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Sous-vide-cooked ω3-enriched chicken hamburger: Physicochemical and sensory characterization

Hamburguesa de pollo cocida al vacío enriquecida con ω3: Caracterización fisicoquímica y sensorial

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ABSTRACT

We designed a chicken-meat hamburger enriched with ω3 polyunsaturated fatty acids and cooked by sous-vide. The chicken meat used came from male BB chickens of the Cobb commercial line, fed for approximately 27 days with 3 isoprotein and isoenergetic diets based on: corn and soy; soybeans plus flax oil and soybeans plus fish oil. The hamburgers, made with a mixture of fresh skinless chicken breast and thigh meat, oat bran and a commercial mix of spices, were vacuum-packed and cooked at 80 °C for 10 min. Chemical analyses (moisture, fat, protein, fiber, thiobarbituric acid and fatty acid profile), color and texture profile were performed. The samples enriched with fish oil presented significantly higher values of docosapentaenoic acid (1.53 g of fatty acid per 100 g of fat) than the control sample (0.30 g of fatty acid per 100 g of fat). The sensory characterization was carried out by 54 consumers using the CATA methodology (check all that apply). The chicken-meat hamburger enriched with fish-ω3 oil was the most widely accepted by consumers. Therefore, a functional food product enriched with ω3 polyunsaturated acid close to the daily recommendation (250 mg) was designed. The sensory acceptability of consumers was found based on a pleasant taste, pleasant appearance and chicken flavor.

Keywords: Chicken-meat hamburgers; Consumers; Functional chicken-meat food; Omega-3 polyunsaturated fatty acids; Sous-vide.

RESUMEN

Se diseñó una hamburguesa de carne de pollo enriquecida con ácidos grasos ω3 poliinsaturados y cocida al vacío. La carne de pollo provino de pollos BB machos de la línea comercial Cobb, alimentados durante aproximadamente 27 días con 3 dietas isoproteicas e isoenergéticas en base a: maíz y soja; soja más aceite de lino y soja más aceite de pescado. Las hamburguesas, elaboradas con una mezcla de carne fresca de pechuga y pata muslo de pollo sin piel, salvado de avena y mezcla comercial de especias, se envasaron y cocinaron al vacío a 80 °C durante 10 min. Se realizaron análisis químicos (humedad, grasa, proteína, fibra, ácido tiobarbitúrico y perfil de ácidos grasos), color y perfil de textura. Las muestras enriquecidas con aceite de pescado presentaron valores significativamente mayores de ácidos docosapentaenoico (1,53 g de ácido graso por 100 g de grasa) que la muestra control (0,30 g de ácido graso por 100 g de grasa). La caracterización sensorial fue realizada por 54 consumidores utilizando la metodología CATA (marque todo lo que corresponda). La hamburguesa de pollo y enriquecida con aceite de pescado ω3 fue la más aceptada por los consumidores. Por lo tanto, se diseñó un producto alimenticio funcional en forma de hamburguesa de pollo que se enriqueció con ω3 poliinsaturados cerca de la recomendación diaria (250 mg), y se consideró un producto aceptable por el consumidor sobre la base del sabor agradable, apariencia agradable y sabor a pollo.
Palabras clave: Alimento funcional de carne de pollo; Consumidores; Hamburguesas de carne de pollo; Sous-vide; ω3 poliinsaturados.

INTRODUCTION

The market for prepared food has exhibited a rapid and continuous growth to become one of the most promising sectors in the food industry. In recent decades, these products have proven a real and viable alternative fare for new consumers seeking practicality and convenience in consumption along with nutritional and sensory quality[1].

Sous-vide cooking technology consists of cooking food under controlled temperature conditions (65-95°C) for a specific time inside thermosetting vacuum bags, followed by low-temperature storage. It has the advantages of maintaining sensory quality, extending the shelf-life of products and preserving the nutritional quality of food due to lower losses due to oxidation or diffusion of nutrients[2].

*Sous-vid*e cooking is one such new technology, whose approach consists of vacuum-packing the raw food in a specially designed plastic bag. The cooking is done in a constant water bath, at a low and regulated temperature, but for a longer time than normal, thus enabling an exact cooking temperature in the center of the product. It favors the extension of the useful life and the maintenance of the sensory quality of the products since it prevents losses due to evaporation of water and volatile compounds during cooking[3]. This culinary method preserves the intrinsic characteristics of food (aroma, flavor, texture, color)[4,5] and improves technological characteristics, such as low oxidative deterioration[6]. Therefore, different authors have studied the sous-vide effect on the physicochemical, textural, structural characteristics and oxidative stability on chicken meatballs[7], chicken meat[8], sausages[9]; and on pork ribs[10].

The demands of the current consumer for meat products with an improved composition has motivated the food industry to reduce the content of fat, cholesterol, salt, and nitrite; to improve the profile of fatty acids; and to incorporate bioactive compounds[11]. The meat industry accordingly produces raw materials with healthy ingredients through dietary modification and supplementation during rearing that improves animal husbandry, carcass yield, and meat quality. The reformulation of the finished products through the new processing methods are based on the redefinition of quality meat products in which vegetable and fish oils replace animal fat[11,12].

Functional foods provide benefits for consumer health while not affecting the nutritional characteristics of a diet since those additives otherwise have properties similar to those of the original foods. Meat products could be excellent matrices for the inclusion of functional ingredients because meats not only attract a wide range of consumers but are also versatile and contain high-quality integral nutrients-e. g., proteins, vitamins, and minerals[12]. In this sense, *sous-vide* is an interesting alternative to be explored to extend the shelf life of chicken meat products with ω3 added and respond to the growing demand for easily prepared products for consumers, catering, dining rooms and food service establishments.

The design of the new products has to be based on the retention of sensory and nutritional properties, in addition to maintaining consumer acceptance and perception of products[13,14]. The sensory quality of food is one of the characteristics that most affects consumer satisfaction level and result from the interaction between the intrinsic properties of food and the consumer[15,16]. The check-all-that-apply (CATA) questionnaire consists of multiple questions in which the consumer can mark all the options that are considered appropriate for the sensory characterization of a product[17,18].

Other authors have studied products similar to those that were the objectives of this study-e.g., low-fat poultry[19] and chicken nuggets[20]; but, to the best of our knowledge, none have focused on poultry hamburgers enriched in polyunsaturated acids and cooked by *sous-vide*.

In view of the general profile of current consumers, the technologies enabling producers to adapt to consumer demands, and the lack of studies researching chicken meat supplemented with ω3 fatty acids and cooked by *sous-vide*; the objective of this research was to characterize chicken-meat hamburgers enriched with ω3 polyunsaturated acid and cooked by *sous-vide*.

MATERIALS AND METHODS

Materials. Chicken-meat (from chicken leg quarters and breast without skin) was used with a lipid profile modified in the following way. To increase the content of ω3 polyunsaturated fatty acids in the meat, the broiler chickens used, divided into 3 groups, were fed either with a corn-and-soybean control diet, corn and soybean plus flax oil diet, and a diet of corn and soybean plus fish oil (Table 1). Chicken breeding and rearing was carried out during a period of 49 days, in the Experimental Station Instituto Nacional de Tecnología Agropecuaria (National Institute of Plant and Animal Husbandry), Concepción del Uruguay, Argentina.

The birds used were male BB chickens from the Cobb commercial line. They were reared in batches on the floor, in a conventional shed, until slaughter age, fed with hopper feeders, while water was supplied through the nipple system. From the day of birth to 21 days, the birds received a standard commercial diet. From day 22, the chickens were divided in three groups fed with the three different diets: a control diet without added ω3 fatty acids and two diets enriched in ω3 by adding flax or fish oil (Table 1). All diets were isocaloric and isoprotein. Animals received the diet until 49 day of age and then slaughtered.

Hamburger formulations and processing

The fresh meat from the boneless and skinned chicken, oat bran and commercial spice mix (Alicante, La Virginia S.A., Argentina) were ground in a mincer (ATMA, mp8601, Argentina) for 5 min. The ingredients and proportions used were (by weight) 86% ω3-containing avian meat (from previous flax or fish feeding), 13% oat bran, 0.10% salt, 0.45% garlic, and 0.45% mixed spices (garlic, thyme, white pepper, and oregano).

The hamburgers were molded considering 15 mm height, 100 mm diameter and 130 g weight using a manual patty maker. Subsequently, they were placed individually in polyamide-polyethylene vacuum-bags (O_2 permeability, 25 to 30 cm^3/m^2/day water vapor permeability of 5 g/m^2/day) (Cryovac®, Sealed Air Co, Argentina) and vacuum-packed in a vacuum sealer (VAC PACK, ICC, 80016, Spain).

The packed samples were cooked by sous-vide in a constant water-circulation bath with temperature and time regulation (RONER COMPACT, ICC, 80060, Spain) at 80 °C for 10 min according to Church et al.[19]. The temperature inside the hamburger was monitored during heating with a thermocouple (HANNA Instruments, HY 93530N, Italy). Until further evaluation, all the samples were stored refrigerated at 3 °C.

Table 1. Percent composition of balanced feed fed to chickens after 21 days of standard commercial diet.

Ingredients	Control diet (%)	Flax-ω3 diet (%)	Fish-ω3 diet (%)
Corn	61.01	61.01	61.01
Soy flour (46 g protein) CAENA 07	17.87	17.87	17.87
Soy oil	4.00	….	2.00
Flax oil	….	4.00	….
Fish oil	….	….	2.00
Shell flour	0.34	0.34	0.34
Meat flour (<50 g fat)	4.60	4.60	4.60
Coccidiostat*	0.05	0.05	0.05
Premix	0.15	0.15	0.15
Salt	0.34	0.34	0.34
Lysine	0.28	0.28	0.28
DL-Methionine	0.18	0.18	0.18
Threonine	0.05	0.05	0.05
Choline	0.08	0.08	0.08
Sunflower flour (32% protein)	11.10	11.10	11.1

*Antiprotozoal agent acting on coccidian parasites.

Compositional and physicochemical characterization
All analyses were carried out 24 h after production

General composition. The determinations made in the samples were the following: the moisture content after heating in an infrared drying oven (RADWAG, Mag. 50/WH, Poland) according to AOAC 7.003-84, water activity (aw) with a Rotronic Hygrolab C1 hygrometer, fat content by Soxhlet method, protein content by Kjeldahl (with 6.25 as a conversion factor), and total fiber contents of the cooked chicken hamburgers were determined according to the methodology proposed by AOAC 47.02120.

Fatty-acid profile. The fatty-acid profile was determined in raw and cooked hamburgers using the procedure described by Folch et al.[21]. An initial lipid extraction with chloroform: methanol (2:1, v/v) followed by a transmethylation upon incubation in methanolic KOH. Gas chromatography on the resulting fatty-acid methyl esters was perform on a SHIMADZU GC-14B instrument, equipped with a flame-ionization detector and a C-R 5A integrator. The chromatographic separation was conducted using a RT-2560 capillary column (100 m x 0.25 mm x 0.2 μm). The fatty-acid profile, expressed as a percent, was obtained by integrating the peaks of the methyl esters and comparing the subsumed areas with those of the peaks of the mixture of fatty-acid–methyl-ester standard: FAME-37 (Supelco Inc., Bellefonte. PA, USA).

Thiobarbituric-acid-reactive substances (TBARS). The degree of lipid peroxidation in the products was evaluated using the TBARS measurements (the TBARS index) as described by Grau et al.[22]. The sample weighing ca. 1.5 g was homogenized with an aqueous solution of disodium EDTA (0.3%, w/v), trichloroacetic acid (5%, w/v), and butylated hydroxytoluene (to quench sample autooxidation during the assay, 0.8%, w/v) in hexane. After filtration through Whatman # 1 filter paper, 3 ml of the filtrate was mixed with 2 ml of thiobarbituric-acid solution (0.8% v/v) and transferred to a water bath for 30 min at 70° C. After cooling in an ice bath for 5 min and equilibration for 45 min at room temperature, the absorbance of the solution was measured at 532 nm in a spectrophotometer (BIOCHROM, LIBRA S22, UK). The concentration of the reaction product malondialdehyde (MDA) was determined from a standard curve of 1, 1, 3, 3-tetraethoxypropane.

Texture. The products were evaluated by textural-profile analysis through the use of a TAXT2i universal texturometer (SMS Ltd, UK). Eight replicas per sample (chicken-meat cylinders of 14 ± 0.2 mm in diameter and 14 ± 1.0 mm in height) were compressed to 60% of their original height at room temperature with a P75 probe (75-mm-diameter circular plate) and a spindle speed of 1.00 mm/s. The restoration time between the two compression cycles was 3 s. From the force curve obtained, the following mechanical properties were measured: hardness (N), adhesiveness (N.s), elasticity, cohesiveness, rubberiness (N) and chewiness (N.mm). Before performing the textural-profile analysis, the equipment was calibrated with a weight of 5 kg, according to the standard procedure.

Color. The color was measured in a colorimeter (HUNTER ASSOCIATES LABORATORY, Inc., MiniScan EZ Model, EE UU) with the CIELAB system and D65 lighting, equivalent to normal daylight. The indices of color luminosity (L^*), redness (a^*), and yellowness (b^*) were obtained from the reflection spectrum of the samples. Four chicken hamburgers of each diet (control, flax-ω3, and fish-ω3) were analyzed in different parts of the surface. The color change (Equation 1) was calculated, where L^0, a^0, and b^0 represent the readings of the control samples.

$$\Delta E=\sqrt{(\Delta L)^2+(\Delta a)^2+(\Delta b)^2} \qquad \text{Equation 1}$$

Sensory characterization

Six hamburgers were strictly designed for sensory analysis, changing only the type of seasoning and the experimental design and compositions are given in Table 2. In this study, the sensory characterization was carried out with 54 consumers (students, teachers, and administrative staff of the University). CATA sensory analysis requires a minimum of 50 consumers[17,23].

The day before the analysis, five hamburgers of 130 g were prepared, cooked and stored in refrigeration as previously described in section 2.2: control hamburger with garlic flakes (CGF), control hamburger with powdered garlic (CGP), flax-ω3 hamburger with garlic flakes (FlGF), flax-ω3 hamburger with powdered garlic (FlGP), fish-ω3 hamburger with garlic flakes (FiGF), and fish-ω3 hamburger with powdered garlic (FiGP).

On the day of the test, the hamburgers were cut into 10 g portions and kept at 75 °C inside the RONER bath and in identified bags until analysis. The six formulations were presented to consumers following balanced randomization (multiple orthogonal Latin square), on plastic plates coded with 3-digit random numbers, and accompanied by salt-free water crackers and mineral water to rinse between samples. To avoid systematic bias, the assignment of the order of presentation of the samples among the evaluators was randomized, as well as the terms within the CATA list to avoid the same effects[24].

Firstly, a 7-point hedonic scale was used containing the categories "I dislike it a lot" (valued at 1 point) to "I like it very much" (valued at 7 points) to evaluate global acceptability. Later, with a CATA questionnaire, consumers indicated the attributes considered appropriate to describe the sensory characteristics of hamburgers. The terms were defined by using a previous focus group.

Consumer tests were carried out in a sensory laboratory that was designed in accordance with ISO 8589 (ISO, 1988). Evaluations were performed under artificial daylight type illumination, temperature control (between 22 °C and 24 °C) and air circulation. Data were

Table 2. Percent composition of the six hamburgers sensory characterized.

Ingredients	CGP	CGF	FlGP	FlGF	FiGP	FiGF
Chicken meat	86	86	-	-	-	-
Chicken meat ω3	-	-	86	86	86	86
Oat bran	13	13	13	13	13	13
Salt	0.10	0.10	0.10	0.10	0.10	0.10
Mixed spices	0.45	0.45	0.45	0.45	0.45	0.10
Garlic powder	0.45	-	0.45	-	0.45	-
Garlic flakes	-	0.45	-	0.45	-	0.45

Key to samples: CGF, control hamburger with garlic flakes; CGP, control hamburger with powdered garlic; FlGF, flax-ω3 hamburger with garlic flakes; FlGP, flax-ω3 hamburger with powered garlic; FiGF, fish-ω3 hamburger with garlic flakes; FiGP, fish-ω3 hamburger with powdered garlic.

collected in paper ballots, through self-administered questionnaires previously explained to each consumer.

Statistical analysis

The experimental design chosen to study the effect of the treatments was bifactorial, selecting the factors and levels according to the test performed. The statistical analysis consisted of ANOVA calculated through the use of the software SYSTAT (SYSTAT, Inc., Evanston, IL). The standard error of each medium was reported in each instance. The difference between the means and in the F-test were considered significant when $p < 0.05$. The Duncan test was used to compare the means.

The attribute frequency for each sample judged was determined to analyze the results of the sensory evaluation. The Cochran Q test was used to assess differences in each attribute of the CATA question between the six poultry-hamburger preparations.

A correspondence analysis was used to obtain a two-dimensional representation of the relationship between the attributes for each of the identified groups. The results were statistically analyzed by means of the XLSTAT program for Windows, version 2018.7.5 (Addinsoft, 2020).

RESULTS

Physicochemical and nutritional parameters

Moisture, water activity, fat, protein, total fiber and the fatty-acid profile were evaluated to determine the efficiency of the sous-vide technique. Table 3 summarizes the results obtained. The physicochemical parameters measured did not reveal specific differences between the three types of meat (*i. e.*, the control and those modified in their lipid profiles).

Fatty-acid profile of raw and sous-vide-cooked chicken hamburgers

The chicken hamburgers prepared contained approximately 5.1 g of fat in their formulation. Significant differences in fatty acid profiles were not only caused by diets but also processes.

The effects of the diets of broiler on meat and process are shown in Table 4. The diets had no significant effect on saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA) fatty acids and ω6, whereas the content of MUFA was affected significantly ($p<0.05$) by the *sous-vide* process.

The interaction between diets and processes had a significant ($p<0.05$) effect on ω3, ω3/ω6 and LCω3. The hamburgers made with meat modified in its lipid content presented higher ω3 content in the raw samples, while in the cooked samples only those enriched with flax showed a difference.

The ω3-fatty-acid concentration of the control poultry meat was 2.60 vs 2.91%, whereas the flax- and fish-supplemented chicken hamburgers contained 9.61 vs 5.77% and 6.00 vs 3.57% raw and cooked respectively (Table 4).

The LCω3-fatty-acid content per serving exhibited values for linseed hamburgers of 60 mg and 151 mg for fish hamburger.

The *sous-vide* cooking did not cause changes in the levels of SFA, PUFA, ω6, while MUFA and ω6/ω3 was significantly increased in cooked hamburgers. The effect of cooking was not significant for ω3 in the control hamburger but ω3 was significantly reduced ($p<0.05$) in the flax-ω3 and fish-ω3 hamburgers. A similar response was observed in LCω3.

TBARS

Hamburgers made with meat from chickens fed with the flax-ω3 diet presented significantly higher values of TBARS (0.347 ± 0.040 mg MDA/kg) than the levels in the hamburgers made with chickens fed with the control diet or with the fish-ω3 diet (0.273 ± 0.025 and 0.255 ± 0.010 mg MDA/kg, respectively).

Table 3. Physicochemical and nutritional parameters of the hamburger enriched with ω3.

Parameter	Control hamburger (Mean ± SD)	Flax-ω3 hamburger (Mean ± SD)	Fish-ω3 hamburger (Mean ± SD)
Moisture (%)	65.5 ± 0.03[a]	65.5 ± 0.04[a]	64.9 ± 0.17[a]
Water activity	0.97 ± 0.003[a]	0.96 ± 0.006[a]	0.96 ± 0.004[a]
Protein (%)	21.6 ± 0.31[a]	21.7 ± 0.25[a]	21.5 ± 0.34[a]
Soluble fiber (%)	3.60 ± 8.4[a]	3.80 ± 8.2[a]	3.20 ± 8.8[a]
Total fat (%)	5.00 ± 0.25[a]	5.10 ± 0.09[a]	5.10 ± 0.05[a]

Different letters indicate significant differences by the Tukey test ($p<0.05$).

Texture

Table 5 summarizes the values for the texture parameters for each treatment. Adhesiveness (-39.0165 ± 4.865 J), elasticity (0.571 ± 0.009 mm), and cohesiveness (0.305 ± 0.007 J/J) did not show significant differences and thus are not listed.

The hardness, rubberiness, and chewiness parameters were significantly different between the control samples and the hamburgers with ω3 polyunsaturated fatty acids.

Color

Table 5 lists the means and standard deviations of the results obtained for the parameters L*, a*, and b* associated with hamburgers made with chicken meat from poultry fed with three different diets.

The average values of L*, a*, and b* obtained in the different samples indicated a light pink and slightly yellowish color, according to the coordinates of the CIELAB system.

The means of the parameters L* manifested significant difference ($p < 0.05$) among the three preparations, while the a* and b* values did not show any difference between the different samples.

An analysis of the ΔE values demonstrated that the control-fish (0.88) and control-flax (0.70) hamburgers did not reveal obvious differences detectable by the human eye. By contrast, the fish-flax (1.41) hamburgers presented a small color difference that could be distinguished visually.

Sensory characterization

Among all samples tested, the FiGP proved to be the most widely accepted ($p < 0.5$) in the "I really like it" category, while the least accepted sample was CGF.

According to the Cochran Q-test (Table 6), the samples of hamburgers were significantly different ($p < 0.05$) with respect to the following items: *dryness, poorly seasoned, crunchy, too spicy,* and *good taste*.

Figure 1A Shows the representation of the CATA task performed in the first two dimensions. The first and second dimensions (F1 and F2) represented 41.90% and 28.92% of the variance of the experimental data, respectively.

According to their sensory attributes, samples were sorted into three main groups, as shown in sample representation in the first and second dimensions of the CA (Figure 1A). A first group of hamburgers, composed of samples CGF, CGP and FlGP, were located at positive values of the second dimension being mainly described as *crumbly* and of *suitable thickness*. Samples FiGP and FiGF were located at negative values of the first dimension and were associated with their taste. Finally, sample FlGP was located at positive values of the first and second dimension and was described as *excessively seasoned, crunchy,* and *too spicy*.

In the association between liking the samples and their attributes (Figure 1B), agreeable appearance, suitable thickness, appetizing smell, chicken flavor, and good taste were the terms that determined a wider acceptability of the chicken hamburgers containing ω3 fatty acids cooked by *sous-vide*.

DISCUSSION

The chicken hamburgers (control, flax-ω3 and fish-ω3) did not present significant differences in the values of the physicochemical and nutritional parameters. The recommended daily intake of ω3 polyunsaturated fatty acids per adult is 250 mg[25], so a serving of enriched hamburger provides ω3 polyunsaturated close to the daily recommendation. Sufficient intake of omega-3 polyunsaturated fatty acids and in particular docosahexaenoic acid during pregnancy, lactation and early childhood is vital for brain and eye development[25].

Table 4. Fatty-acid composition (g of fatty acid per 100 g of fat) of raw control, flax-ω3, and fish-ω3 hamburgers and after cooking by sous-vide.

Fatty acids	Control hamburger (Mean ± DS) Raw	Control hamburger (Mean ± DS) *Sous-vide*	Flax-ω3 hamburger (Mean ± DS) Raw	Flax-ω3 hamburger (Mean ± DS) *Sous-vide*	Fish-ω3 hamburger (Mean ± DS) Raw	Fish-ω3 hamburger (Mean ± DS) *Sous-vide*
C 14:0	0.55 ± 0.01[a]	0.45 ± 0.03[a]	0.36 ± 0.01[a]	0.44 ± 0.05[a]	0.42 ± 0.03[a]	0.62 ± 0.08[a]
C 14:1 (*cis* 9)	0.09 ± 0.08[a]	0.10 ± 0.01[a]	0.16 ± 0.03[a]	0.11 ± 0.01[a]	0.12 ± 0.10[a]	0.09 ± 0.02[a]
C 15:0	0.71 ± 0.40[a]	0.58 ± 0.05[a]	2.80 ± 0.03[a]	0.55 ± 0.03[a]	2.80 ± 0.03[a]	0.58 ± 0.19[a]
C 16:0	21.96 ± 1.42[ab]	20.29 ± 0.85[b]	20.24 ± 0.57[b]	20.94 ± 0.27[ab]	23.42 ± 1.16[a]	21.46 ± 0.85[ab]
C 16:1 (*trans*)	0.25 ± 0.22[a]	0.17 ±0.15[a]	0.00 ±0.00[a]	0.16 ± 0.14[a]	0.12 ± 0.21[a]	0.32 ± 0.02[a]
C 16:1 (*cis* 9)	4.10 ± 0.67[a]	3.45 ± 0.16[a]	3.77 ± 1.23[a]	3.53 ± 0.09[a]	4.37 ± 1.13[a]	3.29 ± 0.36[a]
C 17:0	0.27 ± 0.11[a]	0.16 ± 0.01[a]	0.13 ± 0.04[a]	0.17 ± 0.01[a]	0.18 ± 0.11[a]	0.23 ± 0.10[a]
C 17:1 (*cis* 10)	0.39 ± 0.04[a]	0.24 ± 0.02[ab]	0.08 ± 0.07[b]	0.18 ± 0.05[ab]	0.12 ± 0.14[ab]	0.23 ± 0.04[ab]
C 18:0	5.51 ± 2.40[a]	5.13 ± 0.17[a]	4.73 ± 1.42[a]	5.13 ± 0.17[a]	5.64 ± 1.00[a]	5.85 ± 0.50[a]
C 18:1 (*trans* n9)	0.07 ± 0.06[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.16 ± 0.05[a]	0.06 ± 0.10[a]	0.08 ± 0.07[a]
C 18:1 (*cis* n9)	31.25 ± 2.63[a]	33.45 ± 1.43[a]	32.88 ± 4.60[a]	35.62 ± 1.58[a]	32.03 ± 0.87[a]	36.64 ± 0.70[a]
C 18:2 (trans 9,12 n6)	0.02 ± 0.03[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.06 ± 0.10[a]	0.00 ± 0.00[a]	0.00 ±0.00[a]
C 18:2 (*cis* 9,12 n6)	27.86 ± 4.48[a]	30.77 ± 0.28[a]	25.13 ± 3.53[a]	24.41 ± 1.14[a]	24.22 ± 1.85[a]	25.02 ± 0.62[a]
C 20:0	0.22 ± 0.03[a]	0.15 ± 0.02[b]	0.17 ± 0.02[ab]	0.14 ± 0.01[bc]	0.13 ± 0.02[bc]	0.10 ± 0.01[c]
C 18:3 (*cis* 6,9,12 n6)	0.21 ± 0.04[a]	0.26 ± 0.01[a]	0.26 ± 0.24[a]	0.30 ± 0.07[a]	0.27 ± 0.26[a]	0.44 ± 0.07[a]
C18:3 (*cis* 9,12,15 n3)	1.91 ± 0.41[c]	1.88 ± 0.07[c]	8.99 ± 0.94[a]	5.03 ± 0.38[b]	1.66 ± 0.18[c]	1.54 ± 0.08[c]
C 21:0	0.07 ± 0.00[ab]	0.02 ± 0.03[b]	0.00 ± 0.00[b]	0.12 ± 0.06[a]	0.03 ± 0.03[ab]	0.02 ± 0.03[b]
C 20:2	0.02 ± 0.02[a]	0.01 ± 0.01[b]	0.20 ± 0.16[a]	0.00 ± 0.00[b]	0.01 ± 0.01[b]	0.00 ± 0.00[b]
C 22:0	0.27 ± 0.18[a]	0.20 ± 0.01[a]	0.03 ± 0.04[a]	0.21 ± 0.01[a]	0.30 ± 0.21[a]	0.27 ± 0.01[a]
C 20:3 n6	0.35 ± 0.20[a]	0.21 ± 0.01[a]	0.38 ± 0.05[a]	0.24 ± 0.03[a]	0.36 ± 0.08[a]	0.20 ± 0.02[a]
C 22:1 n9	0.17 ± 0.30[a]	0.00 ± 0.00[a]	0.06 ± 0.07[a]	0.02 ± 0.04[a]	0.02 ± 0.03[a]	0.02 ± 0.03[a]
C 20:4 n6	2.60 ± 1.15[a]	1.25 ± 0.14[ab]	1.42 ± 0.49[ab]	1.01 ± 0.17[b]	1.67 ± 0.59[ab]	0.78 ± 0.08[b]
C 22:2	0.02 ± 0.02[ab]	0.00 ± 0.00[b]	0.04 ± 0.04[ab]	0.02 ± 0.03[ab]	0.10 ± 0.04[a]	0.02 ± 0.04[ab]
C 24:0	0.08± 0.08[a]	0.00 ± 0.00[a]	0.01 ± 0.01[a]	0.10 ± 0.15[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]
C 20:5 n3	0.63 ± 0.22[ab]	0.23 ± 0.03[cd]	0.47 ± 0.10[bc]	0.16 ± 0.02[d]	0.90 ± 0.11[a]	0.50 ± 0.05bc
C 24:1	0.00 ± 0.00[a]	0.19 ± 0.03[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.06 ± 0.11[a]	0.18 ± 0.21[a]
C 22:5	0.30 ± 0.17[c]	0.00 ± 0.00[c]	0.04 ± 0.07[c]	0.29 ± 0.09[c]	3.44 ± 0.01[a]	1.53 ± 0.29[b]
C 22:6 n3	0.16 ± 0.15[ab]	0.80 ± 0.12[a]	0.15 ± 0.26[ab]	0.59 ± 0.54[ab]	0.00 ± 0.00[b]	0.00 ± 0.00[b]
SFA	29.60 ± 4.25[ab]	26.98 ± 0.61[ab]	25.93 ± 1.05[b]	28.11 ± 0.19[ab]	30.45 ± 2.66[a]	29.12 ± 0.93[ab]
MUFA	36.33 ± 1.93[b]	37.6 ± 1.33[ab]	36.94 ± 4.23[ab]	39.85 ± 1.55[ab]	36.89 ± 0.92[ab]	40.84 ± 2.71[a]
PUFA	33.97 ± 4.01a[b]	35.41 ± 0.51[ab]	37.08 ± 4.98[a]	32.11 ± 2.05[ab]	32.94 ± 3.70[ab]	30.27 ± 0.89[b]
ω3	2.60 ± 0.24[c]	2.91 ± 0.13[c]	9.61 ± 0.84[a]	5.77 ± 0.43[b]	6.00 ± 1.11[b]	3.57 ± 0.27[c]
ω6	28.43 ± 4.51[ab]	31.24 ± 0.3[a]	25.77 ± 3.82[b]	25.01 ± 1.32[b]	24.86 ± 2.01[b]	25.66 ± 0.59[b]
ω6/ω3	10.52 ± 0.81[b]	10.75 ± 0.4[b]	2.66 ± 0.21[e]	4.36 ± 0.13[d]	9.71 ± 0.19[c]	12.61 ± 0.15[a]
LCω3	0.73 ± 0.37[c]	1.03 ± 0.10[c]	1.03 ± 0.49[c]	0.91 ± 0.44[c]	4.34 ± 1,12[a]	2.28 ± 0.37[b]

Fatty acids with different letters indicate significant differences by the Tukey test ($p<0.05$).

Table 5. Textural parameters and chromatic coordinates (L*, a*, b*) determined in control, flax-ω3 and fish-ω3 hamburgers cooked by sous-vide.

Parameter	Control hamburger (Mean ± SD)	Flax-ω3 hamburger (Mean ± SD)	Fish-ω3 hamburger (Mean ± SD)
Hardness (N)	26.10 ± 0.73[a]	23.27 ± 0.71[b]	33.87 ± 0.69[c]
Rubberiness (N)	6.77 ± 0.51[a]	7.46 ± 0.51[b]	9.90 ± 0.51[c]
Chewiness (N.mm)	3.42 ± 0.27[a]	4.39 ± 0.27[b]	5.90 ± 0.27[c]
L*	71.12 ± 0.61[b]	71.71 ± 0.76[a]	70.3 ± 1.08[c]
a*	2.79 ± 0.13[a]	2.92 ± 0.18[a]	2.85 ± 0.22[a]
b*	21.92 ± 0.44[a]	21.54 ± 0.83[a]	21.61 ± 0.80[a]
ΔE	…	1.41[a]	0.70[b]

Different letters indicate significant differences by the Tukey test ($p<0.05$).
ΔE: color difference between samples determined by Equation 1.

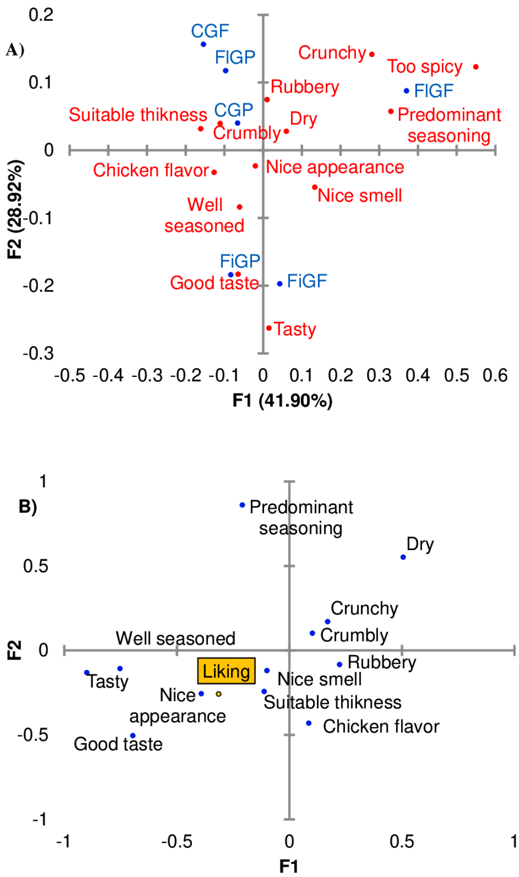

Figure 1: Correspondence-analysis plot of (A) consumer-assessed sensory attributes per se for different hamburger preparations and (B) those sensory attributes related to consumer liking for the same preparations. Key to samples: CGF, control hamburger with garlic flakes; CGP, control hamburger with powdered garlic; FlGF, flax-ω3 hamburger with garlic flakes; FlGP, flax-ω3 hamburger with powered garlic; FiGF, fish-ω3 hamburger with garlic flakes; FiGP, fish-ω3 hamburger with powdered garlic.

Table 6. Frequency (n) with which the indicated terms of the CATA question were used by consumers to describe the five hamburger samples and the results from Cochran's Q test for comparison between the samples.

Attributes	CGP	CGF	FlGP	FlGF	FiGP	FiGF
Rubbery	10	11	13	7	9	11
Dry*	21	16	6	13	10	15
Excessively seasoned	54	53	54	54	54	54
Well-seasoned	12	18	19	18	21	13
Agreeable appearance	24	28	28	26	29	24
Poorly seasoned*	10	5	15	8	4	4
Chicken flavor	25	27	26	21	25	16
Tasty	11	19	8	11	17	11
Suitable thickness	20	23	20	21	14	15
Crumbly	16	9	15	13	17	7
Attractive/ Agreeable	20	16	17	15	21	20
Crunchy*	21	6	8	11	11	17
Too spicy*	12	4	7	6	8	16
Good taste*	19	29	20	20	29	16

*Significant ($p<0.05$) attributes of the CATA questionnaire according to the Cochran Q test.
Key to samples: CGF, control hamburger with garlic flakes; CGP, control hamburger with powdered garlic; FlGF, flax-ω3 hamburger with garlic flakes; FlGP, flax-ω3 hamburger with powered garlic; FiGF, fish-ω3 hamburger with garlic flakes; FiGP, fish-ω3 hamburger with powdered garlic.

The protein, fat, and moisture results were similar to those detected by Naveena et al.[9] in chicken sausages precooked by *sous-vide*. Santhi et al.[26] found slightly lower values of moisture, protein, fiber, and fat in low-fat nuggets containing added of oat flour.

Andrés et al.[27] made innovations in the development of chicken-meat sausages formulated with different sources of fat (pre-emulsified squid oil and beef tallow). In their study, similar values of moisture and fat were obtained, whereas the protein content was slightly (*ca*. 14-16%) lower.

The product elaborated in this study provides fiber by incorporating oat bran in its formulation and a low-fat content compared to commercial hamburgers. The availability of low-fat products is one of the most pressing and widespread demands of current consumers. Therefore, the food industry replaces fats with proteins and other extenders or binders in the attempt to preserve the water-retention capacity and textural properties[28].

SFA, MUFA, PUFA and ω6 content in chicken hamburgers were not significantly different according to the diet. These results differ from those obtained by Narciso-Gaytán et al.[8], who found a lower content of SFA and higher content of MUFA, PUFA and ω3 in breasts with menhaden fish oil and flaxseed oil, compared to control samples.

Bonoli et al.[29] observed a total fat content in breaded chicken hamburgers similar to the values reported here. The chickens were fed with a beef-fat-pork-lard diet and a sunflower-oil-soybean diet. The poultry meat with the vegetable-oil diet contained similar values for the MUFA and PUFA to those reported here, whereas the concentrations of the SFA and those of the ω6 family along with the ω6/ω3 ratios were higher than those obtained in the present work.

Andrés et al.[27] developed a reduced-fat sausage using chicken-breast meat and deodorized refined squid oil. The contents of SFA, MUFA, PUFA and the ω6/ω3 ratios were slightly lower-and the levels of total and ω3 polyunsaturated acid were higher-than the corresponding data obtained in this investigation.

The values for lipid composition-and especially the concentrations of polyunsaturated fatty acids-are associated with water loss and meat peroxidation[30]. The fatty-acid content of chicken meat is influenced by cooking temperature and the technique employed. *Sous-vide* cooking-at modest temperatures and greatly reduced levels of oxygen-accordingly causes fewer changes in meat than conventional methods such as frying and grilling[31].

The increase in TBARS values in the hamburgers made with meat from chickens fed with the flax-ω3 diet may occur due to the increased amount of double bonds in the carbon chain of fatty acids in flax-ω3 patties that increase MDA production[8]. Can et al.[7] observed similar values for TBARS of 0.21-0.36 mg MDA/kg in chicken meatballs cooked by the *sous-vide* technique.

Naveena et al.[9] obtained values of TBARS between 0.17 and 0.21 mg MDA/kg in chicken sausages cooked by *sous-vide*, slightly lower than those in the present study. Akôglu et al.[32], however, reported higher values (0.61 mg MDA/kg) in turkey cutlet cooked by *sous-vide*.

Lipid oxidation can cause rancidity in meat products. Consumers almost never detect such unpleasant flavors in foods cooked by *sous-vide* with values close to 0.5 mg MDA/kg. This cooking methodology-widely used in the gastronomy and catering industry-delays the biochemical processes of deterioration that require oxygen[7].

The hardness, rubberiness, and chewiness parameters of hamburgers with the ω3 polyunsaturated acid were significantly higher than the control sample. Barros et al.[33] observed slightly higher values of hardness and chewiness in nuggets of chicken meat enriched in ω3 and fiber after the replacement of chicken skin with chia flour (*Salvia hispanica L.*).

The parameters a* and b* did not show any difference between samples, this may be because hamburgers in each group were prepared from a single dough mixture[7].

Can et al.[7] obtained similar L* and b* values in chicken meatballs cooked by *sous-vide*. Naveena et al.[9] found higher values of L*, a*, and b* in chicken sausages cooked by *sous-vide* using different temperature-time combinations. Barros et al.[33] observed similar values for all the color parameters in chicken nuggets after enrichment with ω3 and replacement of fiber by chicken skin with chia flour. Andrés et al.[27] reported a* values for chicken-meat sausages formulated from different lipid sources approximating that parameter in this study.

Sensory analysis using the CATA questionnaire showed good acceptability of hamburgers enriched with ω3 cooked by *sous-vide*. Certain authors have used this technique to evaluate different food products, however, no studies have been reported that focused on the creation of preference maps for chicken-meat products.

CONCLUSIONS

A functional-food product was made through the enrichment in ω3 polyunsaturated fatty acids close to the daily recommendation (250mg).

The improvement achieved in the nutritional profile of this preparation of chicken hamburgers provides a real and viable means of compensating for the otherwise low consumption of foods containing ω3 fatty acids in the typical consumer diet.

The sensory questionnaire employed (CATA) was a facile evaluation method for consumers that enabled the collection of information on the sensory attributes needed for a complete characterization of the product. The sous-vide chicken hamburger enriched with ω3 fatty acids was judged to be a product acceptable by the consumer on the basis of the palatable taste, agreeable appearance, and thorough retention of the chicken flavor.

The designed product enriched with ω3 represents an interesting option in diets for weight control, cholesterol and triglyceride reduction, for pregnant or lactating mothers and the prevention of hypertension and various diseases, due to a fat composition of less than 5%, no added salt, with dietary fiber. This combination of factors constitutes an excellent opportunity for diversification in an emerging market for healthy meat products.

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