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Optimization of textural properties of reduced-fat and reduced-salt emulsion-type sausages treated with high pressure using a response surface methodology

Huijuan Yang [a], Muhammad Ammar Khan [b], Minyi Han [a], Xiaobo Yu [a], Xiangjun Bai [c], Xinglian Xu [a], Guanghong Zhou [a,*]

[a] Synergetic Innovative Center of Food Safety and Nutrition, Key Laboratory of Meat Processing and Quality Control, Ministry of Education, Key Laboratory of Animal Products Processing, Ministry of Agriculture, College of Food Science and Technology, Nanjing Agricultural University, Nanjing 210095, PR China
[b] Food Science & Technology, University College of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Pakistan
[c] Anhui Kanghongyuan Food Co., Ltd, PR China

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ABSTRACT

This study optimized the high pressure conditions for development of a reduced fat sausage. A three-factor-three-level Box–Behnken design was adopted to study the simultaneous effects of one compositional variable (15, 20 and 25% fat content) and two processing variables (150, 200 and 250 MPa high pressure, along with 5, 6 and 7 min high pressure treatment time) on firmness of emulsion-type sausages. Analysis of variance (ANOVA) was performed to evaluate the potential interactive and quadratic effects between these variables. The results revealed that, the optimum processing conditions for an optimum gel setting were 22.19% fat content, 197.30 MPa high pressure and 5.92 min pressure treatment time. The adequacy of the model equation for predicting the optimum response values was effectively verified. In conclusion, the emulsion-type meat sausages using a novel high pressure based processing method were preferred for their improved textural properties and reduced fat content.

Industrial relevance: For health reasons, there is a need to reduce fat content of processed meat products. This study developed a novel processing method using high pressure to produce emulsion-type meat sausages with reduced-fat, with improved functional qualities, including objective appearance, textural properties and sensory evaluation. Importantly, this was achieved with a model, mainly based on prediction of the firmness of the pressure treated sausages with reduced fat contents.

1. Introduction

Lipids, mainly fats and oils, are important constituents of foods. Fat may either be obtained from plants or animal origin. The traditional emulsion-type sausages, usually, have a high fat content (30%), which is mainly obtained from pork meat (Ventanas, Puolanne, and Tuorila, 2010). The amount of fats in a particular product strongly influences the rheological properties and sensory characteristics of foods, including flavor, mouth-feel and texture (Baer and Dilger, 2014; Mun et al., 2009). In addition, fats from different species or different anatomical locations within the animal can also markedly affect characteristics of a product (Gallier et al., 2013). The consumption of high amounts of fat has been associated with several chronic diseases, such as obesity, cardiovascular diseases and cancer (Shen, Luo, and Dong, 2011). Various non-fat ingredients may replace fat contents in meat products, but their use does not exhibit desired product quality attributes (Martinez, Miranda, Franco, Cepeda, and Vazquez, 2011; Petersson, Godard, Eliasson, and Tornberg, 2014b). Water and other substances, such as being either protein- or carbohydrate-based, have been used to substitute fat contents in emulsion-type sausages (Toldra and Reig, 2011). Using water alone to replace fat, however, as a common method, can result in poor textural properties of the product and a higher cooking loss (Claus, Hunt, and Kastner, 1989). It is, therefore, difficult to reproduce the traditional product quality using reduced-fat recipe, with existing processing technologies. Application of high pressure has given some positive result for improved product characteristics (Yang, Han, Wang, Han, Wu, Xu, & Zhou, 2015). However, little work has been done on optimization of process conditions for reduced-fat sausages treated with high pressure.

High pressure processing (HPP) is a non-thermal processing technique used in the food industry. It has established a wide-spread interest because of its beneficial effects on textural properties, as well as reducing microbial numbers, without deterioration of flavor or nutritional constituents, within a food system (Bravo, Felipe, Lopez-Fandino, and Molina,

* Corresponding author. Tel.: +86 25 84395376; fax: +86 25 84395939.
E-mail address: guanghong.zhou@hotmail.com (G. Zhou).

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Table 1
Formulation for raw pork sausage batters (3.0 kg).

Fat content (%)	Lean pork (kg)	Back fat (kg)	Water (kg)	Salt (kg)
0	1.86	0.0	1.11	0.03
10	1.86	0.3	0.81	0.03
20	1.86	0.6	0.51	0.03
30	1.86	0.9	0.21	0.03

2015; Girgih et al., 2015; Guo et al., 2015). HPP has been successfully used to alter the textural properties and color of reduced-fat sausages and other meat products (Colmenero, 1996; Yang, Han, Bai, Han, Xu, & Zhou, 2015). HPP modifies the secondary and tertiary structures of myofibrillar proteins, thus affecting the rheological properties related to these proteins (Cando, Herranz, Borderias, and Moreno, 2015; Torres, Saraiva, Guerra-Rodriguez, Aubourg, and Vazquez, 2014). The integrity of these myofibrillar proteins is directly associated with myowater, which ultimately affects the properties of meat and products. HPP has been associated with increase in hydrogen bonding, which causes equilibrium shift of water from inter myofibrillar spaces to intra myofibrillar spaces, that results in greater water holding capacity of these proteins (Chattong and Apichartsrangkoon, 2009). Substitution of fat with water in emulsion type sausages can take advantage of this property of HPP in reduced-fat emulsion-type meat sausages.

Response surface methodology (RSM) is a simulation modeling tool, widely used to predict process conditions in various scientific as well as industrial processes, for optimization of processing operations (Fang, Xie, Chen, Yu, and Chen, 2012; Guo, Wang, and Jiang, 2005; Harkouss, Safa, Gatellier, Lebert, and Mirade, 2014; Luo et al., 2011; Mohtar, Perera, Quek, and Hemar, 2013; Pappa, Bloukas, and Arvanitoyannis, 2000; Teng, Chin, and Yusof, 2011; Zhao et al., 2005). The reduction in fat content in meat emulsion-type sausages by HPP requires optimization of process conditions, including pressures and holding times, for each of the specific fat percentages. Once this has been established, we will evaluate the reduced-fat sausages for texture (firmness) as a measure of their quality and compare them with the non-HPP sausages having 30% fat content. Firmness is generally considered as the index of textural properties of meat emulsion-type sausages. It is associated with eating quality and doneness of meat and meat products (Cofrades, Antoniou, Solas, Herrero, and Jimenez-Colmenero, 2013), so it was measured here to evaluate the textural property change. Therefore, the objectives of this study were to investigate the effects of fat contents (0 to 30%), high pressure (0.1 to 400 MPa) and high pressure holding times (0 to 9 min) at 10 °C on the firmness of sausages, and to develop RSM using a Box–Behnken design for predicting optimum processing conditions for sausages with reduced fat. These studies developed a simulation model using HPP that resulted in improved textural properties of reduced-fat meat products, and is recommended for processing of emulsion-type meat sausages on industrial scale.

2. Materials and methods

2.1. Materials

Pork meat and high-grade pork back fat of homogeneous white color were purchased from Su Shi group (Nanjing, China). Pork meat (*M. vastus intermedius*, round muscle) was trimmed free of major connective tissues, packed and immediately stored at −18 °C. For each trial, the frozen pork was control thawed at 4 °C for 24 h prior to preparation of the batters.

2.2. Preparation of batters

The pork meat batters were prepared according to the formulation given in Table 1. Protein concentrations were maintained constant among all the treatments, by replacing fat contents with cold ice water. High pressure processing altered textural and functional properties of sausages with reduced-salt content (Sikes, Tobin, and Tume, 2009; Yang et al., 2015b; Yang et al., 2015b). In this study, 1% salt was chosen to be added to prepare the sausages with reduced-fat content, based on those with reduced-salt, as reported previously (Yang et al., 2015a; Yang et al., 2015b). All the ingredients were placed in a bowl cutter, along with salt, mixed and cut into a fine emulsion. The indoor temperature was maintained below 12 °C at all times. The batters were then stuffed into 24 mm diameter sausage cellulose casings and linked every 150 mm, giving each sausage an approximate weight of 60 g. The linked raw sausages were then vacuum packed in polyamide/polyethylene bags (oxygen permeability < 1 $cm^3/m^2/h$ at 20 °C), and stored at 4 °C.

2.3. Application of HPP

HPP was carried out in a 0.3 L capacity 850 Mini FoodLab high pressure vessel (Stansted Fluid Power Ltd., UK). Water was used as the pressure-transfer medium and the whole system was cooled to an initial temperature of 10 °C by a thermostated jacket. The vacuum packed meat batters linked into sausage casings were subjected to 100, 200, 300 or 400 MPa for 2 min at 10 °C, and were compared to non-pressure-treated (0.1 MPa, atmospheric pressure) controls. During the processing, the pressure was increased at a rate of 20 MPa/s. Pressure was maintained for either 3, 6 or 9 min, and then released to 0.1 MPa in 15 s. Upon release of pressure and removal from the vessel, the samples were kept at 4 °C. During the HPP, adiabatic heating resulted in a temperature increase of approximately 4 °C, and so the control samples were held in water (0.1 MPa) at 14 °C for the same time as the pressure treated samples. Then those samples were cooled at 4 °C until SEM and TEM analyses.

2.4. Scanning electron microscopy

The micro-structure of emulsion-type sausages was examined by scanning electron microscopy (SEM), according to the method of Chattong, Apichartsrangkoon, and Bell (2007). The cooked sausage samples were fixed in 2.5% glutaraldehyde for 24 h, followed by dilution in 0.1 M phosphate buffer having pH 7.2. The samples were cut into 1 mm × 1 mm × 2 mm pieces, transferred into tertiary butyl alcohol, freeze-dried and coated with gold to 10 nm thickness. Samples were observed by using a scanning electron microscope (S-3000N, Hitachi, Tokyo, Japan) with the accelerating voltage of 15 kV and the magnification of 2000×.

Table 2
Codes and levels of factors for response surface method experiment.

Run	Independents and code variables			Response[a,b] (N)	
	Fat content (%) x_1	High pressure (MPa) x_2	High pressure treatment time (min) x_3	Actual value	Predicted value
1	15 (−1)	150 (−1)	6 (0)	4.54	4.53
2	25 (1)	150 (−1)	6 (0)	6.83	6.90
3	15 (−1)	250 (1)	6 (0)	4.91	4.84
4	25 (1)	250 (1)	6 (0)	6.72	6.73
5	15 (−1)	200 (0)	5 (−1)	4.83	4.87
6	25 (1)	200 (0)	5 (−1)	7.01	6.97
7	15 (−1)	200 (0)	7 (1)	4.72	4.76
8	25 (1)	200 (0)	7 (1)	6.94	6.90
9	20 (0)	150 (−1)	5 (−1)	7.11	7.08
10	20 (0)	250 (1)	5 (−1)	6.09	6.12
11	20 (0)	150 (−1)	7 (1)	5.98	5.95
12	20 (0)	250 (1)	7 (1)	7.03	7.06
13	20 (0)	200 (0)	6 (0)	7.53	7.52
14	20 (0)	200 (0)	6 (0)	7.49	7.52
15	20 (0)	200 (0)	6 (0)	7.57	7.52
16	20 (0)	200 (0)	6 (0)	7.51	7.52
17	20 (0)	200 (0)	6 (0)	7.54	7.52

[a] Average value of triplicate experiments.
[b] Numbers in parentheses are coded symbols for levels of independent parameters.