Food Sci. Biotechnol. 20(3): 687-694 (2011)
DOI 10.1007/s10068-011-0097-3

RESEARCH ARTICLE

Optimizing the Replacement of Pork Fat with Fractionated Barley Flour Paste in Reduced-fat Sausage

Jin-Woong Choi, So-Hee Kim, Saehun Mun, Sung-Joon Lee, Jae-Yong Shim, and Yong-Ro Kim

Received: 9 December 2010 / Revised: 7 March 2011 / Accepted: 7 March 2011 / Published Online: 30 June 2011

Abstract Reduced-fat sausages were prepared by replacing pork back fat with barley flours of different particle sizes. Three barley flour fractions with different particle size were obtained by passing the ground barley material through a sieve. Fraction 1 and 2 had a higher water absorption index than other fraction and showed higher peak and final viscosities due to higher β-glucan content. Therefore, fraction 1 and 2 were used as a fat replacer in preparation of reduced-fat sausages. Response surface methodology was employed to optimize the formulation of reduced-fat sausage and the effects of fat content and barley flour paste concentration on the textural properties were analyzed simultaneously. Using a regression model, the optimum formulation of reduced-fat sausage was calculated. For fraction 1, calculated levels of fat content and paste concentration were 7.6 and 3.9%, and for fraction 2, levels were 6.7 and 6.9%, respectively.

Keywords: reduced-fat, sausage, barley flour, fractionation

Introduction

A major goal of the meat industry in recent years has been to develop healthier meat products, containing less fat and more health-enhancing ingredients. Fat in meat products plays important roles in product quality by stabilizing meat emulsions, reducing cooking loss, improving water holding capacity, and providing juiciness and hardness (1-4). However, recent concerns about the adverse effects associated with overconsumption of fat have led to the reduction of fat content in meat products (5,6).

The production of low-fat meat products is normally associated with problems such as poor texture, flavor, and mouth feel. Fat replacers or fat mimetics are often used as an effective way to overcome these problems. Nonfat ingredients such as dietary fiber, carrageenan, starch, oat β-glucan, maltodextrins, isolated soy protein, and *konjac* have been used in attempts to eliminate processing problems by improving rheological properties and stability of low-fat food products. In particular, oat β-glucan has been often used in the formulation of low-fat meat products due to its highly viscous nature and water-binding capacity. Many researchers have reported that β-glucan may have health benefits such as serum cholesterol lowering effects, blood glucose regulation, decreasing insulin response, and weight control through prolonged satiety (7,8).

Barley is an excellent source of both soluble and insoluble dietary fiber, especially β-glucan. However, extraction of β-glucan is a long and complicated process. Previous research showed that sieving of barley flour was the most convenient and effective way to produce enriched fractions of β-glucan (9-11). Applying the high β-glucan fraction of barley flour as a fat replacer to reduced-fat sausage would be practically meaningful. To minimize texture deterioration due to fat reduction and barley flour addition, the amount of fat replacement and the barley flour content need to be optimized. Response surface methodology (RSM) has been employed for optimizing a surimi-supplemented pork sausage formulation (12).

Jin-Woong Choi, So-Hee Kim, Saehun Mun, Yong-Ro Kim (✉)
Center for Agricultural Biomaterials and Department of Biosystems & Biomaterials Science and Engineering, Seoul National University, Seoul 151-742, Korea
Tel: +82-2-880-4607; Fax: +82-2-873-2049
E-mail: yongro@snu.ac.kr

Sung-Joon Lee
Division of Food Bioscience and Technology, College of Life Science and Biotechnology, Korea University, Seoul 136-713, Korea

Jae-Yong Shim
Department of Food and Biotechnology, Food and Bio-Industrial Research Center, Hankyong National University, Anseong, Gyeonggi 456-749, Korea

Therefore, the objectives of this study were to prepare barley flour fractions with increased β-glucan content by milling and sieving and to optimize the added levels of barley flour fractions and fat replacement to minimize changes in the textural properties of reduced-fat sausage compared to those of high fat sausage using RSM.

Materials and Methods

Materials Commercial waxy barley was purchased from a local grocery store and barley flour was prepared by grinding roasted barley grain with a commercial pin mill (Dae Hwa, Daegu, Korea). The milled barley flour was separated into 3 fractions by passing through a sieve with 150-μm openings and a sieve with 75-μm openings in a series. Barley flour was classified into 3 fractions: 150 μm <fraction 1 (F1), 75 μm<fraction 2 (F2) <150 μm, fraction 3 (F3)<75 μm.

Chemical composition Moisture, fat, protein, and ash contents of barley flour and each barley flour fraction were determined in triplicate according to AACC methods (13). Starch and β-glucan contents were determined according to AOAC methods 995.16 and 996.11 using a Megazyme mixed-linkage β-glucan assay kit (Wicklow, Ireland) and a Megazyme total starch assay kit, respectively.

Particle size analysis The size distributions of unsieved barley flour and flour fractions were determined using a particle size analyzer (Mastersizer-2000; Malvern Instruments Ltd., Worcestershire, UK). For size measurement, samples were dispersed in 10 mL of distilled water at a 1:400 (w/v) ratio. The suspensions were stirred continuously at room temperature for 30 min and then measured at 25°C with a scattering angle of 90°.

Determination of water absorption index For unsieved barley flour and flour fractions (F1, F2, and F3), each sample (0.4 g) were mixed with 12.5 mL of distilled water in conical tubes by vortex mixer, equilibrated at 25°C for 5 min, and then heated to 90°C (or held at 25°C) and held at that temperature for 30 min with stirring. The samples were centrifuged at 3,000×g for 10 min. The supernatant was carefully removed, and the wet flour sediment was weighed. The water absorption index was determined with the following equation:

Water absorption index (WAI)
=wet sediment weight/dry sample weight

Thermal properties Thermal properties of unsieved barley flour and flour fractions (F1, F2, and F3) were investigated with a Pyris Diamond differential scanning calorimeter (DSC, Perkin Elmer, Waltham, MA, USA) equipped with an Intracooler 2P and nitrogen gas purge. Each sample (8±0.1 mg, d.b.) was weighed in a large volume DSC pan (Perkin Elmer) and water was added at the level of 1:2.5. The sample pan was sealed and equilibrated for 5 h at room temperature before analysis. The sample pan was cooled to 10°C, and scanned from 10 to 90°C at a rate of 5°C/min. An empty pan was used as a reference. The onset temperature (To), peak temperature (Tp), end temperature (Te), and enthalpy (ΔH) were determined from DSC curves.

Pasting properties A rapid visco-analyzer (Newport Scientific Pvt., Ltd., Warriewood, Australia) was used to determine the pasting properties of barley flour and its fractions according to a modified AACC method (14). The flour (3 g, 12% m.b.) was transferred into 25 mL of distilled water within the canisters and stirred manually by rotating the plastic paddle for 15-30 s to disperse the sample thoroughly. The temperature was maintained at a uniform 50°C for 1 min and then raised to 95°C over 3 min 42 s. The samples were maintained at 95°C for 2 min 30 s, cooled to 50°C over 2 min, and held at 50°C for 2 min. Each measurement was performed in duplicate.

Experimental design RSM was used to study the simultaneous effects of 2 variables, replacing a quantity of fat with barley flour fraction paste (X1) and the concentration of the paste (X2) for unsieved barley flour and flour fractions. The experiment was based on a small composite design. Five levels of each variable were chosen (Table 1). Experimental data were fitted to a second-order polynomial model and regression coefficients were obtained. The generalized second-order polynomial model used in the response surface analysis was as follows:

$$Y=\beta_0+\sum_{i=1}^{2}\beta_i x_i+\sum_{i=1}^{2}\beta_{ii} x_2+\sum_{i<j}\beta_{ij} x_i x_3$$

where β_0, β_i, β_{ii}, and β_{ij} are the regression coefficients for intercept, linear, quadratic, and interaction terms, respectively. Y1, Y2, Y3, and Y4 represented the hardness, springiness, cohesiveness, and chewiness of TPA parameters, respectively. To optimize formulations of reduced-fat sausages prepared with each barley flour fraction, X1 and X2 values were determined from the regression model. X1 and X2 levels were determined by selecting the levels at which TPA parameters of reduced-fat sausages (Y1, Y2, Y3, and Y4) were within the range found in normal sausages (average± standard deviation). Common values of independent variables (X1 and X2) were selected. Among common values, the biggest X2 values were chosen as the optimum level.

Table 1. Levels of variables used to prepare reduced-fat sausages by central composite design with rotatable axial scaling (unit: %, w/w)

No.	Paste quantity (X1)	Paste concentration (X2)
1	19.18	3.17
2	19.18	8.83
3	86.13	3.17
4	86.13	8.83
5	5.31	6.00
6	100.00	6.00
7	52.65	2.00
8	52.65	10.00
9	52.65	6.00
10	52.65	6.00
11	52.65	6.00

Table 2. Formulations of sausages

	Normal sausage	Reduced-fat sausage[1)]
Pork red meat	54.88	54.88
Pork fat	20.71	20.71-X1
Barley flour paste	0	X1
Ice	20.71	20.71
Salt	1.55	1.55
Phosphate	0.26	0.26
Vit-C	0.07	0.07
Spice	1.47	1.47
Sugar	1.35	1.35

[1)]X1, barley flour paste quantity (%)

Sausage preparation For unsieved barley flour and flour fractions (F1, F2, and F3), 5 kinds of pastes with different paste concentrations (2.00, 3.17, 6.00, 8.83, and 10.00%) were prepared (Table 1), respectively. To prepare barley flour paste, unsieved barley flour and flour fractions were gelatinized at 90°C for 20 min and then they were cooled to room temperature with stirring.

After preparation of barley flour paste, all ingredients were mixed in the bowl mixer for 2 min to obtain a base mixture (Table 2). The mixture was stuffed into 17 mm casings and linked into 40 to 45 g portions to form sausages. Sausages were then steamed for 9 min and cooled with ice water for 9 min.

Texture analyses The textural properties of sausages were measured using a texture analyzer (TA-XT2i, Stable Microsystems, Surrey, UK). The samples were placed on the platform of the texture analyzer. An aluminum cylinder probe (Ø 50 mm) was used and texture profile analysis (TPA) test was performed with pre-test speed, test speed and post-test speed of 2.0 mm/s and 50% of strain. Hardness, cohesiveness, springiness, and chewiness were response variables.

Statistical analyses All statistical analyses except for RSM were executed using PASW (V17; SPSS Inc., Chicago, IL, USA). Duncan's multiple range tests were used to determine differences in mean values. Significance was established at $p<0.05$.

Results and Discussions

Particle size analysis of barley flour fractions Before the optimization of replacing pork fat with barley flour paste for preparation of reduced-fat sausages, barley flour was sieved to obtain β-glucan enrichment and particle size of each fraction was measured. Previous studies have sieved or air-classified barley flours to produce fractions with enhanced levels of different chemical components, mostly β-glucan and protein. However, it has been suggested that sieving of barley flour was more effective than air classification in producing enriched fractions of β-glucan (9-11).

The average particle sizes of unsieved barley flour and flour fractions (F1, F2, and F3) which were passed through sieves of different sizes were 100.2, 317.0, 158.9, and 22.4 μm, respectively. F1 and F2 had larger average particle size than unsieved barley flour. The full particle size distributions are shown in Fig. 1. As for the sieved fractions (F1, F2, and F3), the upper and lower limits of measured particle size distributions slightly exceeded the mesh sizes of sieves (F1>150 μm, 75 μm<F2<150 μm, F3<75 μm). The over estimation of particle size compared to sieve mesh size was probably due to hydration of particles during measurement. However, the trend of measured distribution did not deviate to a great extent from expectation. The particle size distributions of F1 and F2 had a higher percentage of relatively large particles (100<size<1,000 μm). On the other hand, F3 had a higher percentage of particles with size ranging from 10 to 100 μm compared to unsieved barley flour and other fractions. Barley starch consisted of large, lens-shaped particles (10-20 μm diameter) and small particles less than 5 μm in diameter (15,16). Therefore, much of the barley starch present would be able to pass through the 75-μm sieve. A previous study (17) reported that finely ground barley had the highest β-glucan content in flour with particle sizes 103-149 μm and considerably lower content in flour with particle sizes >250 μm or <103 μm.

Chemical composition of barley flour fractions The proximate compositions of barley flour fractions are given in Table 3. Fractionation of barley flour by passing through different size sieves made a difference in the content of β-glucan and starch of fractions. F1 and F2 with a relatively large particle size had higher levels of β-glucan and lower

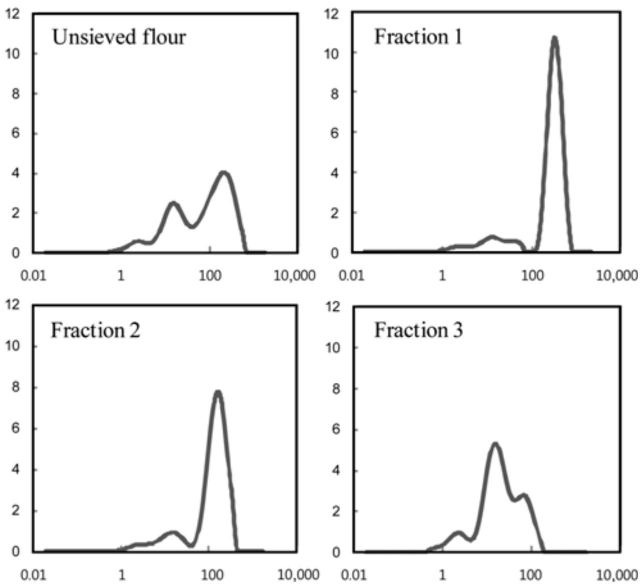

Fig. 1. Particle size distributions of unsieved flour and fractions.

levels of starch content compared to the unsieved barley flour. Unsieved flour had 4.5% β-glucan and F1 and F2 had 8.4 and 9.1%, respectively. After fractionation, β-glucan content increased more than 2-fold compared to that of unsieved barley flour. F3 with relatively small particle size had the opposite result of those of fraction 1 and 2. The starch content was the highest in F3, but the β-glucan content was the lowest (1.5%). Protein and ash contents were higher in F2 with the higher content of β-glucan. Zheng *et al*. (18) reported that in cereal, including barley, bran is characterized by high protein and low starch concentrations. Among bran tissues, the aleurone layer is known to be high in protein. They also suggested that β-glucan was relatively high in the subaleurone region for low β-glucan hull-less barley, but not for high β-glucan hull-less barley that contained medium to high β-glucan, as the starchy endosperm contained more β-glucan than subaleurone (18). Hence, the higher concentration of protein and β-glucan of F2 might be related to a higher prevalence of the aleurone and subaleurone layers than in other fractions.

Water absorption index (WAI) WAI is one of the factors which can affect the processing and texture of the product. Therefore, WAI of unsieved flour and fractions was measured at room temperature and 90°C (Table 3). WAI values of F1 and F2 measured at room temperature were almost 2-fold higher than those of unsieved flour and F3. The ability of water to be absorbed depends on limitations in mass transport as well as chemical composition of the samples (19). The higher WAI of F1 and F2 at room temperature were more likely due to their higher content of β-glucan. As the temperature was raised to 90°C, WAI of samples increased, with those of unsieved flour and F3 increasing greatly. Unsieved flour and F3 had higher starch contents and lower β-glucan contents compared to F1 and F2. Thus, the large increase in WAI of unsieved flour and F3 at 90°C might be attributed to the relatively higher content of starch and gelatinization of starch.

Pasting properties Leached soluble carbohydrate and swollen granules are known to cause viscosity changes of starch during gelatinization. Different additives and ingredients can be used to modify the pasting properties. Among ingredients, gums and hydrocolloids are often used to modify the pasting properties of starch-containing products due to their desirable effect on the acceptability of foodstuffs. Some researchers reported that pasting properties of barley starch were changed when isolated β-glucan was added into starch suspension (20,21).

Pasting properties of barley flour and fractions were examined (Table 4). The interaction between β-glucan and starch could be an important factor in viscosity during flour pasting. The initial pasting temperatures of unsieved flour and fraction suspensions were not different. The different composition of fractions had no effect on the gelatinization temperature of starch in flours. A noticeable result was that F1 and F2, containing relatively higher amounts of β-glucan and lower contents of starch, had significantly higher peak, trough, and final viscosity and setback compared to those of unsieved flour and F3. In particular, F1 had the highest of these values among the samples. This result indicated that the interaction between β-glucan and starch might cause an increase in the viscosity. F1 and F2 were β-glucan-concentrated fractions, and even though these fractions had lower starch content compared to F3,

Table 3. Yield, chemical analysis, and water absorption index (WAI) of barley flour and flour fractions

	Yield	β-Glucan	Starch	Protein	Fat	Ash	WAI (g/g, d.b.)	
	%(w/w)						25°C	90°C
Unsieved barley flour	-	4.31	54.92	11.64	3.13	1.72	1.09±0.16[a]	9.22±0.15[a]
Fraction 1	17.39	8.46	40.24	12.29	3.22	1.91	2.13±0.25[b]	11.54±0.25[b]
Fraction 2	19.15	9.12	33.96	13.84	4.19	2.24	1.91±0.29[b]	7.54±0.32[c]
Fraction 3	62.85	1.46	71.39	9.95	3.03	1.37	0.95±0.18[a]	8.67±0.53[ac]

Table 4. RVA parameters of barley flour fractions

	Unsieved flour	Fraction 1	Fraction 2	Fraction 3
Pasting temp.	69.78±0.53[a]	69.83±0.53[a]	71.05±1.20[a]	68.98±0.67[a]
Peak time	4.83±0.05[a]	4.70±0.05[ab]	4.60±0.09[b]	5.23±0.05[c]
Peak viscosity	955.00±26.87[a]	1,794.00±76.37[b]	1,198.05±0.71[c]	962.50±75.66[a]
Trough	704.00±9.90[a]	1,571.50±61.52[b]	982.00±1.41[c]	621.00±55.15[a]
Final viscosity	1,300.50±21.92[a]	2,096.50±65.76[c]	2,040.00±0.00[c]	1,146.00±101.82[b]
Breakdown	251.00±16.97[a]	222.50±14.85[a]	216.50±2.12[a]	341.50±20.51[b]
Setback from trough	596.50±12.02[a]	1,335.00±4.24[b]	1,058.00±1.41[c]	525.00±46.67 [d]

Table 5. DSC characteristics of unsieved barley flour and fractions

	Onset temp. (°C)	Peak temp. (°C)	ΔH (J/g)	End temp. (°C)
Unsieved barley flour	73.74±0.20[a]	77.68±0.51[a]	6.00±0.25[a]	82.12±0.81[ab]
Fraction 1	74.35±0.18[a]	79.15±0.01[b]	4.24±0.01[b]	83.54±0.18[a]
Fraction 2	73.89±0.42[a]	78.83±0.47[b]	4.48±0.49[b]	82.80±0.45[ab]
Fraction 3	72.72±0.13[b]	77.05±0.24[a]	6.85±0.19[c]	81.65±0.58[b]

Table 6. Analysis of variance of regression models for TPA parameters of reduced-fat sausage formulated with flour F1 and F2

	F1		F2	
	Significant value	R_y^2	Significant value	R_y^2
Hardness	0.0012	0.9655	0.0245	0.8783
Springiness	0.0239	0.8796	0.0764	0.8009
Cohesiveness	0.0143	0.9029	0.0019	0.9581
Chewiness	0.0018	0.9589	0.0268	0.8735

these fractions still had 30-40% starch. Therefore, interactions between β-glucan and starch within F1 and F2 seemed to cause different pasting properties. Two phenomena may possibly explain these pasting property results of barley flours with different compositions. First, the interaction between β-glucan and starch caused an increase in the shear forces exerted on the granules (22,23). Second, a combination of swollen starch particles, effused amylose, and β-glucan competed for water particles (24).

Thermal properties DSC characteristics of unsieved flour and fractions are shown in Table 5. Only F3 had significantly different onset temperature among samples. F3 was mainly composed of starch (71.4%) and had only 1.5% β-glucan; therefore, the swelling and gelatinization of starch were more easily attainable compared to other fractions. The peak temperatures of F1 and F2 were higher than those of unsieved flour and F3 and the enthalpy was lower. These results seemed to be caused by the interaction of starch and β-glucan. β-Glucan competes with starch for water, consequently, the amount of available water which would be used to gelatinize starch decreases. Furthermore, β-glucan can affect the structural changes of molecules occurring during starch gelatinization. These factors might be related to the changes in DSC characteristics of barley flour fractions with different compositions.

Development of reduced-fat sausage formulated with F1 As described above, F1 and F2 had higher β-glucan contents and higher viscosities than unsieved barley flour and F3. Thus, F1 and F2 were chosen as fat replacers to prepare reduced-fat sausages. Due to their higher viscosity and β-glucan, it was expected that these fractions could improve water holding capacity and cooking yield of reduced-fat sausages and would have the potential health benefits offered by β-glucan.

Analysis of variance of regression models was significant for hardness ($p<0.01$), springiness ($p<0.05$), cohesiveness ($p<0.05$), and chewiness ($p<0.01$) of reduced-fat sausages formulated with F1 (Table 6). The different effects (linear, quadratic, and interaction) exerted by the studied variables are shown in Fig. 2. These results indicate that changes in paste quantity (fat-replacing quantity) and paste concentration affected the textural characteristics of reduced-fat sausages prepared with F1. Hardness, springiness, cohesiveness, and chewiness increased as paste concentration increased, while hardness, cohesiveness, and chewiness decreased as paste quantity increased.

Conflicting results have been reported regarding the influence of β-glucan or other hydrocolloids on textural parameters when they were added to meat products. Owing to their water binding ability and swelling properties, β-glucan and other hydrocolloids can influence food texture.

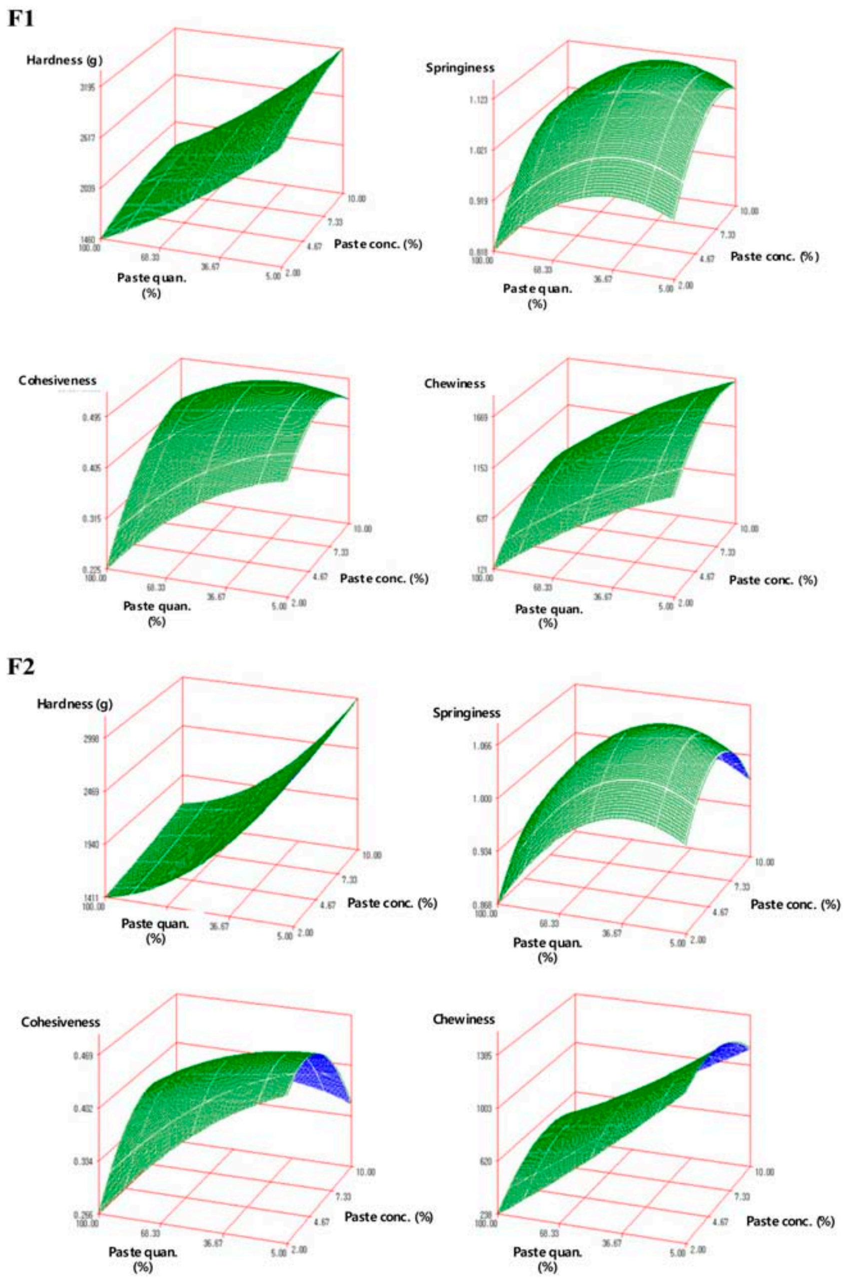

Fig. 2. Response surface plot of hardness, springiness, cohesiveness, and chewiness of reduced-fat sausages formulated with paste of flour F1 and F2.

Usually, fat reduction is accompanied by an increase in moisture levels in the products and causes changes in the food characteristics. Piettrasik and Duda (3) reported that as fat content was reduced by increasing water content, hardness decreased. However, other studies reported that adding starch, β-glucan, or protein could make hardness increase (25,26). Another study suggested that certain polysaccharides inhibited the precipitation of some water-soluble proteins following thermal denaturation, thus hindering the formation of a strong protein-protein network (27).

In the case of chewiness, response surface plots showed results similar to those for hardness. Cohesiveness and springiness also had similar response surface plots to hardness; however, in a specific range, the 2 parameters showed maximum values. From TPA parameters of normal sausages, optimum X1 and X2 were calculated to coincide with values obtained from normal sausages. Selected levels of X1 and X2 and predicted TPA parameters of optimized reduced-fat sausages prepared with F1 are shown in Table 7.

Development of reduced-fat sausage formulated with F2 Analysis of variance (Table 6) showed significance

Table 7. Predicted TPA parameters of optimized reduced-fat sausages using barley flour F1 and F2

Reduced-fat sausage (predicted)		
	F1[1)]	F2[2)]
Hardness	2,873.85	2,873.78
Springiness	1.03	N/A
Cohesiveness	0.47	0.42
Chewiness	1,376.30	1,332.37

[1)]Paste quantity (X1)=7.6 (%), paste concentration (X2)=3.9 (%)
[2)]Paste quantity (X1)=6.7 (%), paste concentration (X2)=6.9 (%)

for hardness (p<0.01), cohesiveness (p<0.05), and chewiness (p<0.01) of reduced-fat sausages formulated with F2. The effect of paste quantity and paste concentration on the textural characteristics of reduced-fat sausages prepared with F2 was similar to that for F1 and response surface plots were also similar (Fig. 2). However, in the case of springiness, the regression model was not significant (p> 0.05). In acquiring optimum values, springiness was excluded. Selected levels of X1 and X2 and predicted TPA parameters of optimized reduced-fat sausages prepared with F2 are shown in Table 7. The selected levels of X1 and X2 were 6.7 and 6.9%, respectively.

In conclusion, ground barley flour was divided into 3 fractions using sieves to increase the β-glucan content of barley flour. As a result, β-glucan contents of fractions 1 and 2 increased 96.09 and 111.39%, respectively. In the gelatinization process, the swelling power of fractions was mainly affected by particle size except for fraction 3. However, β-glucan contents were affected by particle size only at room temperature. Fraction 1 and 2 had higher swelling powers. The water absorption index showed a similar tendency. Pasting properties of fractions were affected by particle size and β-glucan contents. For that reason, fraction 1 and 2 had higher peak and final viscosity than unsieved barley flour. Because fraction 1 and 2 had higher β-glucan contents and final viscosity, the barley flour paste of fraction 1 and 2 were selected as a fat replacer in reduced-fat sausage. Using RSM, TPA parameters (hardness, springiness, cohesiveness, and chewiness) of reduced-fat sausages were analyzed. In sausages formulated with fraction 1, hardness (Y1), springiness (Y2), cohesiveness (Y3), and chewiness (Y4) fit well. The regression model for springiness of sausages formulated with fraction 2 was not significant (p>0.05). Using the regression model, the optimum formulations of reduced-fat sausages were calculated. For fraction 1, paste quantity (X1) was 7.6% and paste concentration (X2) was 3.9%, while for fraction 2 these values were 6.7 and 6.9%, respectively.

Acknowledgments This research was supported by Technology Development Program for Agriculture and Forestry, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea.

References

1. Carballo J, Barreto G, Jimenez-Colmenero F. Starch and egg white influence on properties of bologna sausage as related to fat content. J. Food Sci. 60: 673-677 (1995)
2. Hughes E, Confrades S, Troy DJ. Effects of fat level, oat fibre, and carrageenan on frankfurters formulated with 5, 12, and 30% fat. Meat Sci. 45: 273-281 (1996)
3. Pietrasik Z, Duda Z. Effect of fat content and soy protein/ carrageenan mix on the quality characteristics of comminuted, scalded sausages. Meat Sci. 56: 181-188 (2000)
4. Yang HS, Choi SG, Jeon JT, Park GB, Joo ST. Texture and sensory properties of low fat pork sausages with added hydrated oatmeal and Tofu as texture-modifying agents. Meat Sci. 75: 283-289 (2007)
5. Khalil AH. Quality characteristics of low-fat beef patties formulated with modified corn starch and water. Food Chem. 68: 61-68 (2000)
6. Cofrades S, Guerra MA, Carballo J, Fernandez-Martin F, Jimenez Colmenero F. Plasma protein and soy fiber content effect on bologna sausage properties as influenced by fat level. J. Food Sci. 65: 281-287 (2000)
7. Hecker KD, Meier ML, Newman RK, Newman WC. Barley β-glucan is effective as a hypocholesterolaemic ingredient in foods. J. Sci. Food Agr. 77: 179-183 (1998)
8. Yokoyama WH, Hudson CA, Knuckles BE, Chiu MCM, Sayre RN, Turnlund JR, Schneeman BO. Effect of barley β-glucan in durum wheat pasta on human glycemic response. Cereal Chem. 73: 293-296 (1997)
9. Knuckles BE, Chiu MM. β-Glucan enrichment of barley fractions by air classification and sieving. J. Food Sci. 60: 1070-1074 (1995)
10. Sundberg B, Tilly AC, Åman P. Enrichment of mixed-linked (1-3), (1-4)-β-D-glucans from a high-fibre barley-milling stream by air classification and stack-sieving. J. Cereal Sci. 21: 205-208 (1995)
11. Stevenson DG, Jane JL, Inglett GE. Structure and physicochemical properties of starches from sieve fractions of oat flour compared with whole and pin-milled flour. Cereal Chem. 84: 533-539 (2007)
12. Murphy SC, Gilroy D, Kerry JF, Buckley DJ, Kerry JP. Evaluation of surimi, fat, and water content in a low/no added pork sausage formulation using response surface methodology. Meat Sci. 66: 689-701 (2004).
13. AACC. Approved Method of the AACC. 10th ed. Methods 44-15A, 46-11A, 08-01, and 30-10. American Association of Cereal Chemists, St. Paul, MN, USA (2000)
14. AACC. Approved Method of the AACC. 10th ed. Methods 61-02. American Association of Cereal Chemists, St. Paul, MN, USA (2000)
15. Lee YT, Seog HM, Cho MK. β-Glucan enrichment from pearled barley and milled barley fractions. Korean J. Food Sci. Technol. 29: 888-894 (1997)
16. Hoseney RC. Principles of Cereal Science and Technology. 2nd ed. American Association of Cereal Chemists, St. Paul, MN, USA. pp. 1-26 (1994)
17. Yoon SH, Berglund PT, Fastnaught CE. Evaluation of selected barley cultivars and their fractions for β-glucan enrichment and viscosity. Cereal Chem. 72: 187-190 (1995)
18. Zheng GH, Rossnagel BG, Tyler RT, Bhatty RS. Distribution of β-glucan in the grain of hull-less barley. Cereal Chem. 77: 140-144 (2000)
19. Kerr WL, Ward CDW, McWatters KH, Resurreccion AVA. Effect of milling and particle size on functionality and physicochemical properties of cowpea flour. Cereal Chem. 77: 213-219 (2000)
20. Choi HD, Seog HM, Kim SR, Park YK, Lee CH. Effect of β-glucan on gelatinization of barley starch. Korean J. Food Sci. Technol. 35: 545-550 (2003)
21. Kim SR, Choi HD, Seog HM, Kim SS, Lee YT. Physicochemical characteristics of β-glucan isolated from barely. Korean J. Food Sci.

Technol. 31: 1164-1170 (1999)
22. Rojas JA, Rosell CM, Benedito de Barber C. Pasting properties of different wheat flour-hydrocolloid systems. Food Hydrocolloid. 13: 27-33 (1999)
23. Song JY, Kim YC, Shin MS. Textural properties and structures of wheat and maize starch-gum mixed gels during storage. Food Sci. Biotechnol. 17: 20-25 (2008)
24. Lee MH, Baek MH, Cha DS, Park HJ, Lim ST. Freeze-thaw stabilization of sweet potato starch gel by polysaccharide gums. Food Hydrocolloid. 16: 345-352 (2002)
25. Shand PJ, Texture, water holding, and sensory properties of low-fat pork bologna with normal or waxy starch hull-less barley. J. Food Sci. 65: 101-107 (2000)
26. Morin LA, Temelli F, Mcmullen L. Physical and sensory characteristics of reduced-fat breakfast sausages formulated with barley β-glucan. J. Food Sci. 67: 2391-2396 (2002)
27. Aleson-Carbonell L, Fernandez-Lopez J, Perez-Alvarez JA, Kuri V. Functional and sensory effects of fibre-rich ingredients on breakfast fresh sausages manufacture. Food Sci. Technol. Int. 11: 89-97 (2005)