LWT - Food Science and Technology 163 (2022) 113522

Contents lists available at ScienceDirect

LWT

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

Influence of pork backfat replacement by microencapsulated fish oil on physicochemical, rheological, nutritional, and sensory features of pork liver pâtés

Márcio Vargas-Ramella [a,b], José M. Lorenzo [b,c,*], Sol Zamuz [b], Leticia Montes [d], Eva María Santos López [e], Ramón Moreira [d], Daniel Franco [b,**]

[a] *Centro de Educação Superior da Região Sul - CERES da Universidade do Estado de Santa Catarina, Laguna, Santa Catarina, 88.790-000, Brazil*
[b] *Centro Tecnológico de la Carne de Galicia, Avd. Galicia N° 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900, Ourense, Spain*
[c] *Universidade de Vigo, Área de Tecnología de los Alimentos, Facultad de Ciencias de Ourense, 32004, Ourense, Spain*
[d] *Department of Chemical Engineering, Universidade de Santiago de Compostela, rúa Lope Gómez de Marzoa, s/n., 15782, Santiago de Compostela, Spain*
[e] *Área Académica de Química, Universidad Autónoma del Estado de Hidalgo, Ctra, Pachuca-Tulancingo Km 4.5 s/n, Col. Carboneras, Mineral de la Reforma, 42183, Hidalgo, Mexico*

A R T I C L E I N F O

Keywords:
Healthy pâté
Physicochemical composition
Rheological characterization
Fish oil
Microencapsulation
Sensorial analysis

A B S T R A C T

The present work aimed to evaluate the effect of partial pork backfat replacement by microencapsulated fish oil (FO) on rheological characteristics, nutritional features (proximate composition and fatty acid profile), physicochemical parameters (pH, colour, and texture), and sensory quality (descriptive analysis and hedonic study) of pork liver pâtés. Three different batches were elaborated: (i) control (CON) with 100% of pork backfat, (ii) FO25 with 75% of pork backfat and 25% of FO, and (iii) FO50 with 50% of pork backfat. The rheological properties were modified showing fewer stable structures, and lower firmness and viscous characteristics on samples with FO. The fat replacement was accompanied by an increase ($P < 0.01$) in moisture, ash, and cholesterol (FO > CON), and a decrease ($P < 0.001$) in fat (FO50 < FO25 < CON) contents. The fatty acid profile of pâtés with FO changed, decreasing ($P < 0.001$) the total amount of saturated fatty acids (FO50 < CON, FO25) and monounsaturated fatty acids (FO50 < FO25 < CON) and increasing ($P < 0.001$) polyunsaturated fatty acids (FO50 > FO25 > CON). In relation to the physicochemical traits, the incorporation of FO caused a significant ($P < 0.001$) change on redness (FO25 > FO50 > CON) and yellowness (FO25 < CON, FO50). In addition, concerning textural parameters, lower ($P < 0.001$) hardness, gumminess, and chewiness were observed in reformulated pâtés. Descriptive analysis showed significant ($P < 0.05$) difference only for fish flavour attribute, meanwhile the consumers score for overall liking and preference did not display significant ($P \geq 0.05$) differences among pâtés.

1. Introduction

In the last years, traditional meat-based products were the target of the food industry for innovation and improved products development. This trend is consistent with recent concerns about the consumption of these products due to their high saturated fat content, which is linked with disorders such as heart, diseases, cancers and obesity (Bis-Souza et al., 2019; Martins et al., 2020). The meat industry is paying attention to those strategies that aim to change the fat source to promote healthier dietary intake (Paglarini et al., 2022). To this purpose, fish oil (FOL) is an interesting alternative to be utilized for meat reformulation by fat replacement. FOL is a rich source of polyunsaturated fatty acids (PUFA), particularly long-chain n-3 PUFA, which have health-promoting functions for the cardiovascular, neurological, and immunological systems (Ramos et al., 2021).

However, the inclusion of seafood oils in food formulas represents a challenge because of their inherent fishy flavour and chemical composition. Indeed, strategies to elaborate healthy food that implies the substitution of animal fat by FOL could influence the product quality and consumer acceptability (Vasile et al., 2019). In addition, due to their fatty acid profile, FOL is not suitable for direct incorporation into foodstuffs because of their high susceptibility to oxidation, which leads

* Corresponding author. Centro Tecnológico de la Carne de Galicia, Avd. Galicia N° 4, Parque Tecnológico de Galicia, San Cibrao das Viñas, 32900, Ourense, Spain.
** Corresponding author.
E-mail addresses: jmlorenzo@ceteca.net (J.M. Lorenzo), danielfranco@ceteca.net, danielfranco@ceteca.net (D. Franco).

https://doi.org/10.1016/j.lwt.2022.113522
Received 8 February 2022; Received in revised form 29 March 2022; Accepted 30 April 2022
Available online 4 May 2022
0023-6438/

to undesirable effects on flavour, functional properties, and shelf-life of the product (Di Giorgio et al., 2022). Furthermore, due to the technological fat properties in pâtés, its partial or total replacement frequently result in a final product with unpleasant organoleptic properties such as unpleasant taste, rubbery appearance and dry texture (Rezler et al., 2021).

To overtake these issues, new strategies should be tested. In this sense, microencapsulation is a suitable technology to improve food product storage (*i. e.*, increasing the oil oxidative stability) and consumer acceptability (Solomando et al., 2021).

The pâté consists of minced liver, fat (*e.g.*, pork backfat), meat mixed with water and additives followed by thermal treatment (Pateiro et al., 2014). However, despite the pâté being a popular food in many countries, its components, specially backfat, provide a caloric product with high saturated fatty acids (SFA). Consequently, these types of products are questioned by government agencies and consumers (Domínguez et al., 2017). Therefore, with the purpose to encourage the consumption of this traditional product, the lipid profile improvement (lower SFA and high proportion of PUFA) of pâté emerged as a promising approach to obtain a healthier product.

Thus, considering above mentioned perspectives, the present study aimed to evaluate the effect of pork backfat replacement by FO on rheological characteristics, physicochemical parameters, nutritional features, and sensorial properties of the pork liver pâté. From previous studies, we hypothesise that animal fat replacement by FO could be an interesting strategy to enhance the healthy lipid fraction of pâtés obtaining a higher long fatty n-3 fraction and a lower n-6/n-3 ratio. In addition, the microencapsulation of FOL could be a method to incorporate it into meat products to avoid sensory quality loss compared to previous studies where the free FOL was directly incorporated.

2. Materials and methods

2.1. Microencapsulation of fish oil

The FOL was supplied by Biomega Natural Nutrients S.L. (Boiro, Spain) from fish liver. Afterwards, FOL was microencapsulated according to (Calvo et al., 2010) with modifications. Firstly, a stable emulsion (100 g of lactose and sodium caseinate in a ratio 1:1, dissolved in 400 mL of distilled water) was prepared. This emulsion was dispersed with an ultra-Turrax (12000 rpm; 10 min). Then, 50 g of FOL and 250 mL of distilled water were mixed under continuous agitation until a homogeneous emulsion was obtained. Finally, to obtain the FO, the emulsion was dried in a mini spray-dryer (B-290, Buchi, Meierseggstrasse, Switzerland). The operation conditions were as follow: feed rate set at 30% (9 mL/min), inlet temperature was 145 °C ± 2 °C and the aspirator was adjusted at 80% (32 m^3/h). The average microencapsulation yield of 77.04 ± 1.80% was obtained. Finally, the powders obtained were stored under vacuum conditions (V900, Tecsaclor, S.L., Spain) until the pâté elaboration. The morphological aspects of the microparticles produced by the microencapsulation were observed using a scanning electron microscope (Fesem ultra plus with EDX, Zeiss, Oberkochen, Germany) at an accelerating voltage of 3 kV, to confirm the protection and retention of the encapsulated FOL (Fig. 1). To obtain these parameters samples were sputtered with iridium using a vacuum metallizer/-shader model Q150T S (Quorum Technologies Lewes, UK) with a thick layer of 5–10 nm was deposited. Samples micrographs were obtained using a scanning electron microscope (Zeiss FESEM GEMINI500 with EDX, Zeiss, Germany) at 3 Kv using a SE/InLens secondary electron detector.

2.2. Elaboration of pâté

Three different batches (30 units, 10 per batch) of pork liver pâté were formulated in the pilot plant of the Meat Technology Centre of Galicia. For the control batch (CON) elaboration, 100% of pork backfat was used as a fat source. In the other two batches, 25% (FO25) and 50% (FO50) of pork backfat were replaced by FO. Except for the fat source, the same ingredients were used in all batches: 20% of lean pork meat, 30% of fat source (CON: 100% of pork backfat; FO25: 75% of pork backfat and 25% of FO; and FO50: 50% of pork backfat and 50% of FO), 33% of pork liver, 11.5% of water, 2% of sodium chloride, 2% of milk powder, 1% of sodium caseinate, 0.5% of sodium phosphate, 0.015% of sodium nitrite, and 0.025% of sodium ascorbate. Before the pâté manufacture the cholesterol concentration (mg/100 g), the fatty acid profile (% of the area), and the lipid oxidation measured by TBARS index (mg MDA/kg) were assessed for the pork backfat, the FOL and the FO. In addition, the fat content of the FO was also assessed (Table 1). To determinate this information, the same analytical procedures described in sections 2.3 and 2.4 for pâté samples were employed.

To elaborate the liver pâté, the main ingredients (lean, pork backfat, and liver) were previously chopped and scalded at 80 °C for 30 min. After cooled, they were mixed with the remaining ingredients according to each batch. Finally, the mixture was canned, cooked by immersion in a hot water bath (100 °C for 8 min from reaching this temperature in the core) and allowed to cool at −21 °C for 30 min. Samples were stored at 4 ± 1 °C for 2 days until all analyses were started. The elaboration was replicated in August and September of 2021 and five cans from each treatment were analysed (Fig. 2).

2.3. Rheological characterization of the pâtés

The rheological characterisation of the samples was performed with a stress-controlled rheometer (MCR 301; Anton Paar Physica, Graz, Austria) equipped with a Peltier heating system (±0.01 °C). For the analysis, the sample perimeter was covered with a thin layer of silicone to avoid water evaporation. In addition, samples were allowed to rest for 15 min before analysis to ensure both thermal and mechanical

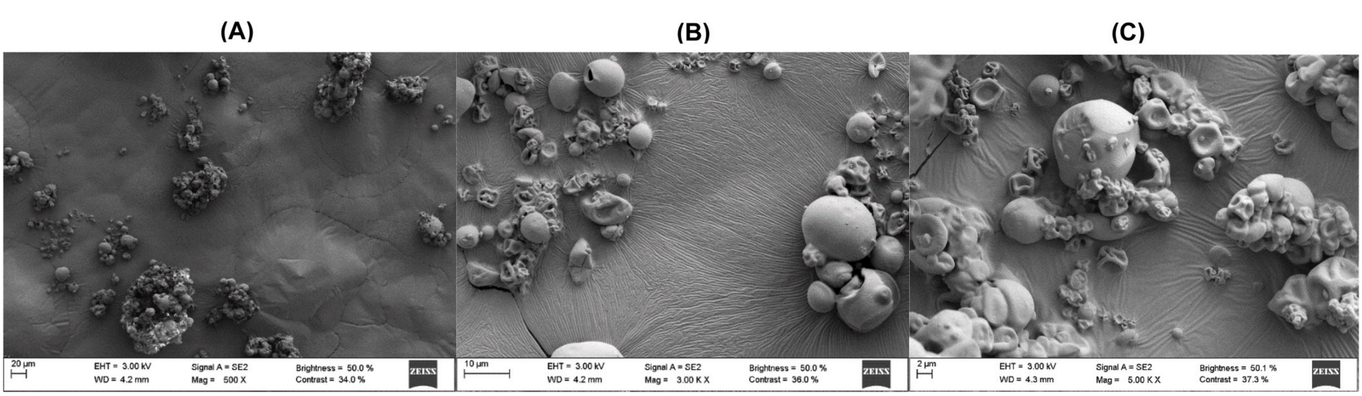

Fig. 1. Scanning Electron Microscope micrographs showing the fish oil microparticles; (A): 20 µm, (B): 10 µm, and (C): 2 µm.

Table 1
Characterization of pork backfat, fish oil, and microencapsulated fish oil.

Parameters	Pork backfat	Fish oil	Microencapsulated fish oil
Fat content (%)	–	–	26.13 ± 0.29
Cholesterol (mg/100 g)	47.12 ± 3.73	319.07 ± 14.08	144.88 ± 0.41
Fatty acid profile (% area)			
C12:0	0.09 ± 0.00	0.07 ± 0.00	0.10 ± 0.00
C14:0	1.75 ± 0.02	3.63 ± 0.02	4.00 ± 0.02
C15:0	0.05 ± 0.00	0.50 ± 0.00	0.56 ± 0.00
C16:0	26.24 ± 0.09	15.45 ± 0.24	17.71 ± 0.08
C16:1n-7	3.29 ± 0.08	5.94 ± 0.01	5.82 ± 0.03
C17:0	0.27 ± 0.00	0.70 ± 0.00	0.74 ± 0.00
C18:0	10.88 ± 0.09	3.31 ± 0.07	3.65 ± 0.02
9t-C18:1	0.19 ± 0.01	0.09 ± 0.00	0.17 ± 0.00
11t-C18:1	0.13 ± 0.00	1.89 ± 0.02	1.81 ± 0.06
C18:1n-9	43.16 ± 0.03	18.60 ± 0.06	18.40 ± 0.01
C18:1n-7	3.77 ± 0.01	3.90 ± 0.03	3.72 ± 0.01
C18:2n-6	7.29 ± 0.04	1.33 ± 0.01	1.45 ± 0.00
C18:3n-3	0.47 ± 0.00	0.57 ± 0.00	0.53 ± 0.01
C20:0	0.21 ± 0.01	0.16 ± 0.01	0.15 ± 0.00
C20:1n-9	1.13 ± 0.03	9.86 ± 0.55	9.72 ± 0.00
C20:2n-6	0.46 ± 0.00	0.61 ± 0.01	0.58 ± 0.01
C20:4n-6	0.13 ± 0.00	1.15 ± 0.00	1.08 ± 0.00
C20:5n-3	0.03 ± 0.00	5.86 ± 0.01	5.73 ± 0.03
C22:5n-3	0.05 ± 0.01	2.35 ± 0.01	2.14 ± 0.07
C22:6n-3	0.02 ± 0.00	21.15 ± 0.09	19.35 ± 0.09
SFA	39.60 ± 0.02	23.97 ± 0.31	27.15 ± 0.08
MUFA	51.72 ± 0.02	42.52 ± 0.45	41.51 ± 0.02
PUFA	8.68 ± 0.04	33.51 ± 0.14	31.34 ± 0.06
n-3	0.68 ± 0.01	30.14 ± 0.12	27.95 ± 0.05
n-6	8.01 ± 0.05	3.37 ± 0.01	3.39 ± 0.02
TBARs (mg MDA/Kg)	0.09 ± 0.05	0.14 ± 0.05	0.67 ± 0.06

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.

equilibrium. All tests done were performed in triplicate.

2.3.1. Small amplitude oscillatory shear (SAOS) tests

A plate-plate geometry with 25 mm of diameter and a gap of 1 mm was employed for SAOS measures. Strain sweeps were carried out to determine the linear viscoelastic region (LVR) from 0.01 to 1% of strain at a constant frequency (0.1 Hz) and temperature (22 °C). Then, frequency sweeps were carried out from 0.1 to 10 Hz at constant strain (0.1%) and temperature (22 °C) inside LVR. Temperature sweeps were made from 20 to 90 °C at constant strain (0.1%) frequency (0.1 Hz) to determine thermal behaviour of samples.

Finally, values of complex modulus [G* (Pa)] evaluated from G´and G´ data obtained through angular frequency (ω, Hz) sweep tests were correlated following a power law (Gabriele et al., 2001), Eq (1):

$$G^{*} = \sqrt{(G')^{2} + (G'')^{2}} \quad (1)$$

where A (G* at 1 Hz) is the proportional coefficient and evaluates the strength of the interaction between units and z (–) is the coordination number, which measures the number of rheological units with one another in the 3-D structure.

2.3.2. Steady shear tests

For steady shear analysis, a Couette geometry (CC24-SN40990) bob radius of 12 mm and a gap of 1 mm was utilized. The viscometric rebuild analysis was carried out to study the sample recovery following a protocol previously proposed by Alvarez et al. (2017). Three steps at constant shear rates for 3 min at constant temperature (22 °C) were used. First, a constant shear rate of 0.1 s^{-1} was implemented to obtain the viscosity values of the sample at rest. Then, a shear rate of 100 s^{-1} was used to break down the sample structure and, finally, a constant shear rate of 0.1 s^{-1} was employed to observe the sample recovery. The ratio of initial (μ_0) and final (μ_f) apparent viscosities were evaluated as the last data measured during the first step and the first data of the third step, respectively, to evaluate the recovery of the samples.

2.4. Physicochemical parameters of the pâtés

The pH of the pâtés was evaluated with a digital portable pH-meter equipped with a penetration probe (HI 99163, Hanna Instruments, Eibar, Spain). To estimate the colour of the samples in the CIELAB space (Lightness – L*, redness – a*, and yellowness – b*) a portable spectrophotometer (Konica Minolta CM-600d, Osaka, Japan) with the following settings (pulsed xenon arc lamp, D65 illuminant, 10° viewing angle geometry, and 8 mm aperture size) was utilized. For each can, the colour measurement was performed in triplicate. A texture analyser TA-XT plus (Stable Micro Systems, Godalming, UK) at room temperature (22 °C) was used to assess the texture traits. The texture parameters were obtained with a 6 mm diameter penetration probe using a 5 kg cell at a velocity of 0.8 mm/s and a distance of 8 mm. Parameters of hardness (N), adhesiveness (N s), springiness (mm), cohesiveness, gumminess (N) and chewiness (N mm) were assessed using the software Texture Exponent 32, version 1.0.0.68 (Stable Micro Systems, Godalming, UK). All tests were carried out in triplicate.

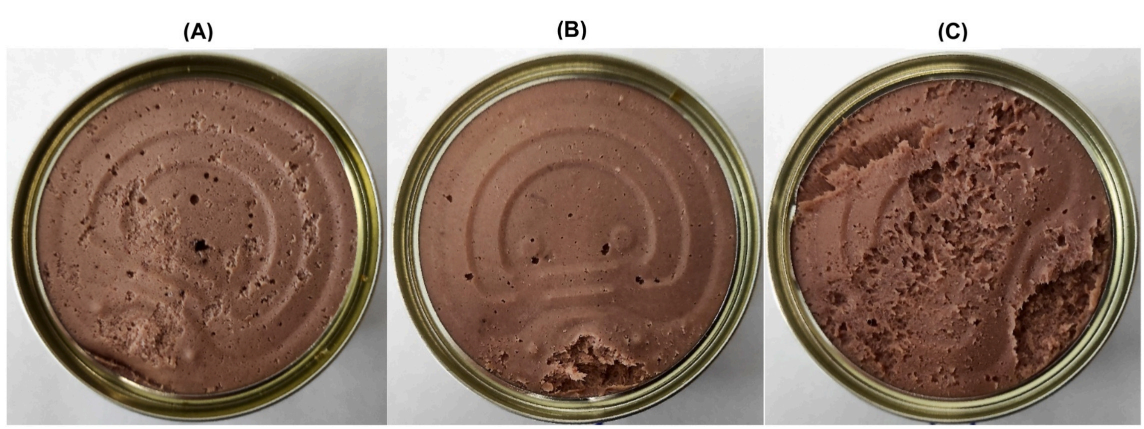

Fig. 2. Appearance of the pâtés manufactured with pork backfat and microencapsulated fish oil; (A) CON with 100% of pork backfat, (B) FO25 with 75% of pork backfat and 25% of FO, and (C) FO50: 50% of pork backfat and 50% of FO.

2.5. Lipid oxidation parameters of the pâtés

Lipid oxidation was assessed through the development of thiobarbituric acid reactive substances (TBARs) following the procedure described by Vyncke (1975). The TBARs values were expressed as an mg MDA/kg pâté.

2.6. Nutritional properties: chemical composition and fatty acids profile

Moisture, fat, protein, ash, and total cholesterol were assessed according to the methodology of Pateiro et al. (2013). The determination of carbohydrates was carried out by difference according to FAO/WHO recommendations, based on the results obtained for fat (F), ash (A), protein (P) and moisture (M), hence: carbohydrates (%) = 100 - (F + A + P + M) (FAO/WHO, 1997). On the other hand, the energy value of pâtés was obtained by adding the energy values of the protein, carbohydrates and fat of each sample. For this, conversion factors (4 kcal/g for proteins and carbohydrates; 9 kcal/g for fat) were used according to the Atwater numbers (FAO/WHO, 2005).

For fatty acid analysis total fat was extracted from 10 g of pâté, employing 20 mL of methanol and 10 mL of chloroform in a vortex for 30 s. Then, a solution composed of 10 mL of chloroform and 10 mL of NaCl 1% was added and homogenized for 30 s. Afterwards, the chloroform phase was separated from the aqueous phase by centrifugation (4000 rpm for 10 min) and the chloroform was evaporated using N_2 gas. The fatty acids were transesterified, extracted, and analysed by GC-FID (Barros et al., 2020) using a GC (GC-Agilent 7890B, Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector (FID) and PAL RTC-120 autosampler and a DB-23 fused silica capillary column (60 m, 0.25 mm i.d., 0.25 μm film thickness; Agilent Technologies). Results were expressed as a percentage of area.

2.7. Sensory analysis

The sensory analysis aimed to determine the intensities of the attributes that could be influenced by the pâtés reformulation as well the acceptability and preference of consumers to the replaced pâtés. The sensory evaluation (descriptive and hedonic analysis) of the pâtés was conducted in the sensory laboratory of the Meat Technology Centre of Galicia. The sensory analysis was realized in individual cabins under normalized white light (ISO 8589:2010/A1:2014 regulation; ISO, 2014). The samples were maintained at room temperature 1 h before the panellist's evaluation. Samples were presented to the taster in disposable plastic dishes with a 3-digit random number to the identification (Macfie et al., 1989). Unsalted toasted bread and water were supplied to clean the palate and remove residual flavours at the beginning of sessions and among samples.

2.7.1. Descriptive analysis: quantitative descriptive analysis (QDA)

Several publications that have studied FO inclusion on meat products have applied QDA and hedonic techniques to evaluate their sensory quality (Pérez-Palacios et al., 2018; Solomando et al., 2021). For this reason, a quantitative descriptive analysis (QDA) was carried out with a trained panel constituted by 8 panellists (4 females and 4 males) selected from the staff of CTC. Training sessions were held for 3 days a week for 2 weeks, and each training session lasted approximately 1 h. The panellists evaluated the intensities of seven attributes that could be influenced by the partial pork fat replacement by FO (spreadability, graininess, adhesiveness, gumminess, fatty character, liver flavour, and fish flavour). The intensity of each attribute was rated using a lineal structured scale from 0 (minimum attribute intensity) to 10 (maximum attribute intensity). The sensory analysis was done in three sessions in which each panellist evaluated the 3 samples (one per batch). The samples were served following a balanced block complete randomized to minimize carry-over effects.

2.7.2. Hedonic study

The hedonic study was realized with 96 consumers (52 females and 44 males aged from 25 to 50 years) from Ourense (Spain). Consumers were selected based on their interest to participate and their availability for the evaluation. A trained interviewer, before starting, informed consumers about the objectives of the study and the instructions to complete the tests. Further, consumers read and signed the consent form for the sensory assessment. The acceptance test to determine the overall liking was realized to evaluate whether the consumers liked or disliked the pâtés samples. To carry out the test a 7-point hedonic scale (1 = dislike very much and 7 = like very much) was applied (Meilgaard, 2007). In addition, simultaneously with the acceptance test, a preference test was realized using a score from 1 point (less favourite) to 3 points (more favourite).

2.8. Statistical analysis

A total of 60 pâté cans were utilized in the present experiment for the rheological characterization, physicochemical parameters, lipid oxidation, nutritional properties, and sensory analysis: 10 units per treatment x 3 batches x 2 manufacture process (replicates). The pâtés manufacture was replicated in two different months. Values from rheological characterization, nutritional properties, physicochemical parameters, intensity of sensory attributes and global acceptance were evaluated using an analysis of variance (ANOVA) with the mixed model. Data from rheological, nutritional, and physicochemical parameters were introduced in the model as dependent variables while fat source as fixed effect and manufacture process as random effect. Except for global acceptance in which the Tukey test was used, the pairwise differences between least squares means (LSM) were evaluated by Duncan's test for all parameters. Differences were considered significant at $P < 0.05$.

Concerning sensory analysis, a Friedman two-way ANOVA was performed with samples and tasters introduced as independent variables to analyse the preference test results. When a significant effect ($P < 0.05$) was observed a least significant difference (LSD) was employed as a multiple comparison test. Correlation analyses among rheological behaviour, nutritional properties, physicochemical parameters, and sensorial attribute intensity values ($P < 0.05$) were determined using Pearson's linear correlation coefficient. Moreover, partial least-squares regression (PLS-R) was conducted to assess the relationship between consumer acceptability and descriptive attributes, rheological and texture parameters and fat content, using the physicochemical, rheological and descriptive ratings as dependent variables (X data set) and the mean values of the consumer overall liking as explanatory variables (Y data set) (Yang & Lee, 2020).

Statistical analysis of nutritional properties and physicochemical parameters were performed using IBM SPSS Statistics for Windows (version 23.0. IBM Corp., New York, NY, USA). The XLSTAT-Sensory version 2018.5.52745 (Addinsoft SARL, Paris, France) software was used to determine all the sensory analysis results and correlations.

3. Results and discussion

3.1. Rheological behaviour of pâtés

3.1.1. Oscillatory tests/Small amplitude oscillatory shear (SAOS) tests

Fig. 3A shows the mechanical spectra (frequency sweep tests) that were obtained for all samples studied. Elastic modulus (G) and viscous modulus (G) were analysed in the range from 0.1 to 10 Hz at a constant strain (0.1%) and temperature (22 °C) within the LVR (data not shown). In all ranges, elastic prevailed over the viscous character (G' > G), which indicated that pâtés had a solid-like behaviour. Both moduli, clearly increased with increasing frequency, suggesting that a non-structured matrix is present independently of FO addition. On the other hand, both moduli decreased with the substitution of the pork backfat by FO. For instance, the CON sample showed a value of G' (at 1 Hz) of 50 kPa,

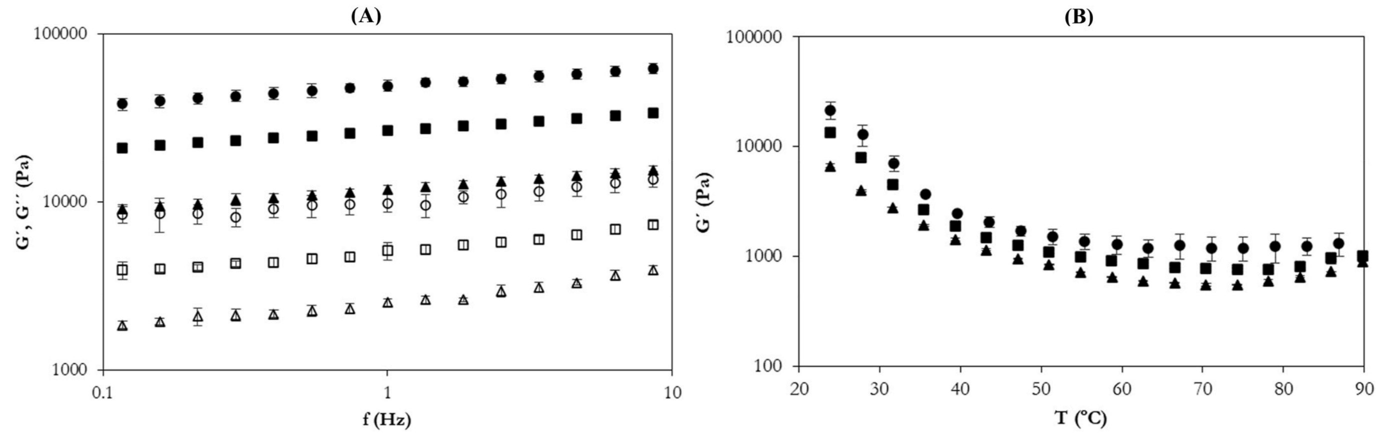

Fig. 3. (A) Frequency sweep tests (0.1% and 22 °C) G' (filled markers) and G´ (hollow markers) of samples: CON (●, ○), FO25 (■, □), and FO50 (▲, Δ). (B) Temperature sweep from 20 to 90 °C (0.1% and 0.1 Hz) for CON (●), FO25 (■) and FO50 (▲). CON: 100% of pork backfat; FO25: 75% of pork backfat and 25% of FO; FO50: 50% of pork backfat and 50% of FO.

while the corresponding values for FO25 and FO50 were 27 and 12 kPa, respectively.

To study the effect of the FO addition in the samples, the slope of both moduli was analysed. Table 2 summarizes the slope of G´ and G´ during the frequency sweep. G´ slope values varied in a narrow range (from 0.11 to 0.12). Comparing treatments, significant ($P < 0.05$) differences in G´ were found only in samples with the maximum content of FO (CON, FO25 < FO50). Otherwise, G´ slope values varied in a wider range (from 0.12 to 0.17) with significant ($P < 0.05$) differences between CON and FO samples (CON < FO25, FO50). The increase of the G´ slopes regarding G´ slopes indicated that some fewer stable structures were promoted by FO addition.

The tan δ (G/G) was practically constant for CON (from 0.19 to 0.22) and increased slightly for FO25 and F050 samples (from 0.20 to 0.24) with the frequency. These results revealed that both firmness and viscous characters of pâtés varied with FO addition with a constant viscoelastic relation (characteristic of viscoelastic solids). Our results disagreed with Rezler et al. (2021) who found G´ values (at 1.2 Hz and 20 °C) much lower (~5000 Pa) for control compared to alternative formulations with modified starch. In addition, the authors also reported that the partial substitution of the pork fat by starch in pâtés caused a loss of elasticity of over 50% and an increased tan δ from ~0.5 to ~1. The values obtained by the aforementioned researchers are more characteristic to creams than pâtés. However, it is important to highlight those authors utilized a lower pork liver content (14.6%) compared to the present study. On the other hand, our data partially agreed with Delgado-Pando et al. (2012) who studied the behaviour of the low-fat (15%) pork liver pâtés (pork liver content of 33%) replaced by oil-in-water emulsion. The authors obtained G´ values of 37.5 kPa (at 0.1 Hz and 25 °C) in a similar range that those obtained in the current research. However, the G´ values of samples obtained by authors in pâtés with partial fat replacement (39.95 kPa) and total fat replacement (33.47 kPa) were higher than the present study.

The complex modulus of all tested systems was successfully fitted ($R^2 > 0.98$) to Eq. (1) (section 2.3.1) and values of parameters are reported in Table 2. The greatest value of A (50.20 kPa) corresponded to the CON pâtés, decreasing linearly up to 12 kPa for FO50. Indeed, a linear correlation was found between the amount of pork backfat replaced and the value of parameter A ($R^2 > 0.98$). Similar results were found by Delgado-Pando et al. (2012) who studied the total substitution of pork backfat in pâtés by the oil-in-water emulsion. Concerning z values varied in a narrow interval (from 9.0 to 7.9) decreasing with the highest FO addition. These results suggested that FO substitution could affect in greater relevance the strength of the structural interactions regarding the number of unions developed.

Fig. 3B shows temperature sweeps (evolution of G) from 22 to 90 °C. Within temperature range studied G´ was higher than the G´ (data not shown). CON samples showed the higher G´ values in whole temperature range. All samples showed a drastic decrease in G´ for the temperature range from 22 to 45 °C. According to Ospina-E et al. (2010), this result could be linked to the melting of the pork fat which is found in a solid state when maintained at room temperature. Nevertheless, different thermal behaviour at high temperatures was observed. CON samples achieved a stationary value of G´ above 60 °C and samples with FO showed a minimum value in the interval from 75 to 80 °C, clearer with the FO replacement increase. Kawecki et al. (2021) previously reported that the rheological properties can be affected by heating according intensity as well as Rezler et al. (2021) attributed this behaviour to the formation of a stiffer elastic matrix structure by the apparition of thermally promoted protein aggregates. Our results allow us to hypothesise that FO replacement promoted this thermal process and showed the convenience of these pâtés to be used at room temperature and non-thermally treated.

Table 2
Effect of fat replacement by microencapsulated fish oils on rheological, physicochemical and oxidative parameters of pâté.

Parameters	CON	FO25	FO50	SEM	P-value
Rheological [a]					
Slope G´	0.111 [b]	0.109 [b]	0.124 [a]	0.006	0.015
Slope G´	0.118 [b]	0.144 [a]	0.167 [a]	0.008	0.006
A (KPa)	50.20 [a]	27.14 [b]	12.16 [c]	5.571	<0.001
z	8.99 [a]	9.04 [a]	7.93 [b]	0.200	0.009
Physicochemical					
pH	5.87 [b]	5.80 [c]	5.91 [a]	0.013	<0.001
L*	57.98	58.02	57.96	0.120	0.979
a*	10.36 [c]	11.27 [a]	10.86 [b]	0.110	<0.001
b*	19.17 [a]	17.74 [b]	19.58 [a]	0.233	<0.001
Hardness (N)	0.39 [a]	0.31 [b]	0.32 [b]	0.011	0.001
Adhesiveness (N s)	−1.73 [b]	−1.24 [a]	−1.44 [a]	0.066	0.003
Springiness (mm)	0.98 [a]	0.98 [a]	0.97 [b]	0.002	0.004
Cohesiveness	0.63	0.62	0.64	0.006	0.287
Gumminess (N)	0.25 [a]	0.19 [b]	0.20 [b]	0.007	<0.001
Chewiness (N mm)	0.24 [a]	0.19 [b]	0.20 [b]	0.007	<0.001
Oxidative					
TBARs (mg MDA/Kg sample)	0.50	0.49	0.51	0.013	0.821

[a-c] Mean values in the same row (corresponding to the same parameter) with different letter differ significantly (P < 0.05; Duncan test); SEM: Standard error of the mean.

[a] Slopes values from mechanical spectrum (0.1–10 Hz) at 0.1% and 22 °C for G´ and G´ and values of Eq. (1) parameters.

3.1.2. Steady shear tests

According to the steady shear tests assays, at the beginning of each stage at a constant shear rate, a decrease in viscosity was observed indicating the thixotropic behaviour of the samples. CON samples displayed higher viscosity at rest than FO25 and FO50, which could be related to its high firmness. In addition, the ratio of initial (μ_0) and final (μ_f) apparent viscosities was useful to evaluate the recovery of the samples. CON samples achieved the higher recovery in the value of μ_f/μ_0 (0.41 ± 0.02) and this ratio decreased significantly ($P < 0.05$) with increasing pork backfat replacement by FO (0.35 ± 0.08 and 0.31 ± 0.03, for FO25 and FO50, respectively). Lastly, a linear correlation was found between the amount of fat replaced and μ_f/μ_0 ratio ($R^2 > 0.97$). These results indicated that the substitution of pork backfat by FO disfavoured the sample recovery and agreed with the predominance of the elastic character of the samples and the increase of viscous character with the FO replacement.

3.2. Physicochemical (pH, colour, and texture) parameters of pâtés

Changes in the pH values should be carefully evaluated in the emulsified meat products since if the pH increase it reduces the solubility of proteins moving them away from the isoelectric point. As a result, the hydrophobic interactions between proteins and lipids decrease as well as their fat emulsification ability. In consequence, the protein concentration responsible for forming the matrices that keep the water and fat emulsion is reduced (Rezler et al., 2021). Our results for pH (Table 2) were different from those obtained by Kawecki et al. (2021) who assessed lower pH values in FO sausages. However, in this study, it seems that the pH did not influence the emulsion stability.

Colour parameters of meat products are closely linked to the colour, the amount, and the characteristics of the raw material used in the formulation (Lorenzo & Pateiro, 2013). There were statistical differences among treatments for a* and b* (Table 2), although the numerical values were close. Our results disagree with those previously reported for pâtés with FOL replacement by pork fat (Domínguez et al., 2017) in which authors assessed higher a* and b* values in the reformulated products. A possible explanation for this might that these authors did not microencapsulate the FOL. Indeed, in our study the yellow colour of the FOL did not increase the yellowness of the reformulated pâtés (19.58 *vs.* 19.17, $P > 0.05$, for FO50 and CON, respectively). This finding is encouraging since one of the principal issues reported for the FOL utilization as an ingredient in food reformulation is the sensorial properties implications (*e.g.*, colour modification) in the final product (Domínguez et al., 2017; Vasile et al., 2019).

Despite FO25 presenting the lower pH values (FO25 < CON < FO50), the texture properties displayed a different behaviour, with lower values for hardness, gumminess and chewiness in reformulated pâtés versus CON samples (FO25 and FO50 < CON; Table 2). These textural outcomes in pâtés are coherent with the water-binding features and fat and the protein and fat content effect (Delgado-Pando et al., 2011). The inclusion of FO decreased ($P < 0.01$) all texture parameters excepting adhesiveness and cohesiveness with respect to CON samples, which is in agreement with rheological properties assessed: the decrease of G' (lower A value), the tan δ increase (section 3.1.1) as well the lower apparent viscosity (section 3.1.2). Indeed, relations between rheological (G′ and A) and textural properties (hardness, chewiness and gumminess) have been established using Pearson's correlation. The regression analysis showed a positive correlation of G′ and A (respectively) with hardness (r = 0.925; r = 0.930; $P < 0.01$), gumminess (r = 0.846; r = 0.850; $P < 0.01$), and chewiness (r = 0.902; r = 0.905; $P < 0.01$). The adhesiveness obtained (FO25, FO50 > CON) could be a consequence of the less binding activity provided by the FO caused by mechanical movements that were applied during the grinding process of pâté elaboration (Martins et al., 2020). This fact (loss of meat-binding properties regarding CON samples) would explain the aforementioned textural differences.

Differences among batches observed in the pâtés manufactured with FOL were also reported by previous researchers who found a reduction in the texture parameters when animal fat content was substituted by n-3 PUFA-rich oils (Domínguez et al., 2016; Martin et al., 2008). It is well-known that the fat amount and its properties have a strong effect on the texture traits of meat products (Martins et al., 2020; Rezler et al., 2021). Moreover, encapsulated oil is a dry powder with completely different properties (*i.e.*, consistency) from pork backfat (Vargas-Ramella et al., 2020). Concerning hardness, pâtés with the partial substitution of pork backfat by FO displayed the lower ($P < 0.001$) values (0.31 N and 0.32 N *vs.* 0.39 N, for FO25 and FO50 *vs.* CON, respectively). In addition, similar to hardness, the FO inclusion resulted in a significant ($P < 0.001$) reduction in chewiness and gumminess. The lower results assessed for these parameters were coherent since chewiness and gumminess are linked to hardness (Domínguez et al., 2016).

3.3. Lipid oxidation (TBARS) parameters of pâtés

Microencapsulation can improve oil oxidative stability, especially those rich in n-3 PUFA (with a high content of EPA and DHA) in reformulated meat products as previously reported by several authors (Aquilani et al., 2018; Jiménez-Martín et al., 2016; Josquin et al., 2012; Keenan et al., 2015; Vasile et al., 2019). However, the encapsulation process is performed under conditions of temperature and airflow that could initiate oxidation reactions, that release carbonyl compounds resulting in unpleasant off-flavour in rancid FOL (Ramos et al., 2021). Considering this, TBARS values were assessed in the FOL and the FO before the manufacturing of the pâtés (Table 1) and in the three batches of the pâtés (Table 2). No significant ($P \geq 0.05$) effect was found as a consequence of FO incorporation. This finding is in disagreement with data found in reformulated pâtés (Delgado-Pando et al., 2012; Domínguez et al., 2017; Vargas-Ramella et al., 2020). Differences in microencapsulation conditions (*e.g.*, evaporation temperature, airflow, exposition time, material wall used, etc) and lipid source in terms of susceptibility to the oxidative processes could explain this discrepancy. Indeed, Pateiro et al. (2014) and Vargas-Ramella et al. (2020) noticed that natural antioxidants added into emulsion can avoid oxidative degradation during the pâté elaboration.

In the present study, morphological aspects assessed for the particles resulting from the microencapsulation showed a continuous wall and no apparent fissures. It was found that the microcapsules were spherical with some wrinkle on the surface as observed by a scanning electron microscope. Overall, the small size particle of microcapsules (~10 μm) could raise interparticle adhesion phenoms, because the specific surface is increased. Particles mainly exhibited a concave and shrivelled surface while a few others displayed a rounded external surface and smooth (Fig. 1). This absence of holes in the membrane around the oil droplets is desired to avoid the premature release of oil volatile compounds or facilitate the oxygen permeation leading to oxidative degradations (Ramos et al., 2021). Therefore, a mixed using healthy oils and an adequate microencapsulation technique could be a recommendable option to elaborate healthy meat products without impairing their oxidative stability.

3.4. Nutritional properties of pâtés

3.4.1. Chemical composition: moisture, fat, protein, ash, and cholesterol

The partial substitution of pork backfat by FO showed a significant ($P < 0.01$) impact in all chemical composition parameters of the pâtés (Table 3). This result was expected as reformulation carried a reduction of fat content. In addition, the FO utilized in present study had only 26% of total fat in its composition (Table 1). The increase in protein and ash contents, especially in FO50, was due to the implicit dilution and the wall material composition (lactose and sodium caseinate) employed in the microencapsulation process.

The moisture percentages increased in the reformulated pâtés (52.48

Table 3
Effect of fat replacement by microencapsulated fish oils on chemical composition and fatty acid profile of pâté.

Parameters	CON	FO25	FO50	SEM	P-value
Chemical composition					
Moisture (%)	51.63[b]	52.62[a]	52.33[a]	0.145	0.005
Fat (%)	29.26[a]	28.23[b]	24.24[c]	0.591	<0.001
Protein (%)	14.02[b]	14.29[b]	15.70[a]	0.203	<0.001
Ash (%)	3.07[c]	3.09[b]	3.20[a]	0.017	<0.001
Carbohydrates (%)	2.03[b]	1.77[b]	4.53[a]	0.339	<0.001
Energy (Kcal/100g)	327.50[a]	318.31[b]	299.50[c]	3.301	<0.001
Cholesterol (mg/100g sample)	86.99[c]	96.20[b]	107.91[a]	2.591	<0.001
Fatty acid profile (% area)					
C12:0	0.15[c]	0.16[b]	0.17[a]	0.002	<0.001
C14:0	1.80[c]	1.96[b]	2.26[a]	0.050	<0.001
C15:0	0.07[c]	0.10[b]	0.17[a]	0.011	<0.001
C16:0	25.39[a]	25.21[b]	23.92[c]	0.178	<0.001
C16:1n-7	3.03[c]	3.23[b]	3.51[a]	0.052	<0.001
C17:0	0.29[c]	0.31[b]	0.38[a]	0.011	<0.001
C18:0	11.55[a]	11.45[b]	10.68[c]	0.105	<0.001
9t-C18:1	0.20	0.20	0.19	0.004	0.447
11t-C18:1	0.16[c]	0.22[b]	0.39[a]	0.026	<0.001
C18:1n-9	42.17[a]	39.91[b]	36.58[c]	0.613	<0.001
C18:1n-7	3.71[a]	3.67[b]	3.65[b]	0.009	0.011
C18:2n-6	7.17[a]	6.95[b]	6.21[c]	0.110	<0.001
C18:3n-3	0.44[b]	0.45[b]	0.46[a]	0.003	0.005
C20:0	0.22[a]	0.21[b]	0.20[b]	0.002	0.003
C20:1n-9	1.22[c]	1.63[b]	2.73[a]	0.171	<0.001
C20:2n-6	0.48[b]	0.47[b]	0.50[a]	0.004	0.021
C20:4n-6	0.89[c]	1.14[b]	1.48[a]	0.065	<0.001
C20:5n-3	0.07[c]	0.39[b]	1.11[a]	0.116	<0.001
C22:5n-3	0.15[c]	0.29[b]	0.57[a]	0.047	<0.001
C22:6n-3	0.22[c]	1.29[b]	3.72[a]	0.392	<0.001
SFA	39.69[a]	39.63[a]	38.06[b]	0.203	<0.001
MUFA	50.61[a]	49.08[b]	47.53[c]	0.336	<0.001
PUFA	9.71[c]	11.29[b]	14.41[a]	0.522	<0.001
n-3	1.01[c]	2.54[b]	6.01[a]	0.559	<0.001
n-6	8.70[a]	8.75[a]	8.40[b]	0.042	<0.001
n-6/n3	8.63[a]	3.44[b]	1.40[c]	0.814	<0.001
AI	0.54[a]	0.55[a]	0.53[b]	0.002	0.003
TI	1.19[a]	1.06[b]	0.80[c]	0.043	<0.001
h/H	2.04[b]	2.02[c]	2.09[a]	0.008	<0.001

[a-c] Mean values in the same row (corresponding to the same parameter) with different letter differ significantly ($P < 0.05$; Duncan test); SEM: Standard error of the mean. AI: atherogenic index. TI: thrombogenic index. h/H: ratio hypocholesterolemic/hypercholesterolemic fatty acids.

vs. 51.63; $P < 0.05$). This fact may be attributed to the microencapsulation process and its water incorporation procedure. During the emulsion step, water is mixed with the lactose and sodium caseinate to improve water retention and to obtain a stable FOL emulsion. This finding was also reported previously in microencapsulated oil as a fat replacement in pâtés (Vargas-Ramella et al., 2020). In line with this, previous studies (Estévez et al., 2005) also reported an opposite behaviour between moisture and fat content in reformulated pâtés.

Moisture content in meat-based products as well its fat content relation are important components in the pâté properties from a physicochemical point of view. Indeed, the fat reduction accompanied by an increase in the moisture levels can affect the emulsion matrix (maintained by protein) of products by reducing their water-binding properties (Delgado-Pando et al., 2011). Certainly, the FO addition effect on the water holding capacity and the rheological properties of meat products (sausages) was previously suggested by Kawecki et al. (2021). Despite the beforementioned authors found that FO improved the water-binding properties of the reformulated sausages (lower water activity), in our study these chemical composition factors could explain, in addition to those already discussed the fewer stable structures and strength of structural interactions promoted by the FO addition (section 3.1), the lower texture results assessed in FO pâtés.

A decrease of fat content is positive from a nutritional point of view. On the contrary, the cholesterol content significantly ($P < 0.05$) increased a 24.05% from 86.99 to 107.91 mg 100/g for CON and FO50 samples, respectively. This expected finding, since FOL used was obtained from fish liver and the cholesterol is an inherent compound of this organ, is in agreement with other authors who replaced 50% of pork fat with FOL in pâtés and obtained a value of 115.86 mg 100/g (Domínguez et al., 2017).

3.4.2. Fatty acids profile of pâtés

The substitution of fat by FO modified ($P < 0.05$) the fatty acid (FA) profile of the pâtés (Table 3). In all batches, the main FA for CON, FO25, and FO50 were monounsaturated fatty acids (MUFA), followed by saturated fatty acids (SFA), and polyunsaturated fatty acids (PUFA). Except for 9t-C18:1 (elaidic acid), C18:3n-3 (linolenic acid), and C20:2n-6 (*cis*-11,14-eicosadienoic acid), all individually FAs presented significant ($P < 0.05$) differences between CON and replaced pâtés (FO25 and FO50). Most abundant FA in all batches were: C18:1n-9 (oleic acid) > C16:0 (palmitic acid) > C18:0 (stearic acid) > C18:2n-6 (linoleic acid), with all of them presenting the highest ($P < 0.001$) values in the CON treatment. This profile was expected since previous studies (Delgado-Pando et al., 2011; Martins et al., 2020; Vargas-Ramella et al., 2020) already published a similar profile when pork backfat was utilized as a fat source in pâtés.

Modifications of FA profile in replaced pâté are mainly focused on MUFA and PUFA content. Indeed, the total amount of MUFA in the reformulated pâtés decreased 3.02% for FO25 and 6.09% for FO50, while the PUFA increased 16.27% for FO25 and 48.40% for FO50 in comparison to CON pâtés. Changes are a consequence of the FA profile of the fat sources, especially the n-3 levels of the FO employed (27.95% *vs.* 0.68%, for FO *vs.* pork backfat, respectively; Table 1).

Foods rich in n-3 PUFA [*e.g.*, C20:5 n-3 (eicosapentaenoic acid = EPA) and C22:6 n-3 (docosahexaenoic acid = DHA)] can diminish the cardiovascular diseases risk and prevent some types of inflammatory and neurodegenerative diseases. For this reason, health organizations proposed recommendations for the daily intake of these FA. For example, EFSA and FAO suggest the intake of 0.25 g of EPA + DHA per adult/day (EFSA, 2017; FAO, 2021). EPA and DHA are commonly found as major FA in fish and seafood (Solomando et al., 2021). However, their consumption is not sufficient to obtain the EPA and DHA recommended ingestion. It is notable that in many developed countries the fish consumption is under the recommended, with an intake amount of n-3 PUFA of 0.15 g per person/day (Pérez-Palacios et al., 2019). Thus, an interesting strategy to raise the n-3 PUFA intake by consumers could be the inclusion of FOL in meat-based products such as pâtés.

On the other hand, the high percentage of PUFA ingest is not necessarily healthy if the n6/n3 ratio reach high values (Vargas-Ramella et al., 2021). In this sense, the EPA and DHA content in replaced pâtés contributed to obtaining the healthier n-6/n-3 ratio (up to 6-fold lower; Table 3). Previous studies published that the decrease of this ratio is one of the most important objectives to achieve in the field of healthier meat products research (Martins et al., 2020; Pérez-Palacios et al., 2019).

In spite of FAO do not recommend a specific n-6 to n-3 ratio intake in relation to human dietary requirements (FAO, 2010), experts agree that a healthy n-6/n-3 fatty acids intake (1–2/1 ratio) contributes to reduce the prevalence of overweight and obesity in the population (Simopoulos, 2016). Therefore, the results obtained in our study were encouraging since n-6 and n-3 PUFAs must be derived from the diet (essential fatty acids) and FO pâtés showed a significant lower n-6/n-3 ratio (3.44 and 1.40, for FO25 and FO50, respectively) compared to CON pâtés (8.63).

3.5. Sensory analysis of pâtés

3.5.1. Descriptive analysis of pâtés: QDA

QDA is the sensory highly detailed and valid method routinely employed to characterize a product in all its sensory features of texture, appearance, mouthfeel, odour, flavour and after flavour (Solomando et al., 2021). The sensory attributes intensity (Fig. 4A) displayed that

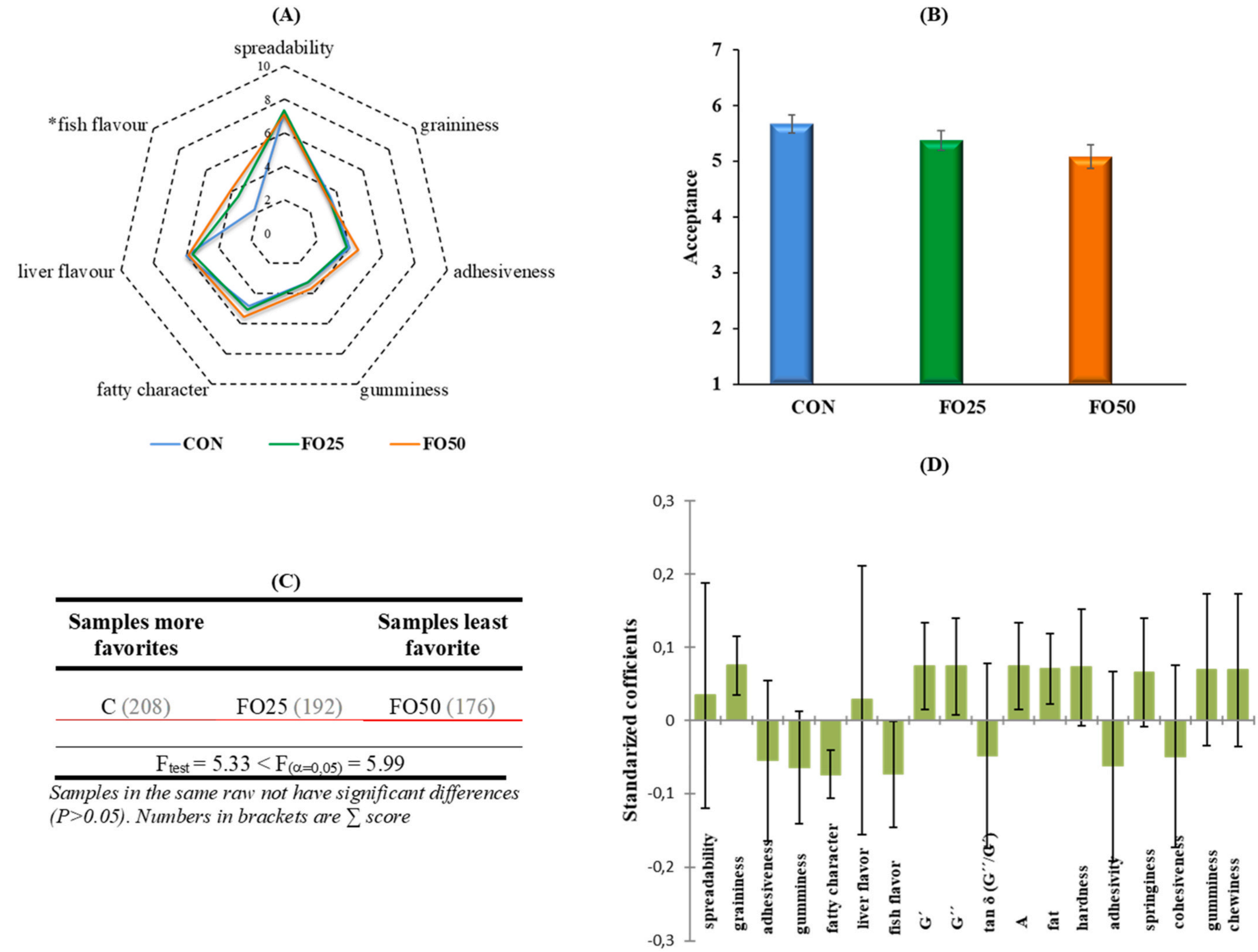

Fig. 4. (A) Mean intensity of the sensory attributes of pâtés (*P < 0.05 (Duncan's test)); (B) Scores for overall liking; (C) Total preference. (D) Standardized coefficients of PLS-R (95% Jack-knife confidence intervals) using overall liking as Y-variables (Y data set) and physicochemical, rheological and descriptive ratings as X-variables. CON: 100% of pork backfat; FO25: 75% of pork backfat and 25% of FO; FO50: 50% of pork backfat and 50% of FO.

only fish flavour indicated significant ($P < 0.05$) differences among batches. FO50 treatment showed the highest value (4.1) followed by FO25 (3.5) and CON (2.3) batches. Despite instrumental measurements for texture parameters showed significant differences among batches (section 3.3), these differences varied within a narrow range, and they were undetectable to the panellists. This finding partly disagrees with earlier studies evaluating burgers (Aquilani et al., 2018) and sausages (Solomando et al., 2021) enriched with FO which detected, in addition to flavour, differences in textural parameters and odour attributes in comparison to the control. Therefore, considering the panellists evaluation, FO25 had the better scores since showed lower values for the fish flavour attribute, an undesirable characteristic of reformulated products by FOL.

3.5.2. Hedonic study: consumers acceptance and preference

The score consumers for overall liking (Fig. 4B) and preference (Fig. 4C) of reformulated pâtés did not show significant ($P \geq 0.05$) variations among the three treatments. Despite QDA being a method commonly employed to establish the sensory profile of the foodstuffs, this technique is applied at a single point in time and is expensive since requiring a trained panel. For this reason, a complementary sensory analysis should be realized to establish a more adequate sensory profile of a product. In this sense, hedonic studies allow evaluating subtle changes in taste, flavour and texture in the sensory perception of the foods during consumption (Solomando et al., 2021).

Different from QDA, the hedonic study indicated that the FO can be used as a partial fat replacement without impairing off-odours and off-flavours (fishy attributes) to the final product. The absence of undesirable sensory attributes in reformulated meat products as a consequence of the microencapsulation of FOL was previously reported by several authors (Jiménez-Martín et al., 2016; Josquin et al., 2012; Keenan et al., 2015; Pérez-Palacios et al., 2018; Stangierski et al., 2020). Our findings suggest that microencapsulation could be useful in terms of masking potential off-flavours arising from FOL and they are congruent with already discussed in section 3.3, where no differences were assessed for lipid oxidation values among CON, FO25, and FO50 treatments.

Therefore, our hedonic studies results were encouraging concerning the possibility to offer a healthy meat-based product to consumers. According to data obtained in the acceptance and preference analysis, we can conclude that when FO is used as a fat replacer in pâtés (25% or 50% of FO) the habitual pâté consumers (traditional composition) demonstrate a similar acceptance and preference between traditional and reformulated products. These findings support our initial hypothesis in which we suggest the FO as a fat replacer to pork backfat as a strategy to elaborate healthier food without impairing its sensorial attributes. Moreover, despite the QDA analyses showing differences between treatments (fish flavour), this attribute was only perceived by panellists.

Finally, PLS-R was employed to evaluate the relationship between consumer acceptability of pâtés and their rheological and physico-chemical parameters, fat content, and descriptive attributes. The quality of the model ability was measured by the Q^2 (cum) index, with a value of 0.995. In addition, the values for DModX and DModY obtained for C, FO25 and FO50 are (0.584, 0.075; 1.045, 0.135; 0.461, 0.029, respectively) were lower than DCritX (2.575) and DCritY (1.881) hence there were no outliers. The resultant regression standardized coefficients (with a 95% Jack-knife confidence interval) are shown in Fig. 4D. The variables with VIP (variable importance in the projection) values > 1 were considered the most important for the prediction model (Nguyen et al., 2020).

The graininess (VIP = 1.165), the rheological parameters (A (VIP = 1.157), G' (VIP = 1.156) and G′′(VIP = 1.149)), hardness (VIP = 1.128) and fat content (VIP = 1.094) were positively correlated with overall liking, meanwhile fatty character (VIP = 1.143), fish flavour (VIP = 1.140), and gumminess (VIP = 1.069) were negatively correlated.

4. Conclusions

The findings showed that the pork backfat partial substitution by microencapsulated fish oil is an interesting strategy to elaborate healthier pâtés by decreasing the fat content and improving the fatty acid composition, especially in terms of the MUFA and PUFA values and n-6/n-3 ratio. Rheological properties were affected (lower G′and A; $P <$ 0.01) by the inclusion of microencapsulated fish oil in comparison to control, with elastic character predominating over de viscous (solid-like behaviour) and due to the fewer structures promoted by fat replacement. In addition, softer textural parameters were achieved in reformulated pâtés, probably associated with moisture and PUFA contents increase in these batches.

Notwithstanding the n-3 PUFA-rich oil addition, no susceptibility of the modified pâtés to oxidation was observed. In addition, despite the sensorial attributes of pâtés evaluated by QDA test showing a higher fish flavour for reformulated batches, according to the hedonic test the microencapsulated fish oil could be an adequate option for the substitution of pork backfat because its addition did not affect the acceptance and preference scores.

Finally, considering the above mentioned, batches elaborated with 50% of microencapsulated fish oil showed to be the more adequate treatment due to its lower ($P < 0.001$) fat, energy, SFA, MUFA and n6/n3 values and higher protein, ash, carbohydrates, and PUFA contents. Therefore, our findings suggest the possibility for the meat industry to produce a novel healthier pâté by replacing animal fat with fish oil without its undesirable sensory effects for consumers.

Funding for open access charge

Universidade de Vigo/CISUG.

CRediT authorship contribution statement

Márcio Vargas-Ramella: Formal analysis, Writing – original draft, Writing – review & editing. **José M. Lorenzo:** Writing – review & editing, Conceptualization. **Sol Zamuz:** Formal analysis, Writing – review & editing. **Leticia Montes:** Formal analysis, Writing – original draft. **Eva Maria Santos Lopez:** Writing – review & editing. **Ramón Moreira:** Conceptualization, Writing – Review & editing. **Daniel Franco:** Writing – review & editing, Conceptualization, Supervision.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgements

Daniel Franco Jose M. Lorenzo belong to the competitive reference research group, FunMeat (Axencia Galega de Innovación, GAIN-IN607A2019/01) and Jose M. Lorenzo, Eva M. Santos and Daniel Franco are members of the HealthyMeat network, funded by CYTED (Ref.119RT0568). Sol Zamuz acknowledges the financial support PTA program (PTA2017-141). Ramón Moreira acknowledges the financial support of the Xunta de Galicia (Consolidation Project ED431B 2019/01).

This research received external funding by the EU Commission through the BBI-JU H2020 Project AQUABIOPRO-FIT "Aquaculture and agriculture biomass side stream proteins and bioactives for feed, fitness and health promoting nutritional supplements" (Grant Agreement no. 79095).

References

Alvarez, M. D., Fuentes, R., Guerrero, G., & Canet, W. (2017). Characterization of commercial Spanish hummus formulation: Nutritional composition, rheology, and structure. *International Journal of Food Properties, 20*(4), 845–863. https://doi.org/10.1080/10942912.2016.1186692

Aquilani, C., Pérez-Palacios, T., Sirtori, F., Jiménez-Martín, E., Antequera, T., Franci, O., Acciaioli, A., Bozzi, R., & Pugliese, C. (2018). Enrichment of Cinta Senese burgers with omega-3 fatty acids. Effect of type of addition and storage conditions on quality characteristics. *Grasas Y Aceites, 69*(1). https://doi.org/10.3989/gya.0671171. e235–e235.

Barros, J. C., Munekata, P. E. S., De Carvalho, F. A. L., Pateiro, M., Barba, F. J., Domínguez, R., Trindade, M. A., & Lorenzo, J. M. (2020). Use of tiger nut (*Cyperus esculentus* L.) oil emulsion as animal fat replacement in beef burgers. *Foods, 9*(1), 44. https://doi.org/10.3390/foods9010044

Bis-Souza, C. V., Barba, F. J., Lorenzo, J. M., Penna, A. L. B., & Barretto, A. C. S. (2019). New strategies for the development of innovative fermented meat products: A review regarding the incorporation of probiotics and dietary fibers. *Food Reviews International, 35*(5), 467–484. https://doi.org/10.1080/87559129.2019.1584816

Calvo, P., Hernández, T., Lozano, M., & González-Gómez, D. (2010). Microencapsulation of extra-virgin olive oil by spray-drying: Influence of wall material and olive quality. *European Journal of Lipid Science and Technology, 112*(8), 852–858. https://doi.org/10.1002/ejlt.201000059

Delgado-Pando, G., Cofrades, S., Rodríguez-Salas, L., & Jiménez-Colmenero, F. (2011). A healthier oil combination and konjac gel as functional ingredients in low-fat pork liver pâté. *Meat Science, 88*(2), 241–248. https://doi.org/10.1016/j.meatsci.2010.12.028

Delgado-Pando, G., Cofrades, S., Ruiz-Capillas, C., Triki, M., & Jiménez-Colmenero, F. (2012). Low-fat pork liver pâtés enriched with n-3 PUFA/konjac gel: Dynamic rheological properties and technological behaviour during chill storage. *Meat Science, 92*(1), 44–52. https://doi.org/10.1016/j.meatsci.2012.04.002

Di Giorgio, L., Salgado, P. R., & Mauri, A. N. (2022). Fish oil encapsulated in soy protein particles by lyophilization. Effect of drying process. *Journal of the Science of Food and Agriculture, 102*(1), 206–213. https://doi.org/10.1002/jsfa.11347

Domínguez, R., Agregán, R., Gonçalves, A., & Lorenzo, J. M. (2016). Effect of fat replacement by olive oil on the physico-chemical properties, fatty acids, cholesterol and tocopherol content of pâté. *Grasas Y Aceites, 67*(2). https://doi.org/10.3989/gya.0629152

Domínguez, R., Pateiro, M., Sichetti Munekata, P. E., Bastianello Campagnol, P. C., & Lorenzo, J. M. (2017). Influence of partial pork backfat replacement by fish oil on nutritional and technological properties of liver pâté. *European Journal of Lipid Science and Technology, 119*(5), 1600178. https://doi.org/10.1002/ejlt.201600178

EFSA. (2017). Dietary reference values for nutrients summary report. *EFSA Supporting Publications, 14*(12). https://doi.org/10.2903/sp.efsa.2017.e15121

Estévez, M., Ventanas, S., & Cava, R. (2005). Physicochemical properties and oxidative stability of liver pâté as affected by fat content. *Food Chemistry, 92*(3), 449–457. https://doi.org/10.1016/j.foodchem.2004.08.014

FAO. (2010). Fat and fatty acid requirements for adults. *Fats and fatty acids in human nutrition, 91*, 55–62.

FAO. (2021). *A simple overview of omega-3*. Food and Agriculture Organization of United Nations. http://www.fao.org/in-action/globefish/fishery-information/resource-detail/en/c/1052098/.

FAO/WHO. (1997). *Carbohydrates in human nutrition. Report of a joint FAO/WHO expert consultation*.

FAO/WHO. (2005). Codex alimentarius. Food labelling: Complete texts. In *Codex alimentarius commission* (4th ed.). FAO/WHO https://www.fao.org/publications/card/en/c/248636be-3632-5d21-83a6-6ee6a66cc93b.

Gabriele, D., De Cindio, B., & D'Antona, P. (2001). A weak gel model for foods. *Rheologica Acta, 40*(2), 120–127. https://doi.org/10.1007/s003970000139

Jiménez-Martín, E., Pérez-Palacios, T., Carrascal, J. R., & Rojas, T. A. (2016). Enrichment of chicken nuggets with microencapsulated omega-3 fish oil: Effect of frozen storage time on oxidative stability and sensory quality. *Food and Bioprocess Technology, 9*(2), 285–297. https://doi.org/10.1007/s11947-015-1621-x

Josquin, N. M., Linssen, J. P. H., & Houben, J. H. (2012). Quality characteristics of Dutch-style fermented sausages manufactured with partial replacement of pork back-fat with pure, pre-emulsified or encapsulated fish oil. *Meat Science, 90*(1), 81–86. https://doi.org/10.1016/j.meatsci.2011.06.001

Kawecki, K., Rezler, R., Baranowska, H. M., & Stangierski, J. (2021). Influence of fish oil and microencapsulated fish oil additives on water binding and the rheological properties of poultry sausage batters. *Journal of the Science of Food and Agriculture, 101*(3), 1127–1133. https://doi.org/10.1002/jsfa.10723

Keenan, D. F., Resconi, V. C., Smyth, T. J., Botinestean, C., Lefranc, C., Kerry, J. P., & Hamill, R. M. (2015). The effect of partial-fat substitutions with encapsulated and unencapsulated fish oils on the technological and eating quality of beef burgers over storage. *Meat Science, 107*, 75–85. https://doi.org/10.1016/j.meatsci.2015.04.013

Lorenzo, J. M., & Pateiro, M. (2013). Influence of fat content on physico-chemical and oxidative stability of foal liver pâté. *Meat Science, 95*(2), 330–335. https://doi.org/10.1016/j.meatsci.2013.04.045

Macfie, H. J., Bratchell, N., Greenhoff, K., & Vallis, L. V. (1989). Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests. *Journal of Sensory Studies, 4*(2), 129–148. https://doi.org/10.1111/j.1745-459X.1989.tb00463.x

Martin, D., Ruiz, J., Kivikari, R., & Puolanne, E. (2008). Partial replacement of pork fat by conjugated linoleic acid and/or olive oil in liver pâtés: Effect on physicochemical characteristics and oxidative stability. *Meat Science, 80*(2), 496–504. https://doi.org/10.1016/j.meatsci.2008.01.014

Martins, A. J., Lorenzo, J. M., Franco, D., Pateiro, M., Domínguez, R., Munekata, P. E. S., Pastrana, L. M., Vicente, A. A., Cunha, R. L., & Cerqueira, M. A. (2020). Characterization of enriched meat-based pâté manufactured with oleogels as fat substitutes. *Gels, 6*(2), 1–14. https://doi.org/10.3390/gels6020017

Meilgaard, M.C., C. G. V. and C. B. T. (2007). Sensory evaluation techniques. In CRC Press (4th ed.). Taylor and Francis Group. https://doi.org/https://doi.org/10.1201/b16452.

Nguyen, A. N. H., Johnson, T. E., Jeffery, D. W., Capone, D. L., Danner, L., & Bastian, S. E. P. (2020). Sensory and chemical drivers of wine consumers' preference for a new shiraz wine product containing ganoderma lucidum extract as a novel ingredient. *Foods, 9*(2), 224. https://doi.org/10.3390/foods9020224

Ospina-E, J. C., Cruz-S, A., Pérez-Álvarez, J. A., & Fernández-López, J. (2010). Development of combinations of chemically modified vegetable oils as pork backfat substitutes in sausages formulation. *Meat Science, 84*(3), 491–497. https://doi.org/10.1016/j.meatsci.2009.10.003

Paglarini, C. de S., Vidal, V. A. S., Martini, S., Cunha, R. L., & Pollonio, M. A. R. (2022). Protein-based hydrogelled emulsions and their application as fat replacers in meat products: A review. *Critical Reviews in Food Science and Nutrition, 62*(3), 640–655. https://doi.org/10.1080/10408398.2020.1825322

Pateiro, M., Lorenzo, J. M., Amado, I. R., & Franco, D. (2014). Effect of addition of green tea, chestnut and grape extract on the shelf-life of pig liver pâté. *Food Chemistry, 147*, 386–394. https://doi.org/10.1016/j.foodchem.2013.09.153

Pateiro, M., Lorenzo, J. M., Diaz, S., Gende, J. A., Fernandez, M., Gonzalez, J., Garcia, L., Rial, F. J., & Franco, D. (2013). Meat quality of veal: Discriminatory ability of weaning status. *Spanish Journal of Agricultural Research, 11*(4), 1044–1056. https://doi.org/10.5424/sjar/2013114-4363

Pérez-Palacios, T., Ruiz-Carrascal, J., Jiménez-Martín, E., Solomando, J. C., & Antequera, T. (2018). Improving the lipid profile of ready-to-cook meat products by addition of omega-3 microcapsules: Effect on oxidation and sensory analysis. *Journal of the Science of Food and Agriculture, 98*(14), 5302–5312. https://doi.org/10.1002/jsfa.9069

Pérez-Palacios, T., Ruiz-Carrascal, J., Solomando, J. C., & Antequera, T. (2019). Strategies for enrichment in ω-3 fatty acids aiming for healthier meat products. *Food Reviews International, 35*(5), 485–503. https://doi.org/10.1080/87559129.2019.1584817

Ramos, F. de M., Silveira Júnior, V., & Prata, A. S. (2021). Impact of vacuum spray drying on encapsulation of fish oil: Oxidative stability and encapsulation efficiency. *Food Research International, 143*, 110283. https://doi.org/10.1016/j.foodres.2021.110283

Rezler, R., Krzywdzińska-Bartkowiak, M., & Piątek, M. (2021). The influence of the substitution of fat with modified starch on the quality of pork liver pâtés. *Lebensmittel-Wissenschaft & Technologie, 135*, 110264. https://doi.org/10.1016/j.lwt.2020.110264

Simopoulos, A. P. (2016). An increase in the Omega-6/Omega-3 fatty acid ratio increases the risk for obesity. *Nutrients, 8*(3), 128. https://doi.org/10.3390/nu8030128

Solomando, J. C., Antequera, T., Ventanas, S., & Perez-Palacios, T. (2021). Sensory profile and consumer perception of meat products enriched with EPA and DHA using fish oil microcapsules. *International Journal of Food Science and Technology, 56*(6), 2926–2937. https://doi.org/10.1111/ijfs.14932

Stangierski, J., Rezler, R., Kawecki, K., & Peplińska, B. (2020). Effect of microencapsulated fish oil powder on selected quality characteristics of chicken sausages. *Journal of the Science of Food and Agriculture, 100*(5), 2043–2051. https://doi.org/10.1002/jsfa.10226

Vargas-Ramella, Márcio, Lorenzo, J. M., Rois, D., Arias, A., Justo, J. R., Pateiro, M., López-Pedrouso, M., & Franco, D. (2021). Effect of finishing diet on carcass characteristics and meat quality of mos cockerel. *Spanish Journal of Agricultural Research, 19*(1). https://doi.org/10.5424/sjar/2021191-16870. e0601–e0601.

Vargas-Ramella, Marcio, Pateiro, M., Barba, F. J., Franco, D., Campagnol, P. C. B., Munekata, P. E. S., Tomasevic, I., Domínguez, R., & Lorenzo, J. M. (2020). Microencapsulation of healthier oils to enhance the physicochemical and nutritional properties of deer pâté. *Lebensmittel-Wissenschaft & Technologie, 125*, 109223. https://doi.org/10.1016/j.lwt.2020.109223

Vasile, F. E., Romero, A. M., Judis, M. A., & Mazzobre, M. F. (2019). Physicochemical, nutritional, and stability aspects of a meat product (*gluteus medius*) enriched with encapsulated fish oil in polyelectrolyte beads containing *Prosopis alba* exudate gum. *Food and Bioprocess Technology, 12*(4), 654–664. https://doi.org/10.1007/s11947-019-2240-8

Vyncke, W. (1975). Evaluation of the direct thiobarbituric acid extraction method for determining oxidative rancidity in mackerel (*Scomber scombrus* L.). *Fette Seifen Anstrichmittel, 77*(6), 239–240. https://doi.org/10.1002/lipi.19750770610

Yang, J. E., & Lee, J. (2020). Consumer perception and liking, and sensory characteristics of blended teas. *Food Science and Biotechnology, 29*(1), 63–74. https://doi.org/10.1007/s10068-019-00643-3