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WHEY POWDER, ι-CARRAGEENAN, AND FAT INTERACTIONS AND THEIR INFLUENCE ON INSTRUMENTAL TEXTURE AND SENSORY PROPERTIES OF TURKEY MEAT SAUSAGE USING A MIXTURE DESIGN APPROACH

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A 10-point simplex lattice design was used to investigate the effect of varying the ratios of whey powder, ι-carrageenan, and fat, and their interactions on instrumental texture and sensory properties of mechanically separated turkey meat sausages. Regression models have been developed and contour plots were drawn in order to better understand the global tendency of measured responses. Whey powder had a more notable influence than that of ι-carrageenan on all textural parameters as whey powder proportion increased. At a higher proportion (8 g/100 g sausage), whey powder improved essentially hardness, gel stress, and chewiness of extra low-fat sausage (formulation 3, 4.2 ± 0.3 g of fat/100 g sausage). Environmental scanning electron microscopy of the corresponding sausage showed a compact microstructure characterized by large network connections. Sensory evaluation also indicated that whey powder increased the flavor, the firmness, and the sliceability scores of mechanically separated turkey meat sausage, in comparison to the high-fat standard sausage (formulation 1, 13.2 ± 0.2 g of fat/100 g sausage).

Keywords: ***Turkey meat, Extra low-fat sausage, Mixture design, Whey, ι-Carrageenan, Texture.***

INTRODUCTION

Turkey meat has been perceived and marketed as a healthy alternative to red meat due to its leanness, low cholesterol content, and favorable fatty acid profile.[1] Turkey meat production in Tunisia reached 38,577 tons in 2007. France (produced 633,000 tons of turkey in 2005) is the highest producer in the European Union countries and the second producer in the world after the USA (2,460,000 tons).[2] Consequently, large amounts of mechanically separated turkey meat can be produced and used for the manufacture of sausages, which are consumed because of their economical and nutritional values. The

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apparent relationship between dietary fat and the development of cardiovascular disease and hypertension has prompted consumers to be more concerned about the amount of fat in their diet and to be interested in reduced fat foods. Furthermore, lipid oxidation is a major cause of organoleptic quality deterioration especially for turkey meat-processed products. Different animal species may be classified on the basis of lipid sensibility to oxidation in the following order: fish > turkey > chicken > pork > beef > lamb.[3] Thus, meat and fat from turkey are highly susceptible to oxidation. For these reasons, developing an extra-low fat turkey meat sausage, while assuring the necessary palatability demanded by consumers, is of prime importance. To ensure optimum quality, the active approach to fat replacement is to add ingredients, such as non-meat proteins and/or hydrocolloids, having different functional properties playing a significant role in the structure and the stability of such processed foods.

Previous works focused on using functional ingredients to improve the quality of reduced-fat ground meat products, such as frankfurters and bologna sausages[4–8] and meatballs.[9–12] Whey powder, a by-product of cheese and casein manufacture, has been used as a filler and binder in various ground meat products.[10,13] Whey powder was also shown to function as a flavor enhancer in some meat products because of the presence of lactose.[14] Hydrocolloids, such as carrageenan, are also of great interest in processed meat products because of its gelling, thickening, and water binding properties.[15–17] Furthermore, the influence of simultaneous incorporation of both non-meat proteins and hydrocolloids on the functional properties of various processed meat products was also studied. Lyons et al.[18] showed that addition of carrageenan, whey protein concentrate, and tapioca starch produced low-fat pork sausages with similar textural and organoleptic characteristics to those of full-fat (20 g/100 g sausage) controls. Pietrasik and Duda[19] studied the effect of fat content and soy protein/κ-carrageenan mix on the quality of scalded sausage made from pork and beef meat. They showed that soy protein/κ-carrageenan (3:1, ratio) favorably affected water holding capacity and thermal stability of sausages regardless of the fat content (ranging from 20 to 40 g/100 g sausage), but did not improve textural parameters.

Unlike processed products made from beef and pork meat, few studies investigated the effect of non-meat ingredients on the properties of sausages made with mechanically separated turkey meat. The objective of the present work was to determine, using a three-component mixture design, the effect of whey powder, ι-carrageenan, and turkey fat mixture interaction on the instrumental texture and sensory properties of mechanically separated turkey meat sausage.

MATERIALS AND METHODS

Materials

Mechanically separated turkey (MST) meat and turkey fat (TF) were obtained from local processors (Chahia, Tunisia). MST meat was produced from turkey carcass after meat cutting. Chemical composition of MST meat (g/100 g MST meat) was: water, 72; proteins, 10; fat, 8; and ash, 7. Analytical grade NaCl, $NaNO_2$, ascorbic acid, and sodium tripolyphosphate were used. Modified starch (E1422) was from Sigma Chemical Co. (St. Louis, MD, USA). ι-carrageenan (ICR) was from PhytoTechnology Laboratories (Shawnee Mission, KS, USA). Whey powder (WP) containing 12.5 g of proteins/100 g was from Lactopol (Białystok, Poland). Cold distilled water (4°C) was used in all formulations.

Sausage Preparation

The standard sausage formulation (g/100 g sausage) consisted of: MST meat, 60; cold water, 23.6; turkey fat, 8; modified starch, 6; NaCl, 1.3; $NaNO_2$, 0.78; tripolyphosphate, 0.28; and ascorbic acid, 0.04 (Formulation 1, Table 1). Proportions of ingredients (WP, ICR, and TF) in each formulation are indicated in Table 1. Experimental ingredients (WP and TF) varied in the range of (0–8 g/100 g sausage) and ICR varied in the range of (0–1.5 g/100 g sausage). WP and ICR were incorporated instead of water. The removed TF proportion, however, was replaced by water. Cold water was added to frozen MST meat, which was then ground in a commercial food processor (Moulinex, Paris, France), equipped with a 5-cm blade for 5 min at the highest speed. Salts, WP, TF, and other ingredients were slowly added to the ground MST meat while processing. After that, modified starch and ICR were incorporated until completely blended (2–3 min). Stuffing was carried out manually into 27-mm-diameter reconstituted collagen casings and hand-linked to form approximately 8-cm-long links. After that, sausages were heat-processed in a temperature controlled water-bath (Haake, Kalsruhe, Germany) maintained at 90°C until a final internal temperature of 74°C was reached. The temperature was measured using a type-T (copper–constantan) thermocouple inserted into the center of a link. Sausages were then cooled immediately using tap water and stored at 4°C until analysis. Sausage fat content was determined as described in a previous work.[20]

Experimental Design

The following section is a brief reminder of some principles governing the construction and analysis of the mixture designs characterized by lower and upper bound restrictions on their component proportions. A mixture experiment is a special type of response surface experiment in which the factors are the components of a mixture and the response is a function of the proportions of each ingredient. A three-component, constrained simplex-lattice mixture design was used. The mixture components consisted of turkey fat (X_1), ι-carrageenan (X_2), and whey powder (X_3). With three components, the experimental region is a triangle where each of the three vertexes corresponds to a mixture that is made up of a pure component.

In this study, to limit the feasible space for the original simplex, restrictions taking the form of lower (*Lj*) and upper (*Uj*) constraints on the component proportions were

Table 1 Mixture compositions in sausages formulated with whey powder (WP), ι-carrageenan (ICR), and turkey fat (TF) in a three-component constrained simplex-lattice mixture design.

Formulations	TF (X_1)	ICR (X_2)	WP (X_3)
1	1.000	0.000	0.000
2	0.000	1.000	0.000
3	0.000	0.000	1.000
4	0.500	0.500	0.000
5	0.500	0.000	0.500
6	0.000	0.500	0.500
7	0.333	0.334	0.333
8	0.667	0.167	0.167
9	0.167	0.667	0.167
10	0.167	0.167	0.667

considered. Component proportions were expressed as fractions of the mixture and the general form of the constrained mixture problem is presented in Eq. (1):

$$\sum_j Xj = 1 \quad \text{and} \quad Lj \leq Xj \leq Uj. \tag{1}$$

The ten design points (Table 1) were three single-ingredient treatments, three two-ingredient mixtures, and four three-ingredient mixtures. Four other design points were conducted in order to assess the model lack of fit.

Statistical and Data Analysis

Scheffe's canonical special cubic equation for three components was fitted to the data as recommended by Cornell and Harrisson.[21] Variables in the regression models, which represented two-ingredient or three-ingredient interaction terms, were referred to as "non-linear" terms. The postulated canonical special cubic equation (Eq. 2) was:

$$y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3, \tag{2}$$

where y or response is the predicted dependant variables (instrumental texture and sensory parameters); β_1, β_2, β_3, β_{12}, β_{13}, β_{23}, and β_{123} are the corresponding parameter estimates for each linear and cross constituent term for the prediction models for X_1 (TF), X_2 (ICR), and X_3 (WP). Results relative to the physical parameters are the mean of four reproducible repetitions. Response means were compared and significant differences were determined with a Duncun multiple range test using SPSS (version 13) program (IBM, USA). Regression equations were determined using NemrodW procedure.[22] Triangular contour plots were constructed on the basis of the generated regression models by the NemrodW program.

Optimization (maximization) of multiple responses was carried out using a desirability function (one-sided specification test, NemrodW software). The desirability function is a guide in optimizing a formulation using multiple response data from a statistically planned experiment. The desirability function was used to supply the satisfaction percentage with relation to different measured responses. The target value for the measured responses (instrumental texture and sensory parameters), which seem very satisfactory, correspond to the maximum recorded for the different analyzed responses. Moreover, the lower threshold below, the result of which does not seem satisfactory, corresponds to the responses obtained for the standard sausage (formulation 1). The largest value that the desirability can take is 1 and the desirability function for all parts of the domain where an individual response is outside the acceptable range is therefore zero.

Instrumental Texture Analysis

Sausage texture analysis was done on cooked samples stored at least for 24 h at 4°C, using a texturometer (texture analyzer, Lloyd Instruments, Ltd., West Sussex, UK). The center cores of the sausage samples were cut (2 cm in diameter, 2 cm height) and placed between flat plates and a cylindrical probe (12 mm in diameter). Then, samples were compressed to 50% of their original height in a double cycle at a constant rate of 40 mm/min. The texture profile parameters, namely hardness (N), cohesiveness (dimensionless), elasticity (mm), and chewiness (hardness × cohesiveness × elasticity) (N mm) were computed from the resulting force-deformation curves.[23]

The sausage instrumental texture was also analyzed by a uniaxial compression test until fracture of the sample with a cylindrical probe (35 mm in diameter) and a compression speed of 50 mm/min. Recording of force (N) and displacement (m) were converted to true axial stress σ (Eq. 3) and Hencky strain ε (Eq. 4), where F: force (N); A: initial surface (m^2); H_i: initial gel height [m]; and H: height (m).

$$\sigma = (F/A) \times (H/H_i), \tag{3}$$

$$\varepsilon = \text{In}\,(H/H_i). \tag{4}$$

σ_f and ε_f were obtained as gel stress (Pa) and gel strain [dimensionless], respectively, at the fracture point and used for statistical analysis.[24] Gel stress, gel strain, and texture profile analysis parameters contribute to better understand sausage texture evolution after non-meat ingredients addition.

Sausage Microstructure Observation

Small sausage samples (formulations 1, 2, and 3), with a size of around 3 mm^3, were cut from the center of the links. Then, they were fixed to the support using a double adhesive tape and they were observed directly in an environmental scanning electron microscope (FEI Quanta 200, Tokyo, Japan). This technique allows the observation of samples in their natural state, under controlled conditions of temperature and pressure. This environmental mode doesn't require any preliminary preparation. Furthermore, it removes completely the electronic loads effect on the surface and, thus, preserves the native structure and the water content of the sample. In this study, microscopic observation was carried out in low vacuum mode with a pressure of 0.1 kPa.

Sensory Evaluation

Sensory analysis was conducted by a 10-member trained panel composed of staff members of the poultry processing industry (Chahia, Tunisia). A 7-point descriptive scale for sensory descriptors of flavor intensity, firmness, and sliceability was used. Sausage sliceability is evaluated by examining the quality of the sample periphery after slicing. Good and acceptable sliceability corresponds to unaltered and homogeneous periphery. The intensity of every attribute increased from 1 (very low) to 7 (very high). Sausage slices of 3-mm thickness were distributed in white polystyrene plates and presented to the panelists with codes in random order. Experiments were conducted in an appropriately designed and lighted room and water was served for the purpose of cleaning the mouth between samples.

RESULTS AND DISCUSSION

Instrumental Texture Properties

The high-fat standard sausage (formulation 1) contains 8 g of added turkey fat (TF)/100 g sausage. Fat content analysis showed that a standard sausage contained

13.2 ± 0.2 g of lipids/100 g sausage. Whether TF substitution by whey powder (WP) and/or ι-carrageenan (ICR) could improve textural and sensory properties of mechanically separated turkey (MST) meat sausage was checked. If so, the obtained product would be extra-low fat. A mixture plan design using three components—TF, WP, and ICR—was used to study the change in the textural and sensory characteristics of formulated sausages (Table 1). Regression equations have been developed to predict the responses of the textural parameters of the processed meat products. Regression analysis showed that the model used was adequate to describe the measured responses; in addition to the main linear terms (concentration of whey powder, ι-carrageenan, and turkey fat), significant interaction terms were identified (Table 2).

A high ICR or WP percentage (formulations 2 and 3) resulted in slightly higher elastic structure, in comparison to the high-fat standard sausage (formulation 1) (Table 3). Higher elasticity values were observed in the (ICR-WP) edge of the isoresponse plot including ICR and WP vertexes (Fig. 1a). Furthermore, gel strain values, which were correlated to the elastic gel behavior, were also slightly higher as WP or ICR content increased. This parameter was the highest in the formulation containing 8 g of WP/100 g sausage (formulation 3) in comparison to the high-fat standard sample (8 g of TF/100 g sausage) (formulation 1) (Table 3). In the contour plot, gel strain of samples increased essentially toward WP vertex (Fig. 1b).

The high-fat standard sample (formulation 1) showed the lowest hardness value (Table 3, Fig. 1c). An increase in the sample hardness was observed outwardly from the isoresponse contour plot center with a tendency towards the (ICR-WP) edge (Fig. 1c). Gel stress, which indicated maximal force supported by sausage gel structure before its fracture, was recorded. The highest gel stress values were observed for the samples containing the highest percentages of WP (formulations 3 and 10). The high-fat standard sausage (formulation 1), however, showed the lowest gel stress value (Table 3, Fig. 2d). An increase in sausage gel stress was observed outwardly from the isoresponse contour plot center with a tendency toward the WP vertex (Table 3, Fig. 1d).

A slightly higher cohesive structure was observed in the (TF-WP) and (ICR-WP) edges of the isoresponse plot with a tendency towards WP vertex (Fig. 1e). The high-fat standard sausage (formulation 1) showed the lowest chewiness value (Table 3). An increase in sample chewiness, outwardly from the isoresponse contour plot center was observed, with a tendency toward the WP vertex (Table 3, Fig. 1f).

Although the effect of carrageenan or WP addition on the functional properties of meat products was assessed, few studies focused on the combined effect of WP and carrageenan on textural properties of processed meat products. The results showed that substitution of added TF by ICR (formulation 2) increased essentially hardness, gel stress, and chewiness of the sausage. Nevertheless, elasticity and gel strain increased slightly in formulation 2 (Table 3). Many studies showed that carrageenan addition resulted in an increase in gel strength and other textural profile analysis parameters for low-fat processed beef or pork meat products.[13,25–27] In the present study, Fig. 1 shows clearly that the effect of WP seems to be more effective than ICR in increasing overall instrumental texture parameters of the sausage as compared to the standard high-fat product (formulation 1). Nevertheless, El-Magoli et al.[28] showed that there was no significant improvement in low-fat beef patties texture upon incorporation of WP. Likewise, Hughes et al.[29] showed that cohesion was not affected by WP addition in frankfurter sausages. Lyons et al.[18] studied the effect of WP and carrageenan gels addition on the textural properties of low-fat pork sausages. They showed that as pre-gelled WP addition was increased, the shear

Table 2 Regression coefficients and correlation for the adjusted model to experimental data relative to instrumental texture and sensory parameters in mixtures design.

	Linear terms			Non-linear terms					
Variables	β_1	β_2	β_3	β_{12}	β_{13}	β_{23}	β_{123}	R^2	${R_A}^2$
Elasticity	8.888***	9.118***	9.140***	−0.177	−1.42**	−0.29	7.073**	0.819	0.720
Hardness	13.683***	17.562***	20.153***	7.517	0.208	5.791	11.379	0.824	0.728
Cohesiveness	0.405***	0.358***	0.416***	0.047	0.027	0.224**	−0.978*	0.797	0.686
Chewiness	48.462***	57.982***	78.599***	34.303	16.803	23.454	182.464	0.886	0.823
Gel strain	2.511***	2.857***	3.338***	−1.023	−1.177	−2.621	7.942**	0.864	0.864
Gel stress	1843.29***	2612.76***	4196.87***	1582.7	−877.63	−512.54	19,319.69**	0.94	0.907
Flavor	3.797***	4.75***	27.581***	5.516***	−1.167	−0.372	3.381***	0.893	0.834
Firmness	3.983***	4.67***	32.913***	0.83	−0.7	−0.472	11.512	0.811	0.708
Sliceability	3.642***	3.838***	29.330***	0.967	5.117**	−2.756	39.364***	0.880	0.815

β_1: turkey fat (TF); β_2: ι-carrageenan (ICR); β_3: whey powder (WP).
***Highly significant ($P < 0.001$); **Significant ($P < 0.01$); *Significant ($P < 0.05$).

Table 3 Experimental results relative to instrumental texture and sensory parameters for each formulation.

Formulations	Elasticity (mm)	Hardness (N)	Cohesiveness	Chewiness (N mm)	Gel strain	Gel stress (Pa)	Flavor	Firmness	Sliceability
1	8.88 ± 0.17^{ab}	13.61 ± 0.453^{a}	0.40 ± 0.060^{abc}	48.34 ± 5.80^{a}	2.51 ± 0.076^{a}	1824.03 ± 86.79^{a}	3.6 ± 0.51^{a}	3.8 ± 0.42^{a}	3.8 ± 0.42^{a}
2	9.13 ± 0.10^{c}	17.48 ± 0.723^{b}	0.37 ± 0.010^{ab}	67.81 ± 5.60^{bc}	2.94 ± 0.047^{b}	2614.98 ± 145.49^{b}	4.6 ± 0.51^{ab}	4.8 ± 0.42^{b}	4.4 ± 0.51^{ab}
3	9.18 ± 0.08^{c}	20.78 ± 1.722^{c}	0.42 ± 0.005^{bcd}	76.02 ± 1.30^{ef}	3.39 ± 0.242^{cd}	4033.46 ± 93.00^{d}	5.6 ± 0.51^{c}	6.6 ± 0.51^{c}	6.0 ± 0.0^{c}
4	8.98 ± 0.002^{abc}	17.11 ± 1.779^{b}	0.39 ± 0.010^{ab}	59.54 ± 5.96^{bc}	2.45 ± 0.056^{a}	2645.96 ± 192.23^{b}	5.4 ± 0.51^{c}	5.0 ± 0.47^{b}	4.6 ± 0.51^{ab}
5	8.65 ± 0.160^{a}	17.40 ± 0.911^{b}	0.41 ± 0.034^{bcd}	67.28 ± 3.59^{bc}	2.70 ± 0.015^{b}	2711.47 ± 142.88^{b}	4.4 ± 0.51^{ab}	5.4 ± 0.51^{bc}	3.4 ± 0.51^{a}
6	9.12 ± 0.080^{c}	20.05 ± 0.867^{c}	0.45 ± 0.026^{cd}	73.85 ± 7.10^{def}	2.53 ± 0.102^{a}	3256.59 ± 223.95^{c}	5.0 ± 0.47^{bc}	5.6 ± 0.51^{bc}	4.8 ± 0.42^{b}
7	9.22 ± 0.170^{c}	19.34 ± 0.273^{bc}	0.38 ± 0.027^{ab}	75.74 ± 3.34^{ef}	2.88 ± 0.157^{c}	3214.99 ± 240.18^{c}	5.4 ± 0.51^{c}	6.2 ± 0.42^{c}	5.8 ± 0.42^{c}
8	8.89 ± 0.025^{ab}	17.82 ± 0.211^{b}	0.43 ± 0.040^{cd}	72.53 ± 5.24^{def}	2.50 ± 0.113^{a}	3153.77 ± 159.76^{c}	4.8 ± 0.42^{bc}	4.6 ± 0.51^{ab}	4.6 ± 0.51^{ab}
9	8.97 ± 0.065^{abc}	21.97 ± 0.400^{c}	0.38 ± 0.007^{ab}	76.81 ± 5.30^{f}	2.50 ± 0.047^{a}	3189.28 ± 107.74^{c}	5.8 ± 0.42^{c}	5.4 ± 0.51^{bc}	4.8 ± 0.42^{ab}
10	8.98 ± 0.065^{abc}	18.66 ± 1.626^{b}	0.41 ± 0.010^{bcd}	79.38 ± 2.13^{f}	2.50 ± 0.035^{a}	3765.69 ± 218.72^{d}	5.0 ± 0.47^{bc}	5.0 ± 0.47^{b}	5.2 ± 0.42^{bc}

Proportion of ingredients formulations are described in Table 1. Means in the same column with the same letter are not significantly different ($P < 0.05$).

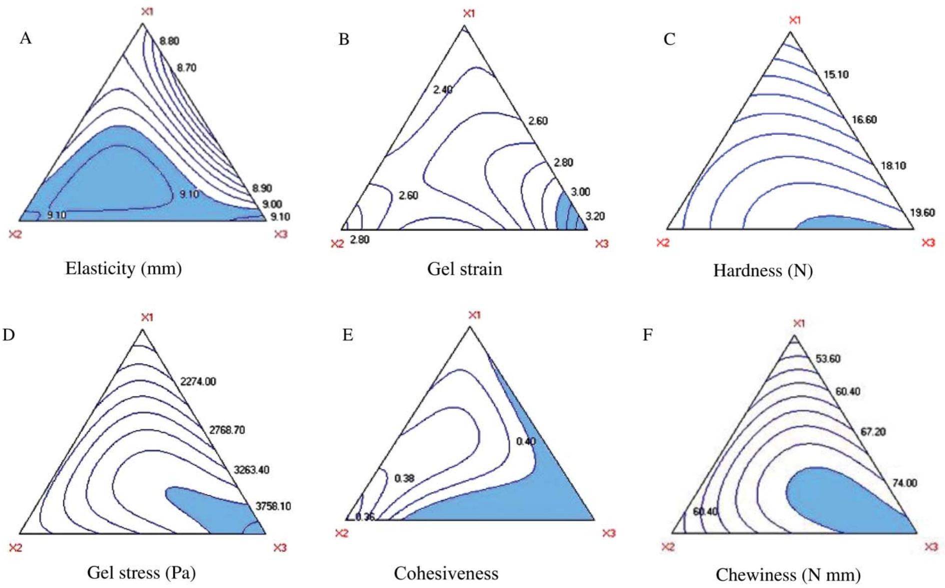

Figure 1 Isoresponse contour plots for predicted instrumental texture parameters of formulated sausages elaborated with turkey fat (TF), ι-carrageenan (ICR), and whey powder (WP). Colored zone indicates the maximum of obtained response. (Color figure available online.)

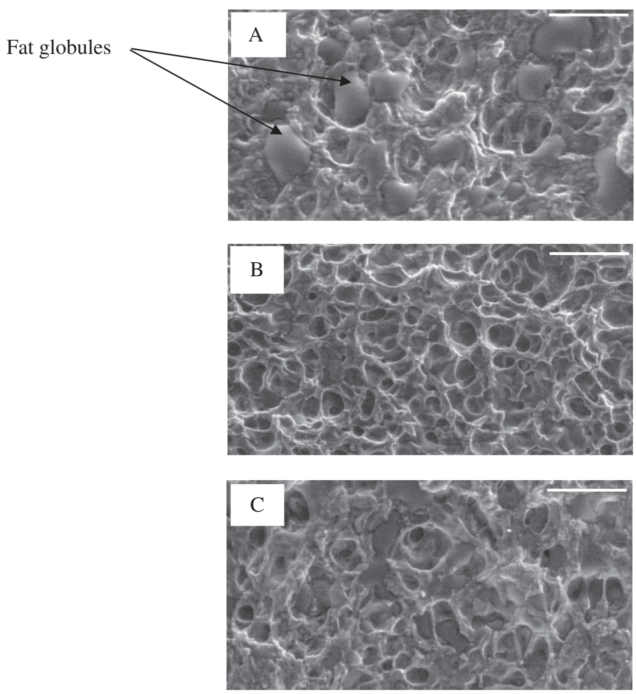

Figure 2 Microscopic observation of sausage gels formulated with: (a) 8 g of TF/100 g sausage (formulation 1); (b) 1.5 g of ICR/100 g sausage (formulation 2); and (c) 8 g of WP/100 g sausage (formulation 3). Scale bar (150 μm).

force value decreased. In contrast, when pre-gelled carrageenan was added, an increase in shear force value of the final sausages was observed. Pietrasik and Duda[19] observed that soy protein/ι-carrageenan (3:1, ratio) favorably affected water holding capacity of low-fat sausages, but did not improve textural parameters.

Sausages Microscopic Observation

Textural changes obtained in formulated MST meat sausages can be explained in terms of the influence of WP and ICR on the gelling process of meat proteins. However, non-meat ingredients and meat protein interactions changed the texture and microstructure of the formulated sausages. The interactions between MST meat proteins and WP proteins or ι-carrageenan chains formed gels examined using environmental scanning electronic microscopy. This technique allows observation of a gel under its natural state. Figure 2a relative to the high-fat standard sausage (formulation 1) showed clearly the presence of fat globules in the three-dimensional gel network. Figures 2b and 2c showed the microstructure of gelled low-fat meat products formulated with 1.5 g of ICR/100 g sausage (formulation 2) and 8 g of WP/100 g sausage (formulation 3), respectively. Figure 2b showed a continuous gel characterized by an open and aerated matrix. This fact can explain the sausage textural changes, such as increasing the hardness and gel stress. Figure 2c showed a compact gel as compared to the structure shown by Fig. 2b. This fact might be due to WP-MST meat proteins aggregation and gelation reinforcing the gel building blocks. Altogether, these results explain the increase of WP-added sausage textural parameters.

Sensory Evaluation

Sensory analysis of prepared sausages was carried out by checking flavor intensity, firmness, and sliceability of the formulated sausages. As was found for instrumental texture parameters, regression analysis showed that the model used was adequate to describe the tested sensory parameters (Table 2). The MST meat products containing WP and/or ICR displayed an increase of sensory parameters scores as compared to the high-fat standard sausage (formulation 1) (Table 3, Fig. 3a). Higher flavor scores were observed in the (TF-ICR) edge of the isoresponse contour plot and in the WP vertex (Fig. 3a). The lowest flavor score observed for the high-fat standard sausage can be explained by the effect of turkey fat. In fact, turkey fat, known for its high sensibility to oxidation, causes changes in the taste and flavor. The results showed that incorporation of WP improved MST meat sausage flavor. As a matter of fact, it was reported that whey proteins could act as a carrier of volatile flavors in food systems. Furthermore, the lactose in whey powder was shown to mask bitter aftertastes of salts and phosphates and act as a stabilizing agent as well as a flavor enhancer in processed meat products.[14,27] Moreover, El-Magoli et al.[28] have shown that increasing the lactose in whey powder significantly improved the flavor profile of low-fat beef patties and was accompanied by an increase in non-enzymatic browning lactose compounds. In contrast, it was reported that whey proteins had no effect on the sensory characteristics of the frankfurters.[13,29,30]

It has been reported that compact texture is an important characteristic of sausages. Consumers usually prefer a harder structure. Nevertheless, a too hard structure could have a negative effect on sensory qualities of MST meat sausages. The authors' results indicated that as was found for sausage flavor, the high-fat standard sausage (formulation 1)

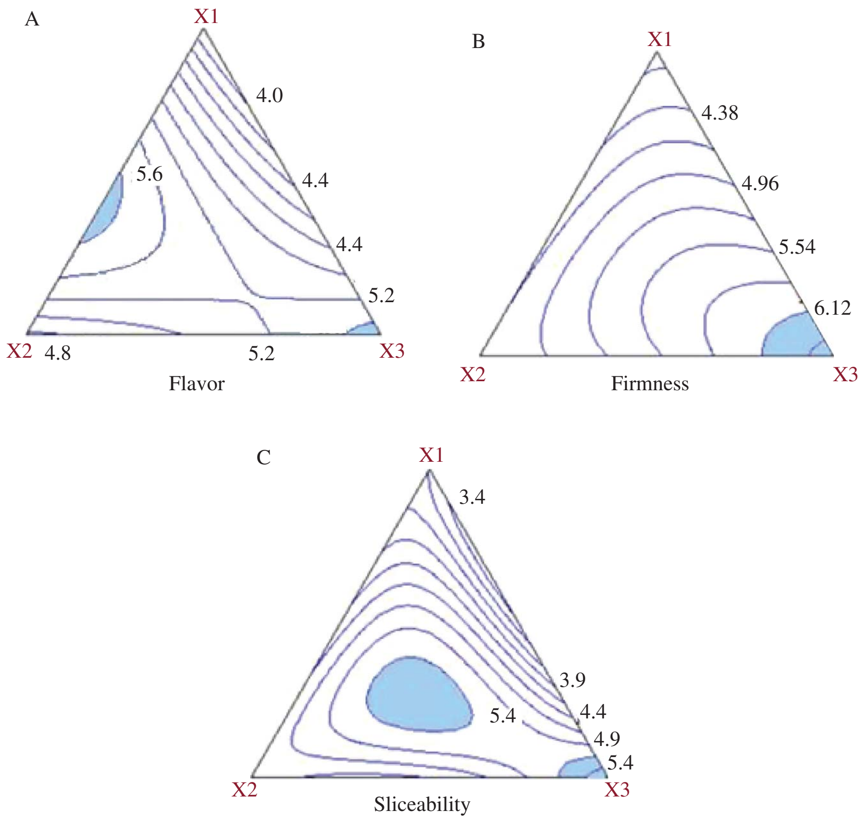

Figure 3 Isoresponse contour plots for predicted sensory parameters analysis of formulated sausages elaborated with turkey fat (TF), ι-carrageenan (ICR), and whey powder (WP). Colored zone indicates the maximum of obtained response. (Color figure available online.)

showed the lowest firmness score (Table 3). A higher firmness score was obtained for the product processed with 8 g of WP/100 g sausage (formulation 3) (Table 3, Fig. 3b). In the isoresponse contour plot, higher firmness scores were observed toward the WP vertex (Fig. 3b). Sensory evaluation relative to the sausage firmness was in concordance with the instrumental texture analysis. Our findings also showed that presence of WP and/or ICR increased the sausage sliceability scores (Table 3). In the contour plot, the highest sliceability scores were found in the domain center and along the WP vertex (Fig. 3c). Therefore, substitution of fat by WP was positively correlated with the firmness, the flavor, and the sliceability scores of MST meat sausages.

Figure 4 showed various contour plots of the desirability surface taking into account all experimental (instrumental texture and sensory) responses. The reliable acceptance region ($0.6 \leq$ desirability ≤ 1) was found in the (ICR-WP) edge and essentially toward the WP vertex. The maximum desirability (D = 99.46%) could be obtained for the MST meat sausage formulation containing: [X_1 (TF) = 0, X_2 (ICR) = 0.028, and X_3 (WP) = 0.97)]. It can be said that substitution of TF by WP (formulation 3) provides an extra-low fat MST meat sausage (4.2 ± 0.3 g of fat/100 g sausage) with improved all sensory and textural characteristics.

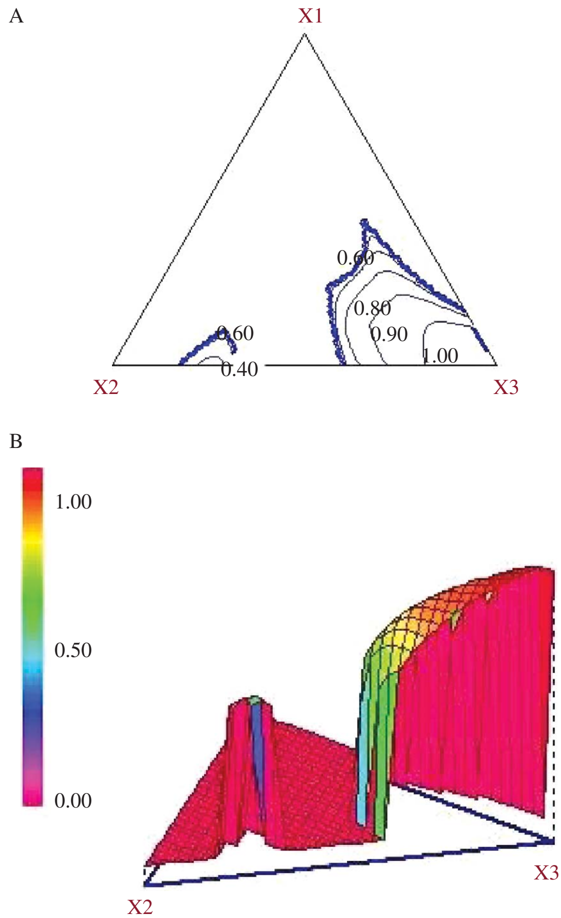

Figure 4 (a) Contour plots (2D graphical study) and (b) three-dimensional surface plot (3D graphical study) of isodesirability curve. (Color figure available online.)

CONCLUSION

Consumer demand for processed poultry meat products has increased. Turkey is now being used to manufacture many processed meat products that traditionally have been made from pork or beef. The effects of the incorporation of the whey powder, ι-carrageenan, and fat on the instrumental texture, the microstructure, and the sensory properties of sausages formulated with mechanically separated turkey meat were studied. Whey powder was successfully used to improve instrumental texture properties of extra low-fat sausages (4.2 ± 0.3 g of fat/100 g sausage). Therefore, incorporation of 8 g of WP/100 g sausage into MST meat sausages improved essentially hardness and chewiness of the extra low-fat sausages and the corresponding sausage showed a more compact microstructure. In comparison to the high-fat standard sausage (13.2 ± 0.2 g of fat/100 g sausage), extra low-fat sausage processed with 8 g of whey powder/100 g sausage displayed the highest scores for the flavor, the firmness, and the sliceability. The impact of whey powder was found to be more important than that of ι-carrageenan on the textural and sensory quality of MST meat sausage.

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