characterized by specific preferences: SC1 (22.9% of participants) favors larger pink varieties with intense tomato ID odor and taste; SC2 (11.3%) leans towards cherry-sized fruits with high sweetness, complemented by fruity or floral odor; SC3 (21.6%) displays a preference for round, intermediate-sized fruits with a light tomato odor and low taste intensity; SC4 (31.2%) exhibits an affinity for large, ribbed, and flat fruits, striking a balance between medium sweetness and acidity, alongside moderate taste intensity; finally, SC5 (12.0%) demonstrates a preference for green, unripe fruits characterized by acidity and crispiness. Comparing these results to prior publications is challenging due to the utilization of different attributes, methodologies, and sets of varieties (Berna et al., 2005; Le and Ledauphin, 2006; Serrano-Megías and López-Nicolás, 2005; Sinesio et al., 2010). Importantly, Causse et al. (2010) noted the limited presence of European regional distinctions in consumer segmentation. Our strategy, employing two focus groups to establish a comprehensive list of attributes and intensity levels, has proven effective in capturing the broadest spectrum of the tomato's sensory profile.

The enrichment of specific sensory attributes in some sensoclusters can be regarded as sensory cues of consumer concerns in their own segment. Mealiness is positively enriched in SC3, which represents round-supermarket-tomato consumers, and negatively in SC4, which represents beefsteak tomato consumers, pointing out that in these tomato segments this attribute is more present than others, and for this reason consumers maybe emphasize it. Mealiness is related to the texture of the pericarp (Chaib et al., 2007; Verkerke et al., 1998), and has been described as a character that negatively affects consumer overall liking (Oltman et al., 2014), especially in beefsteak tomatoes (Sinesio et al., 2021). However, it seems that some consumers (SC3) are used to this sensory attribute, and do not judge it negatively. The presence of hollows in the locular cavities was also an enriched attribute in SC1, which groups consumers that focus on high-tasty tomatoes. Probably, in the search for fruits with high taste, these consumers look for fruits with different shapes and colors, some of which, such as those highly ribbed, tend to present this attribute. Lastly, individuals favoring cherry fruits (SC2) appear to exhibit a keen interest in accessing a broader range of fruit shapes and colors, suggesting potential breeding targets within this particular group. Actually, tomato color diversification has acquired popularity, especially among small-fruited varieties (Rocha et al., 2013), thus supporting this interest among consumers preferring cherry tomatoes.

Tomato landraces represent a narrower group of consumers. These have a cultural and gastronomical link to their variety, which presents singular quality attributes that drive the distinction of the landrace in the market (Casals et al., 2011), and nurtures the link between the consumers and the variety (Casañas et al., 2017). However, in our work, we have identified that consumers of a landrace may represent different sensory ideotypes, as is the case for the Valenciano (two sensoclusters) or the Bulgarian Oxheart (three sensoclusters). In both landraces, the ripening stage was the main sensory attribute driving the segmentation of consumers, half of them preferring fruits at the red ripe stage (Valenciano1, and Oxheart3), and the other half preferring fruits at earlier ripening stages (Valenciano2, and Oxheart1 and 2). These differences also lead to differences in taste preferences: consumers who prefer ripe fruit expect a greater intensity of taste and sweetness, a lower skin perception or a fleshy internal aspect, while those who prefer less ripe fruits expect a lower intensity of taste and sweetness, a greater skin perception and flesh and jelly equally present. By contrast, within the Montserrat landrace there seems to be only one sensory group, characterized by the attributes that reflect its historical sensory profile (flesh predominant over jelly, consumption at turning stage, presence of a light tomato and herbaceous odors) (Casals et al., 2011). The breadth of the cultivation area can be a differentiating element between these landraces; Montserrat (Casals et al., 2011) and Valenciano (Figàs et al., 2015) have a regional distribution, the latter with a much higher market presence, while the Bulgarian Oxheart has a much wider distribution (Danailov, 2012) and therefore includes a greater diversity of consumers, which perhaps translates into a greater diversity of consumer preferences. Altogether, these results indicate the targets for future breeding programs devoted to the recovery of the cultivation of these landraces, promoting their sensory differentiation from the modern counterparts that share the same market niches (Sinesio et al., 2021).

The definition of tomato sensory ideotypes is a necessary step toward breeding tomato varieties that fulfill consumer preferences, including those related to flavor, curbing the widespread consumer perception, appeared in the 1980s (Hobson, 1988; Kramer, 1980), that the tomato has no taste anymore. Recent sensory studies revealed that modern breeding programs, which have focused on quality attributes (Causse et al., 2020; Schouten et al., 2019), have all the information needed to produce tasty varieties comparable with the "old ones" (Sinesio et al., 2021; Tieman et al., 2017a). However, consumers' beliefs that the "tomato has lost its taste" remain: 46.0% of respondents agreed with this affirmation. Consumers from Montserrat and Valenciano1 sensoclusters are the ones who present a greater disagreement with the current quality, indicating that they do not find varieties on the market that come close to their preferences. By contrast, consumers from SC3, and

from Oxheart1 and 2, are the ones who show less dissatisfaction with the quality of the current tomatoes. These results signal priorities in breeding programs, which may target specific sensoclusters. Another element that impacts consumer liking is their own beliefs unrelated to the intrinsic quality of the fruit (e.g. labeling, production factors or price) (Jürkenbeck et al., 2020; Oltman et al., 2014). In this study, most consumers (42.5%) considered that organic farming is the short way to recover tomato quality. The positive effect of the organic farming label on the sensory perception of tomato quality is a well-known issue (Johansson et al., 1999; Schutz and Lorenz, 1976), which seems a derivative of the negative sensory tradeoffs caused by massive conventional productions (Folta and Klee, 2016). Interestingly, younger individuals (<18 years) exhibit a significantly distinct perception of current tomato quality, displaying lower agreement with the widespread notion that "tomato has lost its taste" and a divergent perception of where to find good-tasting tomatoes. This finding may indicate a shift in market trends, with preferences favoring labels such as "local production" and "ancient variety" over the popular "organic farming". Surprisingly, despite its known impact on the final sensory quality (Bertin and Génard, 2018; Klee and Tieman, 2013), the recent harvesting of the fruit was considered the least important factor driving high-quality tomatoes by the surveyed population. This underscores the importance of supplementing breeding programs aimed at producing flavorful varieties with consumer education on agronomic and gastronomic topics.

Overall, the results of this work, where the sensory profiles expected by consumers are defined, coupled with current knowledge about the management, environmental (Beckles, 2012; Bertin and Génard, 2018), and genetic factors that determine sensory attributes (Tieman et al., 2017b, 2017a; Zhao et al., 2019), open the door to designing high-quality tomato varieties targeting specific consumer segments.

5. Conclusions

Complementing previous works, this study describes the main sensory attributes that determine European consumer preferences for tomatoes. Attributes previously unexplored in consumer surveys have been included in the general preference map, creating a complete sensory description of European consumer preferences. Furthermore, the study presents the main sensory attributes that discriminate the five sensoclusters into which consumers can be segmented. For the first time, this approach has been employed in the examination of sensory ideotypes within European landraces, revealing the emergence of distinct ideotypes from individual landraces. The results draw different sensory ideotypes that can be used to breed tomato varieties, in order to fulfill the diversity of consumer quality expectations. In the case of landraces, this work shows that for some of them (Oxheart, Valenciano) there is a need to diversify the sensory profile, with the aim of maintaining the “high-quality” perception that consumers expect; while for others (Montserrat) breeders should focus on the historical sensory profile that most of the consumers prefer.

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CRediT authorship contribution statement

Joan Casals: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Roser Romero del Castillo:** Methodology, Conceptualization. **Clara Pons:** Writing – original draft, Formal analysis. **Andrea Mazzucato:** Resources, Methodology, Investigation. **Ivanka Tringovska:** Resources, Methodology, Investigation. **Gancho Pasev:** Investigation. **Amalia Barone:** Methodology, Investigation. **Salvador Soler:** Methodology, Investigation. **Ludovica Fumelli:** Methodology, Investigation. **Stanislava Grozeva:** Methodology, Investigation. **Daniela Ganeva:** Investigation. **Jaime Prohens:** Methodology, Investigation. **Maria José Díez:** Writing – review & editing, Validation, Project administration, Methodology. **Antonio Granell:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Antonio Granell reports financial support was provided by European Commission H2020. Antonio Granell reports financial support was provided by RoxyCOST Action. Joan Casals reports financial support was provided by Serra Hunter. If there are other authors, they 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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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scienta.2024.113351.

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