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Development of reduced fat minced meats using inulin and bovine plasma proteins as fat replacers

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ABSTRACT

This work deals with the effect of the addition of inulin and bovine plasma proteins as fat replacers, on the quality of minced meat. The proteins are obtained by ultrafiltration and freeze-drying. The following determinations were carried out: chemical composition, sensorial analysis (color, flavor, taste and consistency), emulsion stability and instrumental texture analysis of samples. The resulting formulations were compared with full-fat minced meat, as control. The results showed an increase of protein contents after fat replacement, while a fat reduction of 20–35% produced light products enriched with proteins and inulin as the functional ingredient. No change was observed in color, flavor, or taste among the samples. However, the sensory analysis showed that the combination of plasma protein (2.5%w/w) and inulin (2%w/w) had the best acceptability with respect to consistency, and had a lower fat drain from the emulsion. Texture profile analysis revealed that this formulation assimilated the control texture properties, being that this result is required for adequate consumer acceptance.

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1. Introduction

Meat and meat products are important sources of proteins, fats, essential amino acids, minerals, vitamins and other nutrients. However, the high saturated fat content of such products results in a restriction of consumption for those who are prone to cardiovascular diseases and/or suffer from overweight (Weiss, Gibis, Schuh, & Salminen, 2010). Yet, fat is an important constituent of human nutrition and contribute to the flavor, tenderness, juiciness, appearance, texture and shelf life of meat products. Thus, the challenge for meat industry is to develop low-fat meat products without compromising sensory and texture characteristics (Mun, Kim, & Kang, 2009; Zhang, Xiao, Samaraweera, Lee, & Ahn, 2010). In this regard, a number of hydrocolloid systems have been examined due to their ability to replace fat (Weiss et al., 2010). Polymers, such as proteins and polysaccharides, are often incorporated into fat-reduced products to provide some of the lost functional properties. Furthermore, proteins are a source of amino acids, providing foods with a higher nutritional value (Viana, Silva, Delvivo, Bizzotto, & Silvestre, 2005; Zhang et al., 2010). Proteins act as emulsifiers decreasing the surface tension and thus, the free energy of the system imparting, therefore, the desired kinetic stability to dispersions (emulsion or foam) (Rodríguez Patino, Carrera Sánchez, & Rodríguez Niño, 2008). The stability and formation of emulsions, the water holding capacity, and the oil binding capacity depend, among others, on the type of protein used and the presence of other components in a mixture (Borcherding, Lorenzen, Hoffmann, & Schrader, 2008; Glaser, Paulson, Speers, Yada, & Rousseau, 2007; Nikovska, 2010). With respect to polysaccharide, inulin is frequently used in meat formulations. In this respect, Cardoso, Mendes, and Nunes (2008) reported that the addition of dietary fiber obtained from inner chicory root improved gel strength and hardness of low-fat fish sausages, reducing fat and energy intake. Álvarez and Barbut (2013) studied the effect of inulin on emulsion stability, color and textural parameters of cooked meat batters, and reported that the addition of inulin resulted in a creamy and softer product. Beriain, Gómez, Petri, Insausti, and Sarriés (2011) found that the addition of inulin to low-fat sausages (20% less fat than traditional sausage) retained sensory notes similar to those of the traditional chorizo, and achieved a good acceptability rating. Inulin is a fructooligosaccharide consisting of fructose molecules linked by β(2–1) glycosidic bonds, which are responsible for its nutritional characteristics. It may contain either a terminal β-D-fructose or a α-D-glucose molecule (Zimeri & Kokini, 2003). The incorporation of inulin, in foods is known to reduce the risk of colon cancer, diabetes, obesity, and cardiovascular diseases in human beings. It is considered a prebiotic (Mendoza, García, Casas, & Selgas, 2001; Zhang et al., 2010). The functionality of the carbohydrate-based fat substitutes is established in relation to their ability to increase viscosity, form gels, provide mouthfeel and texture, and to increase water-holding capacity. The ability to form a gel is critical for its use as fat substitute in spread products (Hennelly, Dunne, O´Sullivan, & O'Riordan, 2006; Kip, Meyer, & Jellema, 2006; Rodriguez Furlán, Pérez Padilla, & Campderrós, 2011).

As previously discussed, the combined use of proteins and inulin as functional ingredients improves the nutritional and technological properties of foods. Therefore, the objective of this work was to study

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the incorporation of bovine plasma proteins and the polysaccharide inulin as fat substitutes in minced meats.

2. Materials and methods

2.1. Raw materials

Spray dried bovine blood plasma has been provided by a local supplier (Yerubá S.A., Esperanza, Argentina). The molecular weights of proteins were in the range of 15,000 to 80,000 Da. The proximate composition provided by the manufacturer was: 76 ± 5% proteins, 0.1% fat, 10% ash, 4% water, and 1% low molecular weight compounds.

Inulin obtained from chicory was provided by Orafti Chile S. A. The commercial inulin employed was mainly constituted by linear chains of fructose molecules with a terminal glucose unit. It has a molecular weight of 2400 g/mol and a polymerization grade (PG) of 12.

Inulin, bovine plasma protein and their mixtures in different proportions were evaluated to establish the effect of these components as fat replacers. Selection of the amounts was based on preliminary studies of their functional properties.

The additives used in the formulations were: sodium diphosphate, sodium triphosphate, sodium nitrite, citric acid, sodium citrate, and ascorbic acid. The ingredients employed to prepare the minced meat formulations, such as meat courts, beef fat, starch, sucrose, salt, and seasonings were purchased from a local grocery store.

2.2. Ultrafiltration and freeze drying of bovine plasma proteins

The feed solution was the bovine plasma which was dissolved in deionized water to a concentration of 3% w/v using a mixer at low speed to avoid the formation of vortex and to minimize the appearance of foam. The obtained solution was passed through a porous support (Viledon FO 2431D, Germany) to remove macroscopic aggregates. The feed (3 L) was thermostated in a water bath and impelled with a centrifugal pump, first through a frontal flow stainless steel filter, with a pore size of 60 μm (Gora, Argentina). This procedure of microfiltration (MF) reduces the amount of bacteria and spores and acts as cold pasteurization, moreover this stage protects the ultrafiltration (UF) membrane from fouling. The UF was performed using Pellicon cassette module (Millipore, Bedford, MA, USA), containing modified polyethersulfone membranes with a molecular weight cutoff (MWCO) of 10 kDa, with a membrane area of 0.5 m^2. The concentration of proteins by UF was carried out by continuously removing the permeate stream until the desired concentration of 4% (w/v), was achieved. The operating conditions were the following: transmembrane pressure (ΔP) of 1.5 bars, flow rate of (2.9 ± 0.05) L/min and a temperature of 10 °C. A discontinuous diafiltration (DD) process was applied to removal salts and other contaminant of low molecular weight. For this operation the starting material was the UF concentrate, which was diluted to the initial volume (3 L) with deionized water in a single state and ultrafiltrated to the desired concentration range. The cleaning of the fouled membrane was performed by applying a "Cleaning in Place" (CIP) procedure according to the manufacturer's instructions. At the end of each run, a cycle of water/alkali (NaOH, pH = 12.5 ± 0.5)/water wash was applied to the membrane at (40 ± 2) °C and at a transmembrane pressure of 1×10^5 Pa. Furthermore, a cleaning step using 300 ppm NaClO (commercial grade) was carried out at the same temperature and pressure to ensure sanitation and cleaning. Measurements of normalized water permeability were performed in order to verify the recovery of flow through the membrane and the optimal performance during the separation process. The obtained bovine plasma protein concentrate was then mixed with inulin in order to use as a protective agent, placed on stainless steel trays, frozen at −40 °C and freeze-dried in a lyophilizer (Rificor, Model L-A-B4, Buenos Aires, Argentina) during 48 h at 1 bar. The composition of the fat substitute dried concentrate was 27.80 ± 0.4% w/w proteins, <0.1% w/w fat, 2.80 ± 0.13% w/w ash and 64 ± 1 °Brix carbohydrate content. In previous papers, it was demonstrated that the procedure described reduced the protein denaturation, improving the functional function of plasma proteins (Rodriguez Furlán, Lecot, Pérez Padilla, Campderrós, & Zaritzky, 2012; Rodriguez Furlán, Pérez Padilla, & Campderrós, 2010).

2.3. Inulin characterization

Functional inulin characterization was carried out in order to determine the adequate polysaccharide content and predict its behavior in the formulation. The following tests were performed:

- Water holding capacity (WHC) was measured weighing 1 g of inulin (w_0) and mixed with 10 mL of deionized water for 5 min. After 30 min, the samples were centrifuged at 20,000 rpm at 5 °C for 30 min (Beckmann J2-HS, California, USA, ultracentrifuge). The supernatant was decanted and the sediment was weighted (w_2) and dried in a stove for 30 min (w_1). Water holding capacity was calculated as follows: $WHC = (w_2 - w_1)/(w_0)$.
- Oil binding capacity (OBC) was determined using the method of Chakraborty (1986). One gram of inulin (w_0) was thoroughly mixed with 10 mL of vegetable oil (V_1). After 30 min the samples were centrifuged at 20,000 rpm at 5 °C for 30 min. Then, the supernatant volume was recorded (V_2). The OBC was calculated as $OBC = (V_1 - V_2)/w_0$.
- The emulsifying capacity (EC) determination was performed as described by Rodriguez Furlán et al. (2010). One gram of inulin was mixed with 200 mL of deionized water for 2 min before addition of 500 mL of vegetable oil under continuous mixing. Blending was stopped every 2 min to check for emulsion breakage. When a clear emulsion breakage was observed, the total volume of oil added was recorded and used to calculate EC as volume (mL) of oil emulsified per gram of inulin.

2.4. Preparation of minced meats

The minced meats were elaborated using a 2 kg batch per treatment, according to legal regulations: moisture <68% and meat content >30% in the final product (Argentinean Alimentary Code (AAC), 2012). The formulations were: i) a control sample (C) containing a regular amount of fat (18% w/w), full fat minced meat and, ii) reduced fat samples (13% w/w) where bovine plasma proteins, inulin and their mixtures were used as fat replacers, in different proportions according to the experimental design. Each formulation was replicated three times including the control (36 batches), and all the analyses were carried out in independent form. Each set of formulations was made in the same day. The control sample containing a regular amount of fat (18%) without adding inulin and proteins was prepared to evaluate the effect of fat reduction on technological properties of minced meats. The ingredients used for preparing minced meat per kg of meat were: bovine fat: 135 g for control sample and 99 g for reduced fat samples; broth 680 g; bovine plasma protein (P) and inulin (I) were added in reduced fat samples according to the experimental design (Table 1), cornstarch 4 g, wheat flour 1 g, sodium diphosphate 3.75 g, sodium triphosphate 3.75 g, salt 22.5 g, sucrose 1.75 g, nitrite 17.5 mg, ascorbic acid 0.5 g, citric acid 1.5 g, sodium citrate 1.5 g, onion 3 g, garlic 1 g, pepper 2 g, paprika 2 g, parsley 1.5 g, oregano 1 g, and beet (betaine coloring) 1 g.

Table 1
Applied factor and level ranges of processed plasma protein (P) and inulin (I) in the minced meat formulation design used to study the influence of composition on the their properties.

Factor	Low level (−1)	Center point (0)	High level (+1)
P — Protein concentration (%, w/w)	2.5	2.7	3
I — Inulin concentration (%, w/w)	0	1	2

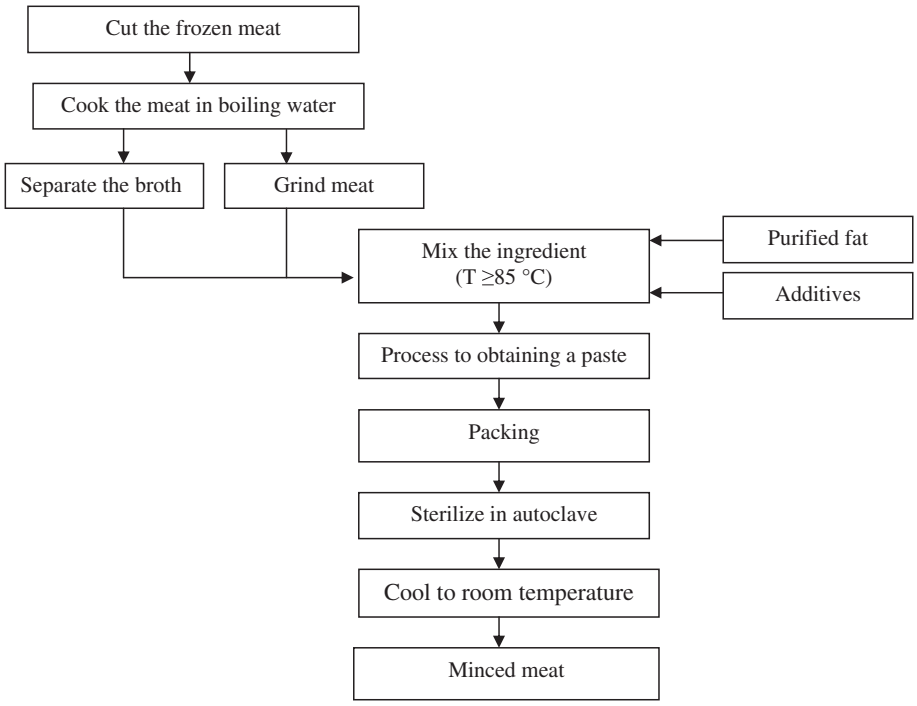

Fig. 1. Flow sheet of main steps for preparing minced meat.

The main steps for preparing minced meat formulation are shown in Fig. 1. The frozen meat was cut in small pieces and cooked in a pot with boiling water (1 L per kg of meat), during 20 min. The obtained broth was reserved for later use. The meat was ground in a cutter (Coolbrand, Cool 8060 model, Buenos Aires, Argentina) using a 1 mm disk. Bovine fat was purified by melting and subsequent filtering and then mixed with the broth and the protein for 5 min at 60 °C for better training of the emulsion. Afterwards, meat was incorporated and the preparation was mixed for 10–15 min, the remaining ingredients were added, mixing others 10–15 min, at 80 ± 5 °C. The mixture was processed into a paste. After that, 90 g of sample was put in each glass containers and was sterilized in an autoclave at 100 °C for 15 min. Finally, the samples were submerged in a cold bath and stored at ambient temperature (25 ± 3 °C).

2.5. Minced meats characterization

Chemical composition of minced meats was performed after seven days of storage. The contents of protein, ash, and moisture were determined according to the AOAC methods (AOAC, 1995). For the total fat determination the technique of Bligh and Dyer (1959) was used: 20 mL methanol and 10 mL of chloroform ($CHCl_3$) were added to 5 g of sample and mixed for 2 min. Then, another 10 mL of $CHCl_3$ was added and the mixture was shaken vigorously. Eighteen milliliters of distilled water were added and the mixture was vortexed again for 2 min. The layers were separated by centrifugation at 2000 rpm for 10 min (Rolco Model 2070, Buenos Aires, Argentina, centrifuger). The lower layer was transferred to a pear-shaped flask with a Pasteur pipette. A second extraction was done with 20 mL 10% (v/v) methanol in $CHCl_3$. After centrifugation, the $CHCl_3$ phase was added to the first extract. Evaporation was carried out by rotavapor (Buchi, 451, Flawil, Switzerland) and the residue was further dried at 104 °C for 1 h.

The emulsion stability based on a method developed by Hughes, Mullen, and Troy (1998) was determined as follows: 5 g of the sample was placed in a centrifuge tube heated in a water bath (HAAKE, E3, Vreden, Germany) at 75 °C for 30 min and centrifuged at 1500 rpm for 3 min. Then the sediments (pellets) were removed and weighed and the supernatants were poured into pre-weighed crucibles and dried. The percentage of the separate fluid (%*SF*) and the fat percent (%*F*) contained therein, were calculated as follows:

$$\%SF = \left[\left(w_{t+s}\text{-}w_{t+p}\right)/w_s\right]x100 \quad (1)$$

$$\%F = \left[\left(w_{c+d}\text{-}w_c\right)/SF\right]x100 \quad (2)$$

were w_{t+s}; w_{t+p}; w_s; w_{c+d}; w_c are the weights of: centrifuge tube and sample; centrifuge tube and pellets; sample weight; crucible and dried supernatant, and crucible, respectively.

The sensorial analysis was conducted based on the design described by Babiker, Fujisawa, Matsudomi, and Kato (1996) and Viana et al. (2005). The parameters evaluated were color, flavor, taste and consistency (degree of firmness). Twenty grams of each sample in random order was served to panelist. The samples were tested at 25 °C, in a uniformly illuminated room, by a 25-member panel selected from a pool of students and staff members of our department. The attributes were estimated on a five-point scale (from 1 = I disliked very much to 5 = I liked very much). Water was provided for rinsing between samples.

The texture profile analyses (TPA) of minced meat samples were performed with a texturometer (Stable Micro System, TAXT 2i/25 model, UK). The temperature of the samples was kept around 20 °C. The samples were placed in glass flasks (1.5 cm high and 4 cm diameter) and were compressed twice approximately to 20% of their original height. A plastic cylindrical probe (1.2 cm diameter) penetrated the samples twice in the same place, with a penetration rate of 5.0 mm/s. The following parameters were determined: hardness, cohesiveness, gumminess and adhesiveness.

2.6. Experimental design

The influence of varying concentrations of plasma protein and inulin was studied using a two-level full factorial model with center point (SAS, 1989). Experimental levels of the independent variables (concentrations of bovine plasma protein and inulin) are given in Table 1. The design consisted of five experiments including three repetitions for

the calculation of the pure error and for the lack-of-fit test. Second-order Scheffé polynomials were fitted to the experimental data as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 \quad (3)$$

where Y is the dependent variable; β_0, β_1, β_2, etc., are the coefficient estimates for each linear and cross-product term of the prediction model and X_1 and X_2 are the concentrations of bovine plasma protein and inulin, respectively.

The response surface studies were made based on the regression equations generated with the parameters that showed a statistical difference. According to the results, the sensory data of acceptability (consistence) and the stability data of *%F* of the reduced fat minced meats with a single or a mixture of fat replacements were evaluated using the Statistical 8 program.

2.7. Statistical analysis

The experimental data were statistically evaluated by the Tukey–Kramer multiple comparison test in the cases where two or more comparisons were considered. Otherwise, the *t*-test was used, assuming that a $P<0.05$ was statistically significant (SAS, 1989). The experiments were performed in triplicate for each formulation.

3. Results and discussion

3.1. Inulin characterization

The results obtained from the characterization of inulin were WHC: 2.0 ± 0.1 mL of water/g of product; OBC: 5.0 ± 0.1 mL of oil/g of product; and EC: 100 ± 5 mL of oil/g of product. The result of WHC was similar to that obtained by Collar, Santos, and Rosell (2007) who reported a value of 2.06 (g water/g solid). In addition, inulin showed similar properties to starches, according to the results obtained with native African yam bean (*Sphenostylis stenocarpa*) starch (Adebowale, Henle, Schwarzenbolz, & Doert, 2009), with a WHC of 1.4 mL of water/g of product and a OBC of 3.9 mL of oil/g of product. Starches are polysaccharides, also used as fat replacers in food products (Thaiudom & Khantarat, 2011).

From these results and those obtained in previous works for bovine plasma protein concentrates (Rodriguez Furlán et al., 2010; Rodriguez Furlán et al., 2011), it was possible to assume the concentrations of these compounds used in the experimental design.

3.2. Characterization of minced meat formulations

The proximate composition of minced meat is shown in Table 2. As expected, the samples with the incorporation of plasma protein had higher protein content than the control. Similarly, Hughes et al. (1998) described an increase of protein content using whey protein to reduce fat by 25% in frankfurter sausages. Considering samples with the same protein content as P2.5–P2.5 I2, the addition of inulin to the formulation produced a statistically significant increase ($P<0.05$) in the protein content of the products. The explanation of this behavior may be related to the gel formation of the polysaccharide inulin that increases the protein retention (Hennelly et al., 2006).

With respect to the fat content, as expected, the reduced fat samples showed less fat content than the control sample, achieving a reduction between 20 and 35%. With the increase of inulin and protein content, the reduction of the fat content was lower. This fact could be explained considering the oil retention capacity of the matrix protein–inulin, which reduced the defatting during the cooking. Regarding samples with protein content of 2.5% or 3% (w/w), the incorporation of inulin (samples P2.5 I2 and P3 I2) did not affect the moisture content after cooking ($P>0.05$); however, an increase in the fat retention was observed ($P<0.05$). This behavior suggested that inulin retains better fat than water, corroborating the results obtained in the inulin characterization.

With the incorporation of inulin and/or plasma proteins, the ash content increased slightly with respect to the control. This can be explained taking into account the network of inulin–protein. Similar results were reported by Hennelly et al. (2006). The pH of the samples was 5.96 ± 0.03 without statistically significant differences among the formulations.

3.3. Influence of bovine plasma protein and inulin on emulsion stability

The reduction in the fat content of a meat product decreases the emulsifying stability, possibly due to the drop in the fat positive action that stabilizes the batter by acting as a spacer within the protein network (Álvarez & Barbut, 2013). However, the results in Table 3 (expressed as a separated fluid percentage, *%SF*) show that the addition of bovine plasma proteins and inulin in the reduced-fat formulations improves the stability compared with the control sample ($P<0.001$), suggesting that these compounds participate in fat and water holding capacity, and also as emulsifiers. With respect to an increase in the emulsion stability, a similar result was reported by Youssef and Barbut (2011) who incorporated meat protein, and by Álvarez and Barbut (2013) adding inulin. From the comparison between reduced fat samples with inulin and with plasma proteins, no statistically significant difference ($P>0.05$) was observed.

Regarding the fat/water ratio in the separate fluid, *%F*, it was significantly dependent on the plasma protein and inulin content in the formulations (Table 4). Comparing samples P2.5 and P3, the increase in protein produced a released fluid with a higher fat content than water. Similar results were found by Youssef and Barbut (2009), who reported that raising meat protein level, increased fat loss in emulsified meat products. This increase means that the bovine plasma protein retains water better than fat. This behavior was also verified by previous studies, where it was found that the water holding capacity of bovine plasma protein concentrate was 74% higher than the oil binding capacity (Rodriguez Furlán et al., 2011). This could explain why small increases in the amount of the protein produce large variations in fluid separated composition. Another possibility is that a high protein content forms a denser highly-aggregated protein network (during cooking) which could put pressure on the fat globules to coalesce and squeeze out some of the protein matrix (Youssef & Barbut, 2011).

Table 2
Chemical composition of minced meat formulations.

Composition (%, w/w)	Full fat control	Reduced fat minced meats				
	C	P2.5	P3	P2.7 I1	P2.5 I2	P3 I2
Protein	19.26 ± 0.07^{a}	20.28 ± 0.18^{b}	$20.59 \pm 0.15^{b,c}$	$20.51 \pm 0.08^{b,c}$	20.75 ± 0.19^{c}	20.81 ± 0.12^{c}
Ash	3.25 ± 0.05^{a}	3.44 ± 0.05^{b}	3.39 ± 0.03^{b}	3.56 ± 0.12^{b}	3.66 ± 0.24^{b}	3.75 ± 0.19^{b}
Moisture	62.11 ± 0.44^{a}	60.46 ± 0.63^{b}	60.56 ± 0.06^{b}	59.71 ± 0.76^{b}	59.26 ± 0.74^{b}	59.13 ± 0.68^{b}
Fat	18.30 ± 0.56^{a}	12.01 ± 0.51^{b}	13.17 ± 0.45^{c}	13.61 ± 1.05^{c}	13.67 ± 0.64^{c}	13.79 ± 0.83^{c}

(a–c): Means in a same line followed by a different letter are significantly different ($P<0.05$).
C: control; P2.5: 2.5% of plasma proteins; P3: 3% of plasma proteins; P2.7I1: 2.7% of plasma proteins and 1% of inulin; P2.5I2: 2.5% of plasma proteins and 2% of inulin; P2.5I2: 3% of plasma proteins and 2% of inulin.

Table 3
Effects of plasma protein and inulin on emulsion stability.

Samples	%*SF* (Eq. (1))
C	5.5 ± 0.1^{a}
P2.5	1.4 ± 0.2^{b}
P3	1.7 ± 0.5^{b}
P2.7 I1	1.1 ± 0.1^{b}
P2.5 I2	1.5 ± 0.1^{b}
P3 I2	1.6 ± 0.2^{b}

(a–b): Means in a same line followed by a different letter are significantly different ($P < 0.05$).
C: control; P2.5: 2.5% of plasma proteins; P3: 3% of plasma proteins; P2.7I1: 2.7% of plasma proteins and 1% of inulin; P2.5I2: 2.5% of plasma proteins and 2% of inulin; P2.5I2: 3% of plasma proteins and 2% of inulin.

In contrast, the increase in the inulin percentage, with constant protein content generates a separated fluid with a higher fat holding capacity than water, since as was previously established (Section 3.1), this polysaccharide retains fat better than water. Moreover, this may be due to the fact that the gel that forms the polysaccharide (inulin) favors the formation of a heat-induced protein matrix, diminishing the link with water (Álvarez & Barbut, 2013).

From the average values of %*F* (*Y*), the canonical Scheffé's equation was obtained:

$$\%F = -153.69 + 61.59\,P + 34.48\,I - 13.99\,PI. \quad (4)$$

The model fitted adequately the data at $P \leq 0.05$. A comparison between experimental and predicted values for fat percentage of the separated fluid had an average relative error of 7%. The model was used to generate the surface plot (fitted response) for the %*F* of the reduced fat minced meats (Fig. 2). The highest values of %*F* were observed in the right side of the experimental area, where P3 was tested, while %*F* decreased toward the left side of surface where P2.5 I2 was assayed.

3.4. Texture analysis

Fig. 3 shows the results of TPA applied to minced meat. Comparing sample P2.5 with control (full fat minced meat), the fat content reduction produces an increase in hardness, but has no effect on gumminess, cohesiveness and adhesiveness ($P > 0.05$). As was previously reported by

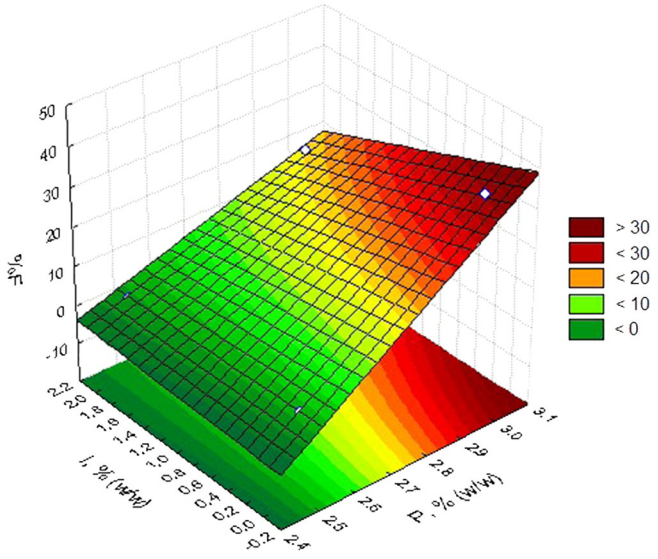

Fig. 2. Surface plot for fat percentage from the separate fluid of emulsion (%*F*) with the incorporation of different concentrations of fat replacers: bovine plasma proteins (P) and inulin (I).

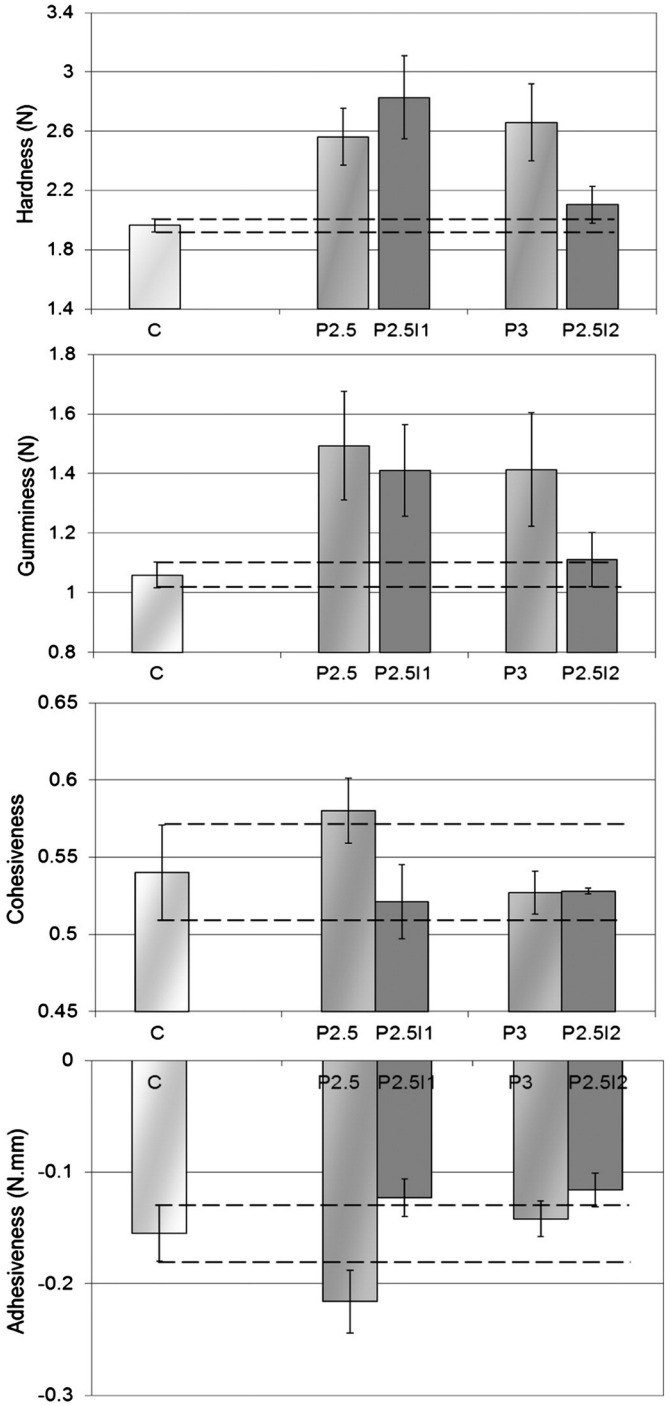

Fig. 3. Effect of fat replacers (plasma proteins and inulin) on the textural properties of minced meat samples. (C: control; P2.5: 2.5% of plasma proteins; P3: 3% of plasma proteins; P2.7I1: 2.7% of plasma proteins and 1% of inulin; P2.5I2: 2.5% of plasma proteins and 2% of inulin; P2.5I2: 3% of plasma proteins and 2% of inulin).

different authors, the incorporation of proteins in meat systems causes an increase in firmness. Thus, Bloukas and Paneras (1993), and Youssef and Barbut (2009, 2011) reported that hardness increased positively in correlation with protein content in different meat products such as low-fat frankfurters, and meat batters formulated with meat protein and soy, or whey proteins. They explained this behavior considering that an increase in the protein content resulted in denser protein matrices and consequently, in more rigid structures (Youssef & Barbut, 2011). Besides, in a previous work using only inulin as fat replacer, Mendoza et al. (2001) observed a reduction of hardness but they could not obtain

the texture of a full fat product, since the sausages were harder than the full fat samples ($P<0.05$).

However, our results showed that in reduced fat samples, the incorporation of inulin at 2% (w/w) along with plasma protein at 2.5% (w/w) (formulation: P2.5I2) significantly reduced hardness ($P < 0.05$), and there was no significant difference ($P>0.05$) with the control (not reduced fat sample). This fact could be explained considering the difference in fat loss between meat emulsions prepared with different proportions of protein and inulin (Youssef & Barbut, 2009). In this regard, the sample P2.5I2 showed higher emulsion stability and lower fat loss in the separate fluid (Table 3).

Therefore, this result suggests that the interactions among inulin and bovine plasma proteins could influence the gel formation by modifying the building blocks of the system, as it was argued by Youssef and Barbut (2011). In this respect, the molecular interaction of inulin with the gel matrix of the bovine plasma proteins and the other meat proteins could weaken the overall protein matrix. Hsu and Sun (2006) reported that the interaction of the proteins with the other components in raw materials, such as carbohydrate, could also affect the formation and stability of the emulsified products and therefore, could have influence in the reduction of sample hardness.

3.5. Sensorial analysis

The flavor of a product is a very important attribute since it determines the consumer preference.

No significant difference was observed between the sensorial qualities of reduced fat samples in relation to color, flavor and taste ($P > 0.05$), when compared with the control. All the panelists graded the attributes with categories between 3 and 4 of the Hedonic scale (~like) (Fig. 4). In previous studies, Viana et al. (2005) prepared ham pâté containing bovine globin and plasma as fat replacers, and although they had similar results with respect to the texture, the products showed a clearing of color after fat replacement. With respect to the consistency (or texture), the reduced fat sample acceptability was less than control in all the formulations except P2.5 I2.

Regarding average acceptability of the consistency attribute of the samples, they rated from 2.2 to 4.8 (Table 4). The lowest acceptability was obtained when bovine plasma proteins as fat replacers (P3) were used. They correspond to the sample with a higher fat loss in the separated fluid (%F). This higher capacity to hold water could produce a more compact meat structure with a higher hardness (Youssef & Barbut, 2011). Among the tested fat reduced minced meats, the most acceptable was that with the mixture protein 2.5% (w/w)–inulin 2% (w/w), having the lowest value of %F and a lower firmness (Fig. 3). This result suggests that the inulin and protein addition could enhance the product sensory acceptability. In this regard, Beriain et al. (2011) reported that the addition of inulin (6%) gave to reduced fat sausages a smoother texture with a reduced hardness and an increased acceptability of the sample. Studies performed by Hsu and Sun (2006) revealed that the incorporation of different protein supplements to emulsifier meat product (Kung-wans) affected textural properties. The product supplemented with skimmed milk powder presented the lowest hardness and the highest overall acceptance. Wang and Zayas (1992) incorporated soy flour, soy concentrate and corn germ protein flour in the formulations of frankfurters. They reported that the products had higher emulsion stability than the control, and according to the sensorial study, they presented no differences in their texture.

The canonical Scheffé's equation for acceptability (Y) for the sensorial consistency attribute (CA) was:

$$CA = 5.56 - 1.1\,P + 3.75\,I - 1.1\,PI. \quad (5)$$

The model fitted adequately the data at $P \leq 0.05$. A comparison between observed measurements and predicted values for acceptance had an average relative error of 4%. The model was used to generate the surface plot (fitted response) for the acceptability of the reduced fat minced meat (Fig. 5). The results showed that combinations of protein (2.5%, w/w) and inulin (2%, w/w), at the left side of the figure, had a higher average acceptability. The acceptability declined towards the right side of the experimental area, where proteins at 3% (w/w) without inulin were tested.

4. Conclusions

According to the analysis of chemical composition, the formulations prepared with inulin and bovine plasma protein as fat replacers had nutritional advantages over full fat samples for the following reasons: they have i) a reduced fat content (20–30%), ii) an increase in protein content (8%), and iii) the incorporation of a dietary fiber as inulin. The sensorial analysis of samples showed that color, taste and flavor were similar to the control (full fat samples). With respect to the attribute of consistency, the model identified by a surface plot, the combination of inulin and protein as fat replacers in P2.5I2 samples gave the highest acceptability to the consistence attribute. The texture study confirmed

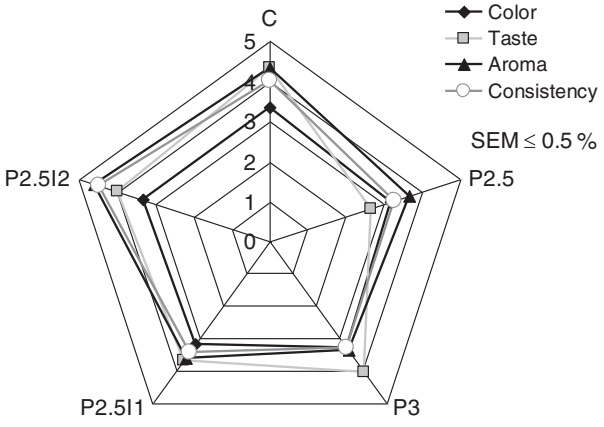

Fig. 4. Sensory attributes (color, taste, aroma and consistency) of control and reduced fat minced meats. (C: control; P2.5: 2.5% of plasma proteins; P3: 3% of plasma proteins; P2.5I1: 2.5% of plasma proteins and 1% of inulin; P2.5I1: 2.5% of plasma proteins and 2% of inulin).

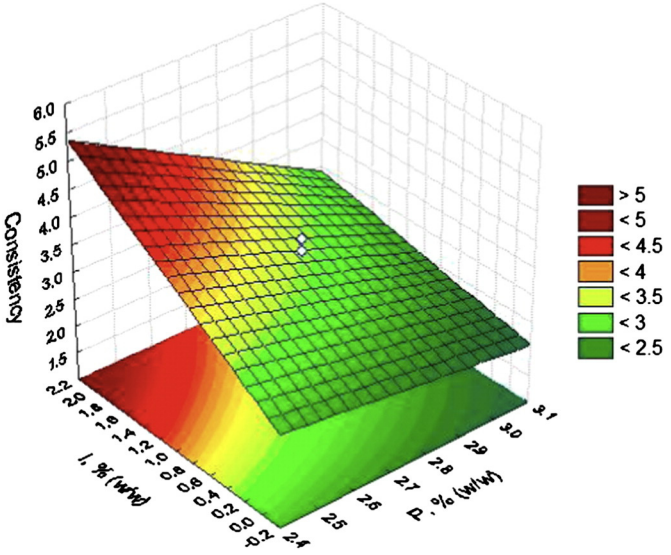

Fig. 5. Surface plot for minced meat acceptability (sensorial consistency) with the incorporation of different concentrations of fat replacers: bovine plasma proteins (P) and inulin (I).

Table 4
Completed design layout: acceptability of the consistency of the samples and %F of the stability test in a two-level full factorial with center point.

Std. run number	Component proportion		%F	Sensory analysis: consistency
	P (processed plasma protein, % w/w)	I (inulin, % w/w)		
1 — P2.5	2.5	0	1.0 ± 0.9	2.8 ± 0.3
2 — P3	3.0	0	35 ± 6	2.2 ± 0.1
3 — P2.5 I2	2.5	2	0.4 ± 0.2	4.8 ± 0.2
4 — P3 I2	3.0	2	17 ± 2	3.0 ± 0.2
5 — P2.7 I1	2.7	1	8 ± 1	3.8 ± 0.1

these results, since this formulation could reproduce adequately the sensory characteristics of the full fat samples. Thus, the formulation prepared with inulin (2%w/w) and bovine plasma proteins (2.5%w/w) presented hardness values similar to those of the control sample, and it had a higher sensory texture than the other products, having the best overall acceptance from the sensory panels. These results suggest that the appropriate combination of protein and inulin in the minced meat formulation acts properly as fat replacers.

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References

Adebowale, K. O., Henle, T., Schwarzenbolz, U., & Doert, T. (2009). Modification and properties of African yam bean (*Sphenostylis stenocarpa* Hochst. Ex A. Rich.) harms starch I: Heat moisture treatments and annealing. *Food Hydrocolloids*, *23*, 1947–1957.

Álvarez, D., & Barbut, S. (2013). Effect of inulin, β-glucan and their mixtures on emulsion stability, color and textural parameters of cooked meat batters. *Meat Science*, *94*, 320–327.

AOAC (Association of Official Agricultural Chemists) (1995). *Official methods of analysis* (16th ed.)Arlington: AOAC International.

Argentinean Alimentary Code (AAC) (2012). *Meat foods and tune (chapter VI) and alimentary preservatives (chapter XVIII).* : Argentina.

Babiker, E., Fujisawa, N., Matsudomi, N., & Kato, A. (1996). Improvement in the functional properties of gluten by protease digestion or acid hydrolysis followed by microbial transglutaminase treatment. *Journal of Agricultural and Food Chemistry*, *44*, 3746–4750.

Beriain, M. J., Gómez, I., Petri, E., Insausti, K., & Sarriés, M. V. (2011). The effects of olive oil emulsified alginate on the physico-chemical, sensory, microbial, and fatty acid profiles of low-salt, inulin-enriched sausages. *Meat Science*, *88*, 189–197.

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, *37*, 911–917.

Bloukas, J. G., & Paneras, E. D. (1993). Substituting olive oil for pork back-fat affects quality of low-fat frankfurters. *Journal of Food Science*, *58*, 705–709.

Borcherding, K., Lorenzen, P. Chr, Hoffmann, W., & Schrader, K. (2008). Effect of foaming temperature and varying time/temperature-conditions of pre-heating on the foaming properties of skimmed milk. *International Dairy Journal*, *18*, 349–358.

Cardoso, C., Mendes, R., & Nunes, M. L. (2008). Development of healthy low-fat fish sausage containing dietary fibre. *International Journal of Food Science and Technology*, *43*, 276–283.

Chakraborty, P. (1986). Coconut protein isolate by ultrafiltration. In M. Le Meguer, & P. Jelen (Eds.), *Food engineering and process applications* (pp. 308–315). New York: Elseiver Applied Science Publishers.

Collar, C., Santos, E., & Rosell, C. M. (2007). Assessment of the rheological profile of fibre-enriched bread doughs by response surface methodology. *Journal of Food Engineering*, *78*, 820–826.

Glaser, L. A., Paulson, A. T., Speers, R. A., Yada, R. Y., & Rousseau, D. (2007). Foaming behavior of mixed bovine serum albumin–protamine systems. *Food Hydrocolloids*, *21*, 495–506.

Hennelly, P. J., Dunne, P. G., O'Sullivan, M., & O'Riordan, E. D. (2006). Textural, rheological and microstructural properties of imitation cheese containing inulin. *Journal of Food Engineering*, *75*, 388–395.

Hsu, S. Y., & Sun, L. Y. (2006). Comparisons on 10 non-meat protein fat substitutes for low-fat Kung-wans. *Journal of Food Engineering*, *74*, 47–53.

Hughes, E., Mullen, A.M., & Troy, D. J. (1998). Effects of fat level, tapioca starch and whey protein on frankfurters formulated with 5% and 12% fat. *Meat Science*, *48*, 169–180.

Kip, P., Meyer, D., & Jellema, R. H. (2006). Inulins improbe sensoric and textural properties of low-fat yoghurts. *International Dairy Journal*, *16*, 1098–1103.

Mendoza, E., García, M. L., Casas, C., & Selgas, M.D. (2001). Inulin as fat substitute in low fat, dry fermented sausages. *Meat Science*, *57*, 387–393.

Mun, S., Kim, Y. L., & Kang, C. G. (2009). Development of reduced fat mayonnaise using 4αGTase-modified rice starch and xanthan gum. *International Journal of Biological Macromolecules*, *44*, 400–407.

Nikovska, K. (2010). Oxidative stability and rheological properties of oil-in-water emulsions with walnut oil. *Advance Journal of Food Science and Technology*, *2*(3), 172–177.

Rodriguez Furlán, L. T., Lecot, J., Pérez Padilla, A., Campderrós, M. E., & Zaritzky, N. (2012). Stabilizing effect of saccharides on bovine plasma protein: a calorimetric study. *Meat Science*, *91*, 478–495.

Rodriguez Furlán, L. T., Pérez Padilla, A., & Campderrós, M. E. (2010). Inulin like lyoprotectant of bovine plasma proteins concentrated by ultrafiltration. *Food Research International*, *43*, 788–796.

Rodriguez Furlán, L. T., Pérez Padilla, A., & Campderrós, M. E. (2011). Assessment of functional properties of bovine plasma proteins compared with other protein concentrates, application in a hamburger formulation. *American Journal of Food Technology*, *6*(9), 717–729.

Rodríguez Patino, J. M., Carrera Sánchez, C., & Rodríguez Niño, M. R. (2008). Implications of interfacial characteristics of food foaming agents in foam formulations. *Advances in Colloid and Interface Science*, *140*, 95–113.

SAS (1989). User guide: Statistic. Version, 1989. Cary, NC: SAS Inst. Inc., USA.

Thaiudom, S., & Khantarat, K. (2011). Stability and rheological properties of fat-reduced mayonnaises by using sodium octenyl succinate starch as fat replacer. *Procedia Food Science*, *1*, 315–321.

Viana, F. R., Silva, V. D.M., Delvivo, F. M., Bizzotto, C. S., & Silvestre, M. P. C. (2005). Quality of ham pâté containing bovine globin and plasma as fat replacers. *Meat Science*, *70*, 153–160.

Wang, C. R., & Zayas, J. F. (1992). Comparative study of corn germ and soy proteins utilization in comminuted meat products. *Journal of Food Quality*, *15*(2), 153–167.

Weiss, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science*, *86*, 196–213.

Youssef, M. K., & Barbut, S. (2009). Effects of protein level and fat/oil on emulsion stability, texture, microstructure and color of meat batters. *Meat Science*, *82*, 228–233.

Youssef, M. K., & Barbut, S. (2011). Effects of two types of soy protein isolates, native and preheated whey protein isolates on emulsified meat batters prepared at different protein levels. *Meat Science*, *87*, 54–60.

Zhang, W., Xiao, S., Samaraweera, H., Lee, E. J., & Ahn, D. U. (2010). Improving functional value of meat products. *Meat Science*, *86*, 15–31.

Zimeri, J. E., & Kokini, J. L. (2003). Rheological properties of inulin–waxy maize starch systems. *Carbohydrate polymers*, *52*, 67–85.