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# Sensory perception and digestibility of a protein pudding-type dessert with an omega-3 nanoemulsion designed for older adults

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ABSTRACT

The development of senior-friendly foods requires balancing nutritional enhancement with sensory acceptance. This study focused on creating a pudding-type dessert enriched with whey protein (10%) and omega-3 nanoemulsions (5%), varying in isinglass concentration (1–4%) to address older adults' nutritional needs. Four formulations (T1–T4) were evaluated for physicochemical properties (digestibility, color, texture) and sensory acceptability by 70 older adults (≥65 years) using Check-All-That-Apply (CATA), 9-point liking, and 5-point purchase intention scales. Digestibility improved significantly with isinglass, from 80.1% (T1) to 92.3% (T4) ($p<0.05$). Texture changed markedly, with hardness increasing from 0.887 N (T1) to 18.000 N (T4). Color differences were noted in a* (3.08–6.86) and b* (3.47–6.48) values ($p<0.05$). Only two sensory attributes, "thick" and "chewy," differed significantly across samples, with T4 rated as the thickest (40%¦vs. 13% for T1). Despite textural and color variations, all formulations showed high liking scores (6.8–7.2/9) and purchase intentions (3.9–4.2/5), with no significant differences ($p>0.05$). Formulations with 2–3% isinglass (T2–T3) offered the best texture–acceptability balance, while T4 maximized digestibility. These results provide quantitative benchmarks for developing senior-specific functional foods that combine high protein digestibility, omega-3 enrichment, and sensory appeal. Future research should validate these findings through clinical trials assessing muscle protein synthesis outcomes.

## 1. Introduction

Adequate nutrition is essential for maintaining health and quality of life in older adults. As individuals age, their physiological and nutritional needs change, making the intake of specific nutrients (particularly high-quality proteins and omega-3 fatty acids) crucial for preserving muscle mass, cognitive function, and cardiovascular health (Johnson & Smith, 2019). However, this population often faces limitations such as reduced appetite, impaired taste and smell, and difficulties in chewing and swallowing, which hinder the consumption of nutrient-dense foods (Smith et al., 2020). These barriers can negatively impact the acceptance of functional foods, including fortified desserts, highlighting the importance of understanding sensory perception and food preferences in this age group (Martínez et al., 2008; Chaffee et al., 2023).

Protein intake is especially important due to the prevalence of sarcopenia, a progressive loss of muscle mass and strength in older adults (Bauer et al., 2013). To mitigate this condition, it is recommended that older individuals consume between 1.0 and 1.2 g of protein per kilogram of body weight per day (Deutz et al., 2014). However, the effectiveness of dietary protein is not solely dependent on quantity; it is also influenced by digestibility, which can be reduced by age-related factors such as diminished digestive enzyme secretion and slower gastrointestinal motility (Volpi et al., 2013). In this context, food matrices that improve the digestibility and bioavailability of protein are essential for

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supporting muscle maintenance and overall health (Phillips et al., 2016).

Omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), have demonstrated anti-inflammatory properties and are associated with benefits for cardiovascular, metabolic, and cognitive health in older adults (Alex et al., 2020; Lei Tang et al., 2025). Nonetheless, incorporating omega-3 into foods poses several challenges due to its oxidative instability and unpleasant taste. Recent advances in food nanotechnology, such as the development of nanoemulsions and microsphere-free nanofibers using whey protein isolate (WPI) and polyvinyl alcohol (PVA), have shown promise in enhancing the encapsulation, stability, and bioavailability of omega-3 (Robabeh et al., 2025). These delivery systems allow for improved protection and controlled release of lipophilic nutrients, thereby increasing their effectiveness in food applications targeted at older adults (Lira-Marcial et al., 2023).

Despite these technological advances, a key research gap remains: most existing studies have not fully integrated these nanoencapsulated nutrients into real, age-appropriate food matrices, nor have they adequately addressed the sensory limitations associated with aging. Moreover, few studies have investigated how older adults perceive fortified foods within familiar formats. While recent sensory studies have assessed preference in traditional dishes such as chicken porridge or braised meat (Seyoung et al., 2024; Yu et al., 2024), and even texture perception in yogurt (Chaffee et al., 2023), they often overlook the influence of formulation variables on acceptance in soft, functional foods. Fernandes et al. (2024), for instance, reported that clean-labeled cookies and mayonnaise were less accepted by older adults compared to more familiar items like ham and yogurt, emphasizing the role of product familiarity and texture in consumer acceptance.

The novelty of this study lies in the development of a soft, familiar food product (a pudding-type dessert) designed specifically for older adults, combining two functional ingredients of high nutritional relevance: nanoemulsified omega-3 fatty acids and high-quality protein (WPI). Unlike previous studies that focus either on nutrient delivery or sensory testing in isolation, this research integrates both aspects in a food matrix tailored to the sensory and physiological needs of older adults. Based on this approach, the study formulates the following hypothesis: A pudding-type dessert containing nanoemulsified omega-3 fatty acids and whey protein isolate can achieve high sensory acceptability in older adults while providing a matrix that supports improved nutrient delivery and digestibility. Therefore, the objective of this study was to develop and characterize a pudding-type dessert enriched with nanoencapsulated omega-3 and high-quality protein, evaluating its sensory acceptability and functional properties relevant to older adults.

## 2. Materials and methods

### 2.1. Raw materials

Oil-in-water (O/W) nanoemulsions were prepared using water purified by a reverse osmosis system (Vigaflow S.A., Santiago, Chile), EPA- and DHA-rich oil (Fish Oil TG400300, Golden Omega S.A., Arica, Chile), and two emulsifiers: soy lecithin (Metarin P, Cargill, Blumos S.A., Santiago, Chile) and Tween 80, a synthetic emulsifier (Sigma-Aldrich S.A., St. Louis, CA, USA). For the pudding formulation, the nanoemulsion was used, a mixture of chocolate-flavored powders (Umsha, Alicorp S.A.A., Lima, Peru), WPI (JD Nutraceuticals, Supplement Supply Co., Canberra, Australia), isinglass (Universal, Productos extragel and Universal SAC, Lima, Peru), and table water (Cielo, AJE group, Lima, Peru).

### 2.2. Pudding development with the nanoemulsion

Oil-in-water (O/W) nanoemulsions were prepared with a formulation composed of 4 % lecithin, 0.5 % Tween 80, 5 % EPA- and DHA-rich oil, and 90.5 % water. The aqueous phase was obtained by dispersing Tween 80 in purified water using magnetic stirring (Arex, Velp Scientifica, Usmate Velate, Italy) at 350 rpm for 10 min. Soy lecithin was then added and the mixture was stirred at 450 rpm for 40 min until completely dispersed. The EPA- and DHA-rich oil was slowly added to the aqueous phase while the mixture was homogenized at 12,000 rpm using a high-speed homogenizer (IKA T25, Ultra Turrax, Germany) for 10 min. The resulting pre-emulsion was subjected to ultrasonic homogenization (VCX500, Sonics, Newtown, CT, USA) using a 13 mm diameter stainless steel probe at 20 kHz and 90 % amplitude, with work-rest cycles of 15 and 10 s, respectively, for 10 min (Arancibia et al., 2016, 2017). For the preparation of the pudding with the nanoemulsion, four treatments were formulated with different concentrations isinglass (1–4 %), a natural fish-derived gelatin used as a gelling agent: T1 (1 % w/w), T2 (2 % w/w), T3 (3 % w/w) and T4 (4 % w/w), keeping the rest of the ingredients constant (Table 1). All components were mixed and stirred at 500 rpm for 5 min at room temperature. Subsequently, the mixture was processed with a propeller stirrer (F20100151, Velp Scientifica, Usmate Velate, Italy) at 450 rpm in a thermoregulated bath (B-100, Buchi, Flawil, Switzerland) at 90 ± 1 °C for 30 min. The obtained samples were cooled to 25 ± 1 °C and stored at 4 ± 1 °C for 24 h before characterization.

### 2.3. Physicochemical analysis

The physicochemical analysis of the protein pudding-type dessert with omega-3 nanoemulsion was performed following standard methodologies. Soluble solids (expressed in °Brix) were determined using a digital refractometer (PAL-3, Atago, Japan) according to the method described by Leandro et al. (2022). The pH was measured using a digital pH meter (Hanna, model HI320, USA), calibrated with pH 4.0 and 7.0 buffer solutions, following the protocol of Andrade et al. (2016). The refractive index (RI) was measured using an Abbe refractometer (JVLAB, model 2WAJ, China) according to the procedure established by Pacheco et al. (2008). Titratable acidity was determined using a titrator (Titronic, model 500, Spain) with 0.1 N NaOH and expressed as a percentage of lactic acid, following the methodology proposed by Calderón et al. (2012). Protein was quantified using the Kjeldahl method (AOAC 981.10), with a conversion factor of 6.25, as described by Lanza et al. (2016). Fat was determined using the Soxhlet method (AOAC 920.39) in a solvent extractor (Velp Scientifica, model SER148, Usmate Velate, Italy), using hexane as the solvent, according to Jahuira et al. (2024). In vitro protein digestibility was evaluated according to the method of Qiongling et al. (2025), based on the simulation of gastrointestinal digestion with pepsin and pancreatin, and the results were expressed as a percentage of protein digestion.

### 2.4. Colorimetric analysis

The color of the protein pudding was analyzed using a portable colorimeter (PCE Instruments, model CSM 3, Spain) on the CIELAB system, obtaining the parameters L* (lightness), a* (red/green bias), b* (yellow/blue bias), C* (chroma), and H* (hue), following the method described by Nguyen et al. (2023). Measurements were performed in a light-controlled chamber to avoid external interference.

**Table 1**
Formulation of the pudding samples studied.

| Ingredients (%) | T1 | T2 | T3 | T4 |
|---|---|---|---|---|
| Nanoemulsión | 10 | 10 | 10 | 10 |
| Chocolate flavor powder | 10 | 10 | 10 | 10 |
| Whey Protein Isolate (WPI) | 3 | 3 | 3 | 3 |
| Isinglass (gelling agent) | 1 | 2 | 3 | 4 |
| Water | 76 | 75 | 74 | 73 |

### 2.5. Texture analysis

The textural properties of the pudding were evaluated using a texturometer (Brookfield Metek Texturometer, model CTX, USA) using TexturePro V1.0 Build 19 software from Brookfield Engineering Labs Inc. The test conditions were: TA25/1000 compression plate probe, double compression, 0.5 mm/s speed, 60 % compression with a 5 kg load cell. Double compression tests (TPA, Texture Profile Analysis) were performed to determine: Hardness (maximum force applied to the sample), Resilience (ability of the pudding to recover its shape after deformation), Cohesion (ratio between the work required for the first and second compression), Elasticity (ability of the pudding to recover its original height after compression) and Gumminess (product of hardness and cohesion), which represents the energy required to disintegrate the pudding. Measurements were performed at room temperature, following the protocol of Jiyoon et al. (2025) and Yusof et al. (2019).

### 2.6. Sensory analysis

#### 2.6.1. Consumers

The sensory analysis of the protein pudding with omega-3 nanoemulsion was performed using the Check-All-That-Apply (CATA) technique, following the methodology described by Lado et al. (2010). Older adults ($n$ = 70) over 60 years of age were recruited and met the following inclusion criteria: (i) good health, (ii) absence of allergies or intolerances to pudding ingredients, (iii) ability to perceive and discriminate flavors and textures, and (iv) willingness to participate in the evaluation. Before the evaluation, participants received a brief orientation session on the use of the CATA question, during which they were explained the evaluation procedure and the importance of selecting all attributes they considered applicable to each sample.

#### 2.6.2. Sample presentation

The pudding samples were prepared on the day of the evaluation and stored at 4 ± 1 °C for 12 h before being presented to the panelists. Each sample (approximately 30 g) was served in containers coded with three-digit random codes and kept at a controlled temperature (10 ± 2 °C) until evaluation. The samples were presented in a completely randomized and counterbalanced design to avoid order effects and sensory fatigue. Water and unsalted crackers were provided to neutralize the palate between samples.

#### 2.6.3. Sensory evaluation by CATA

Each panelist received an evaluation sheet with a list of predefined attributes, selected based on previous studies on pudding-type desserts and protein formulations for older adults (Ares et al., 2010; Varela et al., 2010). The list included descriptive attributes of appearance, aroma, flavor, and texture. The following attributes were evaluated: sweet, delicious, smooth, lumpy, intense flavor, chocolate, vanilla flavor, creamy, pleasant, slightly sweet, thick, tasteless, homogeneous, very sweet, chocolate smell, slightly chocolate flavor, bitter, fatty, and chewy. The panelists marked all the attributes they considered appropriate for each sample, with no restrictions on the number of selections.

#### 2.6.4. Overall liking and purchase intention

The overall liking of the pudding was determined using a 9-point hedonic scale (1 = *I* strongly dislike it and 9 = *I* strongly like it). Purchase intention was assessed using a 5-point scale (1 = *I* definitely would not buy it and 5 = *I* definitely would buy it) (Kamboj et al., 2023).

### 2.7. Statistical analysis

The physicochemical, colorimetric, and textural data were analyzed under a completely randomized design with four treatments, using a one-way analysis of variance (ANOVA) to assess significant differences between treatments. Subsequently, when significant differences were detected ($p < 0.05$), Tukey's multiple comparisons test was applied to identify formulations with statistically significant variations. Furthermore, the assumptions of normality and homogeneity of variance were verified, ensuring the validity of the statistical analysis. The CATA sensory data were analyzed by attribute selection frequencies, using chi-square ($X^2$) tests to determine significant differences between samples ($p < 0.05$). In addition, a multiple correspondence analysis (MCA) was performed to visualize the relationships between the formulations and the sensory attributes selected by the participants. Overall liking and purchase intention results were analyzed using analysis of variance (ANOVA), followed by Tukey's test to compare significant differences between samples ($p < 0.05$). Statistical analyses were performed using XLSTAT 2023 software (Addinsoft, Paris, France).

## 3. Results and discussion

### 3.1. Sociodemographic data

In Table 2, the sociodemographic data of the participants are presented. The study population consisted predominantly of male participants aged 60 to 69 years. This demographic distribution aligns with the study's focus on older adults, a classification recognized in Peru under Law 28,803 – Law of Older Adults (Congreso de la República del Perú, 2006). A decreasing representation was observed in the older age groups, reflecting the natural demographic distribution within the target population. These data provide a relevant context for interpreting the sensory evaluation results, as age-related physiological changes can influence taste perception, texture preference, and overall acceptability of food products.

### 3.2. Physicochemical parameters

The physicochemical analysis revealed significant variations ($p < 0.05$) across all tested parameters (Table 3). Soluble solids (SS) content ranged from 14.17 ± 0.10°Brix in T1 to 17.20 ± 0.20°Brix in T4, showing a clear concentration-dependent relationship with isinglass content. This 21.4 % increase in SS between T1 and T4 corresponds directly with the refractive index values (1.3538 ± 0.0003 to 1.3587 ± 0.0003, respectively), confirming the strong correlation ($r$ = 0.98) between these parameters as previously reported by Carmona et al. (2009). These results demonstrate that isinglass concentration effectively modulates the dissolved solids content, which has important implications for product texture and mouthfeel - critical factors for older adult acceptance. pH measurements showed a narrow but statistically significant range (6.62 ± 0.02 to 6.71 ± 0.02), with T2 exhibiting the highest value. While these differences appear numerically small, they represent a 1.36 % variation in hydrogen ion concentration that could impact both product stability and sensory perception. The non-linear relationship with titratable acidity (0.2501–0.2687 %) supports the findings of Mex-Alvarez et al. (2022) regarding complex acid-base interactions in protein-rich matrices. For clinical applications, this pH range (6.6–6.7) is particularly suitable for older adults as it minimizes risks of acid reflux while maintaining optimal protein stability.

Protein content showed the most dramatic formulation-dependent

**Table 2**
Sociodemographic data of participating older adults.

| Data | n | % |
|---|---|---|
| **Gender** | | |
| Male | 41 | 58.57 |
| Female | 29 | 41.43 |
| **Age** | | |
| 60–69 | 52 | 74.29 |
| 70–79 | 10 | 14.29 |
| 80–90 | 7 | 10.00 |
| >90 | 1 | 1.42 |

**Table 3**
Physicochemical data of pudding formulations.

| Sample | % Soluble solids (°Brix) | pH | Refractive index | % Acidity | % Protein | % Fat |
|---|---|---|---|---|---|---|
| T1 | 14.17 ±0.10[d] | 6.62 ±0.02[c] | 1.3538 ±0.0003[d] | 0.2687 ±0.07[a] | 3.61 ±0.07[d] | 1.05 ±0.01[bc] |
| T2 | 15.43 ±0.05[c] | 6.71 ±0.02[a] | 1.3558 ±0.00006[c] | 0.2501 ±0.08[b] | 4.49 ±0.06[c] | 1.24 ±0.04[a] |
| T3 | 15.80 ±0.20[b] | 6.68 ±0.02[ab] | 1.3564 ±0.0004[b] | 0.2522 ±0.13[ab] | 5.25 ±0.13[b] | 1.12 ±0.04[b] |
| T4 | 17.20 ±0.20[a] | 6.65 ±0.02[bc] | 1.3587 ±0.0003[a] | 0.2549 ±0.06[ab] | 6.24 ±0.06[a] | 1.02 ±0.01[c] |

[a,b,c,d] different letters indicate significant differences ($p > 0.05$).

differences, increasing 72.9 % from T1 (3.61 ± 0.07 %) to T4 (6.24 ± 0.06 %). This progression demonstrates that isinglass incorporation can effectively boost protein levels to meet or exceed the recommended 1–1.2 g/kg/day intake for older adults when consumed in typical serving sizes (150–200 g). The high-quality albumin and collagen proteins in isinglass (Vélez et al., 2024) are particularly valuable for addressing sarcopenia, as they provide both essential amino acids and glycine for connective tissue health. Fat content ranged from 1.02 ± 0.01 % (T4) to 1.24 ± 0.04 % (T2), representing a 21.6 % variation that could significantly impact sensory properties and nutrient absorption. While T2′s higher fat content may enhance flavor perception and fat-soluble vitamin uptake (Alvarado-García et al., 2017), T4′s lower lipid levels might be preferable for clinical populations requiring energy-controlled diets. This flexibility in formulation allows customization for different senior nutrition needs - from undernourished individuals who would benefit from T2′s richer profile to overweight metabolic patients where T4 would be more appropriate.

The findings support the formulation of functional foods for older adults. The correlation between isinglass concentration and physicochemical traits (e.g., soluble solids, refractive index) allows texture and nutrient profile adjustment. The stable pH (6.62–6.71) and titratable acidity (0.25–0.27 %) facilitate flavor masking of omega-3 s, enhancing palatability. Moreover, the low variability in refractive index (CV < 0.02 %) indicates excellent reproducibility, ensuring consistent quality in large-scale production.

### 3.3. *Colorimetric parameters*

The colorimetric analysis revealed significant variations ($p < 0.05$) across all parameters, demonstrating the formulation-dependent visual characteristics of the pudding samples (Table 4). The lightness parameter (L*) ranged from 44.82 ± 2.06 (T1) to 46.89 ± 0.18 (T2), representing a 4.6 % difference in luminosity. This variation is particularly relevant for product appeal, as T2′s higher lightness (46.89) may be perceived as more visually appealing to older adults with potential vision impairments, while T1′s darker appearance (44.82) aligns with expectations for chocolate-flavored products (Chire-Fajardo et al., 2017). The red-green balance (a*) showed particularly striking differences, with values increasing from 3.08 ± 1.08 (T1) to 6.86 ± 0.18 (T3) - a 123 % variation. This progression corresponds to a clear shift from muted reddish tones to more intense red coloration, with T3 and T4 (6.29 ± 0.19) forming a distinct group ($p < 0.05$). The yellow-blue balance (b*) followed a similar pattern, ranging from 3.47 ± 0.97 (T1) to 6.48 ± 0.19 (T3), representing an 87 % increase in yellow intensity. These color coordinates directly impact product perception, with the more saturated colors of T3 and T4 potentially signaling greater flavor intensity to consumers. Color saturation (C) varied dramatically from 4.64 ± 1.44 (T1) to 9.43 ± 0.26 (T3), demonstrating that formulation changes can more than double the vibrancy of the product's appearance. This parameter is particularly important as it correlates with consumer perceptions of freshness and quality. The hue angle (H) showed narrower but still significant differences (43.38 ± 0.19° to 48.79 ± 2.09°), with T1′s higher value (48.79°) indicating a more yellow-dominant red hue compared to T3′s red-dominant profile (43.38°). For senior consumers, T2′s higher lightness (L* = 46.89) enhances visual recognition, addressing age-related vision challenges. The formulation's consistent correlation between chocolate content and darker hues (T1 L* = 44.82) ensures flavor expectations align with visual cues, improving consumer satisfaction. Notably, the vibrant color saturation of T3 (C* = 9.43) and T4 (C* = 9.01) conveys premium quality, driving market differentiation at the time of choice.

### 3.4. *Texture parameters*

The textural analysis revealed significant differences ($p < 0.05$) across all parameters, with particularly notable variations in hardness values ranging from 0.887±0.140 N (T1) to 18.000±2.750 N (T4) - representing a 20-fold difference (Table 5). This dramatic variation is primarily attributed to the isinglass content, which enhanced gel formation and matrix compactness in T4. For elderly consumers with mastication difficulties (Amoah et al., 2021), the softer textures of T1 (0.887 N) and T2 (1.407 N) would be preferable, requiring approximately 95 % less chewing force compared to T4. The resilience parameter showed T2 (0.290±0.010) with superior structural recovery - 29 times greater than T3 (0.010±0.000) - suggesting better maintenance of texture integrity during oral processing. Cohesiveness values decreased progressively from T1 (0.743±0.071) to T4 (0.330±0.020), indicating that while T1 maintained better internal structure during deformation, T4′s lower cohesiveness might facilitate easier breakdown in the mouth - a critical factor for dysphagia management (Forsberg et al., 2022). Springiness (elasticity) measurements revealed T2 (4.767 ±0.249 mm) as the most elastic formulation, while T3 (0.320±0.040 mm) showed minimal recovery capacity. This 15-fold difference in elasticity has important implications for sensory perception, as higher elasticity (T2) may provide a more familiar mouthfeel to traditional puddings. Gumminess values, combining hardness and cohesiveness, ranged from 0.663±0.166 N (T1) to 6.390±0.368 N (T3), with the higher values in T3 and T4 (5.963±1.228 N) indicating denser textures that might require more chewing effort - potentially unsuitable for frail elderly populations (Mutlu et al., 2018). The findings demonstrate how these formulations can be tailored to meet diverse elderly nutritional

**Table 4**
Colorimetric characteristics of the pudding-type dessert.

| Sample | L* | a* | b* | C* | H* |
|---|---|---|---|---|---|
| T1 | 44.82 ±2.06[b] | 3.08 ±1.08[c] | 3.47 ±0.97[b] | 4.64 ±1.44[c] | 48.79 ±2.09[a] |
| T2 | 46.89±0.18[a] | 4.32 ±0.28[b] | 4.43 ±0.25[b] | 6.19 ±0.37[b] | 45.71 ±0.38[b] |
| T3 | 45.62 ±0.16[ab] | 6.86 ±0.18[a] | 6.48 ±0.19[a] | 9.43 ±0.26[a] | 43.38 ±0.19[c] |
| T4 | 45.20 ±0.15[ab] | 6.29 ±0.19[a] | 6.45 ±0.24[a] | 9.01 ±0.31[a] | 45.73 ±0.46[b] |

[a,b,c,d] different letters indicate significant differences ($p > 0.05$).

**Table 5**
Texture parameters of pudding formulations.

| Sample | Hardness | Resilience | Cohesiveness | Springiness | Gumminess |
|---|---|---|---|---|---|
| T1 | 0.887 ±0.140[b] | 0.020 ±0.010[bc] | 0.743 ±0.071[a] | 2.603 ±0.274[b] | 0.663 ±0.166[b] |
| T2 | 1.407 ±0.051[b] | 0.290 ±0.010[a] | 0.540 ±0.017[b] | 4.767 ±0.249[a] | 0.763 ±0.025[b] |
| T3 | 15.343 ±0.843[a] | 0.010 ±0.000[c] | 0.417 ±0.006[c] | 0.320 ±0.040[d] | 6.390 ±0.368[a] |
| T4 | 18.000 ±2.750[a] | 0.027 ±0.006[b] | 0.330 ±0.020[d] | 0.697 ±0.050[c] | 5.963 ±1.228[a] |

[a,b,c,d] different letters indicate significant differences ($p > 0.05$).

needs. Sample T1, with its low hardness (0.887 N) and high cohesiveness (0.743), proves ideal for clinical diets targeting dysphagia or severe chewing difficulties, maintaining structural integrity during swallowing with minimal effort. The observed 20-fold hardness range between T1 and T4 enables development of texture-modified foods adaptable to varying masticatory abilities, from regular (T2) to soft diets (T1). Notably, T2 emerges as the optimal formulation for general elderly populations, combining moderate hardness (1.407 N) with high resilience (0.290) and elasticity (4.767 mm) to provide adequate textural stimulation without excessive chewing demands. These precise texture gradients allow customized product development for specific therapeutic needs - from easy-to-swallow options (T1) to more energy-dense formulations (T3/T4) when required.

### 3.5. Digestibility

The in vitro digestibility analysis revealed significant differences ($p < 0.05$) among formulations, with T4 demonstrating superior protein digestibility at 92.3 % - approximately 15 % higher than T1 (80.1 %) and 10 % greater than T2 (83.5 %) (Fig. 1). This enhanced digestibility suggests T4′s protein matrix is more susceptible to enzymatic breakdown, likely due to its optimized isinglass content which appears to improve gastric accessibility. The intermediate digestibility of T3 (87.2 %) was significantly different from both the higher-performing T4 and lower-performing T1-T2 pair ($p < 0.05$), while T1 and T2 showed comparable values ($p > 0.05$), indicating similar protein bioavailability despite their textural differences. These findings align with recent work by Sahin et al. (2024) reporting 91.79 % digestibility in nut proteins, though our T4 formulation achieved slightly higher values (92.3 %). The digestive performance correlates strongly with the simulated gastric phase conditions (pH 1.5–2.0), where pepsin activation optimally hydrolyzes proteins into absorbable peptides (Luz et al., 2024). The 12.2 percentage point range in digestibility across formulations suggests that protein source and matrix structure significantly impact elderly nutrition outcomes. The superior digestibility of T4 (92.3 %) positions it as an optimal formulation for elderly nutrition, particularly for individuals with compromised digestive function, where it may enhance protein absorption by 15 % compared to conventional options. The established correlation between isinglass content and digestibility offers a clear development target (>90 % digestibility) for creating age-appropriate protein foods. The 8.7 % digestibility advantage of T4 over T3 translates to significant nutritional benefits, providing approximately 2.6 g more absorbable protein per standard 150 g serving - a meaningful difference for maintaining muscle mass in aging populations. Protein- and omega-3-enriched pudding may promote muscle preservation and cognitive function in older adults, contributing to healthy aging. However, its consumption should be adjusted according to individual needs, as excess protein may increase renal burden (Bauer et al., 2013).

### 3.6. Sensory analysis CATA with acceptability and purchase intention

The Check-All-That-Apply (CATA) analysis revealed significant differences ($p < 0.05$) in texture-related attributes ("Thick" and "Gummy"), while flavor and other sensory characteristics showed no significant variation across treatments ($p > 0.05$) (Table 6). Specifically, "Thick" perception increased progressively from T1 (13 % of respondents) to T4 (40 %), while "Gummy" was significantly higher in T4 (14 %) compared to other treatments (5–7 %). These texture differences likely stem from the varying isinglass concentrations, with T4′s formulation creating a more substantial mouthfeel. Notably, none of the flavor attributes (sweet, chocolate, vanilla, bitter) showed significant differences ($p > 0.05$), despite formulation variations. This suggests that while texture perception changed markedly, flavor pro-files remained consistently recognizable across samples - an important consideration for product developers target-ing older adults. These findings align with Pepito and Ross (2024), who emphasized the dual importance of sensory and

**Table 6**
Cochran Q values for different pudding formulations.

| Atributtes | p-value | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| Sweet | 0.1500 | $41^{a}$ | $39^{a}$ | $33^{a}$ | $34^{a}$ |
| Delicious | 0.9609 | $44^{a}$ | $44^{a}$ | $44^{a}$ | $46^{a}$ |
| Soft | 0.1441 | $54^{a}$ | $60^{a}$ | $53^{a}$ | $50^{a}$ |
| Chunky | 0.2083 | $8^{a}$ | $7^{a}$ | $4^{a}$ | $11^{a}$ |
| Intense chocolate flavor | 0.2322 | $35^{a}$ | $26^{a}$ | $32^{a}$ | $29^{a}$ |
| Vanilla flavor | 0.2967 | $13^{a}$ | $13^{a}$ | $11^{a}$ | $7^{a}$ |
| Creamy | 0.3370 | $45^{a}$ | $40^{a}$ | $38^{a}$ | $36^{a}$ |
| Pleasant | 0.6149 | $45^{a}$ | $40^{a}$ | $42^{a}$ | $39^{a}$ |
| Slightly sweet | 0.8944 | $34^{a}$ | $34^{a}$ | $37^{a}$ | $36^{a}$ |
| Thick | 0.0001 | $13^{b}$ | $35^{a}$ | $38^{a}$ | $40^{a}$ |
| Tasteless | 0.6974 | $2^{a}$ | $3^{a}$ | $1^{a}$ | $3^{a}$ |
| Homogeneous | 0.4151 | $20^{a}$ | $22^{a}$ | $19^{a}$ | $26^{a}$ |
| Very sweet | 0.8358 | $2^{a}$ | $1^{a}$ | $2^{a}$ | $1^{a}$ |
| Chocolate smell | 0.8085 | $44^{a}$ | $40^{a}$ | $44^{a}$ | $43^{a}$ |
| Little chocolate flavor | 0.1946 | $22^{a}$ | $31^{a}$ | $28^{a}$ | $28^{a}$ |
| Bitter | 0.5399 | $6^{a}$ | $9^{a}$ | $5^{a}$ | $6^{a}$ |
| Greasy | 0.2539 | $7^{a}$ | $11^{a}$ | $13^{a}$ | $11^{a}$ |
| Gummy | 0.0356 | $5^{b}$ | $7^{b}$ | $6^{b}$ | $14^{a}$ |

$^{a,b}$different letters indicate significant differences ($p > 0.05$).

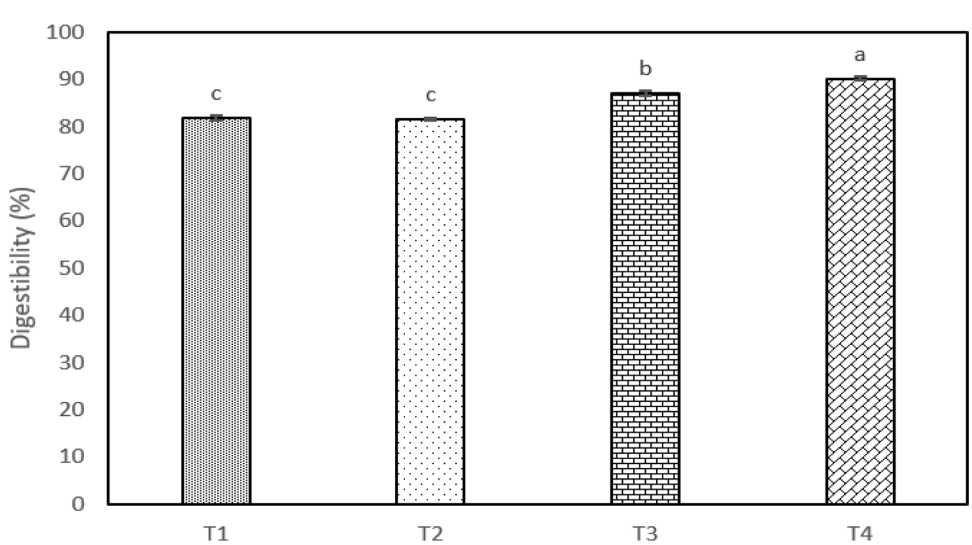


**Fig. 1.** Digestibility of different pudding-type desserts ($^{a,b,c,d}$ different letters indicate significant differences ($p > 0.05$)).

nutritional factors in geriatric food development, and extend Peters et al.'s (2018) work on flavor preservation strategies by demonstrating texture-flavor independence in protein-enhanced matrices. However, the cognitive demands of CATA methodology may have influenced these results, as older adults often experience working memory limitations that could affect their ability to evaluate multiple attributes simultaneously (Seyoung et al., 2024). This cognitive load might explain why only the most salient textural differences ("Thick", "Gummy") reached significance, while subtler flavor variations did not.

Fig. 2 shows the results obtained using the CATA method with purchase intention capture. Fig. 2(a) shows the relationship between the four samples and the sensory attributes evaluated. The graph explains the behavior of 86.90 % of the total variability in the data. T4 was strongly associated with textural attributes (homogeneous, chewy, lumpy, thick; $p < 0.05$), reflecting its structural modifications from higher isinglass content. In contrast, T1 was characterized by sweet/vanilla flavor notes (very sweet, vanilla flavor, creamy; $p < 0.05$), demonstrating independent modulation of flavor and texture dimensions. Intermediate samples T2-T3 exhibited balanced sensory profiles, positioned centrally in the factor map. The projection of supplementary variables (Fig.e 2(b)) onto the correspondence analysis (CA) factor map revealed meaningful relationships between sensory attributes and consumer acceptance metrics. The "Liking" vector showed strong alignment with Dim 1 (63.02 % of variance), indicating that this primary dimension effectively captures hedonic preferences. The 23.89 % variance explained by Dim 2 appears less influential on acceptance measures, reinforcing that major preference drivers are captured by the primary dimension. This pattern persists despite the known age-related sensory declines, as evidenced by the consistently high liking scores (~7/9) across all formulations. The minimal separation between "Liking" and "Purchase Intention" vectors ($r = 0.89$, $p < 0.01$) further confirms that sensory perception directly translates to commercial potential in this demographic, providing valuable guidance for product development targeting senior nutrition markets. Notably, all formulations maintained comparable acceptability (liking ~7/9; purchase intention ~4/5; $p > 0.05$), suggesting that while perceptible differences existed, none negatively impacted overall preference (Fig. 2(c)). These findings have important implications for geriatric food development: the texture and flavor perception enable targeted optimization of either of sample without compromising acceptability. Specifically, T4′s texture-driven profile may benefit dysphagia management, while T1′s flavor dominance could enhance compliance in nutrient-fortified products. The maintained purchase intention across variants (despite textural extremes) confirms market viability for specialized senior nutrition products, supporting the development of product lines tailored to varying physiological needs while ensuring broad consumer acceptance.

Despite the high explained variance (86.9 %), suggesting robust discrimination of sensory attributes, the cognitive complexity of evaluating multiple descriptors simultaneously may have exceeded the working memory capacity of some participants. This may explain why only the most salient textural attributes (e.g., "thick," "gummy") reached statistical significance, while more subtle flavor differences went undetected, an outcome consistent with previous findings indicating reduced attribute discrimination in older adults (Forsberg et al., 2022). Furthermore, the dual task of selecting sensory terms and evaluating purchase intention may have introduced additional cognitive load, potentially reflected in the central clustering of "Liking" and "Purchase Intention" near the origin in the CA plot, possibly indicating

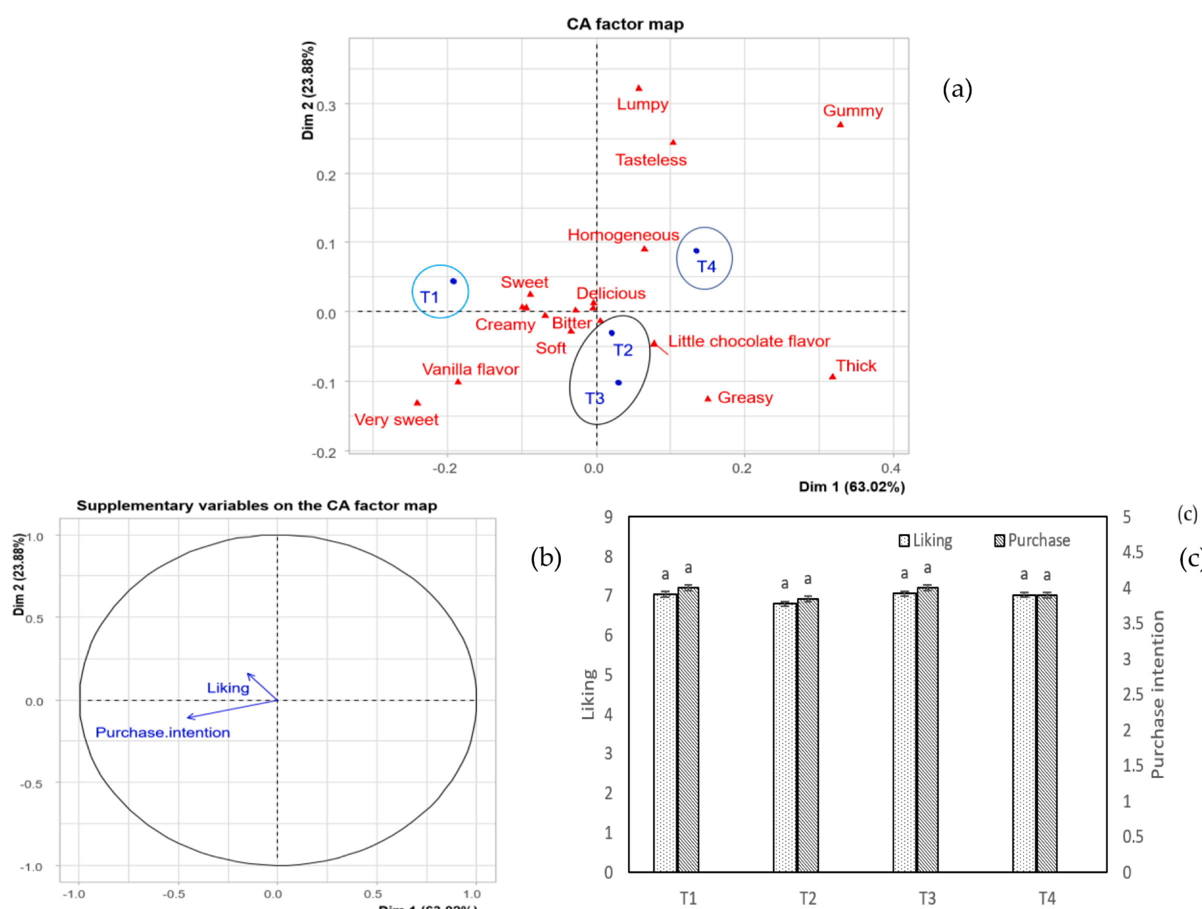


**Fig. 2.** Sensory response of older adults: (a) Sensory map of samples and attributes, (b) supplementary data, and (c) hedonic scale of acceptability and purchase intention of the pudding-type dessert ([a,b] different letters indicate significant differences ($p > 0.05$)).

task-related difficulty rather than true neutrality. While the method successfully identified relevant texture differences (attributes more easily perceived by older adults) the uniformly high liking scores across samples could reflect either genuine broad acceptability, reduced sensory acuity due to aging, or method-induced fatigue. Additionally, although CA showed good alignment between dimensions and supplementary variables, the 23.89 % variance explained by Dimension 2 may partially represent cognitive noise rather than meaningful sensory structure. These observations highlight the need for future research using simplified methods such as paired comparisons, cognitive screening of participants, shorter sessions with breaks, or the inclusion of physiological validation tools. Overall, while the method captured the primary sensory dimensions effectively, its use may have limited the detection of more nuanced attributes in this age group, suggesting the value of adapting sensory methodologies to better align with the cognitive capabilities of older consumers.

## 4. Conclusions

A pudding-like dessert was developed with sensory and nutritional characteristics suitable for older adults. Physicochemical analyses revealed significant differences between samples, with the T4 (4 % Isinglass) formulation standing out for its higher protein content and digestibility, positioning it as a nutritionally favorable option. Sensory evaluations using the CATA method identified key attributes such as homogeneity, chewiness, and chocolate flavor as factors influencing product perception, although no significant differences were observed in overall liking or purchase intent among samples. This suggests that all formulations were well received, highlighting the importance of adapting soft textures and balanced flavors to the preferences and needs of older adults. The results demonstrate the feasibility of designing functional food products that combine sensory appeal and nutritional benefits, thus contributing to improving the quality of life of this population. Future research could explore the incorporation of other functional ingredients and evaluate the long-term impact of these products on the health and well-being of older adults.

## Ethical declaration - studies in humans and animals

All procedures followed ethical standards to ensure participants' rights, privacy, and safety. Written informed consent was obtained prior to participation, which was voluntary and could be withdrawn at any time. All samples were safe for consumption and handled under appropriate hygienic conditions.

## CRediT authorship contribution statement

**Reynaldo J. Silva-Paz:** Writing – original draft, Investigation, Conceptualization. **Yolanda M. Eguilas-Caushi:** Resources, Investigation, Data curation, Conceptualization. **Cecilia M. Mejia-Domiguez:** Resources, Methodology, Investigation. **Amparo Ecco**ñ**a-Sota:** Methodology, Data curation, Conceptualization. **Thalia A. Rivera-Ashqui:** Resources, Investigation, Formal analysis, Data curation. **Nicodemo C. Jamanca-Gonzales:** Writing – review & editing, Project administration, Methodology, Investigation, Conceptualization.

## Declaration of competing interest

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

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2025.101378.

## Data availability

Data will be made available on request.

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