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Storage stability of low-fat chicken sausages

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Abstract

Storage stability of low-fat chicken sausages formulated with fresh breast chicken meat with 0%, 2%, and 5% of added beef tallow was examined during 50-day refrigerated storage. The formulations also contained whey protein, guar and xanthan gums, NaCl, $NaNO_2$, ascorbic acid and sodium tripolyphosphate. Samples were heat-processed until a final internal temperature of 74 °C was reached, cooled, vacuum packaged and stored at 4 °C. Formulations showed good thermal stability, with process yields ranging between 94% and 97%, and purge losses less than 9.7% at the end of the study. Water activity slightly decreased during the first 28 days of storage and remained constant afterwards for all the tested samples, while pH and color parameters remained constant. As fat content increased a harder, more gummy and cohesive product was obtained, with higher chewiness and lower springiness and resilience values. Neither coliforms nor sulfite-reducing Clostridium were detected during the storage of the samples. Psychrotrophic lactic acid bacteria was the dominant microflora reaching levels lower than 7 log CFU/g after 50 days of storage at 4 °C. Formulated low-fat chicken sausages had acceptable sensory scores independently of the added fat. Extra lean products with very good stability and quality attributes were obtained.

Keywords: Low-fat sausages; Texture; Hydrocolloids; Whey proteins; Breast chicken meat

1. Introduction

Health organizations have promoted the reduction of fat and cholesterol in the diet as a means of reducing cardiovascular heart disease and controlling obesity. Diets containing no more than 30% of their calories from fat are recommended and consumer interest in purchasing reduced-calorie, reduced-fat foods has increased (Pearson & Gillett, 1996).

Meat batters are formed by chopping meats, along with other ingredients, to form a coarse dispersion of mainly water, fat and protein. Thermal processing converts the highly viscous sol into a viscoelastic solid that can be viewed as a protein gel filled with fat particles. Since fat acts as a reservoir for flavor compounds and contributes to product texture, reducing the fat content may alter product quality (Foegeding & Ramsey, 1986). Increasing the water level beyond traditional levels tends to diminish the stability of the meat system. This partially explains the excess purge, high cooking loss and soft texture (Claus, Hunt, & Kastner, 1989; Claus, Hunt, Kastner, & Kropf, 1990). In order to achieve favorable product characteristics in reducing fat content, several functional ingredients capable of improving water binding and modifying texture are of interest to meat processors. Hydrocolloids with their unique characteristics in building texture, stability and emulsification are of great interest in low-fat processed meat area due to their ability of binding water and forming gels (Candogan & Kolsarici, 2003a). Xanthan gum was found to be the best gum in retention of added

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water in a low-fat meat emulsion system (Wallingford & Labuza, 1983). Guar gum produces a high viscosity in cold solutions, is a good stabilizer and water binder. It imparts a slick creamy mouth feel to meat products, which mimics fat. It is non-gelling, but reacts synergistically with xanthan gum giving rise to increased viscosity (Pearson & Gillett, 1996). The 30:70 mixture chosen in this study corresponds to the maximum viscosity of guar/xanthan gum solutions (BeMiller & Daniels, 2002). This maximum viscosity is attributed to the synergistic intermolecular interaction between xanthan and guar gums that helps to develop a more entangled network than when either of them is used alone (BeMiller & Whistler, 1996; Casas, Mohedano, & García-Ochoa, 2000; Quintana, Califano, Zaritzky, Partal, & Franco, 2002).

Whey proteins are well-known ingredients for improving food products, because of their high nutritional quality and their versatility functional abilities (Wit, 1988). They form gels upon heating and cooling increasing the firmness of sausage products (Pearson & Gillett, 1996).

Evaluation of the stability to test shelf-life and potential pathogens growth is a requirement for the development of a new food product. Comminuted poultry products contain microorganisms as a result of handling, incorporation of contaminated raw material and ingredients, and contact with equipment. Limited information have been reported on the refrigerated storage stability of low-fat meat products. Morrison, Webb, Blumer, Ivey, and Haq (1971) reported that emulsion stability was highly dependent upon the level of added water. Haq, Webb, Whitfield, and Ivey (1973) failed to obtain stable sausage type emulsion, which did not contain water-binding additives, at the 15% lipid level. Hung and Zayas (1991) evaluated sensory, chemical, and bacteriological stability of frankfurters containing milk protein and corn germ protein flour during 45 days of storage at 1–2 °C. The addition of chitosan to 22% fat Chinese-style sausage resulted in no detrimental effect on textural properties during refrigerated storage at 4 °C; all bacterial counts were lower than 7 log CFU/g after 9 weeks of storage (Lin & Chao, 2001). Candogan and Kolsarici (2003a) studied the storage stability of low-fat frankfurters concluding that the products with carrageenan or pectin had lower thiobarbituric acid values and higher bacterial load as compared to the high fat control.

The objective of this study was to evaluate the effect of different fat levels on the stability of low-fat chicken sausages, formulated with whey protein, guar and xanthan gums, by measuring microbial counts, color, textural characteristics, water activity, pH, and purge loss of products over 50-day refrigerated (4 °C) storage. Chemical composition, sensory analysis, and microstructure of the products were also determined.

2. Materials and methods

2.1. Materials

Low-fat chicken sausages were developed using fresh breast chicken meat and beef tallow obtained from local processors. Whey protein concentrated (WPC) containing 40% protein, (Milkaut, Santa Fe, Argentina), food-grade commercial preparation of xanthan and guar gums (Sigma Chemical Co., St. Louis, MO) and analytical grade NaCl, $NaNO_2$, ascorbic acid and sodium tripolyphosphate (TPP) were used. Cold distilled water was used in all formulations (4 °C).

2.2. Product manufacture

Breast chicken meat was ground with a commercial food processor (Universo, Rowenta, Germany) equipped with a 14 cm blade for 10 min at the highest speed and storage overnight at 4 °C. Dry ingredients were slowly added to the ground chicken meat as powders while processing. Afterwards cold water was incorporated and finally ground fat at room temperature was added. The addition of ingredients took less than 5 min and final temperature of batters varied between 12 and 15 °C. The batters were manually stuffed in collagen reconstituted casing (27 mm diameter) and hand-linked to form approximately 8 cm links in length. The sausages were then placed in "cook-in" bags (PO_2: 35 $cm^3/(m^2$ día bar) at 23 °C, CN510, Sealed Air Argentina), putting three sausages per bag. The bags were heat-processed in a temperature-controlled water-bath (Haake L, Haake Buchler Instruments, Karlsruhe, Germany) maintained at 80 °C until a final internal temperature of 74 °C was reached, according to the recommendations of the FDA-CFSAN (2003). Temperature was monitored by a type-T (copper–constantan) thermocouple inserted in the center of a link, time/temperature data were recorded (Servor 102 NGI, USA). Then, samples were cooled immediately in an ice-water-bath and were vacuum packaged in the same bags. The packages were stored at 4 °C during 50 days.

Three levels of fat were studied by adding different beef tallow mass (0%, 2% and 5%); the corresponding water additions were 30%, 28% and 25%, respectively, to maintain the content of fat plus water added constant (30%). Percentual contents are expressed as g/100 g raw batter. The concentration of sodium nitrite was selected according to the level permitted by Argentinean Regulations (0.015 g per 100 g poultry product CAA, 1996), being this value lower than the maximum permitted by the USA Code of Federal Regulations (USDA-FSIS, 1999), 0.0645 g per 100 g poultry product.

All formulations were prepared with the same common ingredients (Table 1): 65% raw chicken meat, 30% added fat + water, 2% NaCl, 1.95% WPC,

Table 1
Formulations to prepare 100 g of raw batter

Ingredients	Formulation 1 (g)	Formulation 2 (g)	Formulation 3 (g)
Breast chicken meat	65.214	65.214	65.214
Beef tallow	0	2	5
Water added	30	28	25
NaCl	2	2	2
Whey protein concentrated (WPC)	1.95	1.95	1.95
Guar gum	0.098	0.098	0.098
Xanthan gum	0.228	0.228	0.228
Sodium tripolyphosphate (TPP)	0.2	0.2	0.2
White pepper	0.2	0.2	0.2
Ground nutmeg	0.05	0.05	0.05
$NaNO_2$	0.015	0.015	0.015
Ascorbic acid	0.045	0.045	0.045

0.098% guar gum, 0.228% xanthan gum, 0.2% TPP, 0.2% white pepper, 0.05% ground nutmeg, 0.015% $NaNO_2$, and 0.045% ascorbic acid. The process was replicated twice.

2.3. Chemical analysis of the precooked sausages

Moisture, ash and protein contents were determined according to AOAC methods 24.003, 24.009 and 24.027 respectively (AOAC, 1980) in triplicates. Fat content was determined on previously dried samples by Soxhlet method, using ethyl ether and petroleum ether (Bp: 35–60 °C) in a 1:1 relationship as extraction solvent (García, Ferrero, Bertola, Martino, & Zaritzky, 2002).

2.4. pH and water activity

pH was measured during the storage period (7-day intervals) on the different formulations using an spear tip glass electrode (Cole-Palmer, cat. U-05998-20) on a pH meter (model EC30, Hacht, Loveland, USA). Water activity was determined on an AquaLab equipment Serie 3 (Decagon Devices, Inc., WA) initially and after 14, 28 and 50 days of storage.

2.5. Process yield

Process yield was determined by weighing the product before and after cooking, and corresponds to weight loss due to heating. The percent loss in weight during the precooking treatment is reported as "process yield, %" (Candogan & Kolsarici, 2003b).

2.6. Purge loss

Purge loss was measured by removing two packages of each type of sausage from refrigerated storage after 7, 21 and 45 days. The sausages were taken out from the package, placed in funnels to drain (1 min), and carefully bloated with filter paper to eliminate any liquid on the surface of the links. The initial weight of the links had also been measured at the beginning of the experiment. Purge loss was reported as a percentage of content weight.

2.7. Color measurements

Internal color was measured with a tristimulus reflectance colorimeter (Minolta CR-300, Minolta Corp., Ramsey, New Jersey, USA). Color was recorded using the CIE-$L * a * b *$ scale. All the measurements were carried out on transversally cut sections of four different sausages, weekly, during the storage (7-day intervals) at 4 °C.

2.8. Texture measurements

All instrumental texture analyses were done on chilled (4 °C) sausages at 7-day intervals during the storage period. For every formulation two repeated measurements were taken for each replicate and mean values were reported.

Texture profile analysis (TPA) (Brennan & Bourne, 1994; Bourne, 1978) of sausages was performed. Samples 1.5 thick and 1.7 cm in diameter were cut from the center of the links and compressed twice to 30% of their original height between flat plates using a TAXT2i Texture Analyzer (Stable Micro Systems, UK) interfaced with a computer, which controls the instruments and analyses the data, using the software supplied by Texture Technologies Corp. In these experiments the head was operated at 0.5 mm/s. Hardness (peak force of first compression cycle, *N*), springiness (distance of the detected height of the product on the second compression divided by the original compression distance, mm/mm), cohesiveness (ratio of positive areas of second cycle to area of first cycle, J/J), adhesiveness (negative force area of the first byte represented the work necessary to pull the compressing plunger away from the sample, J), chewiness (hardness × cohesiveness × springiness), gumminess (hardness × cohesiveness), and resilience (area during the withdrawal of the first compression divided by the area of the first compression, J/J) were determined.

2.9. Microbial analysis

Bacterial counts were determined by pour plate method every 7 days during refrigerated storage. The initial dilution was made by aseptically blending in Stomacher for 60 s, 10 g of sample with 90 ml 1 g/l peptone solution. Appropriate serial dilutions were plated duplicate with Plate Count Agar (PCA, Oxoid) for total mesophilic

aerobic count (incubated at 30 °C for 2 days) and total psychrotrophic aerobic count (incubated at 4 °C for 7 days), with Violet Red Bile Agar (Merck KGaA, Darmstadt, Germany) for *Enterobacteriaceae* (incubated at 37 °C for 24 h), and with Man Rogosa Sharp Agar (MRS, Oxoid) for lactic acid bacteria (incubated at 30 °C for 2 days). Yeast Glucose Cloranfenicol Agar (YGC) (Merck) was used for mould and yeast counts (incubated for 5 days at 30 °C). Data were expressed as log colony forming units (CFU)/g sample.

Gram coloration was applied to the colonies cultured on both PCA and MRS at 30 °C; microscopy observation was conducted using light microscopy (Ortholux II, Leitz, Germany). Besides, catalase test was performed on isolated colonies from the above mentioned media to confirm that they were lactic acid bacteria.

The quality of the products was tested at 2-week intervals using the most probable number (MPN) method for total coliform counts according to AOAC Method 46016 (AOAC, 1984) and sulfite-reducing Clostridium counts were enumerated in sulphadiazine polymyxin sulphite (SPS) agar (Merck KGaA, Darmstadt, Germany) incubated at 37 °C for 48 h in anaerobic condition.

2.10. Electron microscopy

Small pieces of sausages of 0.5 cm in diameter and 0.2–0.3 cm thick were used for electron microscopy analysis. Samples were fixed with Carnoy fluid (60% ethyl alcohol, 30% chloroform, glacial 10% acetic acid, v/v) at 4 °C for 24 h then they were dehydrated using gradually increasing concentrations of ethyl alcohol: 70% (12 h), 95% (2 h) and 100% (2 h). Samples were mounted on aluminum stubs using a double-sided tape and then coated with a layer of gold (40–50 nm), allowing surface and cross-section visualization. Micrographs of the samples were obtained with scanning electron microscope (SEM 505, Philips, The Netherlands).

2.11. Sensory evaluation

Sensory analyses were conducted by 15 panelists from graduate students and faculty members in our Institute who were experienced in sensory evaluation of foods, but received no specific training relevant to these products. Panelists were asked to indicate how much they liked or disliked each product on a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely) according to flavor, texture and overall acceptability characteristics. Samples that have been stored for 15 days at 4 °C were prepared by steeping the sausages in boiling water for 3 min, draining the liquid and holding on a warming tray in covered plates for no longer than 30 min. Warm, 2 cm long pieces, were distributed in white polystyrene plates and presented to the panelist with three-digit codes and in random order for evaluation. Tap water was supplied to the panelist for rinsing between samples. Experiments were conducted in an appropriately designed and lighted room.

2.12. Statistical analysis

Analysis of variance was conducted separately for the dependent variables of the instrumental texture analysis (hardness, cohesiveness, adhesiveness, springiness, chewiness, gumminess, resilience), color parameters (L^*, a^*, and b^*), aw, pH, purge loss, and microbial counts. The independent variables were fat and storage time. For simultaneous pairwise comparisons, least significance differences (LSD) test was chosen. Differences in means and F-tests were considered significant when $P < 0.05$. Confidence intervals of the means were also calculated at $P < 0.05$. All statistical procedures were computed using the SYSTAT software (SYSTAT, Inc., Evanston, IL).

3. Results and discussion

3.1. Chemical analysis, pH and aw

Initial chemical composition data for thermally processed chicken sausages are shown in Table 2. The protein contents of the three groups were similar even though fat contents were different because the amount of chicken meat per 100 g of raw batter was the same for the three formulations (Table 1). Lipid contents reflected the amount of fat added plus lipids contained in the raw chicken meat. The results indicated ($P < 0.01$) that aw decreased during the first 28 days of refrigerated storage and remained constant afterwards (Table 3). Fat content did not affect aw values ($P > 0.8$). Although a change in pH of the sausages during storage would be expected because of microbial growth, storage time had no effect ($P > 0.08$) on pH values but was affected by fat content (Table 4).

Table 2
Proximate analysis values and process yield of low-fat chicken sausages formulated with different fat levels[1]

	Added fat (g/100 g raw meat)		
	0	2	5
Moisture (g/100 g product)	$76.61^{a} \pm 0.84$	$75.20^{a} \pm 0.43$	$72.25^{b} \pm 1.72$
Protein (g/100 g product)	$14.34^{a} \pm 0.12$	$14.46^{a} \pm 0.16$	$14.38^{a} \pm 0.26$
Lipids (g/100 g product)	$0.61^{a} \pm 0.05$	$3.22^{b} \pm 0.31$	$5.82^{c} \pm 0.11$
Ash (g/100 g product)	$2.74^{a} \pm 0.09$	$2.79^{a} \pm 0.07$	$2.87^{a} \pm 0.19$
Process yield (%)	$95.4^{a} \pm 1.3$	$94.2^{a} \pm 1.8$	$97.0^{a} \pm 1.5$

[1] Mean value ± standard error of the mean. Different superscripts within the same row differ significantly ($P < 0.05$).

Table 3
Effect of added fat on water activity (aw) of formulated sausages along storage time[1]

Days of storage	Water activity Added fat (g/100 g raw meat)		
	0	2	5
0	0.961[c]	0.958[bc]	0.963[c]
14	0.952[b]	0.955[b]	0.955[b]
28	0.942[a]	0.947[a]	0.944[a]
50	0.949[a]	0.946[a]	0.943[a]

[1] LSD = 0.0076. Different superscripts indicate that the average values within a cell differ significantly ($P < 0.05$).

Table 4
Significance levels from the analysis of variance for hardness (N), springiness (mm), cohesiveness (J/J), adhesiveness (J), chewiness (N × mm), gumminess (N), and resilience (J/J) of the TPA analysis

	Source of variation		
	Fat	Storage time	Fat × storage time
Hardness	<0.01	<0.01	<0.01
Springiness	<0.01	N.S.	N.S.
Cohesiveness	<0.01	<0.01	<0.01
Adhesiveness	N.S.	N.S.	N.S.
Chewiness	<0.01	<0.01	<0.01
Gumminess	<0.01	<0.01	<0.01
Resilience	<0.01	<0.01	N.S.

N.S. = non-significant ($P > 0.05$).

3.2. Process yield

Process yield is a practical method for determining weight loss during cooking of sausages. It ranged between 94% and 97% for the tested formulations indicating good thermal stability (Table 2). Similar results were reported by Trout and Schmidt (1986) for restructured beef rolls with 0.321% TPP and no fat added. Process yield depends on the ability of the protein matrix to immobilize both of fat and water. However, in meat batters with extremely low fat, gelling ability and water retention capacity of non-meat ingredients may play a greater role rather than emulsion formation in determining thermal and storage stability of the products (Su, Bowers, & Zayas, 2002).

In the formulations assayed the potential loss of water-binding properties when water was added to the batter was compensated with the addition of whey proteins (WP), gums (G), and TTP, due to their high water holding capacity.

3.3. Purge losses

For 0% and 2% added fat formulations, purge loss remained practically constant during storage (maximum value 9.71%); its values were significantly higher than those corresponding to 5% added fat sausages (Fig. 1). However purge losses for the highest fat formulation increased after 45 days of storage. The observed purge values were similar to those reported for less than 3%-fat beef frankfurters containing starch and polyphosphates (Candogan & Kolsarici, 2003b) and for 10% fat beef frankfurters with 0.5% TTP (Hensley & Hand, 1995).

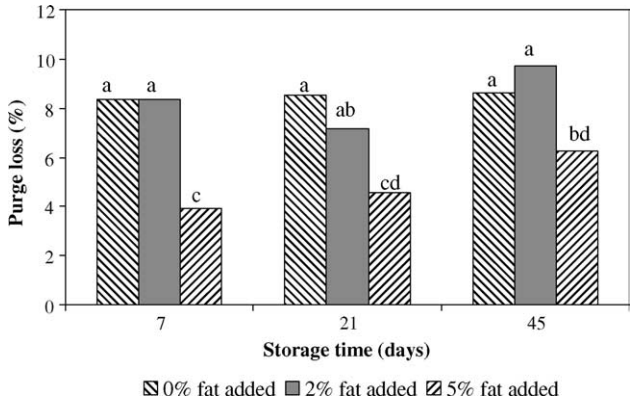

Fig. 1. Purge loss (%) along refrigerated storage (4 °C) for low-fat chicken sausages formulated with different fat levels. Different letters indicate that the average values differ significantly ($P < 0.05$).

3.4. Color measurements

Analysis of variance showed that none of the color parameters (L^*, a^*, and b^*) changed during storage. Table 5 shows the effect of composition on average color values of sausages. There was no apparent relationship between color and fat content, the observed differences might be attributed to the normal biological variability of the chicken meat used.

3.5. Texture measurements

Table 4 shows the significance levels obtained from the ANOVA for the TPA analysis. Significant differences ($P < 0.05$) were found in hardness, cohesiveness, chewiness, gumminess, springiness, and resilience values within the three levels of added fat. Overall, as fat con-

Table 5
Effect of fat content on the pH, color, adhesiveness, cohesiveness and springiness of chicken sausages

Property	Added fat (g/100 g raw meat)		
	0	2	5
pH	6.07[b]	6.01[a]	6.17[c]
Color			
Lightness (L^*)	81.2[a]	83.2[c]	82.0[b]
Redness (a^*)	3.47[c]	2.66[a]	3.11[b]
Yellowness (b^*)	11.4[a]	12.3[c]	11.9[b]
Texture			
Adhesiveness	−0.444[a]	−0.353[a]	−0.529[a]
Cohesiveness	0.581[a]	2.015[b]	2.038[b]
Springiness	0.953[a]	0.943[a]	0.917[b]

Different superscripts within the same row indicate that the average values differ significantly ($P < 0.05$).

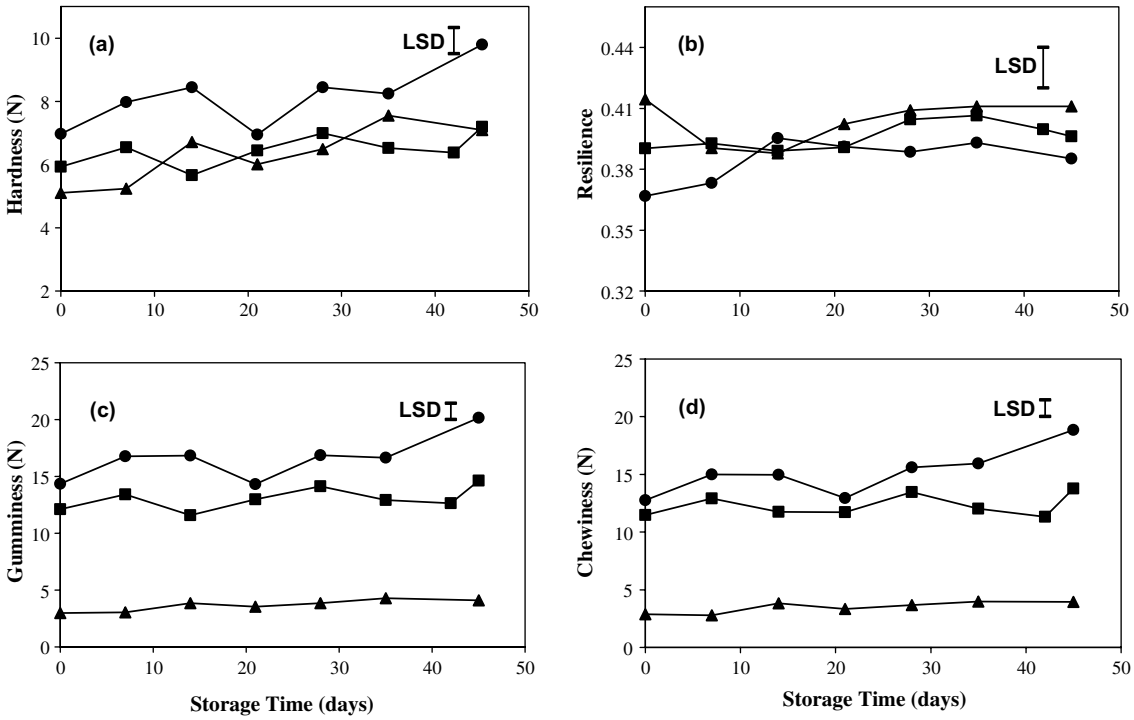

Fig. 2. Effect of fat level and refrigerated storage time on parameters of the texture profile analysis, average values for: (a) hardness, (b) resilience, (c) gumminess and (d) chewiness. Error bars indicate least significant difference, LSD, ($P < 0.05$). (●) 5% fat added; (■) 2% fat added; (▲) 0% fat added.

tent increased a harder, more gummy and cohesive product was obtained, with higher chewiness and lower springiness and resilience values (Fig. 2). Several authors have informed that the higher the fat content in frankfurter formulation the harder the final product (Candogan & Kolsarici, 2003b; Chang & Carpenter, 1997; Hensley & Hand, 1995; Sutton, Hand, & Newkirk, 1995). In order to maintain fat + added water of 30%, as fat content increases the amount of water present that acts as a plasticizer decreases given a less softer product. Hardness increased during storage at 4 °C for the three formulations studied, while chewiness and gumminess only increased along storage for 2% and 5% fat added (Fig. 2). This increase in hardness was likely due to water loss from the product (purge) during refrigerated storage and was also reported by Candogan and Kolsarici (2003b) for low-fat beef frankfurters. Gumminess and chewiness time dependence are mostly the result of the increase in hardness, since cohesiveness and springiness remained constant. Resilience showed different change patterns depending on the fat level of the samples (Fig. 2). Average values of the TPA evaluation of chicken sausages which were independent of storage time are shown in Table 5.

3.6. Microbial analysis

No coliforms were determined throughout 50 days of storage at 4 °C in all the tested samples due to the adequate heat treatment during production. Hung and Zayas (1991) also informed that coliforms were heat sensitive and easily destroyed by the temperature reached during treatment in frankfurter manufacture. No sulfite-reducing Clostridium were noted in any sausages during the storage period either, indicating safe sanitary conditions in the product.

Low initial microbial counts of all formulations, in the different tested culture conditions were found indicating a successful thermal processing, which inactivated most of the microorganisms. Fig. 3 shows lactic acid bacteria, total mesophilic, and total psychrotrophic aerobic counts as a function of refrigerated storage time for the three fat levels studied. When comparing PCA (4 °C), PCA (30 °C) and MRS average counts which corresponded to a given time and formulation the differences were not statistically significant ($P > 0.05$). Gram coloration and catalase test on isolated bacteria confirmed that they were lactic acid bacteria. Thus psychrotrophic lactic acid bacteria was the dominant microflora in these products that increased during storage, reaching levels lower than 7 log CFU/g after 50 days of storage at 4 °C. Microbial growth rate was similar for the groups with 0% and 2% added fat; the group formulated with 5% added fat showed lower rates ($P < 0.05$) than the other two formulations (Fig. 3). This difference in growth rates might be explained by the fact that the products with higher fat composition contained lower moisture. Several authors have suggested that higher

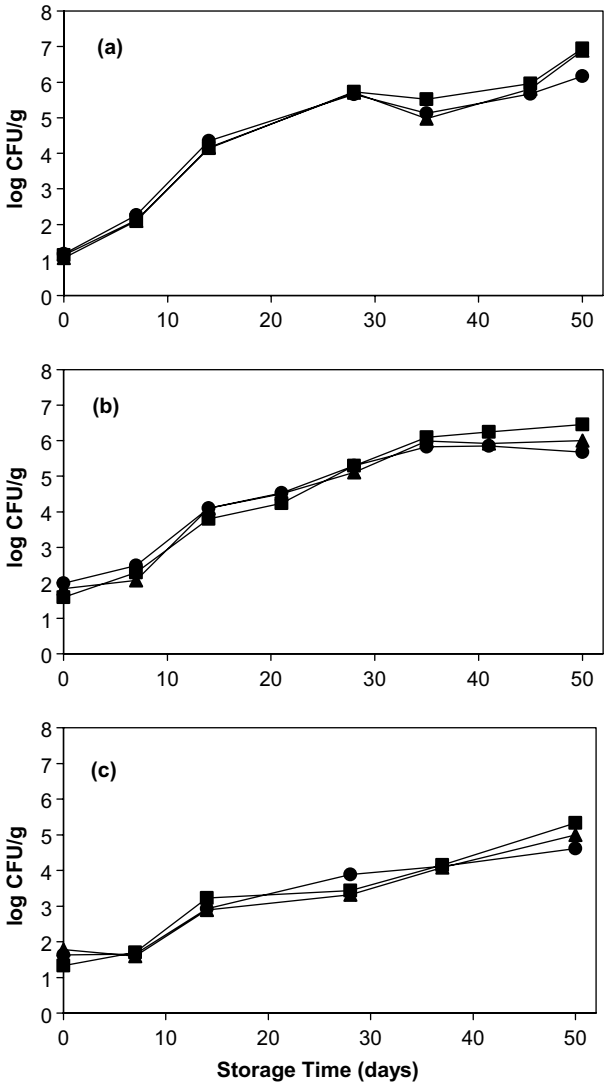

Fig. 3. Effect of fat level and refrigerated storage time on microbial growth. (●) total mesophilic aerobic count; (▲) total psychrotrophic aerobic count; (■) lactic acid bacteria counts. (a) 0% fat added; (b) 2% fat added; (c) 5% fat added.

water contents in low-fat sausage provide better environment for bacterial growth (Bradford, Huffman, Egbert, & Mikel, 1993; Keeton, 1994; Reagan, Liou, Reynolds, & Carpenter, 1983; Yackel & Cox, 1992).

Enteriobacteriaceae, mould and yeast counts were always lower than 2 log CFU/g. Inhibition of mold/yeast growth was probably a result of the growth of lactic acid-producing bacteria under anaerobic packaging conditions during refrigerated storage (Bradford et al., 1993).

3.7. Electron microscopy

Micrographs of the samples are shown in Fig. 4. A cohesive and somewhat granular protein matrix was observed in all formulations. Different sizes of lipid droplets exist, with a relatively smooth shell surrounding them without pores (Fig. 4a). Fine strands and sheets with gel-like appearances are also observed in Fig. 4b, they were probably caused by the addition of whey protein and hydrocolloids to the formulation.

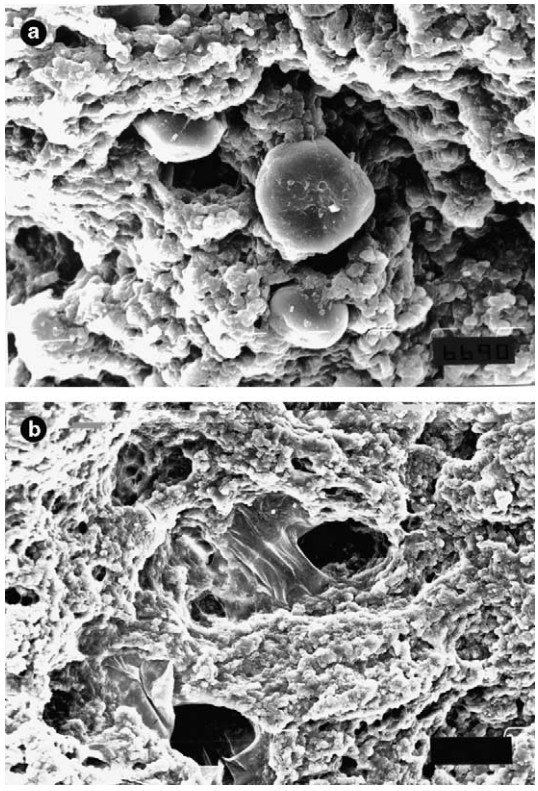

Fig. 4. Scanning electron micrographs of 5% added fat chicken sausage: (a) 1500× (bars = 10 μm); (b) 500× (bar = 30 μm).

3.8. Sensory evaluation

The 15 experienced panelists evaluated the texture, flavor and overall acceptability of the formulations that have been stored for 15 days at 4 °C. Fat content had no significant effect on the mean sensory scores. Average scores for flavor, texture, and overall acceptability were 7.3, 6.9, and 7.1 respectively (like moderately). The observations were classified into three perception

Table 6
Sensory flavor, texture, and acceptability scores on a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely) of low-fat chicken sausages with different fat content at 15 days of refrigerated storage

Added fat (g/100 g raw meat)	Sensory properties		
	Average values on hedonic scale		
	Flavor	Texture	Acceptability
0	7.2 (86.7)	6.3 (73.3)	6.8 (80.0)
2	7.0 (84.6)	7.2 (92.3)	7.1 (92.3)
5	7.7 (90.5)	7.0 (85.7)	7.4 (90.5)

Percentage of panelists that scored each tested property between 6 and 9 is given between parenthesis.

sensorial groups, the first one corresponded to those that disliked the product (scores 1–4, dislike extremely to slightly), the second one was indifferent (scores 5), and the third group expressed that they liked the samples (scores 6–9, like slightly to like extremely). More than 85% of the panelists liked the flavor of the products, and over 80% of the panelists liked the products, considering the overall acceptability of the tested sausages, independently of the added fat (Table 6).

4. Conclusions

All the tested formulations showed good thermal stability, with process yields ranging between 94% and 97%. Sausages containing 0% and 2% fat maintained purge losses practically constant, higher than for the 5% added fat sausages, reaching maximum values of 9.71%. Water activity slightly decreased during the first 28 days of refrigerated storage for all the tested samples and remained constant afterwards, while pH and color parameters remained constant during storage at 4 °C. Hardness values increased during storage for the three formulations studied, while chewiness and gumminess only increased along refrigerated storage for 2% and 5% fat added. As fat content increased a harder, more gummy and cohesive product was obtained, with higher chewiness and lower springiness and resilience values. Neither coliforms nor sulfite-reducing Clostridium were detected during the storage of the samples indicating the safe sanitary conditions of the products. Psychrotrophic lactic acid bacteria was the dominant microflora reaching levels lower than 7 log CFU/g after 50 days of storage at 4 °C. Formulated low-fat chicken sausages had acceptable sensory scores independently of the added fat since over 80% of the panelists liked the products considering the overall acceptability of the tested sausages. Formulated low-fat chicken sausages had generally acceptable sensory scores.

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References

AOAC (1980). *Official methods of analysis* (1018pp) (13th ed.). Washington, DC: Association of Official Analytical Chemists.

AOAC (1984). *Official methods of analysis* (1141pp) (14th ed.). Washington, DC: Association of Official Analytical Chemists.

BeMiller, J. N., & Whistler, R. L. (1996). Carbohydrates. In O. R. Fennema (Ed.), *Food chemistry* (Third Ed., pp. 207–210). New York: Marcel Dekker.

BeMiller, F. S., & Daniels, J. R., (2002). *Guar–xanthan interactions*. Available from: <http://www.cfs.purdue.edu/class/F&N630/Virt_-Class_2/guarandLBG.htm> Accessed November 4, 2003.

Bradford, D. D., Huffman, D. L., Egbert, W. R., & Mikel, W. B. (1993). Potassium lactate effects on low-fat fresh pork sausage chubs during simulated retail distribution. *Journal of Food Science, 58*(6), 1245–1248.

Brennan, J. G., & Bourne, M. C. (1994). Effect of lubrication on the compression behaviour of cheese and frankfurters. *Journal of Texture Studies, 25*, 139–150.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology, 32*(7), 62–66, 72.

CAA, Código Alimentario Argentino. (1996). De la Canale y Asociados. Buenos Aires. Argentina.

Candogan, K., & Kolsarici, N. (2003a). Storage stability of low-fat beef frankfurters formulated with carrageenan or carrageenan with pectin. *Meat Science, 64*(2), 207–214.

Candogan, K., & Kolsarici, N. (2003b). The effects of carrageenan and pectin on some quality characteristics of low-fat beef frankfurters. *Meat Science, 64*(2), 199–206.

Casas, J. A., Mohedano, A. F., & García-Ochoa, F. (2000). Viscosity of guar gum and xantham/guar gum mixture solutions. *Journal of the Science of Food and Agriculture, 80*, 1722–1727.

Chang, H. C., & Carpenter, J. A. (1997). Optimizing quality of frankfurters containing oat bran and added water. *Journal of Food Science, 62*, 194–197, 202.

Claus, J. R., Hunt, M. C., & Kastner, C. L. (1989). Effects of substituting added water for fat on the textural, sensory and processing characteristics of bologna. *Journal of Muscle Foods, 1*, 1–2.

Claus, J. R., Hunt, M. C., Kastner, C. L., & Kropf, D. H. (1990). Low-fat, high added water bologna: effects of massaging, preblending, and time of addition of water and fat on physical and sensory characteristics. *Journal of Food Science, 55*(2), 338–341, 345.

FDA-CFSAN, (2003) U.S. Food and Drug Administration. Center for Food Safety and Applied Nutritions. *Cook it safely*. Available from: <http//:www.foodsafety.gov/~acrobat/f99broch.pdf> Accessed May 15, 2003.

Foegeding, E. A., & Ramsey, S. R. (1986). Effect of gums on low-fat meat batters. *Journal of Food Science, 51*(1), 33–36, 46.

García, M. A., Ferrero, C., Bertola, N., Martino, M., & Zaritzky, N. E. (2002). Edible coatings from cellulose derivatives to reduce oil uptake in fried products. *Innovative Food Science and Emerging Technologies, 3*, 391–397.

Haq, A., Webb, N. B., Whitfield, J. K., & Ivey, F. J. (1973). Effect of composition on the stability of sausage type emultions. *Journal of Food Science, 38*, 271–274.

Hensley, J. L., & Hand, L. W. (1995). Formulation and chopping temperature effects on beef frankfurters. *Journal of Food Science, 60*(1), 55–57, 67.

Hung, S. C., & Zayas, J. F. (1991). Sensory, chemical and bacteriological stability of frankfurters containing milk proteins and corn flour. *Journal of Food Processing and Preservation, 15*(6), 413–431.

Keeton, J. T. (1994). Low-fat meat products-technological problems with processing. *Meat Science, 36*, 261–276.

Lin, K. W., & Chao, J. Y. (2001). Quality characteristics of reduced-fat Chinese-style sausage as related to Chitosan's molecular weight. *Meat Science, 59*, 343–351.

Morrison, G. S., Webb, N. B., Blumer, T. N., Ivey, F. J., & Haq, A. (1971). Relationship between composition and stability of sausage type emultions. *Journal of Food Science, 36*, 426–430.

Pearson, A. M., & Gillett, T. A. (1996). Reduced and low-fat meat products. In A. M. Pearson & T. A. Gillett (Eds.), *Processed meats* (3rd ed., pp. 355–371). New York: Chapman & Hall.

Quintana, J. M., Califano, A. N., Zaritzky, N. E., Partal, P., & Franco, J. M. (2002). Linear and nonlinear viscoelastic behavior of oil-in-water emulsions stabilized with polysaccharides. *Journal of Texture Studies, 33*(3), 215–236.

Reagan, J. O., Liou, F. H., Reynolds, A. E., & Carpenter, J. A. (1983). Effect of processing variables on the microbial, physical and sensory characteristics of pork sausage. *Journal of Food Science, 48*(1), 146–149, 162.

Su, Y. K., Bowers, J. A., & Zayas, J. F. (2002). Physical characteristics and microstructure of reduced-fat frankfurters as affected by salt and emulsified fats stabilized with nonmeat proteins. *Journal of Food Science, 65*(1), 123–128.

Sutton, D. S., Hand, L. W., & Newkirk, K. A. (1995). Reduced fat, high moisture beef frankfurters as affected by chopping temperature. *Journal of Food Science, 60*(3), 580–582.

Trout, G. R., & Schmidt, G. R. (1986). Effect of phosphates on the functional properties of restructured beef rolls: the role of pH, ionic strength, and phosphate type. *Journal of Food Science, 51*(6), 1416–1423.

USDA-FSIS (1999). Food ingredients and sources of radiation listed or approved for use in the production of meat and poultry products; final rule. Subpart C—424.21. *Use of food ingredients and sources of radiation. Code of federal regulations*, Title 9, Vol. 2, Ch. III, Pt. 381 (pp. 72176–72192). Washington, DC: Office of Federal Register, National Archives and Records, GSA.

Wallingford, L., & Labuza, T. P. (1983). Evaluation of the water binding properties of food hydrocolloids by physical/chemical methods and in a low fat meat emulsion. *Journal of Food Science, 48*, 1–5.

Wit, J. N. (1988). Empirical observations and thermodynamical considerations on water-binding by whey proteins in food products. *Journal of Food Science, 53*(5), 1553–1557, 1559.

Yackel, W. C., & Cox, C. (1992). Application of starch-based fat replacers. *Food Technology, 46*, 146–148.