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ORIGINAL ARTICLE

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Sensory optimization of gluten-free hazelnut omelette and sugar-modified chestnut pudding: A free choice profiling approach for enhanced traditional recipe formulations

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Abstract

The Mediterranean region is distinguished by its gastronomic diversity and a wide variety of indigenous nut crops. In line with changing global food consumers' preferences, a noteworthy aspect is the increasing demand to the use of local varieties in recipe formulation. The aim of the present study was to incorporate the Terra Fria chestnut (Portugal) and Negreta hazelnut from Reus (Spain) in traditional Mediterranean recipes. The sensory, technofunctional, nutritional, and shelf-life characterization were investigated in hazelnut omelette (gluten and gluten-free) and chestnut pudding (sugar and sugar-free) formulations. Results conducted by trained assessors using the free choice profiling (FCP) showed that hazelnut omelette samples were described as "creamy," "smooth," and "handmade." In addition, the texture obtained with the hazelnut omelette gluten-free version showed the softest textural profile analysis attributes, with lower values for hardness (2.43 ± 0.36 N), adhesiveness (−0.38 ± 0.00 g s) and gumminess (2.12 ± 0.14). Furthermore, the shelf-life studies revealed a more golden color (>14.43 of a^* CIELAB coordinate) and a lower moisture content (25.36%–43.59%) in the hazelnut flour formulation, in addition to the enrichment in terms of protein (8.36 g/100 g), fiber, and healthy fats. In the case of chestnut pudding, it was observed that the study parameters did not differ significantly from its sweetened analogue with positive attributes in FCP ("toasted," "fluffy," and "sweet"), positioning it as a viable alternative to sugar in this application. Therefore, both hazelnut flour in hazelnut omelette and oligofructose in chestnut pudding proved to be promising ingredients in the formulation of gluten-free

and sugar-free developed products, offering attractive organoleptic and textural characteristics.

KEYWORDS
consumer trend, gluten-free, hazelnut flour, Mediterranean variety, traditional recipe

1 | INTRODUCTION

The Mediterranean region is renowned for its diverse gastronomic offerings, rich culinary traditions, and abundant array of local nut varieties (Ingrassia et al., 2023; Lăcătușu et al., 2019). These indigenous cultivars were grown for generations, representing the unique flavors and characteristics that define the culinary landscape of the Mediterranean area (Cassileth, 2009). Concretely, local nut varieties have adapted and thrived in the distinctive climatic conditions of the Mediterranean region, resulting in resilience to specific soil types and microclimates (Duman, 2019). For this reason, the use of these indigenous cultivars advances a more sustainable agricultural system. Indigenous varieties contribute to environmental preservation by requiring fewer inputs and promoting sustainable land use practices. It enhances agricultural diversity by maintaining a rich genetic reservoir suited to local conditions, thereby increasing resilience to climate change and supporting food security. Additionally, conserves cultural heritage by preserving traditional farming knowledge and practices, fostering community resilience and pride (Shelef et al., 2017, 2018).

However, in the ever-evolving landscape of consumer food preferences, a noticeable trend has emerged, transforming the dietary habits of individuals worldwide (Guasch-Ferré & Willett, 2021). This change stems from an increasing desire among consumers to embrace healthier, more convenient, and sustainable eating choices, as well as an escalating inclination toward veganism and the exploration of alternative protein sources (Alcorta et al., 2021; Aschemann-Witzel et al., 2020). Within this context, the food industry has been driven toward innovation, adapting to the demands of a health-conscious society. One significant aspect that has emerged among this changing landscape is the renewed focus on utilizing local varieties in food recipe formulation (Shelef et al., 2017).

The Mediterranean region has significant varieties of nuts with protected designation of origin (PDO), which show the appropriate interaction between gastronomy and terroir (Reglamento (UE) No 1151/2012). These include the regional chestnut variety from PDO Castanha da Terra Fria (Portugal) and the hazelnut PDO Avellana Negreta de Reus (Spain), grown in the favorable climatic conditions and the rich Mediterranean soils (Hernández-López et al., 2022). The Terra Fria PDO chestnut has a characteristic sweetness accompanied by a velvety texture. The Avellana Negreta de Reus PDO hazelnut captivates with its impressive size and intense flavor profile. These PDO varieties represent a dedication to quality and authenticity, adhering to rigorous production standards that preserve their distinctive sensorial and nutritional characteristics.

The rich culinary heritage of the Mediterranean region includes traditional nut recipes that have been passed down through generations, encapsulating the essence of Mediterranean culinary traditions (Guiné & Correia, 2020; Guiné et al., 2023). Examples such as "hazelnut omelette" and "chestnut pudding" exemplify the fusion of local nut varieties into established dishes. Hazelnut omelette ingeniously incorporates crushed hazelnuts, bringing a unique flavor and texture to the classic omelette. Chestnut pudding combines cooked and crushed chestnuts with a harmonious blend of milk, sugar, and spices, creating a complete conventional dessert. These traditional recipes with local varieties serve as a testament to the region's commitment to preserve its culinary heritage and supporting sustainable agricultural practices (Hernández-López et al., 2022).

Against this backdrop, our objective is to harness the potential of the finest local varieties, leveraging their distinctive physicochemical and nutritional qualities to elevate the formulation of traditional recipes, including versions of it under the demands of current consumer trends. It aims to modernize these traditional recipes by offering gluten-free (hazelnut omelette) and sugar-free (chestnut pudding) alternatives, preserving the culinary heritage of the Mediterranean region while meeting contemporary dietary preferences.

2 | MATERIALS AND METHODS

2.1 | Materials

In the present study, Mediterranean nut varieties were used to prepare the hazelnuto melette and chestnut pudding recipes. The selection of the nut varieties was carried out by studying the nutritional and biochemical

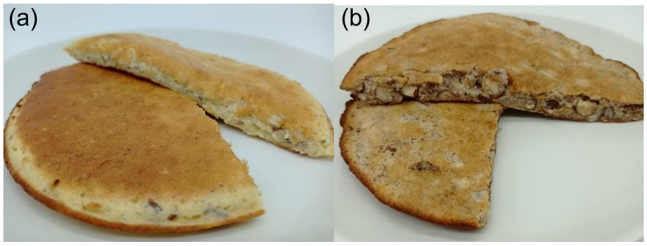

FIGURE 1 Graphical representation of both hazelnut omelette formulations: (a) gluten (wheat flour) and (b) gluten-free (hazelnut flour).

characterization of samples from different PDO, PGI, or indigenous cultivars typical of different Mediterranean regions. In laboratory studies conducted by the Instituto Politécnico do Bragança (IPB, Portugal) and Tel-Hai College (HTC, Israel), the centesimal composition of macronutrients (lipids, carbohydrates, and proteins), fatty acids, free sugars profile, phenolic compounds, organic acids, and tocopherol of all the selected nut varieties were analyzed. The data from these studies have not yet been published, but they are included in Annex 1. These nut samples were provided by different raw material suppliers (Grup Unió SCCL (Spain), Izmir Institute of Technology (IZTECH, Türkiye), Fundació Miquel Agustí (FMA, Spain), and Institut National de Recherche pour l'Agriculture, l'alimentation et l'environnement (INRAE)) and some local suppliers as part of the European LOCAL-NUTLEG project. Among all the hazelnut and chestnut varieties, those with the most attractive nutritional value were selected. The hazelnut variety chosen was Reus PDO hazelnut due to its high protein content (PC) (16.1 ± 0.2 g/100 g). In the case of chestnuts, the PDO Terra Fria variety was chosen due to their highest protein (7.3 ± 0.2 g/100 g) and carbohydrate content (CC) (86.4 ± 1.1 g/100 g), compared to the other varieties from all Mediterranean countries in the project (see Annex 1). The Reus PDO hazelnut was supplied by Grup Unió SCCL. The PDO Terra Fria chestnut puree was supplied by Posada Naturae.

2.2 | Recipes development

For the hazelnut omelette recipe, two variations were tested (Figure 1). The traditional variation was made with wheat flour (Carrefour Classic, Carrefour), Reus PDO hazelnut, milk (Carrefour classic, Carrefour), eggs (Carrefour), extra virgin olive oil (Carrefour), and salt (Carrefour). The other variation was made with hazelnut flour (Reus PDO hazelnut) instead of wheat flour, thus obtaining a gluten-free version. The ratios per 100 g for the traditional recipe were 39.56 g of milk, 18.99 g of egg whites, 14.24 g of egg yolks, 18.99 g of wheat flour, 7.91 g of sugar, and 0.32 g of salt, whereas for the gluten-free version, wheat flour was replaced by hazelnut flour. The final formulation of the hazelnut omelette yielded a product weighing 250 g. For each hazelnut omelette variation, the flour (wheat flour for tradition version (gluten) and hazelnut flour for gluten-free version) was mixed with the salt and milk. The hazelnut flour was prepared with whole hazelnuts. Nuts were ground in the Robotcoupe at speed 9 until a fine flour was obtained and the resulting flour was sieved through a 0.1 mm sieve. The beaten egg yolks were combined with the sugar and the chopped PDO hazelnuts. The egg whites were whipped until stiff and combined with the above mixture. The homogenized dough was divided into 250 g portions, placed in 12 cm aluminum pans, and cooked in the preheated oven at 180°C for 10 min.

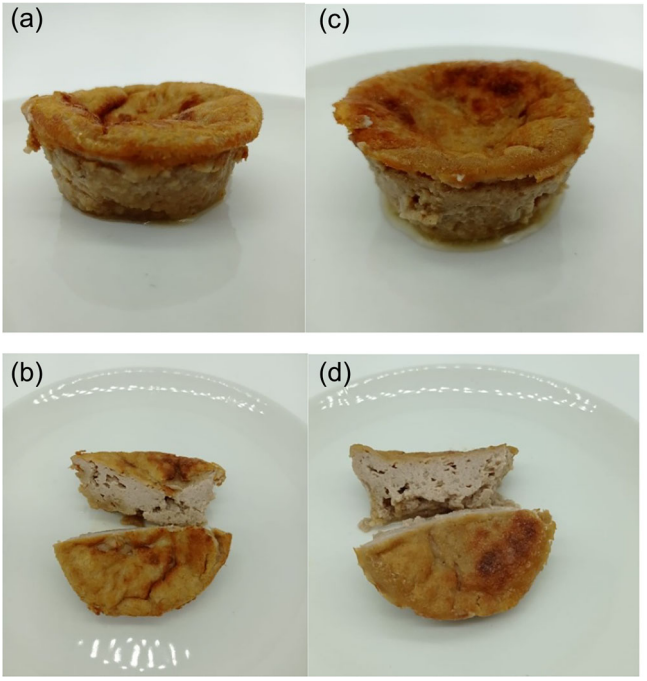

FIGURE 2 Graphical representation of both chestnut pudding formulations: (a) sugar (whole); (b) sugar (Half); (c) oligofructose/sugar-free (whole); (d) oligofructose/sugar-free (half).

For the chestnut pudding, two variations were also produced (Figure 2). The first variation was prepared with PDO Terra Fria chestnut puree, eggs (Carrefour), milk, heavy cream 35% fat content (Carrefour classic, Carrefour), and granulated sugar (Carrefour). The second variation was carried out by replacing sugar with oligofructose (Sosa). The oligofructose used was derived from chicory root, composed of 100% oligofructose with a sweetness power (POD) of 50%, a water absorption capacity (CAP) of 45%, and 97% of soluble solids. The ratios per 100 g for the first variation were 22.12 g of chestnut puree, 22.12 g of milk, 22.12 g of heavy cream, 13.27 g of egg, 13.27 g of

egg white, and 7.08 g of sugar, whereas for the second variation, sugar was replaced by 13.22 g of oligofructose. The final formulation of the chestnut pudding yielded a product weighing 250 g. For the preparation of both recipes, all the ingredients were homogenously mixed together and rested for 5 min. Then, 5 mL caramel (Royal, Carrefour) was added to the bottom of the flan trays were taken and 250 mL of dough was added on the top. The pudding was baked in a preheated oven to 190°C for 25 min.

2.3 | Shelf-life analysis

For shelf-life analyses, the hazelnut omelette was 100% vacuum-packed in 20 × 30 cm^2 polyetilene 90 μm (Monouso, Valencia, Spain) plastic with the LAVEZZINI DG40 950 W (Fiorenzuola d'Arda, Italy). The pudding containers consist in 250 mL ramekins with polypropylene (PP) lids. Samples were stored in a refrigerator at 4°C. For each recipe and variation, shelf-life was determined at sampling points on days 0, 7, 15, and 30. On these days, the physicochemical quality (pH, dry matter, and color) and microbiology (mesophiles and fungi) were assessed. In addition, nutritional analyses (macro and micronutrients), sensory analysis, particle texture analysis (PTA), and antioxidants (FRAP and total phenolic compounds (TPC)) were carried out on day 0.

Methanol, sodium acetate, acetic acid, hydrochloric acid, and ferric chloride hexahydrate were obtained from Panreac (Barcelona, Spain). Gallic acid, ascorbic acid, metaphosphoric acid, 2,4,6-tris(2-pyridyl)-*s*-triazine, 2,2-diphenyl-1-picrylhydrazyl, tris(2-carboxyethyl)phosphine hydrochloride, and sodium carbonate were purchased from Sigma-Aldrich. Folin Ciocalteu's reagent was purchased from VWR. All reagents used were of analytical grade.

2.4 | Nutritional analysis

2.4.1 | Macronutrients

The nutritional profile of the samples was analyzed following the official AOAC methodology. The ash content (AC) was determined by gravimetry using the incineration residue obtained by heating in a muffle furnace at 550°C and the moisture gravimetrically by drying in kiln at 110°C to constant weight (AOAC 925.09-2005). PC was calculated by the Macro-Kjedahl method, following the AOAC 920.87-1920, using a conversion factor of 5.3 for nuts. A Soxhlet apparatus was used to extract and quantify the crude fats (CF), using petroleum ether as an extracting solvent (AOAC 920.85-1920). The CC was determined by the difference. AC, PC, CF, and CC were expressed as g 100 g^1 of dry weight (DW). Finally, the total energy was calculated using the European Parliament and Council Regulation No. 1169/2011.

2.4.2 | Other nutrients

Free sugars

To determine free sugars content, 40 mL of ethanol solution 80% and 1 mL of internal standard (IS, melezitose, 25 mg/mL) were added to 1 g of each dry and delipidated samples. The extraction was then carried out in a water bath at 80°C for 1 h and 30 min, following the protocol described by Spréa et al. (2020). After the extraction period, the mixtures were filtered through Whatman No. 4 paper filters, and the ethanol was evaporated heating at 40°C. The aqueous fractions were then diluted in distilled water to a final volume of 5 mL, filtered into vials using 0.2 μm nylon filters (Millipore), and then subjected to HPLC-RI analysis at 35°C using an HPLC system (Knauer, Smartline system) fitted with a 100-5 NH_2 Eurospher column (4.6 × 250 mm^2, 5 mm, Knauer) equipped with a refraction index detector (Knauer Smartline 2300). Acetonitrile/deionized water (70:30, v/v) was the mobile phase employed, in a flow rate of 1 mL/min. The IS method and chromatographic comparison with commercial standards were used to characterize sugars. The data were recorded in g per 100 g of DW and processed using Clarity software (Data Apex).

Fatty acids

The fatty acid methyl esters (FAME) were characterized from the lipid fraction previously obtained by Soxhlet extraction. As previously reported by Obodai et al. (2017), the transesterification procedure was used to derivatize the lipid extracts of each sample. A volume of 5 mL a methanol:sulfuric acid:toluene solution (2:1:1, v/v/v) was added to each lipid fraction. The mixture was then incubated at 50°C for 12 h and 160 rpm. Afterward, 3 mL of distilled water and 3 mL of diethyl ether were added to each sample and thoroughly mixed with a vortex. Finally, the organic phase, containing the FAME, was extracted, dried with anhydrous sodium sulfate, and filtered through Millipore 0.2 μm nylon filters and directly used for the chromatographic analysis.

Gas chromatography with flame ionization detection (FID) was used to determine the fatty acid profile using a YOUNG IN Chromass 6500 GC System instrument equipped with a split/splitless injector at 250°C and split injection at 1:80, FID at 260°C and Zebron-Fame column (20 m × 0.18 mm × 0.15 μm df). The initial column temperature was 80°C, for 1.5 min; then, the temperature was increased at 40°C/min to 160°C, 5°C/min to 185°C, and 30°C/min to 260°C for 4 min. The hydrogen (carrier gas)

had a flow rate of 0.6 mL/min (0.61 bar), measured at 250°C. For each analysis, 1 μL of the sample was injected. Identification and quantification were performed by comparing the relative retention times of FAME peaks from samples with standards and results were recorded and processed using the Clarity 4.0.1.7 Software (DataApex) and expressed in relative percentage of each fatty acid.

Tocopherols

Tocopherols were analyzed following the procedure previously reported by Spréa et al. (2020). A volume of 100 μL butylated hydroxytoluene solution in hexane (10 mg/mL) and 400 μL of the IS (50 μg/mL) were added to 500 mg of freeze-dried and powdered samples prior to extraction. Subsequently, 4 mL of methanol were added and mixed for a minute using a vortex. After, 4 mL of hexane were added, and the mixture was re-homogenized for 1 min. Lastly, 2 mL of a saturated aqueous NaCl solution was added, the mixture was homogenized on the vortex (1 min), centrifuged for 5 min at 4000 RPM (Multifuge X1R refrigerated centrifuge, Thermo Fisher Scientific), and the supernatant was carefully transferred to an amber vial. Hexane was used twice to extract tocopherols and dried by using anhydrous sodium sulfate. A nitrogen flow was used to dry the extracts. After being redissolved in 2 mL of hexane, filtration was carried out through Millipore 0.2 μm nylon filters into amber vials and subjected to HPLC analysis.

For the chromatographic analysis, an integrated quaternary pump system (Knauer, system Smartline 1000 system), equipped with a degasser (Smartline 5000), an automatic sampler (AS-2057 2500), and a fluorescence detector (FL, Jasco) with excitation set to 290 nm and emission set to 330 nm, was used. A polyamide II normal phase column (5 μm, 250 × 4.6 mm^2, WMC Waters, Japan) operated at 30°C (7971 R Grace oven) was used to separate the chemicals. Hexane/ethyl acetate (70:30, v/v) was used as the mobile phase, with a flow rate of 1 mL/min. Clarity 2.4 software (DataApex) was used to evaluate the data. The IS method was used to measure the fluorescence signal response, and chromatographic comparison with standards served as the basis for quantification. The results were expressed in mg per 100 g of DW.

Mineral content

The mineral content was determined according to the methodology described by Association of Official Analytical Collaboration (AOAC) (2016). The extraction was performed by adding 10 mL of nitric acid to 250 mg of the dry powder from each formulation, followed by the digestion in a microwave system at 200°C and 1600 W for 30 min. After this period, the extracts were then made up to a final volume of 50 mL with distilled water. The mineral content in terms of potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) was determined through atomic absorption spectrometry (Perkin Elmer 1100B).

2.5 | Sensorial analysis

The sensory evaluation was conducted using the free choice profile (FCP) rapid technique. The FCP is a descriptive sensory analysis involving trained panellists to objectively assess organoleptic product characteristics.

The study was conducted in accordance with the Declaration of Helsinki and the Belmont report and granted by the Centre for Agrofood Economics and Development (CREDA) Research Ethics Committee, dtd 03/01/2023. The experimental procedure was authorized in accordance with the basic legislation in force on Data Protection (Spanish Organic Law 3/2018 and Regulation EU 2016/679). A consent report was obtained from each subject (assessor) prior to their participation in the study.

2.5.1 | Assessors

All the assessors ($n = 8$) had previous experience in sensory analysis; their gender was evenly split (four women and four men) and their age ranged from 25 to 55 years. Sensory evaluation was conducted in the tasting room IRTA Fruitcentre facilities, designed according to international standards (UNE-EN ISO 8589:2010).

2.5.2 | Procedure

The FCP technique involves three sessions. Each session lasted around 20–30 min. Assessors were instructed to generate a list of sensory attributes to differentiate the samples: the product's descriptors (Dehlholm et al., 2012). To ease the descriptors generation process, participants were suggested to list them according to human senses' perception order: taste, appearance, flavor, and texture (Dairou & Sieffermann, 2002). Additionally, related lexicons were given to participants. Each assessor's list of attributes was used for the second session. Each participant only evaluated the list of attributes generated by their own. The second session consisted of scoring each sample according to the intensity of each attribute on a 10 cm unstructured linear scale from 0 (low intensity) to 10 (high intensity) (Lazo et al., 2016). The third session was a repetition of the second one, conducted on a distinct day, using the same list of sensory descriptors generated during the first evaluation session. The codification for hazelnut omelette samples was as follows: commercial control pancake type (Pasquier, Carrefour) (A), hazelnut

omelette without gluten (Reus DPO Hazelnut flour) (B), and hazelnut omelette with gluten (wheat flour) (C). The coding for the chestnut pudding samples was as follows: commercial control pudding type (Carrefour classic, Carrefour) (A), chestnut pudding with sugar (B), and chestnut pudding without sugar (oligofructose) (C).

2.6 | Texture analysis

Textural properties changes were assessed through texture profile analysis (TPA) with double compression to simulate mouth chewing. At the end of each measurement, hardness (N), fracturability (N), adhesiveness (g s), springiness (N mm), cohesiveness (N), gumminess (−), chewiness (N mm), and resilience (−) parameters were determined. Each product sample (250 g) was measured twice in each replication. Measures were determined using the TA. XT Plus Connect texture analyzer (Stable Micro systems Ltd.). The firmness test was performed using a cylindrical probe (4 mm). Pretest and test were both run at 5 mm/s speed and using a trigger force of 0.1 N, allowing the probe to enter 8.0 mm deep into the tissue, measuring the maximum force encountered.

2.7 | Biochemical analysis

2.7.1 | Antioxidant activity

The antioxidant activities of the samples were evaluated by assessing their capacity to counteract the ABTS•+ free radical, employing a modified methodology as previously delineated by Ozgen et al. (2006). Using an oxidant (2.45 mM potassium persulfate), ABTS (7 mM in 20 mM sodium acetate buffer, pH 4.5) reacts to generate a stable, dark blue–green radical solution after 12–16 h of incubation in the dark (4°C). Subsequently, the solution was diluted to an absorbance of 0.7 ± 0.01 at 734 nm to form the test reagent. Then, 20 μL of the sample was mixed with 3 mL of the reagent and incubated in a water bath at 30°C for 30 min. As antioxidants in the sample capture unpaired electrons, the test solution becomes colorless, leading to a decrease in absorbance at 734 nm. A portion from each test tube was extracted and transferred to a cuvette to prevent light pathway obstruction by sediment in the juice before measuring the absorbance of each sample. The percentage inhibition was calculated relative to a control and compared to a Trolox standard curve ranging from 10 to 100 mM. A daily-prepared standard curve using gallic acid followed the same procedure as the samples. The results were reported as milligrams of gallic acid equivalents per 100 g of fresh weight (FW).

2.7.2 | Total phenolic content (TPC)

The determination of TPC was carried out using the Folin–Ciocalteu method, employing the same extract applied for antioxidant activity assessment. The process involved the combination of 4.3 mL of distilled water and 0.5 mL of Folin–Ciocalteu's reagent with 0.7 mL of the extract. After thorough mixing and a 5-min incubation at room temperature in the absence of light, 2 mL of saturated sodium carbonate were added. The mixture underwent additional mixing and incubation for 1 h in darkness. Following this, absorbance was measured at 760 nm using the GENESYS™ 10S UV–Vis spectrophotometer (Thermo Fisher Scientific). A daily-prepared standard curve using gallic acid followed the same procedure as the samples. The results were expressed as milligrams of gallic acid equivalents per 100 g of FW.

2.8 | Shelf-life analysis

2.8.1 | Quality analysis (pH, moisture content, and color)

Quality analyses were determined for all recipes and their respective variations. pH was determined using an electrode in a pH meter model GLP22 (Crison Instruments SA). For the moisture content, 5 g of each recipe and variation were dried in an oven at a temperature of 100°C for 24 h. Color of 20 shots on the different products was measured on 3 points of each sample by using a CR-200 Minolta Chroma Meter (Minolta, INC.). Color was expressed as CIE L^*, a^*, and b^* coordinates, using the D65 illuminant and a 10° observer angle.

2.8.2 | Microbiological analysis

To quantify the microbial load, 25 g of each product and variation were weighed and placed in sterile blender bags containing buffered peptone water. The solutions were homogenized using a Masticator Homogenizator (IUL S.A. Instruments, Barcelona). Subsequently, the homogenates were 1:10 diluted with peptone solution (PS: 0.1% peptone, 0.85% NaCl). For the enumeration of total aerobic mesophilic microorganisms (TAM), 100 μL of the dilutions were plated in duplicate on PCA (plate count agar, Biokar Diagnostics) plates and incubated for (72 ± 3) h at 30 ± 1°C, following the guidelines of ISO 4833-2:2013. In accordance with ISO 21527-1:2008, the same dilutions were also plated in duplicate on Dichloran Rose Bengal Chloramphenicol Agar (DRBC, Biokar Diagnostics) plates, specifically designed for the selective isolation of fungi—molds and

TABLE 1 Nutritional, energetic value of the hazelnut omelette and chestnut pudding formulations (mean ± standard deviation (SD), $n = 4$).

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
Nutritional value	(g/100 g DW)			
Fat	14.4 ± 0.8b	39.8 ± 1.2a	34.5 ± 2.1a	21.0 ± 1.8b
Proteins	16.7 ± 0.2a	14.9 ± 0.2b	12.8 ± 0.1a	9.9 ± 0.3b
Ash	2.5 ± 0.2a	2.8 ± 0.1b	1.36 ± 0.03a	1.2 ± 0.1a
Carbohydrates	66.5 ± 0.02a	42.2 ± 0.02b	52.98 ± 0.05b	67.8 ± 0.2a
Energy (Kcal/100 g DW)	462.2 ± 0.07b	587.9 ± 0.09a	558.8 ± 0.1a	501.3 ± 0.2b

Abbreviation: DW, dry weight.
Different lowercase letters indicate significant differences between samples according to an ANOVA test ($p<0.05$)

yeasts—significant in food spoilage. These plates were then incubated at 25 ± 1°C for 3–5 days. The results were reported as log CFU/g, with a detection limit of 20 CFU/g. This experimental procedure was replicated twice.

2.9 | Statistical analysis

The results are presented as mean ± standard deviation (SD) based on three repetitions. A thorough analysis of all data was conducted to identify significant differences through the application of an analysis of variance test. The criterion for determining statistical significance was set at $\alpha = 0.05$ level. In cases where significant differences were detected, Tukey's Honest Significant Difference or Student's *t*-test of the means was employed. All statistical analyses were carried out using JMP 13 (SAS Institute Inc.). For the results obtained from the rapid sensory description method, the FCP, a generalized procrustes analysis (GPA) was performed. GPA involved utilizing the attributes provided by each assessor along with their corresponding intensity ratings on a scale ranging from 0 to 10. XLSTAT software version 2020.1 (2020) (Addinsoft) was employed for the data analysis.

3 | RESULTS AND DISCUSSION

3.1 | Nutritional analysis

The nutritional content of gluten and gluten-free hazelnut omelette is presented in Table 1. As we can see, the fat content is higher in the hazelnut flour formulation (39.8 g/100 g) compared to the fat content of wheat flour variation (14.4 g/100 g), primarily due to the high lipid content of Reus PDO hazelnut (approximately 62.0 ± 0.7 g of crude acids with 663.6 ± 0.9 kcal/100 g of product) (Annex 1). On the other hand, the formulation with wheat flour provides more CC (66.46 g/100 g) (Table 1). In the case of PDO hazelnut, the CC is 15.5 ± 1.4 g/100 g (Annex 1), whereas wheat flour has a content exceeding 70% (Schopf & Scherf, 2021). This distinction is the main factor determining the energy content of both formulations, with the hazelnut flour formulation being 587.9 kcal and the wheat flour formulation being 462.2 kcal/100 g of product. As for PC, both gluten and gluten-free formulations presented 16.7 g and 14.9 g/100 g, respectively. This slight difference can be explained by variances in the PC of the flours and their subjection to thermal processes during the elaboration of the products.

In the case of chestnut pudding formulations (Table 1), sugar-modified chestnut pudding exhibits a higher CC of 67.8 ± 0.2 g/100 g DW, whereas chestnut pudding has a lower value of 52.98 ± 0.05 g/100 g DW. The increase in carbohydrates may result from the addition flour in the different formulations. However, the kcal ratio is balanced when the oligofructose (13.27 g) formulation is almost double that of sugar (7.08 g), calculated per 100 g of product. Although sugar contains 4 kcal/g, oligofructose has 1.5 kcal/g (Roberfroid, 1993). The product has an energy content of 558.8 kcal (sugar) and 501.3 kcal (sugar-free), so the addition of oligofructose or sugar does not affect the energy content of the label. Oligofructose (chicory root fibers) represent an alternative to sugar, not only for their bulking or texturizing properties but also for their sweetness compared to sucrose (Franck, 2002). Studies substantiate that more than 50% of the European consumers express a shared perspective on the expeditious energy liberation attributed to sugar ingestion (Di Monaco et al., 2018; Flamm et al., 2001). This consensus underscores a discernible inclination among consumers toward the exploration of viable substitutes. In the case of oligofructose, it could be considered a sugar substitute with slow and balanced release, allowing for a declaration of healthy properties on the packaging regarding lower blood sugar response and issues related to glycemic control (Flamm et al., 2001).

TABLE 2 Free sugars content of the hazelnut omelette and chestnut pudding formulations (mean ± standard deviation (SD), $n = 4$).

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
Free sugars	**(g/100 g DW)**			
Fructose	0.19 ± 0.01b	0.21 ± 0.02a	3.5 ± 0.3a	1.06 ± 0.01b
Glucose	0.18 ± 0.01a	0.14 ± 0.01b	4.5 ± 0.4a	2.4 ± 0.1b
Sucrose	14.11 ± 0.05b	25.7 ± 0.4a	28.3 ± 0.7a	1.27 ± 0.04b
Trehalose	2.6 ± 0.2b	5.5 ± 0.3a	5.6 ± 0.2a	0.9 ± 0.1b
Total	16.85 ± 0.05b	31.4 ± 0.7a	38.41 ± 0.06a	4.63 ± 0.05b

Abbreviation: DW, dry weight.

Different lowercase letters indicate significant differences between samples according to an ANOVA test ($p<0.05$)

Examining the free sugars component (Table 2), the gluten-free hazelnut omelette exhibits higher levels across all categories. Notably, sucrose content is significantly elevated at 25.7 ± 0.4 g/100 g DW in the gluten-free version, whereas the hazelnut omelette contains 14.11 ± 0.05 g/100 g DW. This difference could be attributed to the choice of hazelnut flour used in the gluten-free recipe. Sugar-modified chestnut pudding significantly reduces free sugar content across all categories compared to chestnut pudding (Table 2). Notably, sucrose content in sugar-modified chestnut pudding is substantially lower at 1.27 ± 0.04 g/100 g DW compared to chestnut pudding (28.3 ± 0.7 g/100 g DW). This reduction indicates a deliberate effort to minimize sugar content in the modified version.

Comparing the relative percentage of fatty acids, both hazelnut omelette recipes exhibit similar profiles with minimal variations (Table 3). Noteworthy points include slight decreases in C6:0, C8:0, C10:0, C12:0, and C14:0 in the gluten-free hazelnut omelette. Although statistical analysis revealed that differences between nutritional values between the two formulations were statistically significant, nutritional values measured moved within the reported range for each recipe, so they could be neglected. Additionally, the proportions of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) remain comparable between the two formulations, indicating that the gluten-free adaptation does not significantly alter the overall fatty acid composition. Examining tocopherols, the total value content in the gluten-free hazelnut omelette is significantly higher at 12.9 ± 0.8 mg/100 g DW, indicating a potential enhancement of antioxidant properties in the presence of hazelnut flour. The comparison of fatty acid and tocopherol profiles between chestnut pudding and sugar-modified chestnut pudding reveals distinctive variations in these nutritional components (Table 3). Both formulations exhibit comparable levels of SFA, MUFA, and PUFA. As is to be expected, the sugar substitution did not affect the relative percentage of fats.

Table 4 presents the mineral content of hazelnut omelette formulations, comparing the standard hazelnut omelette with its gluten-free counterpart. The mean values with SD (mean ± SD, $n = 3$) highlight noteworthy differences in mineral composition between the two recipes. Magnesium (Mg) content exhibits a significant increase in the gluten-free variant, reaching 851.1 ± 1.2 g/kg, whereas the hazelnut omelette has a lower value of 450.8 ± 0.8 g/kg. The mineral composition of chestnut pudding and sugar-modified chestnut pudding reveals that the changes in these components are minimal (Table 4). This is because the only change in formulation is due to the sweetener (sugar or oligofructose).

3.2 | Sensory analysis

The sensory profile obtained with the FCP of the different hazelnut omelette formulations is presented in Figure 3. This figure displays the analyzed samples and the sensory descriptors of the GPA, more in detail, component 1 (F1) and 2 (F2), accounting for 88.94% and 11.06% of the total variance, respectively. Two groups of samples can be distinguished. On the one hand, the commercial pancake sample (A; Pasquier, Carrefour) exhibits attributes such as "homogeneous," likely due to being a commercially sold product. Negative connotation attributes like "dry" are also noticeable because the pancake should ideally be "fluffy" and "moist" according to the traditional recipe. For samples B (gluten-free) and C (gluten), assessors categorized them as "homemade," "creamy," and "spongy," regardless of whether the sample was formulated with hazelnut flour (B) or wheat flour (C). Both formulations also highlight the "hazelnut" attribute, especially in formulation B according to the *Y*-axis (F2), primarily due to the substitution of nut flour in the final formulation.

The sensory profile of the different chestnut pudding formulations using FCP is shown in Figure 4. The sensory descriptors of principal component 1 (F1) and 2 (F2) account for 98.15% and 1.85% of the total

TABLE 3 Chemical composition with regard lipophilic compounds of the hazelnut omelette and chestnut pudding formulations (mean ± standard deviation (SD), $n = 4$).

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
Fatty acids	**Relative percentage (%)**			
C6:0	0.5 ± 0.05a	0.44 ± 0.04a	2.2 ± 0.1a	2.4 ± 0.1a
C8:0	0.34 ± 0.03a	0.32 ± 0.01a	1.4 ± 0.1a	1.6 ± 0.1a
C10:0	0.68 ± 0.01a	0.72 ± 0.04a	3.11 ± 0.2a	3.3 ± 0.3a
C12:0	0.99 ± 0.07a	0.85 ± 0.05a	3.6 ± 0.3a	3.9 ± 0.4a
C14:0	2.22 ± 0.04a	2.14 ± 0.07a	10.5 ± 0.6a	10.9 ± 0.8a
C14:1	0.20 ± 0.01a	0.21 ± 0.01a	1.1 ± 0.1a	1.189 ± 0.004a
C15:0	0.27 ± 0.02a	0.24 ± 0.02a	1.35 ± 0.05a	1.41 ± 0.07a
C15:1			0.203 ± 0.001	0.24 ± 0.01
C16:0	13.0 ± 0.7a	12.9 ± 0.6a	32.9 ± 0.2a	30.8 ± 0.2b
C16:1	0.55 ± 0.03a	0.55 ± 0.03a	1.9 ± 0.04a	1.8 ± 0.2a
C17:0			0.59 ± 0.02b	0.652 ± 0.005a
C18:0	3.8 ± 0.1a	3.9 ± 0.2a	10.2 ± 0.6a	10.5 ± 0.4b
C18:1n9c	68.7 ± 1.0a	68.8 ± 1.0a	23.4 ± 0.8a	25.0 ± 1.2a
C18:2n6c	8.8 ± 0.1a	9.0 ± 0.2a	6.6 ± 0.2a	5.0 ± 0.1b
C18:3n3			0.53 ± 0.04b	0.73 ± 0.07a
C20:3n3			0.56 ± 0.04a	0.57 ± 0.02a
SFA	21.8 ± 1.1a	21.5 ± 0.7a	65.8 ± 1.0	65.5 ± 1.2
MUFA	69.4 ± 0.9a	69.5 ± 1.0a	26.6 ± 0.7	28.2 ± 1.0
PUFA	8.8 ± 0.1a	9.0 ± 0.2a	7.65 ± 0.3	6.3 ± 0.2
Tocopherols	**(mg/100 g DW)**		**(mg/100 g DW)**	
α-Tocopherol	8.9 ± 0.9a	9.6 ± 0.6a	8.9 ± 0.3a	5.9 ± 0.3b
β-Tocopherol	0.62 ± 0.01a	0.5 ± 0.1a	9.5 ± 0.7a	6.1 ± 0.4b
γ-Tocopherol	1.5 ± 0.3a	2.8 ± 0.3a	0.9 ± 0.3a	0.72 ± 0.01b
Total	10.17 ± 0.01a	12.9 ± 0.8a	19.3 ± 0.7a	12.7 ± 0.1b

Abbreviations: DW, dry weight; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acids.
Different lowercase letters indicate significant differences between samples according to an ANOVA test ($p<0.05$)

variance, respectively. The present analysis also utilized a commercial pudding sample (A; Carrefour brand, Carrefour). In this case, a pattern with two distinct groups can also be observed. In terms of flavor, the assessors attributed "sweet," "jelly," and "caramel" attributes to control sample (A). As this sample is a supermarket's own brand, assessors also characterized it as "commercial," "artificial," and "homogeneous." Samples B (sugar) and C (sugar-free) show less variation along the *X*-axis (F1), where assessors described them as "irregular," suggesting they can also be considered "homemade." Both samples also exhibit attributes such as "toasted," "fluffy," and "sweet," indicating no clear distinction in sweetness levels between the two formulations (sugar and oligofructose) (F1 = 98.15%). Sweetness perception on the tongue is mediated by specific receptors located on taste buds (Li, 2013). With sugar, the initial interaction triggers a rapid and significant response, contributing to an intense sweetness sensation. Conversely, carbohydrate oligofructose may have a more gradual sweetness release compared to sugar. As it breaks down or metabolizes in the mouth, its components can interact more extensively with sweetness receptors, generating a sweetness sensation that is perceived more sustained over time (Low et al., 2017). In general, the perception of taste changing over time can be attributed to various factors, including dissolution rate, interaction with specific receptors, release of aromatic molecules, and the nervous system's response to specific substances in the mouth (Flamm et al., 2001).

3.3 | Texture

The textural characteristics of a hazelnut omelette are essential in influencing consumer preferences. The different formulations of hazelnut omelette were subjected

TABLE 4 Mineral content of the hazelnut omelette and chestnut pudding formulations (mean ± standard deviation (SD), $n = 4$).

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
Minerals	(g/kg)			
Potassium, K	3.0 ± 0.3b	4.9 ± 0.3a	2.3 ± 0.1a	1.8 ± 0.1b
Sodium, Na	3.7 ± 0.2a	2.5 ± 0.1b	1.54 ± 0.05a	1.3 ± 0.1a
Calcium, Ca	0.9 ± 0.1b	1.14 ± 0.05a	0.9 ± 0.1a	0.7 ± 0.1b
Magnesium, Mg	450.8 ± 0.8b	851.1 ± 1.2a	205.7 ± 0.1a	159.87 ± 0.03b
Iron, Fe	43.4 ± 1.5a	43.7 ± 1.4a	39.8 ± 1.1a	30.4 ± 1.7b
Manganese, Mn	9.1 ± 0.7b	16.0 ± 0.4a	6.85 ± 0.04a	5.8 ± 0.8b
Copper, Cu	4.9 ± 0.4b	10.9 ± 0.5a	3.1 ± 0.2a	2.6 ± 0.1b
Zinc, Zn	45.7 ± 1.4b	58.5 ± 0.5a	39.2 ± 1.5a	31.3 ± 0.9b

Different lowercase letters indicate significant differences between samples according to an ANOVA test ($p<0.05$)

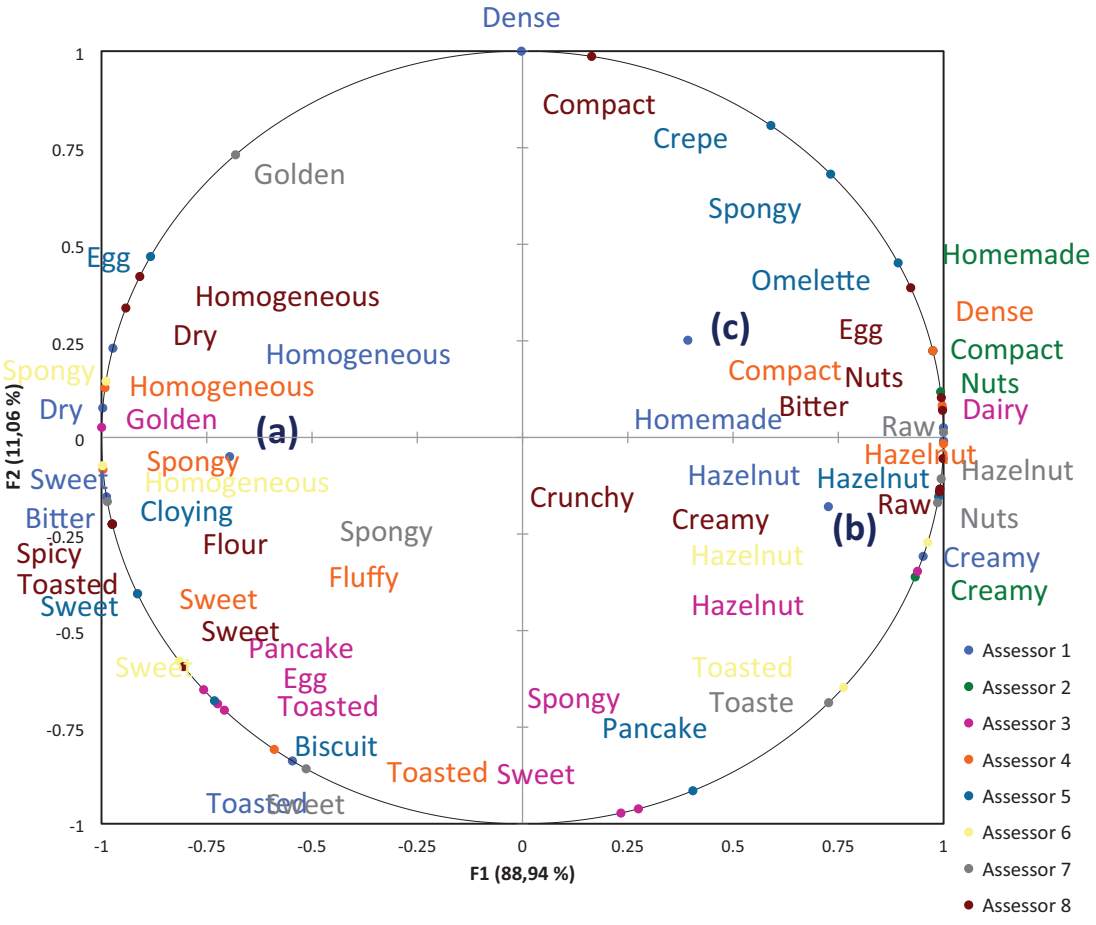

FIGURE 3 Representation of the first (F1) and second (F2) components of the generalized procursor analysis (GPA) of the free choice profile (FCP) data of the different hazelnut omelette formulations: (a) commercial; (b) gluten (wheat flour); (c) gluten-free (hazelnut flour).

to a TPA, including hardness (N), fracturability (N), adhesiveness (g s), springiness (N mm), cohesiveness (N), gumminess (−), chewiness (N mm), and resilience (−) were evaluated (Table 5). It was generally observed that when wheat flour was replaced by hazelnut flour, a decrease in hardness was observed (Tuna et al., 2023). In this study, wheat-flour samples had the highest hardness value (3.29 ± 0.23 N), whereas gluten-free hazelnut omelette with hazelnut-flour had the lowest values (2.43 ± 0.36 N). Like the findings in this study, another research reported that gluten-free breads with the addition of 5%–15% ground hazelnut and walnut had

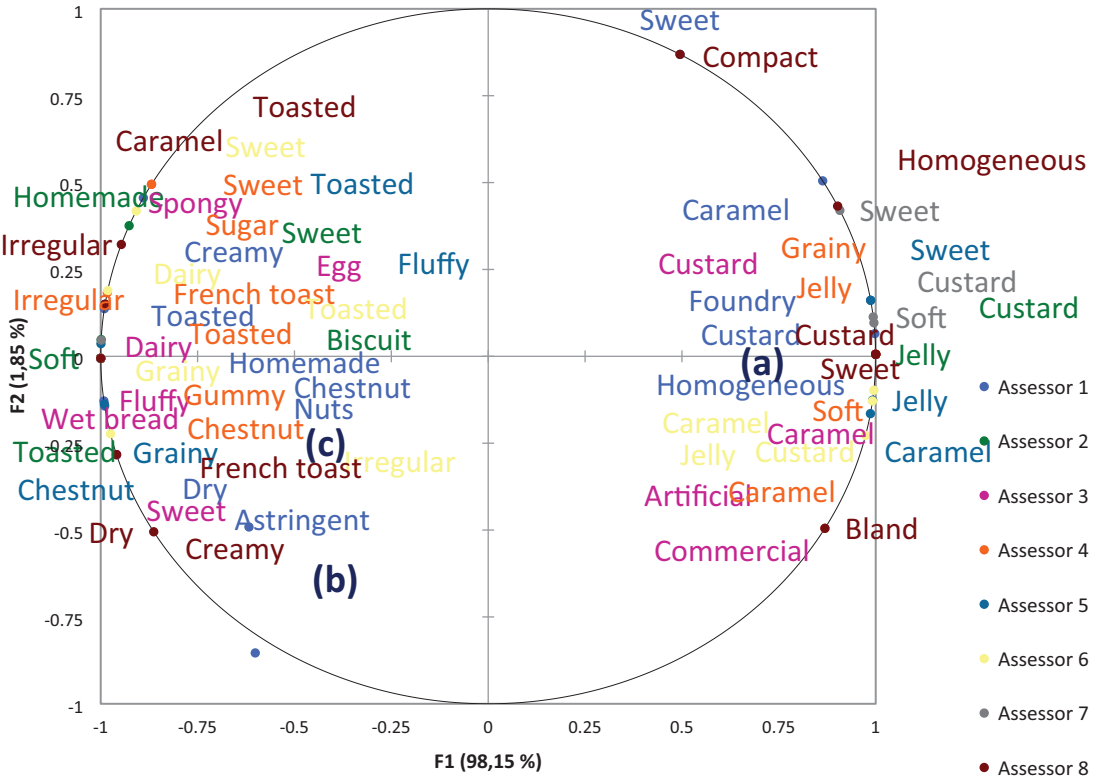

FIGURE 4 Representation of the first (F1) and second (F2) components of the generalized procursor analysis (GPA) of the free choice profile (FCP) data of the different chestnut pudding formulations: (a) commercial; (b) with sugar; (c) sugar-free (oligofructose).

TABLE 5 Values of texture profile analysis (TPA) parameters of the different hazelnut omelette formulations and chestnut pudding after storage for 3, 5, and 7 days at 4°C measured by compression test.

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
Hardness (N)	3.29 ± 0.23a	2.43 ± 0.36b	1.27 ± 0.12a	1.27 ± 0.15a
Fracturability (N)	0.11 ± 0.01a	0.09 ± 0.01a	0.1 ± 0.0a	0.09 ± 0.01a
Adhesiveness (g s)	−0.17 ± 0.00a	−0.38 ± 0.00b	−0.02 ± 0.0a	−0.05 ± 0.00a
Springiness (N mm)	0.96 ± 0.02a	0.82 ± 0.01b	0.65 ± 0.2a	0.68 ± 0.00a
Cohesiveness (N)	0.95 ± 0.02a	0.83 ± 0.02b	0.79 ± 0.1a	0.82 ± 0.01a
Gumminess (−)	2.69 ± 0.03a	2.12 ± 0.14b	1.88 ± 0.02a	1.7 ± 0.01a
Chewiness (N mm)	2.56 ± 0.14a	2.26 ± 0.26a	1.1 ± 0.1b	1.46 ± 0.02a
Resilience (−)	0.45 ± 0.11a	0.47 ± 0.14a	0.33 ± 0.1a	0.37 ± 0.03a

Note: Values are the mean of 20 samples by 3 reps ± standard deviation. Letters indicate significant differences between formulations according to the Student *t*-test ($p < 0.05$).

lower hardness than those made with wheat flour, which weakened the structure of the dough (Pycia & Juszczak, 2022). Other researchers reported that the addition of wheat bran increased the crumb hardness, whereas the addition of inulin decreased the hardness, which was explained by the lower degree of crystallinity (Kiumarsi et al., 2019). An explanation for this observation can be that hazelnut omelette made with hazelnut flour, as a high fiber ingredient, could disrupt the starch structure and reduce the degree of crystallinity (Kiumarsi et al., 2019). For this type of product, the best formulation was determined based on softness, the most attractive characteristic especially in gluten-free formulations (Lee, 2017; Tunç & Kahyaoglu, 2016). In this context, it was found that the optimal formulation involved hazelnut flour, demonstrating significantly lower adhesiveness (−0.38 ± 0.00 g s), cohesiveness (0.83 ± 0.02 N), and gumminess (2.12 ± 0.14) compared to formulations containing

TABLE 6 Values of antioxidant activity (ABTS) and total phenolic content (TPC) of hazelnut omelette and chestnut pudding for each formulation after storage for 3, 5, and 7 days at 4°C.

	Hazelnut omelette		Chestnut pudding	
	Gluten (wheat flour)	Gluten-free (hazelnut flour)	Sugar	Sugar-free (oligofructose)
ABTS (mg EAG/100 g FW)	31.16 ± 0.31a	27.22 ± 1.91b	13.75 ± 0.28a	12.84 ± 0.11a
Total phenolics (mg EAG/100 g FW)	22.83 ± 1.79a	21.92 ± 0.04a	11.79 ± 0.92a	8.84 ± 0.14b

Note: Values as expressed as a mean of 3 reps ± standard deviation. Different letters indicate significant statistically differences ($p < 0.05$) between formulations.
Abbreviations: AGE, acid garlic equivalents; FW, fresh weight.

wheat flour. Consequently, this results in improved softness characteristics, alongside the potential for increased enrichment in protein, fiber, and healthy fat components.

In this study, the PTA of chestnut pudding was also investigated (Table 5). All texture attributes were found to be equivalent between the two formulations studied, so no significant differences were observed except for the chewiness. This suggests that despite the significant disparity in the quantity and type of sweetener used, the textural properties of the resulting products remained remarkably consistent (Milner et al., 2020). This finding underscores the potential of oligofructose as a viable alternative to sugar without compromising the overall texture profile of the final product, thereby offering a valuable insight into the formulation optimization for ready-to-eat desserts catering to specific dietary preferences or health considerations (Di Monaco et al., 2018).

3.4 | Antioxidant capacity and total phenolic content

ABTS results indicated that gluten hazelnut omelette had an antioxidant capacity equivalent to 31.16 ± 0.31 mg gallic acid equivalents (ga eq.)/100 g of FW (Table 6). Gluten-free hazelnut omelette results showed values of 27.22 ± 1.91 mg ga eq./100 g FW, being statistically lower than its analogue. This indicates that the specific antioxidant profile of wheat flour differs from that of hazelnut flour, leading to the observed statistical difference. The antioxidant capacity of the wheat flour pancakes was different from that found by Incoronato et al. (2021). This could be attributed to the use of different ingredients and procedures or to differences in the extraction method (Meyers et al., 2003). However, both the disparity with the latter study and the similarity between the two formulations in the present research suggest that most of the antioxidant activity is due to the presence of olive oil in the formulation of our products. On the other hand, antioxidant activity was maintained in the two variations of chestnut pudding (13.75 ± 5.68 mg ga eq./100 g FW and 12.84 ± 6.12 mg ga eq./100 g FW, for sugar and sugar-free, respectively), as no statistical differences were observed between samples (Table 6).

Values of TPC are shown in Table 6. For hazelnut omelette formulations, phenolic content was 22.83 ± 1.58 mg/100 g FW, which was in similar amounts to those reported with the gluten-free version (21.93 ± 1.21 mg/100 g FW). Even so, Pycia and Ivanišová (2020) found greater values of TPC in hazelnut flour (550 mg/100 g FW). These dissimilarities could be attributed to dried fruit differences in varieties (Simsek et al., 2017) or cultivar (Solar et al., 2022). Furthermore, different extraction methods and interferences by other compounds could mark a difference on the values obtained (Rocchetti et al., 2017). TPC in chestnut pudding formulations did not statistically change either with sugar version (11.56 ± 0.75 mg/100 g FW) or sugar-free (8.84 ± 0.54 mg/100 g FW) formulation (Table 6). Similarly, no significant differences were observed by Belščak-Cvitanović et al. (2015) in chocolate product elaborated with sugar and oligofructose. Contrarily, Scibisz and Mitek (2009) found a significant increase in TPC when sugar is substituted with oligofructose to the final formulation of blueberry jams.

3.5 | Shelf-life

3.5.1 | Physicochemical (pH, humidity, and color)

Physicochemical changes of pH content are shown in Table 7. In the case of hazelnut omelette variations, the pH ranged between 6.57 and 6.84 for the gluten formulation and 6.51–6.80 for the gluten-free option, which agreed with the literature (Lee, 2017). In the case of different chestnut pudding formulations, pH ranged between 6.65–6.76 and 6.30–6.78 for sugar and sugar-free formulations, respectively. Values of pH contents indicated barely

TABLE 7 Values of pH of hazelnut omelette for each formulation after storage for 3, 5, and 7 days at 4°C.

		Day 0	Day 3	Day 5	Day 7
Hazelnutomellete	**Gluten (wheat flour)**	6.57 ± 0.01	6.62 ± 0.01	6.84 ± 0.04	6.75 ± 0.01
	Gluten-free (hazelnut flour)	6.59 ± 0.0	6.51 ± 0.0	6.8 ± 0.09	6.57 ± 0.01
Chestnut pudding	**Sugar**	6.74 ± 0.15	6.65 ± 0.15	6.77 ± 0.11	6.76 ± 0.02
	Sugar-free (oligofructose)	6.3 ± 0.37	6.36 ± 0.07	6.78 ± 0.04	6.6 ± 0.04

Note: Values are expressed as the mean of 3 reps ± standard deviation.

TABLE 8 Values of humidity of hazelnut omelette for each formulation after storage for 3, 5, and 7 days at 4°C.

		Day 0	Day 3	Day 5	Day 7
Hazelnut omelette	**Gluten (wheat flour)**	66.44 ± 15.81abA	73.44 ± 3.07aA	60.29 ± 4.97bA	63.7 ± 13.67abA
	Gluten-free (hazelnut flour)	43.59 ± 8.16B	40.84 ± 11.20B	37.3 ± 8.38B	25.36 ± 13.57B
Chestnut pudding	**Sugar**	62.64 ± 7.64aA	55.07 ± 7.69aB	59.55 ± 4.48aA	62.3 ± 18.04aA
	Sugar-free (oligofructose)	52.35 ± 17.43bB	60.01 ± 7.99aA	69.11 ± 9.98aA	60.3 ± 9.25aA

Note: Values are expressed as the mean of 3 reps ± standard deviation. Upper case letters indicate significant differences between formulations according to the student *t*-test ($p < 0.05$). Lowercase letters indicate significant differences among days according to the Tukey honestly significant difference (HSD) post hoc test ($p < 0.05$).

detectable statistically significant differences among variations. Although existing differences between formulations, there was not a general tendency that explains changes in pH.

Moisture was found to be significantly high in gluten hazelnut omelette compared to gluten-free version throughout the shelf-life (Table 8), which can be explained by the high-water retention capacities of gluten (Schopf & Scherf, 2021). The addition of hazelnut flour caused a decrease in the moisture levels (Anil, 2007). For chestnut pudding variations, the substitution of sugar with oligofructose in a recipe does not result in a change in the moisture content of a product (Table 8). Oligofructose possesses water-holding properties that could contribute to increased final product moisture compared to the use of sugar, mainly due to its soluble dietary fiber nature (Roberfroid, 1993). However, this scenario is contingent upon various factors such as the quantity of oligofructose employed, the specific recipe, and the presence of other ingredients in the final formulation.

In general, hazelnut omelette samples had L^*, a^*, and b^* values that reflected color of the flours used in the formulations (Table 9). Color parameters were significantly affected by the addition of hazelnut flour, as also noted by others (Anil, 2007). The darkest crumbs belonged to the hazelnut-containing samples, with a^* values being dominant in the hazelnut flour samples. Moreover, the different L^*, a^*, and b^* coordinates were significantly the same over the days of shelf-life (Tamanna & Mahmood, 2015). Concerning the chestnut pudding formulations, a minor trend in terms of variation of color coordinates was observed (Table 9). The application of both formulations does not seem to distinguish the color between formulations for each sampling point. However, a decrease in lightness (L^*) parameters was observed over the shelf-life study, probably due to the cold storage and condensation conditions of the product.

3.5.2 | Microbiology analysis

Regarding the initial microbiological load, the total mesophilic aerobic count (TAM) of hazelnut omelette was 2.8 and 2.5 log for gluten-containing and gluten-free variations, respectively (Figure 5). Over the course of the shelf life, population growth was observed, reaching approximately 4.1 for both formulations, with a growth of 1.3 and 1.6 log, respectively. Hazelnut omelette elaboration was vacuum-sealed and stored at 4°C as a gamma-type product (suitable for consumption), so refrigeration is necessary according to RD 135/2010 (Official State Gazette 12/2001) (BOE, 2010). This type of product is a heat-treated prepared meal that has undergone an overall thermal process (temperature increase) during its preparation, making it suitable for direct consumption or with slight heating. The maximum allowable limit for this type of food is less than 5 log of TAM, and it should not contain any other pathogenic microorganisms or their toxins in an amount that would affect consumer health (BOE, 2022).

In the case of pudding, the TAM count was 2.9 and 3.0 log for sugar and sugar-free versions, respectively (Figure 6). After 1 month, the counts were 4.2 log for both formulations, with a growth of 1.3 and 1.2 log, respectively. The pudding was packaged in aluminum flan molds with an unpasteurized PP plastic lid, making it a ready-to-eat

TABLE 9 Values of CIE Lab coordinates (L^*, a^*, and b^*) of the different hazelnut omelette formulations after storage for 3, 5, and 7 days at 4°C.

		Day 0			Day 3			Day 5			Day 7		
		L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Hazelnut omelette	Gluten (wheat flour)	40.65 ± 0.51aB	8.72 ± 0.9aB	10.72 ± 0.4aB	41.09 ± 0.8aA	8.64 ± 1.18aB	11.19 ± 0.88aB	42.47 ± 2.57aA	8.87 ± 1.13aB	10.73 ± 0.55aB	40.65 ± 0.53aA	9.53 ± 0.38aB	11.37 ± 0.83aB
	Gluten-free (hazelnut flour)	43.59 ± 1.00aA	14.91 ± 1.87bA	21.07 ± 0.59bA	40.98 ± 0.99abA	16.10 ± 1.15aA	23.42 ± 2.38aA	42.62 ± 2.95aA	14.43 ± 0.82bA	21.97 ± 0.45bA	39.73 ± 0.58bA	15.00 ± 0.62aA	21.76 ± 1.35abA
Chestnut pudding	Sugar	51.51 ± 5.68aA	8.96 ± 0.53bA	17.9 ± 0.86bA	45.09 ± 2.19bA	12.64 ± 2.51aA	23.90 ± 2.34aA	47.88 ± 0.51bA	12.45 ± 2.33aA	21.93 ± 1.89aA	52.89 ± 7.85aA	11.25 ± 3.22aA	20.94 ± 1.54abA
	Sugar-free (oligofructose)	53.02 ± 2.30aA	10.02 ± 1.95bA	19.16 ± 3.19bA	40.23 ± 6.55bcA	14.59 ± 0.87aA	23.19 ± 3.21aA	42.98 ± 1v67bB	13.64 ± 2.11aA	21.22 ± 1.55aA	36.23 ± 4.55cB	13.53 ± 1.53aA	21.20 ± 1.71aA

Note: Values are the mean of 5 samples by 3 reps ± standard deviation. Upper case letters indicate significant differences between formulations according to the Student t-test ($p < 0.05$). Lowercase letters indicate significant differences among days according to the Tukey honestly significant difference (HSD) post hoc test ($p < 0.05$).

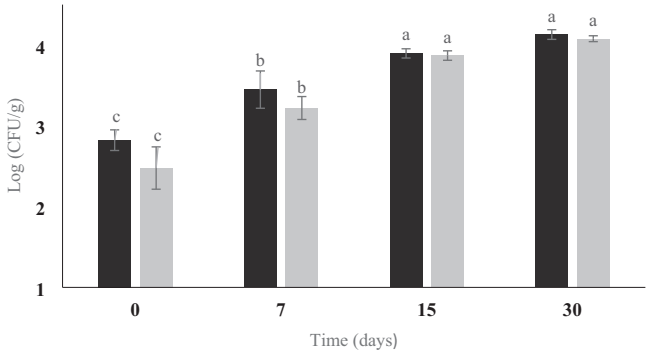

FIGURE 5 Population (log cfu/g product) of total aerobic mesophylls (TAM) of the different hazelnut omelette formulations (black: gluten (wheat flour)—gray: gluten-free (hazelnut flour)) after storage for 0, 7, 15, and 30 days at 4°C. Values are the mean of 3 reps ± standard deviation.

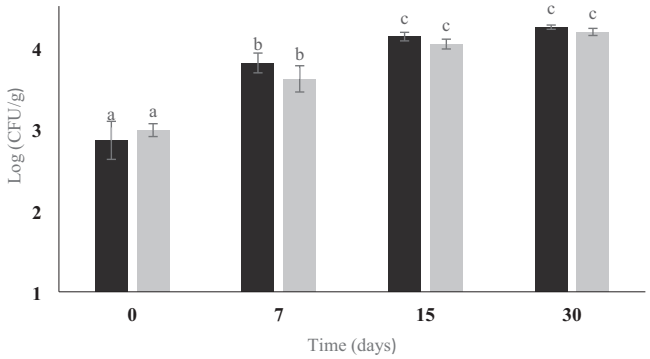

FIGURE 6 Population (log CFU/g product) of total aerobic mesophylls (TAM) of the different chestnut pudding formulations (black: sugar—gray: oligofructose) after storage for 0, 7, 15, and 30 days at 4°C. Values are the mean of 3 reps ± standard deviation.

product that requires refrigeration. In this case, this product is also a ready-to-eat food with heat treatment, where the established maximum limits are 5 log (BOE, 2022). In the case of yeasts, their growth is noticeable for both formulations from day 30, prompting the ending of the shelf-life trial.

4 | CONCLUSIONS

In this study, the technofunctional, nutritional, and shelf-life characterization were investigated in formulations comprising identical ingredients with the only difference being the gluten presence (hazelnut omelette) and sweetening agent (chestnut pudding). Reus PDO hazelnut flour was incorporated into the gluten-free formulation of the "hazelnut omelette," whereas oligofructose was chosen for the "Terra Fria PDO chestnut pudding" recipe. The substitution of hazelnut flour was positively evaluated in the FCP analysis, highlighting favorable attributes such as artisanal preparation, creaminess, and softness, significantly distinguishing it from the most similar commercial product. In particular, the formulation containing hazelnut flour exhibited the highest intensity of nutty flavor. Additionally, the texture obtained with the gluten-free version displayed the smoothest TPA attributes, considered the most prominent feature for this type of product. Shelf-life analysis revealed a more golden color and lower moisture content in the hazelnut flour formulation, in addition to enrichment in terms of protein, fiber, and healthy fat components due to the incorporation of Reus PDO hazelnut. In the case of the chestnut pudding, it was observed that the study parameters did not differ significantly from its sugar analogue with positive attributes in the FCP, positioning it as a viable alternative to sugar in this recipe. Therefore, both hazelnut flour in the "hazelnut omelette" and oligofructose in the "chestnut pudding" proved to be promising ingredients in the formulation of gluten-free and sugar-free products, offering attractive organoleptic and textural characteristics.

AUTHOR CONTRIBUTIONS

J. Ortiz-Solà: Conceptualization; methodology; investigation; writing—original draft; writing—review and editing. **D. Almeida**: Investigation; writing—review and editing. **L. López-Mas**: Formal analysis; writing—review and editing. **Z. Kallas**: Supervision; methodology; formal analysis; writing—review and editing. **M. Abadias L. Barros** and **H. Martín-Gómez**: Supervision; writing—review and editing. **I. Aguiló-Aguayo**: Supervision; funding acquisition; formal analysis; writing—review and editing; writing—original draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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