Original article

The effect of whey protein concentrates and hydrocolloids on the texture and colour characteristics of chicken sausages

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Summary The effects of fat reduction by increasing water content and the addition of whey protein and hydrocolloids on the instrumental texture profile, microstructure and water holding capacity of low-fat chicken sausages were analysed. Low-fat sausages were prepared with fresh breast chicken meat; in all formulations, a 3:7 ratio guar/xanthan gum was used. A factorial design with three levels of added fat (0%, 1.98% and 4.96%), two levels of whey protein concentrate (0.64% and 1.94%), and two levels of the hydrocolloids (0.13% and 0.32%) was applied. Samples were heat-processed (73 °C final internal temperature) and, after cooling, chemical composition of the sausages was determined and scanning electron microscopic images were obtained. Colour was measured with a tristimulus reflectance colorimeter. Texture profile analysis of sausages was performed and the results were related to sample formulations. Extra-lean products with a fat content lower than 0.5 g/100 g product showed very good quality attributes determined by a sensory panel.

Keywords Breast chicken meat, hydrocolloids, low-fat sausages, microstructure, texture, whey proteins.

Introduction

As diets containing no more than 30% of their calories from fat are recommended (HHS-USDA) it is of considerable importance to develop products that are low in fat and perceived as more 'healthful'. Maximum fat levels for frankfurters and similar cooked sausages were set at 30% and added water at 10% (USDA-FSIS, 1990). Reduced fat sausages contain approximately one-half of the traditional fat level (14–15%). Low-fat products must contain no more that 10% fat, while extra-lean products must be under 5% fat. Adding water or other non-meat additives in meat products may be an alternative to reduce fat and calories; this has permitted the production of lower fat processed meats. An alternative to reduce fat and calories may be the use of breast chicken meat, which has approximately a protein content of 23% and a fat content of 1.3% in comparison with lean pork having 21.23% protein and 5.88% total lipid (NAL, 2004).

Lowering the fat content without increasing water content in frankfurters increases toughness and changes product quality (Rongey & Bratzler, 1966; Decker *et al*., 1986; Hand *et al*., 1987), while replacing fat with water has been reported to increase cooking and purge losses (Claus *et al*., 1989, 1990; Gregg *et al*., 1993); besides, increasing water may affect the texture and juiciness of the product (Matulis *et al*., 1995). Phosphates have been added to meat products to improve their binding and water-holding properties (Trout & Schmidt, 1983, 1986; Whiting, 1984). Barbut (1988) reported that the addition of sodium hexametaphosphate (HMP) improved emulsion stability of poultry meat sausages significantly. Proteins and other extenders have also been used in frankfurters-type products to improve their water-holding capacity and textural properties. Most non-meat protein binders and extenders are derived from soybean or milk (Sofos & Allen, 1977; Sofos *et al*., 1977; Whiting, 1984; Su *et al*., 2000). Besides, the ability of some macromolecular hydrocolloids, or gums, to form gels at low concentrations, physically binding water into a three-dimensional structure has also been investigated (Wallingford & Labuza, 1983; Whiting, 1984; Foegeding & Ramsey, 1986; Lin *et al*., 1988).

Guar gum is a galactomannan obtained from the endosperm of the *Cyamopsis tetragonolobus* seed; the specific polysaccharide component of guar gum is guaran, a galactomannan where about one-half of the β-D-mannopyranosyl main-chain units, joined by (1 → 4) bonds, contain an α-D-galactopyranosyl side chain attached at O-6. Xanthan gum is an exocellular

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polysaccharide produced by the bacterium *Xanthomonas campestris* and it may be considered an anionic polyelectrolyte. Its primary structure is based on a β-1,4-linked glucan backbone, as in cellulose, but every second glucose residue is attached to a charged trisaccharide side chain (β-D-mannopyranosyl-(1 → 4)-β-D*-glucuronopyranosyl-(1 → 2)-6-*o*-acetyl-β-D-mannopyranosyl units, about half of them have pyruvic acid attached to a 4,6-cyclic acetal) (BeMiller & Whistler, 1996). Xanthan's commercial success is due to its high viscosity, salt tolerance, thermal stability and food compatibility (Kwon *et al*., 1987). Guar molecules produce high viscosity solutions alone or mixed with xanthan solutions. The synergistic intermolecular interaction between xanthan and guar gum helps to develop a more entangled network than when either of them is used alone (BeMiller & Whistler, 1996; Casas *et al*., 2000; Quintana *et al*., 2002). Maximum viscosity of guar/xanthan gum solutions depends on ionic strength but normally corresponds to a 30:70 mixture (BeMiller & Daniels, 2002).

The aim of this study was to determine the effects of fat reduction by increasing water content and by the addition of whey protein and hydrocolloids on the textural characteristics and colour of low-fat chicken sausages using instrumental and sensory tests to get formulations that would result in a suitable product.

Materials and methods

Materials

Fresh breast chicken meat and beef tallow were obtained from local processors. Whey protein concentrate (WPC) containing 40% protein (42% lactose, 4.5% water and 4% fat) (Milkaut, Santa Fe, Argentina), food-grade commercial preparation of xanthan and guar gums (Sigma Chemical Co., St Louis, MO, USA) and analytical grade NaCl, $NaNO_2$ and sodium HMP were used. Cold distilled water was used in all formulations (4 °C).

Product manufacture and experimental design

Breast chicken meat (500 g per batch) 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 (beef tallow) at room temperature was added. The addition of ingredients took less than 5 min and final temperature of the chicken paste varied between 12 and 15 °C. Plastic tubes (3 cm diameter) were stuffed with chicken paste, and weighted before further heat processing. Two batches of six tubes per replicate 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 73 °C was reached. Then, samples were cooled immediately in an ice-water-bath. One extra tube was loaded, and type-T (copper-constantan) thermocouple was inserted in the centre of the sausage and sealed in to serve as the temperature-monitoring tube; time/temperature data were recorded (Servoger 102, Omni Instruments, Dundee, UK). Afterwards, these precooked sausages were removed from the tubes, weighed again to assess weight losses, and stored in covered plastic lugs at 4 °C for 24 h.

One batch of precooked sausages were steeped in a boiling-water bath (100 °C) for 3 min to simulate consumer cooking in order to analyse the effect on texture properties (cooked samples). Then samples were cooled immediately in an ice-water-bath and kept covered at 4 °C for 24 h.

Three independent variables: added fat (F), whey proteins (WPC), and gums (G) were considered in the formulation of the chicken sausages. A full $3 \times 2 \times 2 \times 2$ factorial design using three levels of added fat (0%, 1.98% and 4.96% beef tallow), two levels of WPC (0.64% and 1.94%) and two levels of hydrocolloids (0.13% and 0.32%) was used for twelve different formulations. Percentual contents were expressed as g/100 g raw sausage.

In all formulations a 3:7 ratio guar/xanthan was used. Water was added to the formulations to maintain constant the quantity of added fat + water content. The keys used for each formulation are shown in Table 1. The entire experimental design was replicated three times.

Table 1 Formulations expressed as g/100 g of raw sausage (%)

Composition	Gums	Added fat	WPC	Chicken meat	Added water
LL1	0.13	0	0.64	64.52	31.76
LL2		0	1.94	63.23	31.76
LM1		1.98	0.64	64.52	29.78
LM2		1.98	1.94	63.23	29.78
LH1		4.96	0.64	64.52	26.80
LH2		4.96	1.94	63.23	26.80
HL1	0.32	0	0.64	64.33	31.76
HL2		0	1.94	63.04	31.76
HM1		1.98	0.64	64.33	29.78
HM2		1.98	1.94	63.04	29.78
HH1		4.96	0.64	64.33	26.80
HH2		4.96	1.94	63.04	26.80

First position in the code notation corresponds to hydrocolloids, second position to fat content, and third position to whey protein concentrate (WPC) content. Codes for hydrocolloids: L = low and H = high. Codes and fat levels: L = low, M = medium and H = high. Codes for WPC: 1 = low, 2 = high. Gums: guar gum/xanthan gum = 3/7. Added fat: beef tallow.

All formulations were prepared with the same common ingredients (% = g/100 g raw sausage) 31.76% added fat + water, 0.2% HMP, 2.48% NaCl, 0.2% white pepper, 0.05% ground nutmeg, and 0.015% $NaNO_2$.

Analysis

The 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. Carbohydrates were determined by subtracting the water, fat, protein and ash contents from the total mass. Chemical composition was analysed on raw chicken meat and sausages for all the treatments; pH was measured on raw sausages with a combination pH electrode. Weight losses were determined by weighting the product before and after the heating treatment on an analytical balance (±0.0001 g) and expressed as per cent weight loss.

Colour measurements

Colour was measured with a tristimulus reflectance colorimeter (Minolta CR-300; Minolta Corp., Ramsey, NJ, USA). Colour was recorded using the CIE-$L^*a^*b^*$ scale. All the measurements were carried out in quadruplicate on transversally cut sections of the sausages.

Texture measurements

All instrumental texture analyses were done on samples (precooked or cooked sausages) at room temperature. For each treatment two repeated measurements were taken for each replicate and mean values were reported.

Texture profile analysis (TPA) (Bourne, 1978; Brennan & Bourne, 1994) of sausages was performed. Samples, 1.5 thick and 1.7 cm in diameter, were compressed twice to 30% of their original height between flat plates using a TAXT2i Texture Analyser (Stable Micro Systems, Surrey, UK) interfaced with a computer which controls the instruments and analyses the data, using the software supplied by Texture Technologies Corp. (Scarsdale, NY, USA). In these experiments the head was operated at 0.5 mm s^{-1}. Hardness (peak force of first compression cycle, Newton), springiness (distance of the detected height of the product on the second compression divided by the original compression distance, dimensionless), cohesiveness (ratio of positive areas of second cycle to area of first cycle, dimensionless), adhesiveness (negative force area of the first byte represented the work necessary to pull the compressing plunger away from the sample, Joule), chewiness (hardness × cohesiveness × springiness, Newton), and resilience (area during the withdrawal of the first compression divided by the area of the first compression, dimensionless) were determined (Bourne, 2002).

Electron microscopy

Small pieces of sausages of 0.5 cm in diameter and 0.2–0.3 cm thick were used for scanning electron microscopy (SEM) 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 aluminium stubs using a double-sided tape and then coated with a layer of gold (40–50 nm) under vacuum (sputtering), allowing surface and cross-section visualisation. Micrographs of the samples were obtained with scanning electron microscope (SEM 505, Philips, Eindhoven, The Netherlands).

Sensory evaluation

Sensory analyses were conducted by fifteen panellists 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. Panellists 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 flavour and texture characteristics. Samples 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 panellist with three-digit codes and in random order for evaluation. Tap water was supplied to the panellist for rinsing between samples. Experiments were conducted in an appropriately designed and lighted room.

Statistical analysis

Analysis of variance was conducted separately for the dependent variables of the instrumental texture analysis (hardness, cohesiveness, adhesiveness, springiness, chewiness, resilience) and colour parameters (L, a^* and b^*). The independent variables were fat, whey protein and gum contents. A complete linear model with second- and third-order interactions was applied. For simultaneous pairwise comparisons, least significance differences test was chosen. When the analysed factor has two levels (as in the case of gums and WPC) and main effects are significant, the analysis involve the comparison of the averages at the 'high' and 'low' levels. In the case of 'fat' that has three levels 'high', 'medium'

and 'low' averages were compared. Proportions of explained variances for significant factors were calculated as the ratio of the sum of squares of the corresponding factor divided by the total sum of squares.

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, USA).

Results and discussion

Chemical composition and weight losses

Chemical composition data for precooked chicken sausages are shown in Table 2; pH values (5.4–5.9) and total protein content depended strongly on the corresponding values of the raw chicken meat, without skin, used, and they were not affected by treatments. Mean moisture, protein, fat, and ash content of the raw breast chicken meat, without skin, were 74.3 (0.02), 19.7 (0.2), 1.05 (0.01) and 1.18 (0.02) g/100 g raw meat, respectively. Values between parentheses correspond to standard errors of the means. Experimentally determined chemical composition of the sausages agrees with the theoretical values calculated from raw chicken meat contents and the different ingredients added. Weight losses ranged between 2% and 4%, but were not significantly ($P < 0.05$) affected by the gums, WPC or fat content. The addition of whey proteins, gums and HMP compensated for the potential loss of some water-binding properties when water was added to the formulation. Wallingford & Labuza (1983) measured the water-binding capacity of several macromolecular food grade hydrocolloids in a low fat meat emulsion system. They found that xanthan gum was the best gum in retention of added water. Protein–polysaccharide interactions also play a significant role in the structure and stability of many processed food. Under specific conditions, such as protein-to-polysaccharide ratio, pH, ionic strength, temperature, mixing processing, the protein and polysaccharides can form hybrid complexes with enhanced functional properties in comparison with protein or polysaccharide alone. Electrostatic complexation of oppositely charged protein and polysaccharide allows better anchoring of the newly formed macromolecular amphiphile onto the oil–water interface (Garti & Aserin, 1996).

Table 2 Proximate analysis values of the formulated sausages (% = g/100 g sausage)

Code	Moisture (%)	Protein (%)	Total fat (%)	Ash (%)
LL1	79.9 (0.13)	14.0 (0.01)	0.31 (0.004)	3.25 (0.004)
LL2	79.2 (0.02)	14.5 (0.13)	0.51 (0.003)	3.34 (0.03)
LM1	77.8 (0.19)	12.7 (0.11)	2.44 (0.004)	3.34 (0.04)
LM2	77.2 (0.16)	13.6 (0.02)	2.60 (0.23)	3.38 (0.02)
LH1	75.4 (0.01)	12.3 (0.19)	6.09 (0.12)	3.16 (0.09)
LH2	74.0 (0.05)	12.2 (0.16)	6.07 (0.06)	3.09 (0.02)
HL1	79.4 (0.11)	13.7 (0.03)	0.22 (0.05)	3.29 (0.03)
HL2	79.5 (0.01)	13.2 (0.06)	0.37 (0.01)	3.27 (0.003)
HM1	77.9 (0.06)	12.6 (0.04)	2.3 (0.29)	3.26 (0.004)
HM2	77.6 (0.11)	12.7 (0.01)	2.88 (0.03)	3.09 (0.04)
HH1	74.5 (0.03)	12.9 (0.08)	5.59 (0.04)	3.32 (0.01)
HH2	75.3 (0.14)	12.3 (0.35)	5.04 (0.05)	3.22 (0.02)

Standard errors of the means are given within parenthesis. Codes are given in Table 1.

Colour

Instrumental (CIE-$L^*a^*b^*$ values) colour evaluation data are shown in Table 3. Table 4 shows the proportion of explained variance for significant factors obtained from the ANOVA for lightness (L^*), redness (a^*+) and yellowness (b^*+).

Increasing fat, WPC or G content increased lightness ($P < 0.05$). The relative importance of the main effects is given by the following order: F > WPC > G according to ANOVA analysis (Table 4). Besides, the second-level interactions (F × G and F × WPC) were significant; increasing WPC at the 0.32% of gums also increased L^* values for the medium and high fat content (Table 3). No third-level interaction was observed for lightness.

Redness was strongly influenced by fat content as reflected by the high proportion of explained variance (Table 4) and the highest redness values corresponded to 0% F. As the third-level interaction (F × WPC × G)

Table 3 Effect of composition on the colour of chicken sausages (average values for: lightness, redness and yellowness)

Chicken sausages						
Gums (%)	Added fat (%)	WPC (%)	Code	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)
0.13	0	0.64	LL1	81.5^{ab}	2.3^{a}	10.6^{a}
		1.94	LL2	80.5^{a}	2.1^{a}	11.4^{b}
	1.98	0.64	LM1	82.1^{b}	1.3^{b}	11.5^{b}
		1.94	LM2	81.8^{b}	1.3^{b}	11.6^{bc}
	4.96	0.64	LH1	82.1^{b}	1.9^{cdf}	10.6^{a}
		1.94	LH2	82.0^{b}	1.9^{cdf}	12.1^{cd}
0.32	0	0.64	HL1	81.7^{b}	2.1^{ac}	10.9^{a}
		1.94	HL2	81.5^{b}	2.0^{cd}	11.7^{bc}
	1.98	0.64	HM1	82.5^{b}	0.9^{e}	11.7^{bc}
		1.94	HM2	84.1^{c}	1.5^{bf}	11.0^{a}
	4.96	0.64	HH1	83.5^{c}	1.8^{df}	12.3^{d}
		1.94	HH2	86.2^{d}	0.9^{e}	10.9^{a}

% = g/100 g raw sausage. Codes are given in Table 1. Different superscripts within the same column indicate that the values differ significantly ($P < 0.05$).

Table 4 Proportion of explained variance for significant factors in the surface colour analysis of the sausages

	Proportion of explained variance		
Source of variation	**Lightness (*L**)**	**Redness (*a**+)**	**Yellowness (*b**+)**
Fat (F)	0.336	0.507	0.069
Whey protein concentrate (WPC)	0.023	NS	0.031
Gums (G)	0.265	0.066	NS
F × WPC	0.071	0.122	0.161
WPC × G	0.083	NS	0.281
F × G	0.090	0.045	0.037
F × WPC × G	NS	0.123	0.288

NS = non-significant ($P > 0.05$).

was significant, the changes produced by increasing WPC depended on the fat and gum composition of the sausage (Table 3); thus formulation HM2 had higher a^* value than HM1, while HH2 was lower than HH1. For yellowness the highest proportion of explained variance corresponded to the third-level interaction (Table 4).

Texture profile analysis

Analysis of variance showed that there were no significant differences ($P > 0.05$) between precooked or cooked sausages on any of the TPA parameters studied; thus, the obtained values for both groups of chicken sausages were pooled within each replicate. Average values for each formulation of the TPA evaluation are shown in Table 5, each value corresponds to the average of twelve samples. Coefficients of determination (R^2) were computed to reflect the magnitude of each variable on the TPA responses. Table 6 shows the proportion of the total variance explained by the significant effects

Table 6 Proportion of explained variance for significant factors in the texture profile analysis of the sausages

	Proportion of explained variance				
Source of variation	**Hardness**	**Chewiness**	**Cohesiveness**	**Resilience**	**Adhesiveness**
F	0.039	0.038	0.040	0.136	NS
WPC	0.147	0.139	0.278	NS	NS
G	0.150	0.138	NS	0.023	NS
F × WPC	NS	NS	NS	0.099	0.040
WPC × G	0.119	0.078	0.078	NS	NS
F × G	0.095	0.111	0.004	0.093	0.055
F × WPC × G	0.194	0.190	0.065	0.045	NS

NS = non-significant ($P > 0.05$). Hardness (N), springiness (mm), cohesiveness, adhesiveness (J), chewiness (N × mm), and resilience.

(R^2) obtained from the ANOVA for the TPA analysis and also indicates with NS when the effect was not significant. Significant differences ($P < 0.05$) were found in hardness, adhesiveness, cohesiveness, chewiness values within various levels of added fat, whey protein and gums. Springiness did not show significant differences among the formulations and was eliminated from Tables 5 and 6. The average springiness value obtained was 0.946 ± 0.0078.

The main effect of the addition of hydrocolloids showed that hardness decreased from 8.59 to 6.93 N when G increased from 0.13% to 0.32% ($P < 0.01$). The same effect was found for chewiness and resilience average values (4.23–3.58 and 0.417–0.411, respectively, $P < 0.05$). These results agree with those informed by Fox *et al.* (1983), Whiting (1984), Foegeding & Ramsey (1986) and Lin *et al.* (1988) who reported that increasing the concentration of hydrocolloids decreased sausage hardness without affecting sausage stability. Increasing

Table 5 Effect of composition on the parameters of the texture profile analysis (average values for: hardness, chewiness, cohesiveness, resilience, and adhesiveness)

Chicken sausages								
Gums (%)	**Added fat (%)**	**WPC (%)**	**Code**	**Hardness (N)**	**Chewiness (N × mm)**	**Cohesiveness**	**Resilience**	**Adhesiveness (J × 10^4)**
0.13	0	0.64	LL1	9.27^{ad}	4.85^{ad}	0.545^{acd}	0.427^{de}	1.15^{a}
		1.94	LL2	7.00^{b}	3.38^{b}	0.545^{acd}	0.414^{cd}	2.26^{bc}
	1.98	0.64	LM1	10.24^{c}	5.39^{c}	0.552^{ab}	0.430^{e}	1.75^{ab}
		1.94	LM2	9.77^{cd}	5.09^{cd}	0.555^{b}	0.433^{e}	1.60^{a}
	4.96	0.64	LH1	6.50^{be}	3.37^{be}	0.556^{b}	0.401^{ab}	1.17^{a}
		1.94	LH2	8.74^{a}	4.48^{a}	0.545^{acd}	0.398^{ab}	1.68^{ab}
0.32	0	0.64	HL1	8.39^{a}	4.30^{a}	0.550^{bcd}	0.427^{de}	1.10^{a}
		1.94	HL2	6.62^{b}	3.49^{b}	0.548^{bcd}	0.410^{bc}	1.84^{b}
	1.98	0.64	HM1	7.29^{b}	3.71^{b}	0.543^{cd}	0.413^{cd}	1.73^{a}
		1.94	HM2	5.68^{e}	2.93^{e}	0.551^{bc}	0.402^{a}	1.89^{a}
	4.96	0.64	HH1	9.79^{cd}	4.99^{cd}	0.541^{d}	0.394^{a}	2.81^{c}
		1.94	HH2	3.81^{f}	2.07^{f}	0.569^{e}	0.418^{cde}	2.12^{bc}

% = g/100 g raw sausage. Codes are given in Table 1. Different superscripts within the same column indicate that the values differ significantly ($P < 0.05$).

WPC decreased average hardness and chewiness values and increased cohesiveness of the sausages ($P < 0.05$). Similar results were reported by Randall *et al.* (1976) working with beef sausage with added levels of soy protein isolate and wheat gluten and by Sofos *et al.* (1977) when textured soy protein was added to the formulation. However, double and/or triple interactions were significant for several of the tested parameters. In particular double interactions are the most important for adhesiveness (F × WPC and F × G) and triple interactions for hardness and chewiness; double and triple interactions are also important for adhesiveness. Thus, the analysis of the effects must consider each specific combination of WPC, hydrocolloids and fat levels (Tables 5 and 6). For example, regarding the effect of WPC on cohesiveness, Table 6 shows that the change in WPC explained 27.8% of total variance; for 0.64% WPC average cohesiveness was 0.548, while for 1.94% average cohesiveness was 0.552, which were significantly different. However, the samples formulated with 0.13% gums and 0% fat containing different amounts of WPC showed no significant difference in cohesiveness. This result is attributed to the effect of the F × WPC × G interaction. This result does not invalidate the conclusions on the main effect of WPC. The gelling properties of WPC come from its ability to denature and unfold during heat treatment. Intermolecular interactions are favoured over intramolecular interactions and this can result in formation of a network (Reiffers-Magnani *et al.*, 1999). It is possible that the addition of xanthan and guar gums to the system disrupted the protein–protein gel network, which in turn decreased gel strength and firmness of the products (Whiting, 1984), but the extent of hybrid complexes formation between WPC and xanthan gum depends on the ratio of protein-to-polysaccharide ratio (Schmidt & Smith, 1992).

The combination of high WPC, G, and highest F, HH2, showed the lowest hardness and chewiness values, and the highest cohesiveness (Table 5). Considering that chewiness = hardness × cohesiveness × springiness, as springiness is a constant value, the marked decrease of the hardness governed the decrease in chewiness, in spite of the increase in cohesiveness values. High levels of G and F led to a more adhesive product.

Scanning electron microscopy

Micrographs of LL1, LM2 and HH1 samples are shown as examples in Fig. 1a–c, respectively. Overall, for similar fat content, increasing whey protein and/or gums concentration resulted in a more cohesive and less granular emulsion matrix, showing gel-type structures (Fig. 1c). Fat globules showed a relatively smooth shell surrounding them without pores (Fig. 1b). At low WPC and G content the matrix appeared coarse, without gel-type structures, and fat globules looked ruptured with small pores on the surface regardless of fat content (Fig. 1a).

Sensory analysis

The panellists evaluated the texture and flavour characteristics of formulations LL1, LM1, HM2 and HH2, which covered a wide range of composition and hardness. The observations were classified into three perception sensorial groups, the first one corresponded to

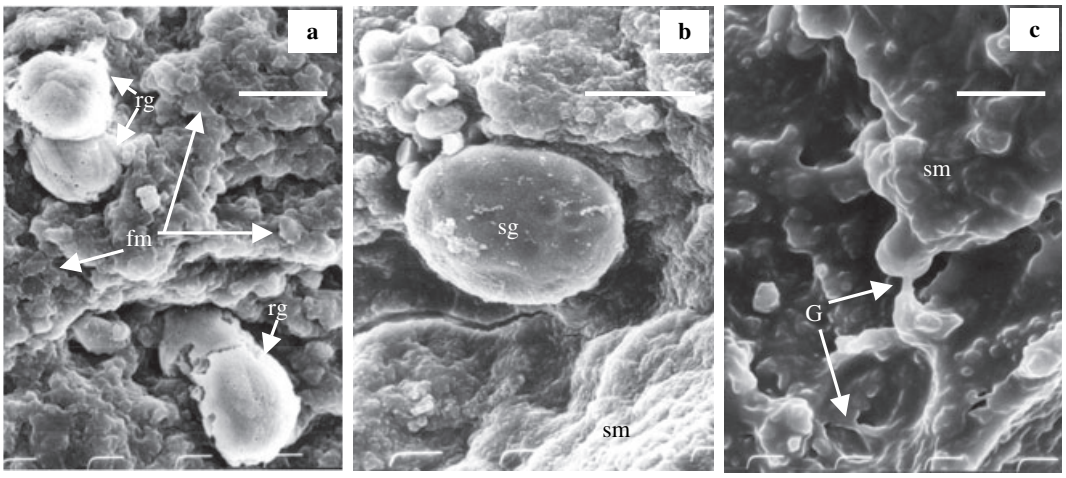

Figure 1 Scanning electron micrographs of low-fat chicken meat formulations: (a) LL1 (0.13% gums, 0% added fat, 0.64% whey protein concentrate); rg = ruptured fat globules with pores, fm = fibrous matrix. (b) LM2 (0.13% gums, 1.98% added fat, 1.94% whey protein concentrate); sg = smooth fat globule, sm = smooth matrix. (c) HH1 (0.32% gums, 4.96% added fat, 0.64% whey protein concentrate); G = gel-type structures, sm = smooth matrix. All percentages are based in 100 g of raw sausage (Bars = 10 μm).

those that disliked the product (scores 1–4), the second one was indifferent (scores 5), and the third group expressed that they liked the samples (scores 6–9). Low-fat chicken sausages had generally acceptable sensory scores (Table 7).

Regarding flavour attribute, LL1 was the most acceptable formulation (66.7%) while the other three tested formulations were accepted by 53.3% of the panellists. Samples with lower gum content (LL1 and LM1) showed an acceptability of 66.7% when texture was considered, while for the 0.32% gums content the acceptability was higher (HH2 and HM2, 73.3 and 80.0%, respectively). Thus, fat replacement with higher amounts of water and with ingredients such as whey proteins or gums led to low-fat chicken sausages with acceptable sensory scores.

Caloric intake for the formulated products

Regular Frankfurter type sausages in Argentina have 315 kcal/100 g; over 80% of these calories come from fat while 'light' type meat sausages have 197 kcal/100 g (68% from fat). Caloric intake for the products formulated in this work was estimated from compositions. The sausages developed without added fat, that is, containing only the fat of the chicken muscle, ranged between 0.22% and 0.51% total lipid (LL1, LL2, HL1 and HL2), and have between 68 and 72 kcal/100 g with less than 6% of the energy coming from fat. The estimated caloric intake from the group of sausages with a fat content between 2.3% and 2.88% (LM1, LM2, HM1 and HM2) was in the range of 87–90 kcal/100 g (about 25% from lipids). Finally, the third group (LH1, LH2, HH1 and HH2), with a total fat content ranging between 5.04% and 6.09%, have about 115–121 kcal/100 g (45% from fat). Thus, the first two groups of chicken sausages met the requirements to be considered 'extra lean' with less than 30% of the calories coming from fat. The third group belongs to the reduced fat category.

Table 7 Sensory flavour, texture and acceptability scores on a 9-point hedonic scale (9 = like extremely; 1 = dislike extremely) of low-fat chicken sausages

	[Sensory properties] Average values on hedonic scale	
Formulation	**Flavour**	**Texture**
LL1	5.9 (66.7)	6.2 (66.7)
LM1	5.5 (53.3)	6.3 (66.7)
HM2	5.7 (53.3)	6.2 (80.0)
HH2	5.7 (53.3)	6.3 (73.3)

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

Conclusions

Chicken sausages with a total lipid content ranging from 0.22% to 6.09% were formulated and tested with respect to weight losses, colour, textural properties, microstructure and acceptability by a sensory panel. Weight losses were low (2–4%) and they were not significantly affected by gums, WPC and fat content within the assayed range. Fat content showed the most marked effect on lightness and redness and on the textural parameter resilience. Increasing gums and WPC concentration decreased sausage hardness. SEM images showed that when increasing WPC and/or gums concentration a more cohesive and less granular matrix was obtained. Low-fat chicken sausages having good functional properties and acceptable sensory scores were produced by incorporating xanthan and guar gums and WPC to the formulation. Even formulations without added fat, that is, containing less than 0.5 g fat/100 g product showed good stability and water retention, and were well liked by the panellists.

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References

AOAC (1980). *Official Methods of Analysis*, 13th edn. Pp. 125, 376–379. Washington, DC: Association of Official Analytical Chemists.

Barbut, S. (1988). Microstructure of reduced salt meat batters as affected by polyphosphates and chopping time. *Journal of Food Science*, **53**, 1300–1304.

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, 2002.

BeMiller, J.N. & Whistler, R.L. (1996). Carbohydrates. In: *Food Chemistry* (edited by O.R. Fennema), Pp. 207–210. New York: Marcel Dekker Inc.

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

Bourne, M.C. (2002). *Food Texture and Viscosity*, 2nd edn. New York: Academic Press.

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.

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

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**, 338–341, 345.

Decker, C.D., Conley, C.C. & Richert, S.H. (1986). Use of isolated soy protein in the development of frankfurters with reduced levels of fat, calories, and cholesterol. *European Meeting of Meat Research Workers*, **7**, 1–2.

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

Fox, J.B., Ackerman, S.A. & Jenkins, R.J. (1983). Effect of anionic gums on the texture of pickled frankfurters. *Journal of Food Science*, **48**, 1031–1035.

Garti, N. & Aserin, A. (1996). Double emulsions stabilized by macromolecular surfactants. In: *Surfactants in Solution*, Vol. 64 (edited by A.K. Chattopadhyay & K.L. Mittal). Pp. 297–332. New York: Marcel Dekker Inc.

Gregg, L.L., Claus, J.R., Hackney, C.R. & Marriott, N.G. (1993). Low-fat, high added water bologna from massaged, minced batter. *Journal of Food Science*, **58**, 259–264.

Hand, L.W., Hollingsworth, C.A., Calkins, C.R. & Mandigo, R.W. (1987). Effects of preblending, reduced fat, and salt level on frankfurter characteristics. *Journal of Food Science*, **52**, 1149–1151.

HHS-USDA (Department of Health and Human Services and United States Department of Agriculture) (2000). *Dietary Guidelines for Americans*. Available from: http://www.health.gov/dietaryguidelines/dga2000/DIETGD.PDF, accessed November 21, 2002.

Kwon, B.D, Foss, P.A. & Rha, Ch.K. (1987). Rheological characterization of high viscosity polysaccharides. In: *Industrial Polysaccharides: Genetic Engineering, Structure/Property Relations and Applications* (edited by M. Yalpani). Pp. 253–266. Amsterdam: Elsevier Science Publishers B.V.

Lin, K.C., Keeton, J.T., Gilchrist, C.L. & Cross, H.R. (1988). Comparisons of carboxymethyl cellulose with differing molecular features in low-fat frankfurters. *Journal of Food Science*, **53**, 1592–1595.

Matulis, R.J., McKeith, F., Sutherland, J.W. & Brewer, M.S. (1995). Sensory characteristics of frankfurters as affected by fat, salt and pH. *Journal of Food Science*, **60**, 42–47.

NAL (2004). *Nutrient Data Laboratory, USDA*. Available from: http://www.nal.usda.gov/fnic/foodcomp/search/ accessed December 11, 2004.

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**, 215–236.

Randall, C.J., Raymond, D.P. & Voisey, P.W. (1976). Effect of various animal and vegetable protein materials on replacing the beef component in a meat emulsion system. *Journal of the Institute of Canadian Science and Technology Alimentaire*, **9**, 216–221.

Reiffers-Magnani, C.K., Cuq, J.L. & Watzke, H.J. (1999). Composite structure formation in whey protein stabilized O/W emulsions. I. Influence of the dispersed phase on viscoelastic properties. *Food Hydrocolloids*, **13**, 303–316.

Rongey, E.H. & Bratzler, L.J. (1966). The effect of various binders and meats on the palatability and processing characteristics of bologna. *Food Technology*, **20**, 1228–1231.

Schmidt, K.A. & Smith, D.E. (1992). Rheological properties of gum and milk protein interactions. *Journal of Dairy Science*, **75**, 36–42.

Sofos, J.N. & Allen, C.E. (1977). Effects of lean meat source and levels of fat and soy protein on the properties of wiener-type products. *Journal of Food Science*, **42**, 875–878.

Sofos, J.N., Noda, I. & Allen, C.E. (1977). Effect of soy protein and their levels of incorporation on the properties of wiener-type products. *Journal of Food Science*, **42**, 879–884.

Su, Y.K., Bowers, J.A. & Zayas, J.F. (2000). Physical characteristics and microstructure of reduced-fat frankfurters as affected by salt and emulsified fats stabilized with nonmeat proteins. *Journal of Food Science*, **65**, 123–127.

Trout, G.R. & Schmidt, G.R. (1983). Utilization of phosphates in meat products. *Meat Processing*, **22**, 48–52.

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**, 1416–1423.

USDA-FSIS (1990). *Definitions and Standards of Identity or Composition, Subpart G – Cooked Sausage*. Code of Federal Regulations, Title 9, Vol. 2, Ch. III, Pt. 319.180. Pp. 305–306. 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.

Whiting, R.C. (1984). Addition of phosphates, proteins and gums to reduced-salt frankfurter batters. *Journal of Food Science*, **49**, 1355–1357.