LWT - Food Science and Technology 203 (2024) 116413

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Are the sensory qualities of prestigious traditional varieties of beans preserved in commercial canned products? A comprehensive sensorial and chemical study on Ganxet beans

Salvador Roselló [a], Joaquin Beltran [b], Ana Rivera [c,d], Laura López-Mas [d], Roser Romero del Castillo [d], Joan Casals [c,d,*]

[a] Joint Research Unit UJI-UPV Improvement of Agri-Food Quality, Universitat Jaume I, Castellón de La Plana, Spain
[b] Environmental and Public Health Analytical Chemistry, Research Institute for Pesticides and Water (IUPA), Universitat Jaume I, Castellón de La Plana, Spain
[c] HorPTA, Department of Agri-Food Engineering and Biotechnology, Universitat Politècnica de Catalunya (UPC)-BarcelonaTech, Castelldefels, Spain
[d] Fundació Miquel Agustí, Castelldefels, Spain

ARTICLE INFO

Keywords:
Legumes
Canned beans
Protected designation of origin (PDO)
Sensory analysis
Volatile organic content

ABSTRACT

The commercial production of legume cans often involves exposing products to elevated temperatures, albeit with potential alterations to sensory traits. For premium products such as the Ganxet bean, which holds a Protected Designation of Origin (PDO) quality label, these adverse effects may influence consumer acceptance. This study investigated sensory and chemical differences between commercial cans and traditionally cooked Ganxet beans. A market survey enabled the identification of 15 commercial Ganxet cans, which were profiled for different physicochemical traits. Five were selected to represent maximum variability and were compared to two traditionally cooked references using standardized descriptive sensory and compositional analyses (volatile and non-volatile fractions). Commercial cans presented significantly higher off-flavor intensity and product darkening, while no significant changes were observed for textural traits. Commercial cans exhibited a broad diversity in their volatile profile and significantly lower content of distinctive non-volatile molecules (citric acid, sucrose, raffinose, and stachyose). A multivariate PLS regression model related off-flavor present in commercial cans with (E,E)-2,4-heptadienal, (E)-2-octenal, 1-nonanol (enhancers), and glutamic, malic, (E,E)-2,4-nonadienal, stachyose, sucrose, and glucose (inhibitors). The deviation of commercial Ganxet cans from PDO sensory quality requirements highlights the necessity for innovations in cooking protocols. These innovations are essential for producing high-quality cans from prestigious bean varieties.

1. Introduction

Legumes are an important component of human diets (Maphosa & Jideani, 2017; Tharanathan & Mahadevamma, 2003) and play a pivotal role in designing sustainable food systems (Poore & Nemecek, 2018). The preparation of dry legumes (primarily lentils, chickpeas, and beans) for human consumption is a laborious process that involves soaking and slow cooking, close to boiling point, to prevent the seeds from breaking (Romero del Castillo et al., 2012). Sometimes sodium bicarbonate ($NaHCO_3$) is added to facilitate softening and reduce cooking time (de León et al., 1992; Pirhayati et al., 2011; Polak et al., 2015). Since the beginning of the XX century, various strategies have been developed to provide easily available cooked legumes to consumers, saving time in their preparation. In Catalonia (north-east of Spain), for example, the preparation of cooked legumes in small establishments in textile industrial settlements, at the end of XIX century and beginning of the XX century, is well documented, as facilitated the housework of working women (Dominguez, 2005). This practice is still maintained by specialized shops that provide cooked legumes in bulk. Later on, long-life sterilized canned legumes in glass jars or cans became popular, and currently, legumes are also marketed pasteurized and packaged in modified atmosphere, in the so-called ready-to-eat products, which must be kept refrigerated.

Heat sterilization and pasteurization processes are traditional

* Corresponding author. HorPTA, Department of Agri-Food Engineering and Biotechnology, Universitat Politècnica de Catalunya (UPC)-BarcelonaTech, Castelldefels, Spain
E-mail address: joan.casals-missio@upc.edu (J. Casals).

https://doi.org/10.1016/j.lwt.2024.116413
Received 15 May 2024; Received in revised form 24 June 2024; Accepted 27 June 2024
Available online 28 June 2024

methods used to extend the shelf life of numerous food products. However, they involve highly aggressive handling that significantly alters foods due to the substantial surpassing of required cooking temperatures. This results in detrimental effects on flavor, color, texture, and nutritional value (Knockaert et al., 2011). In the case of beans, heat treatment adversely impacts nutritional value by degrading antioxidant properties, while also reducing the content of certain substance such as lectins, which could be toxic (Pedrosa et al., 2015; Qureshi & Sadohara, 2019). Overall, there exists a balance trade-off between nutritionally positive and negative aspects (Pedrosa et al., 2015), the effect depending on the raw material (i.e. variety, growing and storage conditions) (Chigwedere et al., 2019; Margier et al., 2018). Moreover, the sterilization process adversely affects sensory attributes of beans (Parmar et al., 2016; Revilla & Vivar-Quintana, 2008) as well as other legumes like chickpeas (Noordraven et al., 2021). However, the extent of influence on nutritional and sensory traits is largely dependent on genetic and environmental pre-harvest factors, and on cooking sterilization procedures (i.e. temperature and treatment duration), which can vary significantly among commercial products (Balasubramanian et al., 1999; Bassett et al., 2020; Margier et al., 2018; Wang et al., 1988).

Spain is a secondary center of diversity of *Phaseolus vulgaris* L., harboring numerous landraces (Pérez-Vega et al., 2009; Rivera et al., 2018). One of the most appreciated is the Ganxet bean, characterized by its white color, slightly flattened and hook shape, medium size (50 g/100 seeds), and high protein content (Bosch et al., 1998; Casañas et al., 1999). It holds the highest European geographic quality label (Protected Designation of Origin (PDO), in accordance with Regulation (EU) 1376/2011). Its cultivation is located in the coastal and pre-coastal area of Catalonia, in the northeast of the Iberian Peninsula. This esteemed bean was historically prepared in households, specialized restaurants, and by small businesses dedicated to cooked legume products. Its reputation has spurred a new array of offerings, predominantly sterilized cans in glass jars. Yet, no studies have explored the extent to which these novel products, utilizing diverse heat treatments, deviate from the sensory attributes conferred by traditional Ganxet bean cooking methods (Romero del Castillo et al., 2012). This seems like a relevant aspect since it is a premium product for which consumers are willing to pay a significantly higher price.

In this context, the aims of the study were: i) to explore the sensory differences between commercial canned Ganxet beans and reference samples of traditionally cooked, non-sterilized Ganxet beans; ii) to study compositional differences (both in volatile and non-volatile compounds) between these two preparation types, and iii) to identify compounds responsible for the sensory differences between traditionally cooked and commercially canned beans.

2. Materials and methods

2.1. Samples: commercial cans

2.1.1. Prospecting the market

An exhaustive search was conducted on commercial cans that use the Ganxet landrace, either in supermarkets, specialized stores, or online shops. Fifteen different brands were found (IND_01-IND_15). All of them are presented on the market in a glass jar and undergo thermal treatments to extend their shelf life. The pre-treatment and sterilization process protocols of each company are confidential and not available.

2.1.2. Characterization of the samples

Commercial samples were studied for various physicochemical traits. The jars were slightly opened and heated in a water bath at around 50 °C to liquefy the covering liquid and facilitate the removal of the beans, while preventing them from breaking. Subsequently, the beans were drained, with the covering liquid being retained for subsequent analysis. *Dry matter of the covering liquid* (g/100g): measured on 15 g of the covering liquid after a treatment in an oven at 100 ± 2 °C for 24 h. *pH*: obtained from a direct measurement by submerging the device's electrode in the covering liquid containing the beans (pH-meter Basic 20, Crison, Alella, Spain). *Soluble solids content* (SSC, °Brix): measured with a refractometer Basic 20 (Crison, Alella, Spain) in the covering liquid after homogenization. *Colorimetry*: a Konica Minolta CR-410 (Minolta, Osaka, Japan) was used to measure the color parameters L*, a*, b* from the CIELAB color space. Each color parameter was estimated in three fractions of each sample: whole beans (Wb), puree (P, beans were manually crushed together with the covering liquid), and the covering liquid (L). *Percentage of whole beans* (%): percentage of beans that were not broken, do not had cracks, flattened or skinless areas, measured according to the protocol described in Romero del Castillo et al., 2008b. *Price* (€/g dry weight): calculated per gram of drained weight of beans. The presence of sulfites, ascorbic acid, salt, and chelating agent (EDTA) was derived from the information provided by each brand (presence (1) or absence (0)). Quantitative measures were obtained by triplicate in two jars per commercial sample.

2.2. Samples: traditionally cooked

As traditional and non-sterilized references, a cooked and ready to eat sample bought in a local market (Rafols Precuinats, Mercat d'Horta, Barcelona) (TRADmark), and a sample prepared in the laboratory following the standardized cooking method described by Romero del Castillo et al. (2012) (TRADlab) were employed. Seeds used in the standardized cooked sample (TRADlab) belonged to the Montcau variety (Bosch et al., 1998), a genotype selected from the Ganxet varietal type and considered a benchmark within the PDO.

2.3. Descriptive sensory analysis

Due to sensory fatigue, tasting panels can only evaluate a limited number of samples (Meilgaard et al., 2007). To reduce the number of samples of the commercial set, we selected five samples that represent the physicochemical diversity. The selected samples were evaluated by a trained tasting panel consisting of 10 tasters, all of whom had more than five years of experience in descriptive sensory analysis of dry beans (Romero del Castillo et al., 2012). The tastings were conducted in the sensory analysis laboratory of the Barcelona School of Agri-food Engineering and Biotechnology, equipped and certified according to the requirements established by the ISO 8589 standard (ISO, 2007). All samples were evaluated in duplicate in different sessions. A maximum of five samples were tasted in each session. The sensory study was approved by the Ethics Committee of the Miquel Agustí Foundation.

2.3.1. Sample preparation

To prepare the commercial samples for a tasting session, the product was placed in a water bath, with the lid slightly unscrewed, covering it at least halfway. When the temperature reached 90 °C, the sample was left for a while to facilitate the liquefaction of the liquid that is often gelatinous. In a separate container, a volume of distilled water equal to the volume of the jar was heated to 90 °C. Then, the canned product was poured into the pot with the distilled water and the contents were mixed for 2 min to disaggregate the beans. The beans from the local market (TRADmark) were bought the same day of the analysis. On the same day of each tasting session, the laboratory personnel prepared the reference sample (TRADlab). All the samples were maintained at 60 °C until the moment they were served to the tasters.

2.3.2. Sample serving

The bean samples were served in stainless steel containers along with the covering liquid necessary to keep the beans hydrated and warm. Each stainless-steel container was covered with a watch glass to prevent the loss of volatile compounds. The service containers were placed on a heating plate inside tasting booths to keep them warm and at a constant temperature. Each sample was identified with a random three-digit

code. The tasting was conducted under green light (except for the color determination which was under white light) to avoid bias due to color.

2.3.3. Sensory descriptors

All attributes were measured on a semi-structured linear scale ranging from 0 (minimum intensity) to 10 (maximum intensity), anchored in the center (Lawless & Heymann, 2010). The following traits were measured. *Color*: sensation of hue, saturation and clarity. Evaluated on a scale ranging from very light cream to brown (hazelnut shell). *Overall flavor intensity*: intensity of olfactory, gustatory and trigeminal sensations perceived during the tasting (ISO, 2008). *Ganxet flavor intensity*: intensity of olfactory, gustatory and trigeminal sensations typical of the Ganxet beans that is a flavor very smooth without notes of any kind. *Off-flavor intensity*: this parameter reflects the divergence between *Overall flavor intensity* and *Ganxet flavor intensity*. Given the study's focus on discerning differences between commercial cans and traditional cooked Ganxet beans, this becomes a crucial sensory element for assessment. Recognizing its complexity for direct panelist recording, it was inferred as the difference between two extensively understood parameters within the tasting panel. *Seed-coat perception*: sensation of perceiving the seed-coat separately from the rest of the cooked bean when chewing. *Mealiness/creaminess*: sensation of perceiving small particles. An example of a non-mealy food is banana, while a very mealy one is boiled egg yolk. Creaminess is the sensation of a smooth, continuous mass. It can be assumed that, when it comes to beans, creaminess is the opposite sensation of mealiness (Romero del Castillo et al., 2008b). *Hardness*: resistance to deformation presented by the sample under slight jaw displacement.

2.4. Chemical analyses

Samples of all materials subjected to sensory analysis were frozen for further chemical analyses. Volatiles described as important in the composition of dry beans (Buttery et al., 1975; Hinterholzer et al., 1998; Oomah et al., 2007), as well as sugars and organic acids that may be relevant to the flavor of cooked beans were analyzed. The samples intended for the quantification of volatiles were kept at −80 °C, and those intended for the quantification of sugars and organic acids were kept at −20 °C until analysis.

Sugars (fructose, glucose, sucrose, raffinose and stachyose) and organic acids (oxalic, malic, citric and glutamic) were jointly quantified by capillary zone electrophoresis using an Agilent 7100 system (Agilent Technologies, Waldbronn, Germany) equipped with a Diode Array Detector, following the method described by Cebolla-Cornejo et al. (2012) with optimizations for bean analysis. Fused silica capillaries (Polymicro technologies, Phoenix, AZ, United States) were used, with a 50 μm internal diameter, 363 μm external diameter, 67 cm total length, and 60 cm effective length. Capillaries were initially conditioned at 50 °C for 5 min with 1M NaOH, 5 min with 0.1M NaOH and 10 min with water, then separation buffer optimized for bean analysis (28.92 mmol/L maleic acid and 0.36 % w:v hexadimethrine bromide, pH = 12.7) was run for 30 min at 20 °C. Samples were defrosted in the dark and centrifuged at 15680 g for 10 min. The upper phase was diluted with deionized water at a 1:20 ratio. The supernatant was diluted (1:5) in deionized water and mixed with 500 mg L^{-1} of IS (D-glucose 6-phosphate sodium salt). The solution was filtered using 0.22 μm syringe filter (Branchia, Labbox Labware, S.L., Vilassar de Dalt, Spain) and analyzed. Samples were injected hydrodynamically for 10 s at 34 mbar. Separation was performed at −17.1 kV fixed voltage and 30 °C for 25 min. Indirect detection at 214 nm wavelength (bandwidth 4 nm) with reference wavelength 360 nm (bandwidth 100 nm) was used. Between runs, capillary was flushed 5 min with 120 mmol/L SDS, 2 min with water and 4 min with BGE. Each sample was analyzed twice and quantification was performed with calibration curves of 5 points and $R^2 > 0.98$.

The extraction and analysis of volatiles related to aroma were performed as described by Fredes et al. (2016) with adaptations for bean analysis. Cooked beans samples of 30 g were added with 50 μL of 15 μg/mL methyl salicylate-D_4 (internal standard) and were extracted by dynamic head space (purge-and-trap), purging with dry nitrogen and using SPE Tenax cartridges (Supelco, Sigma-Aldrich Química S.A., Madrid, Spain) to retain volatile analytes which were then desorbed by solvent elution. Chromatographic determination was carried out using an Agilent 7890B gas chromatograph (Agilent Technologies, Waldbronn, Germany) coupled with a mass spectrometry detector Xevo-TQGC (Waters). Separation of the analytes was carried out on a 30 m × 0.25 mm DB-WAX (0.25 μm film thickness) J&W Scientific capillary column, using helium at 1 mL min^{-1} as carrier gas. The temperature program was as follows: 40 °C for 5 min, then raised to 160 °C at a rate of 4 °C min^{-1}, then raised to 250 °C at a rate of 30 °C min^{-1}, with a final isothermal stage of 2 min (total chromatographic analysis time of 40 min). Injection of 2 μL (splitless mode, temperature 280 °C) was carried out using a PAL3 System (CTC) autosampler. The gas-chromatograph was directly interfaced with the mass spectrometer which was operated in the positive electron ionization mode (energy of 70 eV). Transfer line temperature was established at 250 °C and ion source was adjusted to 200 °C. Mass spectrometry measurements were carried out in the selected ion monitoring mode selecting three m/z ions for each compound in 36 different segments. Quantitation of analytes in the sample extracts was performed using external standard calibration curves using absolute areas for the quantitation m/z ion trace. Reference aroma compounds were obtained from Sigma-Aldrich Química S.A. (Madrid, Spain; including Supelco and Fluka products) as pure compounds. Stock solutions of the aroma standards at 500 mg L^{-1} were prepared in acetone and stored at −18 °C. Working solutions were prepared by volume dilution in diethyl ether-hexane (1:1). Calcium chloride 97 g/100g (Riedel de Haen) was purchased from Supelco (Sigma- Aldrich Química S.A., Madrid, Spain). Organic solvents (hexane, ethyl acetate, diethyl ether) of trace residue analysis quality were purchased from Scharlab (Barcelona, Spain). Results were expressed as ng g^{-1} fresh weight.

2.5. Statistical analysis

Data from the physicochemical characterization of the commercial samples (whole set) was subjected to a one-way analysis of variance (ANOVA), considering the sample as a fixed factor. Mean comparison was performed using the least significant difference test (LSD, $p < 0.05$). To analyze the dissimilarity among commercial samples regarding the physicochemical characterization, a principal component analysis (PCA) was computed using mean values. Sensory data was analyzed using a two-way ANOVA, by using a different model to calculate differences between samples and between treatments (commercial cans *vs.* traditional cooking). To study the differences between samples, the model $X_{ijk} = \mu + S_i + P_j + S_i{*}P_j + \varepsilon_{ij}$ was used, where μ is the grand mean; S_i is the effect of sample i; P_j is the effect of panelist j; $S_i{*}P_j$ is the interaction between sample i and panelist j; ε_{ij} is the residual associated with sample i in panelist j. To study differences between treatments, we used the model $X_{ljm} = \mu + T_l + P_j + T_l{*}P_j + \varepsilon_{ljm}$, where μ is the grand mean; T_l is the effect of treatment l; P_j is the effect of panelist j; $T_l{*}P_j$ is the interaction between treatment i and panelist j; ε_{ij} is the residual associated with treatment l in panelist j. All the factors were considered as fixed effects. Mean comparison for sensory traits was performed using the Tukey's honestly significant difference test (HSD, $p < 0.05$). These analyses were performed with R v4.0.3 (R Core Team, 2020), using 'Agricolae' (Mendiburu & Yaseen, 2020) and 'PcaMethods' (Stacklies et al., 2007) packages.

Results from chemical analysis were analyzed using univariate and multivariate procedures. Univariate analysis included one-way ANOVA, following the same models as described above. Multivariate analyses were used to study the diversity among samples for their volatile organic contents (VOCs). We performed a hierarchical cluster of principal components analysis (HCPC, package 'FactoMineR' (Lê et al., 2008))

with the standardized mean values per sample, using Euclidean distances and the Ward's minimum variance method. The result was plotted in a heatmap using the 'Stats' package.

Finally, a partial least square (PLS) regression model for sensory off-flavor intensity (Y vector) from compositional variables (X matrix) was developed. Compositional variables include not only all the quantified compounds (4 organic acids, 5 sugar and 42 volatiles [Supplementary Table 1]), but also the inverse or quadratic forms of all these variables in order to consider curvilinear responses using a total of 188 X variables in the initial models. Before modeling, the data were pre-treated using auto-scaling (mean-centered and scaled to unit standard deviation for each variable) to correct for variations in variable scaling and units. Venetian blinds were selected as the cross-validation method to estimate the model performance. Outlier identification and elimination were conducted for both the Y vector and X variables, accomplished through the evaluation of Q residuals and leverage coefficients. Similar to previous studies, a variable selection strategy was employed to enhance the initial PLS models, following a multistage criterion (Villena et al., 2023). Initially, an interval PLS (iPLS) forward variable selection procedure (Nørgaard et al., 2000) was executed to identify the initial set of explanatory variables. A subsequent refinement of the variable selection for the model was carried out by discarding variables using the selectivity ratio (Sratio) criterion, removing 0.1 fraction of variables per iteration (Rajalahti et al., 2009) to obtain the final model. The performance of the resulting prediction model was assessed based on several metrics, including the number of latent variables (LV), coefficient of determination for cross-validation (R^2_{CV}), cross-validation bias (CV bias), and root mean square error of cross-validation (RMSECV). All PLS models were performed using Matlab v 9.8 (Mathworks Inc, Natick, MA, USA) and the PLS Toolbox 9.1 for Matlab (Eigenvector Research Inc, Wenatchee, WA, USA).

3. Results and discussion

3.1. Characteristics and sample selection for descriptive sensory analysis of commercially canned Ganxet beans

Fifteen commercial samples were collected from the market, showing considerable variability for the physicochemical parameters studied. Statistically significant differences among samples were observed for all attributes except Wba* (Table 1). Wide variation was found for key quality traits, including the dry matter of the covering liquid (6.4–9.3 g/100g), SSC (5.9–8.3 °Brix), % of whole beans (55.2–92.2%), and price (0.006–0.013 €/g dry weight). All brands incorporated salt as an ingredient. Additionally, three brands used sulfites or ascorbic acid, while four included EDTA. Notably, two brands featured all four additives (IND_05 and IND_07).

In order to investigate the similarities among samples, a Principal Component Analysis (PCA) was performed (Fig. 1), considering the quantitative variables from Table 1. The first two principal axes accounted for 52.6% of the total variation. The variables most strongly correlated with the first axis (PC1, variance explained = 30.0%) included the dry matter of the covering liquid (correlation coefficient, r = 0.94), Wbb* (r = 0.89), SSC (r = 0.84) and WbL* (r = −0.86). The variables most correlated with the second axis (PC2, variance explained = 22.6%) were PL* (r = 0.87), Lb* (r = −0.86), LL* (r = 0.58), and price (r = −0.59). The distribution of the samples in the PC1-PC2 space did not reveal any consistent groupings, with samples scattered throughout the space defined by PC1-PC2. Considering this distribution pattern and the limited number of samples that the sensory analysis panel could effectively manage, a subset of five brands (IND_02, IND_05, IND_10, IND_12, and IND_13) was selected to represent the diverse range of commercial samples. This selection was designed to encompass samples from both ends of the PC1-PC2 diversity spectrum, with one sample located near the central coordinates.

The varietal population, place and year of cultivation before the heat

Table 1
Physicochemical profiling of commercial samples (mean values). Presence (1) or absence (0) of sulfite, ascorbic acid, salt, and chelating agent (EDTA) was extracted from jar information. Statistical differences for quantitative variables were determined using LSD test at $p < 0.05$. Abbreviations: DM: dry matter of the covering liquid; SSC: soluble solids content; Wb: whole bean; P: puree; L: covering liquid; L*, a*, b* color parameters from the CIELAB color space. ns: not significant.

Sample	DM (g/100g)	pH	SSC (°Brix)	% Wb	WbL*	Wba*	Wbb*	PL*	Pa*	Pb*	LL*	La*	Lb*	Price (€/g dry weight)	Salt	Sulfites	Ascorbic acid	EDTA
IND_01	6.57	5.81	6.5	92.15	63.2	0.8	3.8	36.5	3.3	11.2	70.4	4.2	20.3	0.012	1	0	0	0
IND_02	6.94	5.6	6.8	91.06	51.4	1.0	4.3	30.6	2.9	10.7	68.9	3.9	21.3	0.010	1	0	0	0
IND_03	7.25	5.87	7.2	89.88	57.1	0.9	5.0	33.9	2.6	9.9	69.5	3.6	19.1	0.013	1	0	0	0
IND_04	9.29	5.91	8.3	77.48	40.2	1.0	10.2	45.3	3.1	12.9	65.9	3.8	18.2	0.013	1	0	0	0
IND_05	7.79	5.69	7.7	55.19	55.1	0.9	4.0	71.0	2.7	13.7	73.6	2.4	14.6	0.008	1	1	1	1
IND_06	8.11	5.65	8.0	81.07	57.6	1.0	3.1	53.8	3.3	13.0	69.7	4.4	19.7	0.012	1	0	0	0
IND_07	7.30	5.74	7.1	85.77	55.4	0.8	2.4	66.8	3.1	12.6	71.2	2.1	13.8	0.011	1	1	1	1
IND_08	7.67	5.9	7.3	89.31	54.8	1.1	5.3	71.3	4.0	16.1	67.8	3.0	16.7	0.013	1	0	0	0
IND_09	8.78	5.83	7.9	83.95	46.8	1.1	8.0	71.8	2.8	15.4	70.2	3.6	16.3	0.006	1	1	0	1
IND_10	8.17	5.71	8.1	87.90	51.4	0.8	7.4	69.7	3.3	18.3	65.4	2.5	18.9	0.011	1	0	0	0
IND_11	9.01	5.75	7.4	83.11	51.6	0.7	6.1	68.1	2.8	17.9	67.3	3.4	20.1	0.010	1	0	0	0
IND_12	6.41	5.52	5.9	85.78	62.4	1.1	2.6	62.2	2.7	14.3	67.2	2.9	17.8	0.008	1	0	1	0
IND_13	7.68	5.85	7.1	90.46	54.1	0.9	4.4	70.2	2.4	14.4	70.0	1.5	16.9	0.006	1	0	0	1
IND_14	7.50	5.96	7.0	85.47	63.2	1.0	1.6	72.8	3.2	15.8	71.7	1.0	15.0	0.008	1	0	0	0
IND_15	7.27	5.93	7.3	88.18	58.1	1.0	3.0	74.3	1.8	13.6	73.5	1.5	15.1	0.012	1	0	0	0
LSD	1.63	0.09	1.1	26.76	15.4	ns	4.7	15.3	1.8	4.3	7.0	2.8	5.3					

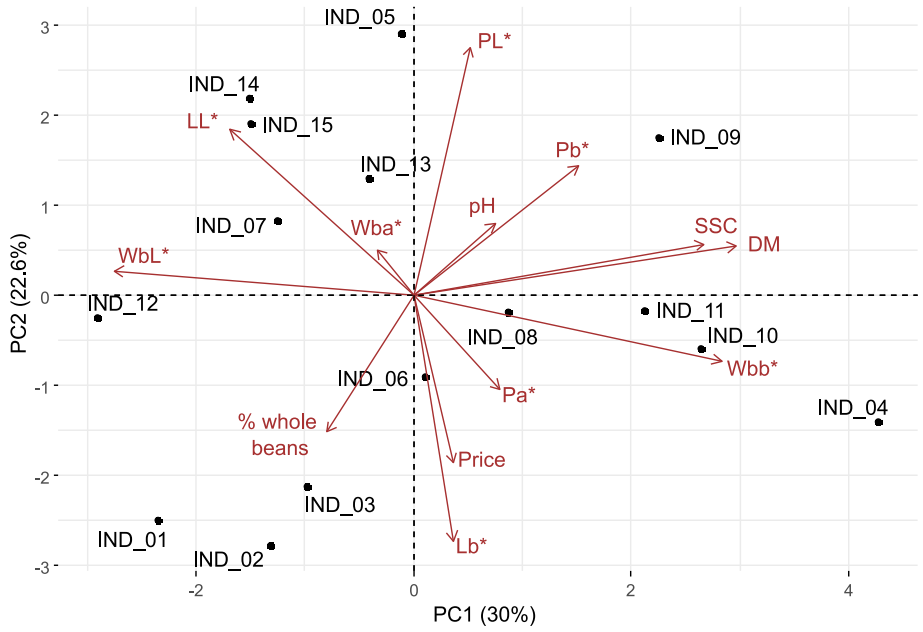

Fig. 1. Principal component analysis (PCA) based on physicochemical traits of the commercial samples. Abbreviations: SSC: soluble solids content (°Brix); DM: dry matter of the covering liquid; Wb: whole bean; P: puree; L: covering liquid; L*, a*, b* color parameters from the CIELAB color space. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

treatment of the beans used in each commercial sample are unknown. However, the Ganxet bean, which meets the PDO morphological regulations, is easily identifiable by the curvature degree of the seed (Bosch et al., 1998; Rivera et al., 2015). All the samples met the curvature characteristic of the landrace; therefore, the differences in results are assumed to be fundamentally due to cooking protocols, although the effect of the place of cultivation and storage time and conditions cannot be ruled out (Florez et al., 2009; Romero del Castillo et al., 2008a).

3.2. *Sensory characteristics of traditionally cooked, and commercial canned Ganxet beans*

The five selected commercial samples and the two traditionally cooked ones were analyzed by a trained sensory panel. Significant differences between samples were found for all the sensory attributes, except for mealiness (Table 2). The panelist effect was significant for all attributes, indicating differences in the use of the scale among them. However, sample*panelist (S*P) interaction was not significant for any attribute, which supports the consistency of the evaluations (O'Mahony, 2017).

Significant differences between treatments (commercial cans *vs.* traditionally cooked) were found for color and off-flavor attributes (Table 2). Beans from commercial cans had, on average, a darker color and significantly higher off-flavor intensity than traditionally cooked beans. The traditionally cooked samples (TRADlab, TRADmark) did not show significant differences between them for any of the sensory attributes (Table 2). Overall, these samples fulfil the recognized standards for the Ganxet bean in the PDO conditions: low seed-coat perception, mealiness and hardness; light color; and low off-flavor perception. For the commercial samples, there were significant differences among them for almost all traits, presenting each sample some difference compared to the traditionally cooked samples. The commercial sample most similar to the references TRADlab, and TRADmark was IND_13. This sample had an exceptionally low color intensity and similar off-flavor intensity than the reference samples. The commercial samples that remain significantly above the references for off-flavor were IND_02, IND_05, and IND_10.

According to these results, cooking process employed in the food industry seems to induce darkening and the development of off-flavors. Different chemical reactions might be involved provoking these sensory alterations, which can be addressed in further studies. For instance, the darkening of beans during thermal treatments has been partly attributed to the caramelization of sugars and the Maillard reaction, which occurs when amino acids react with reducing sugars (Tamanna & Mahmood, 2015; van Boekel, 2006). Off flavor could be attributable to caramelization, changes in the proportions of the compounds commonly present in dry beans or to new products caused by overheating during sterilization. For example the Maillard reaction, which magnitude increases with temperature, can give rise to sulfur-containing compounds (Noordraven et al., 2021; van Boekel, 2006). The Strecker degradation, a secondary reaction of Maillard, can yield short-chain aliphatic

Table 2
Sensory profiles of the commercial (coded as IND_xx) and the traditionally cooked samples (coded as TRAD_xx). Within columns, values followed by the same letter indicate no significant differences (HSD Tukey test, $p < 0.05$). Lowercase letters indicate comparisons among samples, while uppercase letters indicate comparisons among treatments. All descriptors were measured on a linear scale ranging from 0 (minimum attribute intensity) to 10 (maximum intensity). ns: not significant.

Sample	Color	Seed-coat perception	Hardness	Mealiness	Off-flavor intensity
IND_02	4.99 ab	0.75 b	1.76 b	3.03 ns	5.81 ab
IND_05	4.51 ab	0.84 b	2.29 ab	3.11 ns	6.34 a
IND_10	6.45 a	0.66 b	2.38 ab	2.46 ns	5.09 ab
IND_12	5.95 a	3.78 a	3.62 a	3.83 ns	3.78 bc
IND_13	1.09 c	1.65 b	1.53 b	2.42 ns	2.53 cd
TRADlab	2.14 c	2.11 b	2.56 ab	2.83 ns	2.10 cd
TRADmark	3.25 bc	1.54 b	2.32 ab	2.48 ns	1.47 d
Commercial samples	4.50 A	1.87 ns	2.51 ns	2.31 ns	4.71 A
Traditional cooking	2.69 B	1.83 ns	2.44 ns	2.44 ns	1.78 B

aldehydes (Jousse et al., 2002), and sulfur compounds (Chigwedere et al., 2019; Khrisanapant et al., 2022), that can contribute to the off-flavors of canned beans. Thermal degradation of phenolic acids, carotenoids or thiamine, can also have occurred (Roland et al., 2017) although phenol content in white beans is low. It is worth noting that Ganxet beans have a very high content of protein (Rivera et al., 2018) and that this could have favored all these side heat induced reactions. Significantly, our experimental design does not allow us to elucidate the causative factors behind the sensory differences observed between preserved and traditionally cooked beans. Future studies should focus specifically on addressing these issues to gain insights into the sensory modifications of bean preserves.

3.3. Chemical composition of traditionally cooked and commercially canned Ganxet beans: non-volatile fraction

Significant differences were identified between samples and between treatments for all non-volatile compounds (Table 3). Although a wide diversity in the chemical profile was described in each group, the traditionally cooked samples tended to have a higher concentration of all the non-volatile compounds studied. The highest differences were for citric acid, fructose, sucrose, raffinose and stachyose. For oxalic acid, citric acid, sucrose and raffinose, some samples presented a concentration below the detection threshold. Overall, the range of variation for all the chemical variables among the samples was high. Previous research pointed out that the high temperature used during the sterilization process favors the release outside of the bean mass and degradation of non-volatile compounds (Mendoza et al., 2014; Wang et al., 2010), which can explain the tendency for a lower sugar and acid content in the commercial samples. From a sensory point of view, this can have some repercussions such as a less sweet character of commercial beans due to lower sugar content, or the lower flavor intensity due to lower glutamic acid content. On the other hand, the lower levels of raffinose and stachyose found in commercial samples may induce less flatulence (Khattab & Arntfield, 2009; Salunkhe & Kadam, 1989).

3.4. Chemical composition of traditionally cooked, and commercially canned Ganxet beans: volatile organic contents

Out of 50 volatile compounds described as important in bean flavor (Buttery et al., 1975; Hinterholzer et al., 1998; Oomah et al., 2007), 42 were identified consistently in the samples (i.e. present above the detection threshold in all the samples and replicates) (Fig. 2, Supplementary Table 1). Volatiles inconsistently present (i.e. present only in a replicate of some samples) were discarded for further analyses; these were (E)-2-hexenal, nonanal, decanal and 1-octanol. Clustering of samples revealed the existence of 2 main clusters distinguished by the general amount of all the volatiles (Fig. 2). Samples TRADmark (traditionally cooked) and IND_13 (commercial sample) presented lower amounts for all the volatiles. These results agree with the sensory determination of off-flavor intensities. TRADmark was bought in the market on the same day of the analysis, although according to the seller, the beans were cooked the previous night, which may have favored the loss of volatiles. Sample IND_13 had low off-flavor intensity and a striking white color (Table 2). It is therefore more similar to the traditionally cooked samples than to the commercial ones.

Samples in the second cluster presented a richer and more diverse volatile profile. The main trend that permits differentiation within this second group is the higher concentration of hexyl acetate, hexanal, furfural, benzaldehyde, 6-methyl-5-hepten-2-one, and 1-hexanol in samples IND_05 and IND_10. Both samples were characterized by a high off-flavor intensity according to the trained panel (Table 2). The reference sample TRADlab exhibited elevated amounts of most volatiles. The presence of hexanal in cooked beans may arise from polyunsaturated fatty acids, which are abundant in the lipid fraction of common beans (Chigwedere et al., 2019; Reyes-Moreno et al., 1993). On the other hand, benzaldehyde could be produced from phenylalanine, an aromatic amino acid that is likely a precursor of aromatic aldehydes in legumes (Adamiec et al., 2001; Murray et al., 1976). Ketones, such as 6-methyl-5-hepten-2-one, are known to result from the lipoxygenase-catalyzed reaction involving unsaturated fatty acids and hydroperoxides (Chigwedere et al., 2019). Furthermore, the Maillard reaction and caramelization of sugars can lead to the formation of considerable levels of furfural compounds in all heated foods (Srivastava et al., 2018). These compounds generally impart sweet, fruity, and caramel-like characteristics to foods, with odor threshold values at the parts per million level (Mottram, 2007). However, alcohols such as 1-hexanol are not considered important for bean flavor development (Chigwedere et al., 2019).

3.5. Modeling off-flavor intensity

Flavor perception is generally not solely influenced by a single compound, but rather by the relative proportions of volatile and non-volatile compounds that impact human senses (Lawless & Heymann, 2010), along with individual diversity in sensory sensitivities and preferences. Through the analysis of compositional data, it was not possible to pinpoint individual compounds responsible for the off-flavor in the present experiment. Similar challenges were faced by Noordraven et al. (2021), who were also unable to identify the specific volatile compounds responsible for certain sensory changes in sterilized chickpeas. Therefore, to examine which compounds among those analyzed had a greater influence on off-flavor perception, a PLS regression with a multi-stage variable selection procedure (using methods i-PLS and SRatio sequentially) was conducted. The model utilized four latent variables to explain 89.61% of the variability in X compositional variables and 98.52% of the Y off-flavor vector. The model exhibited a high coefficient of determination in cross-validation ($R^2_{CV} = 0.97$, Fig. 3), and a restricted error, with a RMSECV of 0.35, representing 6.09% of the range of variation in off-flavor.

The final PLS model was transformed into a linear regression model to determine the relative contribution of each included compositional

Table 3
Non-volatile chemical composition of five commercial samples (coded as IND_xx) and two traditionally cooked samples (coded as TRAD_xx). Within columns, values followed by the same letter indicate no significant differences (HSD Tukey test, $p < 0.05$). Lowercase letters indicate comparisons among samples, while uppercase letters indicate comparisons among treatments. Results are expressed in mg/g fresh weight.

Sample	Oxalic	Malic	Citric	Glutamic	Fructose	Glucose	Sucrose	Raffinose	Stachyose
IND_02	1.32 d	1.40 cd	0.60 cd	2.99 c	15.15 d	16.90 c	0.34 e	0.50 c	8.22 d
IND_05	0.00 e	0.24 d	0.00 d	0.93 d	2.90 e	3.28 d	0.00 e	0.00 c	1.78 e
IND_10	3.73 b	1.25 cd	0.48 cd	3.58 c	15.27 d	24.00 c	0.83 d	0.71 c	13.68 c
IND_12	0.12 e	1.52 c	0.67 c	6.12 a	32.36 c	49.57 ab	1.16 cd	3.40 b	16.04 c
IND_13	2.84 c	3.43 b	1.00 bc	4.34 bc	31.42 c	52.97 a	1.36 bc	1.21 c	18.99 c
TRADlab	0.00 e	2.31 bc	2.34 a	5.37 ab	51.52 a	42.25 b	1.62 ab	5.42 a	36.65 a
TRADmarket	4.85 a	5.07 a	1.52 b	3.54 c	44.86 b	44.70 ab	1.76 a	3.03 b	28.74 b
Commercial samples	1.60 B	1.57 B	0.55 B	3.59 B	19.42 B	29.34 B	0.74 B	1.16 B	11.74 B
Traditional cooking	2.43 A	3.69 A	1.93 A	4.45 A	48.19 A	43.47 A	1.69 A	4.23 A	32.69 A

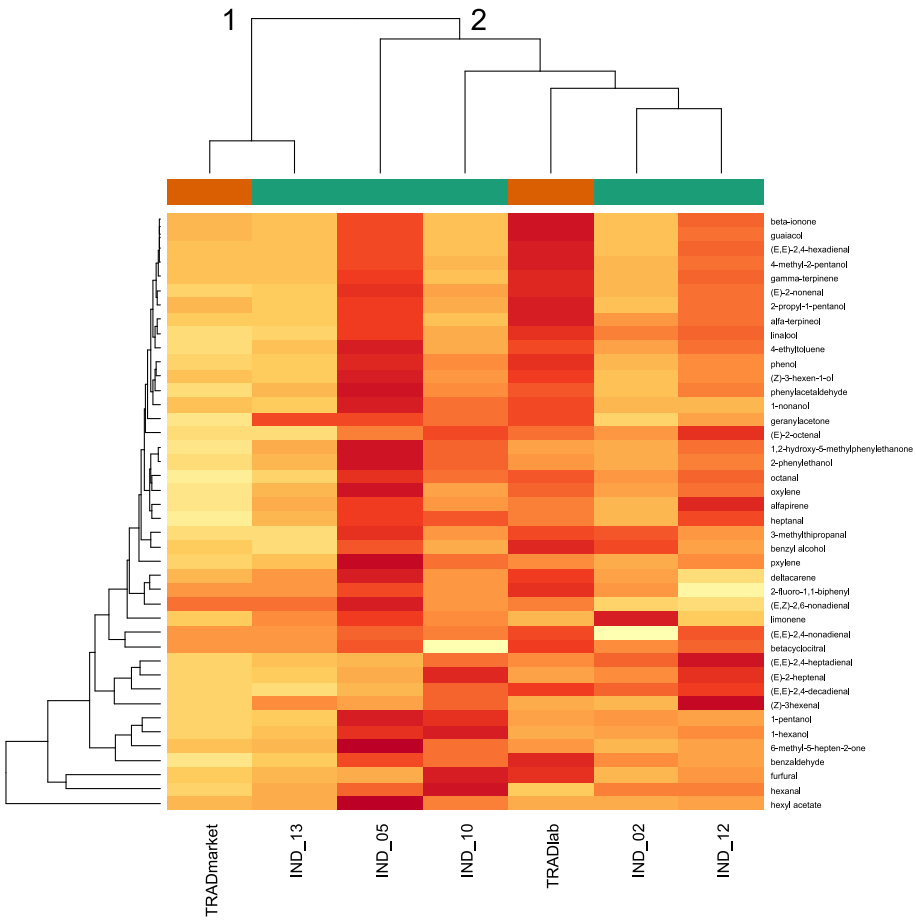

Fig. 2. Heatmap depicting the volatile organic content diversity in traditionally cooked (coded as TRAD_xx), and commercial samples (coded as IND_xx). The color code depicts the enrichment of each volatile in each sample, ranging from low (light yellow) to high (dark red) values. The upper panel indicates whether the samples are traditionally cooked (orange) or commercial samples (green). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

variable in explaining off-flavor perception (Table 4). Since these regression coefficients for each compositional variable are derived from the autoscaled model, they can be compared without being influenced by variable scale bias. As anticipated, the model's complexity encompasses compounds from both non-volatile (organic acids and sugars) and volatile fractions, appearing in both linear and quadratic forms. This finding underscore that off-flavor perception is a multifaceted sensory attribute, with certain compounds acting as enhancers and others as suppressors. The proposed model reveals that three volatile compounds [(E,E)-2,4-heptadienal, (E)-2-octenal, and 1-nonanol] intensify the perception of the off-flavor (Table 4). Their combined contribution constitutes 30.38% of all off-flavor effects. These compounds, derivatives of unsaturated fatty acids in beans, generate odors that are described as fatty or citric (TGSC, 2023). It's not unexpected for (E,E)-2,4-heptadienal and (E)-2-octenal to enhance off-flavor, given their prior identification as contributors to off-flavors in various food products. In fact, (E,E)-2,4-heptadienal is considered a specific indicator of oxidative rancidity in certain foods (Dixon & Hammond, 1984; Yang et al., 2013). Similarly, (E)-2-octenal has been noted for contributing to off-odors in food items supplemented with high-quality protein and lipid ingredients (such as duck egg gels) when exposed to heat treatment (Ren et al., 2021). Both compounds undergo rapid decomposition under thermal conditions (Zamora et al., 2015), explaining their increased presence due to heat sterilization processes. The contribution of 1-nonanol to bean off-flavor perception is less straightforward than that of the other two compounds. Its primary odor has been characterized as fruity or citrus-like (Ebert et al., 2022), but its secondary waxy notes (Anselmi et al., 1992) could potentially contribute to the described off-flavor perception. In contrast, (E,E)-2,4-nonadienal along with organic acids (glutamic and malic) and sugars (stachyose, sucrose, and glucose) dampen off-flavor perception (as indicated by negative coefficients in Table 4), collectively accounting for 69.62% of off-flavor effects. (E,E)-2,4-nonadienal has been recognized as a crucial component in soy milk aroma (Kaneko et al., 2011), while organic acids and sugars can function as enhancers or suppressors of certain flavor-associated molecules (Lawless & Heymann, 2010).

4. Conclusions

The sensory characteristics of the studied Ganxet bean commercial cans display considerable variation. Adhering to the PDO Ganxet regulation, most of the commercial samples deviate in at least one reference attribute. The commercial cooking protocols notably increases the intensity of off-flavor and the product's darkening. Commercial cans exhibit broad fluctuations in their volatile profile and notably lower content of distinctive non-volatile molecules, which carries sensory and nutritional implications that differentiate these products. Overcoming the inherent "canned" taste resulting from heating treatments appears particularly challenging. The Ganxet variety's elevated protein content may foster extensive Maillard reactions during sterilization when very high temperatures are used, as usually occurs in industrial cooking in contrast to traditional cooking. While other molecular effects from heat cannot be ruled out, this explanation appears the most plausible, despite it need further investigation. Univariate analyses of volatiles and non-

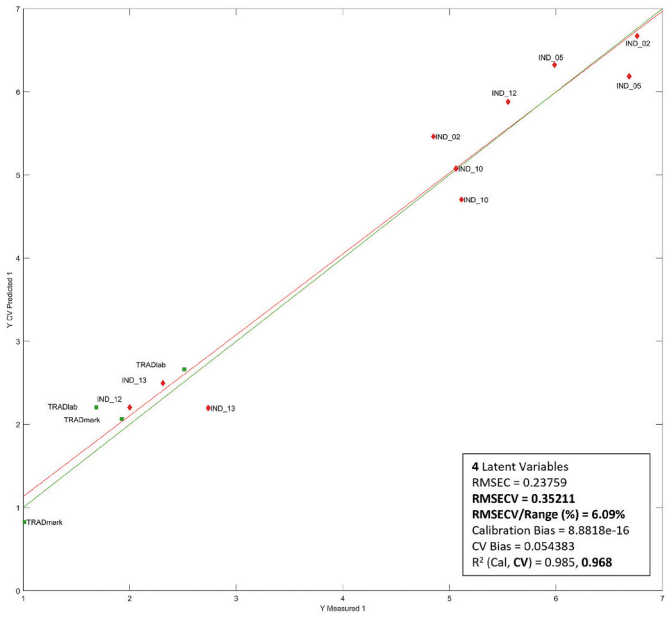

Fig. 3. Performance of PLS model linking off-flavor intensity and chemical composition. RMSE: Root Mean Square Error; C: calibration; CV: cross-validation; RMSECV/Range (%): ratio RMSECV to range of variation of the off-flavor intensity. Red line: calculated linear regression of the model. Green line: relation between predicted and measured values. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Ranked relative contributions of compounds to off-flavor in the autoscaled PLS prediction model using regression vector coefficients.

Compound	Regression vector for Y
Glutamic[2]	−0.2907
(E,E)-2,4-heptadienal[2]	0.2330
Malic[2]	−0.2304
(E,E)-2,4-nonadienal	−0.2133
(E)-2-octenal[2]	0.1886
Stachyose	−0.1840
Sucrose	−0.1505
1-nonanol[2]	0.1257
Glucose	−0.1001
Glucose[2]	−0.0853

Superscript [2] indicates quadratic variables.

volatiles found in dry beans have not pinpointed a specific compound responsible for off-flavors in preserves. However, a multivariate PLS regression model encompassing these variables effectively explains off-flavor identified by panelists. Among the compounds, (E,E)-2,4-heptadienal, (E)-2-octenal, and 1-nonanol (enhancers), along with glutamic, malic, (E,E)-2,4-nonadienal, stachyose, sucrose, and glucose (inhibitors) emerge as the most significant contributors. The observed variability among commercial samples suggests room for enhancing these Ganxet commercial cans. Current PDO regulations restrict the use of additives. Unless additive limitations change to address off-flavor concerns, potential solutions may necessitate innovative systems. Options like Microwave-assisted Thermal Sterilization, the Shaka® Retort System, or Pressure-assisted Thermal Sterilization methods (Mishra et al., 2022), or a combination of thermal treatment, modified atmosphere, and refrigeration could be considered to maintain the distinct sensory value of these high quality beans in commercial products.

Funding sources

The research was funded by the Department of Agriculture of the Generalitat de Catalunya (ref. num. 56 21 010 2017 3A) and by Jaume I University (ref. UJI-B2018-51). Joan Casals is a Serra Húnter Fellow at Universitat Politècnica de Catalunya.

Ethical statement

The sensory study was approved by the Ethics Committee of the Miquel Agustí Foundation. Informed consent was obtained from each panelist prior to their participation in the study.

CRediT authorship contribution statement

Salvador Roselló: Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Joaquin Beltran:** Methodology, Investigation. **Ana Rivera:** Methodology, Investigation. **Laura López-Mas:** Investigation. **Roser Romero del Castillo:** Writing – review & editing, Validation, Methodology. **Joan Casals:** Writing – original draft, Project administration, Formal analysis.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgement

We would like to express our gratitude to the members of the tasting panel of the Miquel Agustí Foundation, for their essential participation in the study. The authors thank Servei Central d'Instrumentació Científica (SCIC) from the Universitat Jaume I for the use of scientific analytical equipment (CE and GC-MS).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2024.116413.

References

Adamiec, J., Rössner, J., Velíšek, J., Cejpek, K., & Šavel, J. (2001). Minor Strecker degradation products of phenylalanine and phenylglycine. *European Food Research and Technology, 212*(2), 135–140. https://doi.org/10.1007/s002170000234

Anselmi, C., Centini, M., Mariani, M., Sega, A., & Pelosi, P. (1992). Odor properties of some tetrahydropyranyl ethers. *Journal of Agricultural and Food Chemistry, 40*(5), 853–856. https://doi.org/10.1021/jf00017a030

Balasubramanian, P., Slinkard, A., Tyler, R., & Vandenberg, A. (1999). Genotype and environment effect on canning quality of dry bean grown in Saskatchewan. *Canadian Journal of Plant Science, 79*(3), 335–342. https://doi.org/10.4141/P98-107

Bassett, A., Dolan, K. D., & Cichy, K. (2020). Reduced retort processing time improves canning quality of fast-cooking dry beans (Phaseolus vulgaris L.). *Journal of the Science of Food and Agriculture, 100*(10), 3995–4004. https://doi.org/10.1002/jsfa.10444

Bosch, L., Casañas, F., Sánchez, E., Pujolà, M., & Nuez, F. (1998). Selection L67, a pure line with true seed type of the Ganxet common bean (Phaseolus vulgaris L.). *HortScience, 33*(5), 905–906.

Buttery, R. G., Seifert, R. M., & Ling, L. C. (1975). Characterization of some volatile constituents of dry red beans. *Journal of Agricultural and Food Chemistry, 23*(3), 516–519. https://doi.org/10.1021/jf60199a053

Casañas, F., Bosch, L., Pujolà, M., Sánchez, E., Sorribas, X., Baldi, M., & Nuez, F. (1999). Characteristics of a common bean landrace (Phaseolus vulgaris L) of great culinary value and selection of a commercial inbred line. *Journal of the Science of Food and Agriculture, 79*(5), 693–698. https://doi.org/10.1002/(sici)1097-0010(199904)79:5<693::aid-jsfa239>3.0.co;2-s

Cebolla-Cornejo, J., Valcarcel, M., Herrero-Martinez, J. M., Rosello, S., & Nuez, F. (2012). High efficiency joint CZE determination of sugars and acids in vegetables and fruits. *Electrophoresis, 33*(15), 2416–2423. https://doi.org/10.1002/elps.201100640

Chigwedere, C. M., Tadele, W. W., Yi, J., Wibowo, S., Kebede, B. T., Van Loey, A. M., Grauwet, T., & Hendrickx, M. E. (2019). Insight into the evolution of flavor compounds during cooking of common beans utilizing a headspace untargeted fingerprinting approach. *Food Chemistry, 275*, 224–238. https://doi.org/10.1016/j.foodchem.2018.09.080

de León, L. F., Elías, L. G., & Bressani, R. (1992). Effect of salt solutions on the cooking time, nutritional and sensory characteristics of common beans (Phaseolus vulgaris). *Food Research International, 25*(2), 131–136. https://doi.org/10.1016/0963-9969(92)90154-W

Dixon, M. D., & Hammond, E. G. (1984). The flavor intensity of some carbonyl compounds important in oxidized fats. *Journal of the American Oil Chemists' Society, 61*(9), 1452–1456. https://doi.org/10.1007/BF02636362

Dominguez, V. (2005). *Treball femení a la indústria tèxtil llanera de Sabadell durant el segle XX [Universitat Autònoma de Barcelona]*. http://hdl.handle.net/10803/5509.

Ebert, S., Michel, W., Nedele, A., Baune, M., Terjung, N., Zhang, Y., Gibis, M., & Weiss, J. (2022). Influence of protein extraction and texturization on odor-active compounds of pea proteins. *Journal of the Science of Food and Agriculture, 102*(3), 1021–1029. https://doi.org/10.1002/jsfa.11437

Florez, A., Pujolà, M., Valero, J., Centelles, E., Almirall, A., & Casañas, F. (2009). Genetic and environmental effects on chemical composition related to sensory traits in common beans (Phaseolus vulgaris L.). *Food Chemistry, 113*(4), 950–956. https://doi.org/10.1016/j.foodchem.2008.08.036

Fredes, A., Sales, C., Barreda, M., Valcárcel, M., Roselló, S., & Beltrán, J. (2016). Quantification of prominent volatile compounds responsible for muskmelon and watermelon aroma by purge and trap extraction followed by gas chromatography–mass spectrometry determination. *Food Chemistry, 190*, 689–700. https://doi.org/10.1016/j.foodchem.2015.06.011

Hinterholzer, A., Lemos, T., & Schieberle, P. (1998). Identification of the key odorants in raw French beans and changes during cooking. *Zeitschrift für Lebensmittel-untersuchung und -Forschung A, 207*(3), 219–222. https://doi.org/10.1007/s002170050322

ISO. (2007). *Sensory analysis - general guidance for the design of test rooms*. ISO 8589:2007).

ISO. (2008). *Vocabulary*. ISO 5492:2008).

Jousse, F., Jongen, T., Agterof, W., Russell, S., & Braat, P. (2002). Simplified kinetic scheme of flavor formation by the Maillard reaction. *Journal of Food Science, 67*(7), 2534–2542. https://doi.org/10.1111/j.1365-2621.2002.tb08772.x

Kaneko, S., Kumazawa, K., & Nishimura, O. (2011). Studies on the key aroma compounds in soy milk made from three different soybean cultivars. *Journal of Agricultural and Food Chemistry, 59*(22), 12204–12209. https://doi.org/10.1021/jf202942h

Khattab, R. Y., & Arntfield, S. D. (2009). Nutritional quality of legume seeds as affected by some physical treatments. Antinutritional factors. *LWT - Food Science and Technology, 42*(6), 1113–1118. https://doi.org/10.1016/j.lwt.2009.02.004

Khrisanapant, P., Kebede, B., Leong, S. Y., & Oey, I. (2022). Effects of hydrothermal processing on volatile and fatty acids profile of cowpeas (Vigna unguiculata), chickpeas (Cicer arietinum) and Kidney beans (Phaseolus vulgaris). *Molecules, 27*(23), 8204. https://doi.org/10.3390/molecules27238204

Knockaert, G., De Roeck, A., Lemmens, L., Van Buggenhout, S., Hendrickx, M., & Van Loey, A. (2011). Effect of thermal and high pressure processes on structural and health-related properties of carrots (Daucus carota). *Food Chemistry, 125*(3), 903–912. https://doi.org/10.1016/j.foodchem.2010.09.066

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food*. Springer. https://doi.org/10.1007/978-1-4419-6488-5

Lê, S., Josse, J., & Husson, F. (2008). FactoMineR : An R package for multivariate analysis. *Journal of Statistical Software, 25*(1), 1–18. https://doi.org/10.18637/jss.v025.i01

Maphosa, Y., & Jideani, V. A. (2017). The role of legumes in human nutrition. In *Functional food - improve health through adequate food*. InTech. https://doi.org/10.5772/intechopen.69127.

Margier, M., Georgé, S., Hafnaoui, N., Remond, D., Nowicki, M., Du Chaffaut, L., Amiot, M.-J., & Reboul, E. (2018). Nutritional composition and bioactive content of legumes: Characterization of pulses frequently consumed in France and effect of the cooking method. *Nutrients, 10*(11), 1668. https://doi.org/10.3390/nu10111668

Meilgaard, M., Civille, G., & Carr, B. (2007). *Sensory evaluation techniques*. CRC Press.

Mendiburu, F., & Yaseen, M. (2020). *agricolae: Statistical procedures for agricultural research*. https://cran.r-project.org/package=agricolae.

Mendoza, F. A., Cichy, K., Lu, R., & Kelly, J. D. (2014). Evaluation of canning quality traits in black beans (Phaseolus vulgaris L.) by Visible/Near-Infrared Spectroscopy. *Food and Bioprocess Technology, 7*(9), 2666–2678. https://doi.org/10.1007/s11947-014-1285-y

Mishra, D. K., Matella, N. J., Sulaiman, R. B., & Dolan, K. D. (2022). Hydration, blanching and thermal processing of dry beans. In M. Siddiq, & M. A. Uebersax (Eds.), *Dry beans and pulses: Production, processing, and nutrition* (pp. 159–190). Wiley. https://doi.org/10.1002/9781119776802.ch7.

Mottram, D. S. (2007). The Maillard reaction: Source of flavour in thermally processed foods. In *Flavours and fragrances* (pp. 269–283). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-49339-6_12.

Murray, K. E., Shipton, J., Whitfield, F. B., & Last, J. H. (1976). The volatiles of off-flavoured unblanched green peas (Pisum sativum). *Journal of the Science of Food and Agriculture, 27*(12), 1093–1107. https://doi.org/10.1002/jsfa.2740271204

Noordraven, L. E. C., Petersen, M. A., Van Loey, A. M., & Bredie, W. L. P. (2021). Flavour stability of sterilised chickpeas stored in pouches. *Current Research in Food Science, 4*, 773–783. https://doi.org/10.1016/j.crfs.2021.10.011

Nørgaard, L., Saudland, A., Wagner, J., Nielsen, J. P., Munck, L., & Engelsen, S. B. (2000). Interval partial least-squares regression (i PLS): A comparative chemometric study with an example from near-infrared spectroscopy. *Applied Spectroscopy, 54*(3), 413–419. https://doi.org/10.1366/0003702001949500

O'Mahony, M. (2017). *Sensory evaluation of food*. Routledge. https://doi.org/10.1201/9780203739884

Oomah, B. D., Liang, L. S. Y., & Balasubramanian, P. (2007). Volatile compounds of dry beans (Phaseolus vulgaris L.). *Plant Foods for Human Nutrition, 62*(4), 177–183. https://doi.org/10.1007/s11130-007-0059-3

Parmar, N., Singh, N., Kaur, A., Virdi, A. S., & Thakur, S. (2016). Effect of canning on color, protein and phenolic profile of grains from kidney bean, field pea and chickpea. *Food Research International, 89*, 526–532. https://doi.org/10.1016/j.foodres.2016.07.022

Pedrosa, M. M., Cuadrado, C., Burbano, C., Muzquiz, M., Cabellos, B., Olmedilla-Alonso, B., & Asensio-Vegas, C. (2015). Effects of industrial canning on the proximate composition, bioactive compounds contents and nutritional profile of two Spanish common dry beans (Phaseolus vulgaris L.). *Food Chemistry, 166*, 68–75. https://doi.org/10.1016/j.foodchem.2014.05.158

Pérez-Vega, E., Campa, A., De la Rosa, L., Giraldez, R., & Ferreira, J. J. (2009). Genetic diversity in a core collection established from the main bean genebank in Spain. *Crop Science, 49*(4), 1377–1386. https://doi.org/10.2135/cropsci2008.07.0409

Pirhayati, M., Soltanizadeh, N., & Kadivar, M. (2011). Chemical and microstructural evaluation of 'hard-to-cook' phenomenon in legumes (pinto bean and small-type lentil). *International Journal of Food Science and Technology, 46*(9), 1884–1890. https://doi.org/10.1111/j.1365-2621.2011.02697.x

Polak, R., Phillips, E. M., & Campbell, A. (2015). Legumes: Health benefits and culinary approaches to increase intake. *Clinical Diabetes, 33*(4), 198–205. https://doi.org/10.2337/diaclin.33.4.198

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Qureshi, A. M. I., & Sadohara, R. (2019). Breeding dry beans (Phaseolus vulqaris L.) with improved cooking and canning quality traits. In A. M. I. Qureshi, Z. Dar, & S. Wani (Eds.), *Quality breeding in field crops* (pp. 173–191). Springer International Publishing. https://doi.org/10.1007/978-3-030-04609-5_8.

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.r-project.org.

Rajalahti, T., Arneberg, R., Berven, F. S., Myhr, K.-M., Ulvik, R. J., & Kvalheim, O. M. (2009). Biomarker discovery in mass spectral profiles by means of selectivity ratio plot. *Chemometrics and Intelligent Laboratory Systems, 95*(1), 35–48. https://doi.org/10.1016/j.chemolab.2008.08.004

Ren, L., Ma, J., Lv, Y., Tong, Q., & Guo, H. (2021). Characterization of key off-odor compounds in thermal duck egg gels by GC-olfactometry-MS, odor activity values, and aroma recombination. *Lebensmittel-Wissenschaft und -Technologie, 143*, Article 111182. https://doi.org/10.1016/j.lwt.2021.111182

Revilla, I., & Vivar-Quintana, A. M. (2008). Effect of canning process on texture of Faba beans (Vicia Faba). *Food Chemistry, 106*(1), 310–314. https://doi.org/10.1016/j.foodchem.2007.02.046

Reyes-Moreno, C., Paredes-López, O., & Gonzalez, E. (1993). Hard-to-cook phenomenon in common beans — a review. *Critical Reviews in Food Science and Nutrition, 33*(3), 227–286. https://doi.org/10.1080/10408399309527621

Rivera, A., Plans, M., Sabaté, J., Casañas, F., Casals, J., Rull, A., & Simó, J. (2018). The Spanish core collection of common beans (Phaseolus vulgaris L.): An important source of variability for breeding chemical composition. *Frontiers in Plant Science, 9*, 1642. https://doi.org/10.3389/fpls.2018.01642

Rivera, A., Roselló, S., & Casañas, F. (2015). Seed curvature as a useful marker to transfer morphologic, agronomic, chemical and sensory traits from Ganxet common bean (Phaseolus vulgaris L.). *Scientia Horticulturae, 197*, 476–482. https://doi.org/10.1016/j.scienta.2015.10.006

Roland, W. S. U., Pouvreau, L., Curran, J., van de Velde, F., & de Kok, P. M. T. (2017). Flavor aspects of pulse ingredients. *Cereal Chemistry Journal, 94*(1), 58–65. https://doi.org/10.1094/CCHEM-06-16-0161-FI

Romero del Castillo, R., Almirall, A., Valero, J., & Casañas, F. (2008a). Protected designation of Origin in beans (Phaseolus vulgaris L.): Towards an objective approach based on sensory and agromorphological properties. *Journal of the Science of Food and Agriculture, 88*(11), 1954–1962. https://doi.org/10.1002/jsfa.3303

Romero del Castillo, R., Costell, E., Plans, M., Simó, J., & Casañas, F. (2012). A standardized method of preparing commong beans (Phaseolus vulgaris L.) for sensory analysis. *Journal of Sensory Studies, 27*(3), 188–195. https://doi.org/10.1111/j.1745-459X.2012.00381.x

Romero del Castillo, R., Valero, J., Casañas, F., & Costell, E. (2008b). Training, validation and maintenance of a panel to evaluate the texture of dry beans (Phaseolus vulgarisL.). *Journal of Sensory Studies, 23*(3), 303–319. https://doi.org/10.1111/j.1745-459X.2008.00157.x

Salunkhe, D. K., & Kadam, S. S. (1989). CRC handbook of world food legumes : Nutritional chemistry, processing technology, and utilization. In *Handbook of world food legumes*. CRC Press.

Srivastava, R., Bousquières, J., Cepeda-Vázquez, M., Roux, S., Bonazzi, C., & Rega, B. (2018). Kinetic study of furan and furfural generation during baking of cake models. *Food Chemistry, 267*, 329–336. https://doi.org/10.1016/j.foodchem.2017.06.126

Stacklies, W., Redestig, H., Scholz, M., Walther, D., & Selbig, J. (2007). pcaMethods a bioconductor package providing PCA methods for incomplete data. *Bioinformatics, 23*(9), 1164–1167. https://doi.org/10.1093/bioinformatics/btm069

Tamanna, N., & Mahmood, N. (2015). Food processing and Maillard reaction products: Effect on human health and nutrition. *International Journal of Food Science*, 1–6. https://doi.org/10.1155/2015/526762, 2015.

TGSC. (2023). *TGSC Information system*. http://www.thegoodscentscompany.com/data/rw1009081.html.

Tharanathan, R., & Mahadevamma, S. (2003). Grain legumes—a boon to human nutrition. *Trends in Food Science & Technology, 14*(12), 507–518. https://doi.org/10.1016/j.tifs.2003.07.002

van Boekel, M. A. J. S. (2006). Formation of flavour compounds in the Maillard reaction. *Biotechnology Advances, 24*(2), 230–233. https://doi.org/10.1016/j.biotechadv.2005.11.004

Villena, J., Moreno, C., Roselló, S., Beltrán, J., Cebolla-Cornejo, J., & Moreno, M. M. (2023). Breeding tomato flavor: Modeling consumer preferences of tomato landraces. *Scientia Horticulturae, 308*, Article 111597. https://doi.org/10.1016/j.scienta.2022.111597

Wang, C., Chang, L., & Grafton, K. (1988). Canning quality evaluation of Pinto and Navy beans. *Journal of Food Science, 53*(3), 772–776. https://doi.org/10.1111/j.1365-2621.1988.tb08953.x

Wang, N., Hatcher, D. W., Tyler, R. T., Toews, R., & Gawalko, E. J. (2010). Effect of cooking on the composition of beans (Phaseolus vulgaris L.) and chickpeas (Cicer arietinum L.). *Food Research International, 43*(2), 589–594. https://doi.org/10.1016/j.foodres.2009.07.012

Yang, N., Hort, J., Linforth, R., Brown, K., Walsh, S., & Fisk, I. D. (2013). Impact of flavour solvent (propylene glycol or triacetin) on vanillin, 5-(hydroxymethyl) furfural, 2,4-decadienal, 2,4-heptadienal, structural parameters and sensory perception of shortcake biscuits over accelerated shelf life testing. *Food Chemistry, 141*(2), 1354–1360. https://doi.org/10.1016/j.foodchem.2013.03.084

Zamora, R., Navarro, J. L., Aguilar, I., & Hidalgo, F. J. (2015). Lipid-derived aldehyde degradation under thermal conditions. *Food Chemistry, 174*, 89–96. https://doi.org/10.1016/j.foodchem.2014.11.034