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The Quality Improvement of Emulsion-type Pork Sausages Formulated by Substituting Pork Back fat with Rice Bran Oil

Hyeon-Woong Yum¹, Jin-Kyu Seo¹, Jin-Yeon Jeong¹, Gap-Don Kim²,
M. Shafiur Rahman¹, and Han-Sul Yang^{1,2*}

¹Division of Applied Science (BK21 plus), Gyeongsang National University, Jinju 52828, Korea

²Institute of Agriculture and Life Science, Gyeongsang National University, Jinju 52828, Korea

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*Corresponding author: Han-Sul Yang

Division of Applied Science (BK21 plus), Gyeongsang National University, Jinju-daero, Jinju, Gyeongnam 52828, Korea

Tel: +82-55-772-1948

Fax: +82-55-772-1949

E-mail: hsyang@gnu.ac.kr

Abstract The effects of pork back fat (PBF) substitution with various concentrations of rice bran oil (RBO) (50%, 45%, 40% and 35%) on the physicochemical characteristics and sensory attributes of emulsion-type pork sausages were studied. The modified pork sausages were compared with control sausages produced using PBF only. The sausages with RBO had significantly lower ($p<0.05$) moisture content than the control sausages. Sausages made from PBF substituted with 40% RBO showed the lowest cooking loss. Substitution of PBF with RBO had no significant effect on the emulsion stability of pork sausages. All sausages with RBO showed significantly lower ($p<0.05$) hardness values than control sausages. Sausages with RBO also had significantly higher values ($p<0.05$) of unsaturated fatty acid and polyunsaturated to saturated fatty acid contents than the controls. RBO substitution had no effect on the flavor intensity of sausages, but it improved the tenderness and produced a softer texture.

Keywords emulsion-type pork sausage, fat replacer, fatty acid composition, pre-emulsion, rice bran oil

Introduction

Traditionally, sausages are prepared using ground meat, fats, salt, spices, and other ingredients. Generally, sausages may consist of almost 30% of animal fat and this fat is an important ingredient for producing the emulsion and gelling of meat products. Because it affects the stability of meat emulsions, reduces cooking losses, improves flavor, texture, and a desired mouth feel of the meat products (Hughes et al., 1996). But the main drawback is diets with high content of animal fats particularly saturated fatty acids and cholesterol have been associated with increased incidence of obesity, hypertension, cardiovascular diseases, and coronary heart diseases (Dupont et al., 1991; Özvural and Vural, 2008; Skeaff and Miller, 2009).

In recent years, efforts have been made to develop the nutritional value of meat products such as sausages by making them phosphate-free (Ruusunen et al., 2004), low-fat (Yang et al., 2007), low-salt (Jiménez-Colmenero et al., 2010), and low-calorie by replacing animal fats with oils from marine or plant sources along with non-meat ingredients (Alejandro et al., 2016). Vegetable oils are the main source of dietary fat, with high contents of unsaturated fatty acids. They have a range of prominent functional properties that provide attractive sensory attributes to food products. The total content of unsaturated fatty acids in sausages can be increased by replacing them with highly unsaturated vegetable oils (Choi et al., 2010; Lee et al., 2015). The World Health Organization (WHO) has proposed three parameters for judging the qualitative characteristics of each oil: the ratio of saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), and polyunsaturated fatty acid (PUFA), the proportion of essential fatty acids, and the presence of antioxidants; the WHO recommends oils with values of 1:1.5:1 (SFA: MUFA: PUFA) and 5~10:1 (linoleic acid: alpha linolenic acid) in the diet (WHO, 2008). Rice bran oil (RBO) has a fatty acid profile similar to the standards recommended by the WHO (Choudhary et al., 2015). In addition, RBO is used as a rich source of antioxidants such as oryzanol which improves the stability of emulsions for processing and storage (Gopala et al., 2006).

However, vegetable oils cannot be used directly in meat products with the currently available technology, because of their different physical properties (Pappa et al., 2000). Physically development of unsaturated fatty acids by replacing fats in meat products might rapidly reduce the stability of the meat product (Juárez et al., 2012). Muguerza et al. (2001) reported that sausages made by blending of PBF and olive oil showed considerable dripping of fat. Therefore, the physicochemical properties of vegetable oils need to be modified. In order to achieve this, method involving hydrogenation and interesterification has been developed (Vural et al., 2004). Microencapsulation is another effective technique to increase oxidative stability of oils rich in n-3 polyunsaturated fatty acids (Bakey et al., 2016; Heck et al., 2017). In another approach for preparing emulsified meat products, a pre-emulsified oil/fat emulsion is initially added to the meat. Pre-emulsification can enhance the water- and fat-binding properties of fats, thus improving the dispersion of fat into meat batters (Jiménez-Colmenero, 2007). The effects of substituting RBO for PBF and the pre-emulsification of RBO with fiber of rice bran on the qualitative characteristics of emulsion-type pork sausages have not yet been evaluated. Substituting lipids into meat products might provide them nutritional advantages, without negatively influencing on the quality and sensory properties.

Therefore, the objective of this study was to investigate the effect of PBF substitution with different concentrations of RBO combined with pre-emulsification treatments on the proximate composition, stability of emulsion, texture attributes, fatty acid composition, and sensory characteristics of emulsion-type pork sausages. In addition, the study aimed to develop a product with better nutritional and qualitative attributes by replacing animal fats with RBO.

Materials and Methods

Materials

Fresh pork loin (castrated boar; Landrace♂ × Yorkshire♀ × Duroc♂; moisture 75.67%, protein 20.76%, fat 1.92%) and pork back fat (PBF) (moisture 11.98%, fat 86.04%) were purchased from a local meat processing plants 2 d post slaughter. The used rice bran oil (RBO) was 100% oil obtained from rice bran. The PBF (35.97% SFA, 47.49% MUFA and 18.82% PUFA) and rice bran oil (RBO) (100% fat or oil including 17.48% SFA, 43.83% MUFA and 38.86% PUFA) were purchased from a local market in Jinju, South Korea. Lean pork loin was trimmed from fat and connective tissues,

and each replication was ground separately through a 5 mm plate (84186, Food cutter, Hobart, USA) twice. The PBF was also ground through an 8 mm plate. The ground pork loin and fat were loosely packaged without vacuum and stored at 0°C until use. The chemicals used in the study were purchased from Sigma Aldrich (USA), and all were of high purity analytical grade.

Preparation of emulsion-type pork sausages

Five different PBF sausages were prepared and the compositions for formulation are listed in Table 1. The sausages were prepared as binary blends between PBF and RBO (w/w) at different ratio. The first sausages indicated as the control (100% PBF) and followed by T1 (50% PBF/50% RBO), T2 (55% PBF/45% RBO), T3 (60% PBF/40% RBO), and T4 (65% PBF/35% RBO). The control had total pork back fat (PBF) and this PBF was replaced by T1, T2, T3 and T4 (Table 1). There was no addition of RBO in the control during pre-emulsification and emulsification process. But different levels of RBO were added in T1, T2, T3 and T4 during pre-emulsification. RBO, obtained from local market, was used to replace pork back fat. RBO was pre-emulsified on the day of use. All ingredients were subsequently added, mixed and homogenized for 10 min and maintained below 15°C at final temperature. Rice bran fiber was added to the samples at 3% and then PBF or pre-emulsified RBO was homogenized for 3 min. After 3 min, other ingredients were added and the batters were emulsified for 7 min. The emulsified sausage batter were stuffed into cellulose casings (approximate diameter of 50 mm) using a stuffer (H15, TALSA, Spain). The sausages were then allowed to equilibrate for 24 h at 4°C in a refrigerator. Then sausages were smoked for 40 min at 60°C and cooked for 60 min at 90°C in a heating chamber (CHS-76, Alto-Shaam Inc., USA) to maintain the core temperature of 75.5°C. The sausages were cooled at 4°C in a refrigerator.

Table 1. The formulations of emulsion-type pork sausages

Ingredients (%)	Treatments ¹⁾				
	Control	T1	T2	T3	T4
Pre-emulsion					
Pork back fat	-	10	11	12	13
Rice bran oil	-	10	9	8	7
Water (Ice)	-	5	5	5	5
Rice bran fiber	-	3	3	3	3
Emulsion					
Pork lean meat	60	60	60	60	60
Pork back fat	20	-	-	-	-
Rice bran oil	-	-	-	-	-
Water (Ice)	20	15	15	15	15
Rice bran fiber	3	-	-	-	-
Salt	1.5	1.5	1.5	1.5	1.5
Sodium tripolyphosphate	0.2	0.2	0.2	0.2	0.2
Sodium nitrite	0.01	0.01	0.01	0.01	0.01
Sugar	0.5	0.5	0.5	0.5	0.5
Garlic powder	0.5	0.5	0.5	0.5	0.5

¹⁾Control: 100% pork back fat, T1: 50% pork back fat substitution by rice bran oil, T2: 45% pork back fat substitution by rice bran oil, T3: 40% pork back fat substitution by rice bran oil, and T4: 35% pork back fat substitution by rice bran oil.

Proximate compositions

The proximate composition analysis of sausage batter was performed following the method of AOAC (2002). Moisture content was determined by drying the samples to constant weight at 102°C and protein content was determined by the Kjeldahl method. Lipids were extracted from the sausage batter with chloroform/methanol (1:2 v/v) according to Bligh and Dyer (1959). Ash content was determined by using a muffle furnace.

Cooking loss and emulsion stability

The loss of sausages due to cooking was determined gravimetrically following a modified method of Boles and Swan (1996). The emulsion stability was determined using the method proposed by Jiménez-Colmenero et al. (2005) with some modification. A 25 g emulsified sample was transferred into 50 mL centrifuge tube, and then heated in a water bath at 70°C for 30 min followed by centrifugation at 1,000 rpm for 10 min. The total amount of fluid released was expressed as a percentage of the same weight. The content of released fat was calculated by the weight difference in the total liquid released after drying at 105°C for 16 h. Cooking loss was calculated by the weight difference of samples before cooking (W_1) and after cooking (W_2).

$$\text{Cooking loss (\%)} = 100 \times \left(\frac{w_1 - w_2}{w_1} \right)$$

The emulsion stability (ES) was calculated by determining the volume of the emulsified layer ($V_{30 \text{ min}}$) after maintaining samples at 70°C for 30 min, V_T is the total volume before centrifugation:

$$\text{ES (\%)} = 100 \times \left(\frac{v_{30 \text{ min}}}{v_T} \right)$$

Where, $V_{30 \text{ min}}$ is the volume of remaining emulsified layer after centrifugation for 30 min and V_T is the volume of original emulsified layer before centrifugation.

pH, color, texture profile analysis

Homogenates were prepared by homogenizing a 3 g of sausage with 27 mL of deionizer water for 30 s using the homogenizer (T25basic, IKA, Malaysia). The pH was measured using a digital pH meter (MP230, Mettler Toledo, Switzerland). The standard buffers was used to pH 4.0, 7.0 and 9.21 for calibration of pH meter at 25°C before measuring. The color (International Commission on Illumination L^* , a^* , b^*) of sausages were measured using a Minolta Chromameter (Minolta CR 300, Japan) standardized with a white calibration plate ($Y = 93.5$; $x = 0.3132$; $y = 0.3198$). The measurements were repeated at five randomly selected positions on each slice and averaged. The texture properties were analyzed following the procedure of Bourne (1978) using a texture analyzer (EZ-SX, Shimadzu Co., Japan). Three sausage cores (diameter 3.0 cm, height 2.0 cm) per treatment were axially compressed at 70% of their original height. Sausage samples were balanced at 20°C to 25°C (room temperature) for 30 min before analysis. Force versus time curves were obtained with a 50 kg load cell applied at a crosshead speed of 100 mm/min and the following parameters were calculated: hardness, cohesiveness, springiness, gumminess and chewiness.

Fatty acid composition

Fat extraction was determined according to the method described by Folch et al. (1957) using organic solvent (chloroform and methanol, 2:1, v/v). An 80 mg of extracted fat and 0.4 mg of tricosanoic acid methyl esters (0.4 mg/mL hexane, international standard) were placed into a screw-capped test tubes and solvent was removed under nitrogen flashing. Analysis was performed by Yang et al. (2009). To determine the total fatty acid composition 0.5 μ L of the supernatant was introduced with an auto-sampler injector into the split injection port of Hewlett-Packard 6890 GC equipped with a flame ionization detector (FID). A fused SUPELCOWAXTM capillary column of 30 m \times 0.32 mm \times 0.25 μ M (Supelco, USA) was used for the separation of the fatty acid methyl esters. The carrier gas, hydrogen, was set at a flow rate of 2 mL/min, the initial temperature of the column was 180°C, and then heated to 230°C at a rate of 1.5°C/min, and was maintained for 2 min. The temperature of the injector and detector was set at 240 and 260°C, respectively.

Sensory evaluations

Sausage samples from each treatment were evaluated by an 8-member trained expert descriptive attribute sensory panel. The panelist were selected and trained according to the procedures of Meilgaard et al. (1999). Panelists were served samples representing anchor points for each attribute, and training sessions using sausage with PBF and RBO in the meat processing lab. The panelists were trained using a 5point scale (“5 extremely intense” and “1 slightly intense”) for sausage color, flavor, and texture characteristics (hardness and juiciness). Final anchor point ratings were decided upon by training panel after initial evaluation and discussion. The evaluation was performed with the samples at room temperature. The panelists rinsed their mouths with water and some neutral crackers between the samples. For the samples, panelists evaluated the samples for color, flavor, odor, juiciness, tenderness and overall acceptability using a 9-point hedonic scale as described by Meilgaard et al. (1999). The samples were provided within glass containers (Pyrex[®], USA) and covered with plastic covers prior to sensory test. Each panelist received at least 2 cubes per sample and evaluated 8 randomly ordered with substituted RBO samples.

Statistical analysis

The results of quality examinations were presented as mean \pm standard deviations of three determinations. The data were analyzed using a software package (SAS version 9.3, SAS Institute, Inc., USA, 2014). Analysis of variance (ANOVA) was performed and significant differences among the means were determined with Duncan’s multiple range tests. A probability value of $p < 0.05$ was considered significant.

Results and Discussion

Proximate compositions

The proximate composition of emulsion-type pork sausages formulated with PBF after substitution with different concentration of RBO is shown in Table 2. The moisture content of the sausage batters ranged from 60.77% to 61.72%, and significant differences were found between the samples. Pork sausages made from PBF substituted with RBO had significantly lower ($p < 0.05$) moisture content than control sausages prepared with PBF. Compared to the control sausages, all RBO-substituted sausages had significantly decreased ($p < 0.05$) protein content and T2 (45% RBO) had the lowest protein content among all RBO-substituted sausages. T2 (45% RBO) and T3 (40% RBO) showed significantly

lower level of fat than control sausages ($p < 0.05$). There was no significant difference between T4 and control sausage for fat content but T4 (35% RBO) had higher fat content than control sausage. All RBO-substituted sausages also had significantly lesser ash content compared to the controls ($p < 0.05$).

Table 2. Proximate composition, cooking loss and emulsion stability of sausage batters formulated by partially substituting pork back fat with rice bran oil

	Treatments ¹⁾					P-value
	Control	T1	T2	T3	T4	
Proximate composition (%)						
Moisture	61.72 ± 0.18 ^A	60.96 ± 0.10 ^B	60.83 ± 0.13 ^B	60.928 ± 0.08 ^B	60.77 ± 0.44 ^B	<0.0001
Protein	17.35 ± 0.28 ^A	16.19 ± 0.21 ^B	14.88 ± 0.04 ^C	16.39 ± 0.08 ^B	15.13 ± 0.09 ^C	<0.0001
Fat	17.66 ± 0.40 ^{AB}	16.97 ± 0.74 ^B	16.03 ± 0.38 ^C	16.33 ± 0.86 ^C	18.08 ± 0.80 ^A	<0.0001
Ash	5.99 ± 0.08 ^A	5.68 ± 0.09 ^B	5.60 ± 0.10 ^B	5.72 ± 0.10 ^B	5.60 ± 0.22 ^B	<0.0001
Cooking loss (%)	10.12 ± 1.44 ^A	6.52 ± 1.11 ^B	6.09 ± 1.65 ^B	4.97 ± 0.78 ^C	5.70 ± 0.55 ^{BC}	<0.0001
Emulsion stability (%)						
Water loss	0.39 ± 0.22	0.23 ± 0.13	0.17 ± 0.16	0.22 ± 0.33	0.11 ± 0.07	0.0933
Fat loss	5.09 ± 0.42	5.25 ± 0.33	5.25 ± 0.28	5.30 ± 0.68	5.24 ± 0.19	0.8644

All values are mean ± standard deviation. n=3.

^{A-B} Means within each row with different superscripts are significantly different ($p < 0.05$).

¹⁾Control: 100% pork back fat, T1: 50% pork back fat substitution by rice bran oil, T2: 45% pork back fat substitution by rice bran oil, T3: 40% pork back fat substitution by rice bran oil, and T4: 35% pork back fat substitution by rice bran oil.

The substitution of PBF with RBO was expected to decrease the total moisture content in the sausages. The moisture content of dry fermented sausages had developed when PBF was substituted with a linseed oil-gelled emulsion (Alejandro et al., 2016). Choi et al. (2010) attributed the high moisture content in frankfurters made with vegetable oil and rice bran fiber to the high water retention capacity of rice bran fiber. Lee et al. (2015) obtained related findings to replacing pork fat with vegetable oils; they found that the substitution decreased the moisture content of pork sausage. Pork fat improves water content; that is, the addition of pork fat increases the moisture content of sausages. The similar results for fat content of this study as the fat content was lower in vegetable oil and rice bran fiber treated frankfurters compared to control frankfurters (Choi et al., 2010).

Cooking loss and emulsion stability

The two quality properties such as cooking loss and emulsion stability of emulsion-type pork sausage batters made from PBF substituted with various concentrations of RBO are presented in Table 2. All sausages made from PBF substituted with RBO showed lesser ($p < 0.05$) cooking loss than the controls and lowest-level ($p < 0.05$) of cooking loss was shown in T3. Similarly results have been previously obtained, where the addition of vegetable oils decreased the cooking loss of sausages (Lee et al., 2015). Pre-emulsified soybean oil in frankfurters has also been shown to be effective for improving the water-holding capacity. (Chen et al., 2015).

Water and fat exudation studies revealed that significant differences were not observed in water and fat loss of all sausage samples. Sausages with enzymatically interesterified blends of 10% and 30% rapeseed oil have been shown to have no excretion of fats (Cheong et al., 2010). In addition, Xiong and Jiang (2015) had reported that the interfacial protein membrane and the size of the emulsion droplet affected the stability of the emulsions formed. Vegetable oils such as canola oil can form emulsions more tightly than beef fat, because of their smaller fat globules, which provide extensive

surface space to the proteins (Youssef and Barbut, 2009). Substituting more than 20% pork back-fat with plant oil (Sunflower and canola oils) combined with pre-emulsification developed water- and fat- binding characteristics in chicken liver paste batters (Xiong et al., 2016). These observations indicated that substituting animal fats with RBO could produce stable meat products with no apparent water or fat dripping.

pH, color, texture profile analysis

The pH and color of emulsion-type pork sausages formulated by substituting PBF with different concentration of RBO are shown in Table 3. Pork sausages made from PBF substituted with 50% RBO (T1) had a lower pH value than the control ($p<0.05$). The pH value of the sausages increased as the concentration of RBO decreased. These results might be attributed to low pH value of RBO.

Table 3. pH, color (CIE L^* , a^* , b^*) and texture profile analysis of pork sausages formulated by partially substituting pork back fat with rice bran oil

	Treatments ¹⁾					P-value
	Control	T1	T2	T3	T4	
pH	6.25 ± 0.03 ^B	6.20 ± 0.03 ^C	6.25 ± 0.03 ^B	6.29 ± 0.03 ^A	6.25 ± 0.01 ^B	<0.0001
Color						
Lightness (L^*)	78.07 ± 0.93 ^D	80.74 ± 0.43 ^A	80.30 ± 0.35 ^B	79.38 ± 0.45 ^C	79.35 ± 0.60 ^C	<0.0001
Redness (a^*)	1.41 ± 0.40 ^A	-0.18 ± 0.86 ^D	0.21 ± 0.39 ^C	0.63 ± 0.18 ^B	0.29 ± 0.20 ^{BC}	<0.0001
Yellowness (b^*)	15.08 ± 0.31 ^E	15.95 ± 0.17 ^D	16.14 ± 0.16 ^C	16.99 ± 0.24 ^A	16.76 ± 0.18 ^B	<0.0001
Texture profile analysis						
Hardness (kg)	0.27 ± 0.03 ^A	0.26 ± 0.02 ^{AB}	0.24 ± 0.03 ^{BC}	0.24 ± 0.02 ^{BC}	0.22 ± 0.02 ^C	0.0007
Cohesiveness	0.80 ± 0.27	0.85 ± 0.16	1.00 ± 0.23	1.14 ± 0.25	1.13 ± 0.50	0.0667
Springiness (cm)	1.74 ± 0.22	1.58 ± 0.26	1.77 ± 0.27	1.95 ± 0.22	1.93 ± 0.71	0.2399
Gumminess (kg)	0.22 ± 0.07	0.22 ± 0.05	0.24 ± 0.05	0.27 ± 0.05	0.25 ± 0.11	0.4410
Chewiness (kg)	0.37 ± 0.13	0.36 ± 0.12	0.44 ± 0.14	0.54 ± 0.15	0.55 ± 0.35	0.1466

All values are mean ± standard deviation. n=3.

^{A-B} Means within each row with different superscripts are significantly different ($p<0.05$).

¹⁾Control: 100% pork back fat, T1: 50% pork back fat substitution by rice bran oil, T2: 45% pork back fat substitution by rice bran oil, T3: 40% pork back fat substitution by rice bran oil, and T4: 35% pork back fat substitution by rice bran oil.

Pork sausages made from PBF substituted with RBO had higher lightness values than the controls ($p<0.05$). The lightness of the sausages increased proportionately with increasing concentration of RBO. These results were rational to those obtained by Chen et al. (2015) and Ambosiadis et al. (1996), who reported that replacing animal fats with vegetable oils increased the lightness value of frankfurters. Youssef and Barbut (2011) reported that replacing beef fat with canola oil or pre-emulsified canola oil increased the lightness of reduced-fat samples. The redness values of pork sausages made from PBF substituted with RBO were lower than those of controls ($p<0.05$). These results were consistent with those of Back et al. (2016), who reported that replacing PBF with canola and flaxseed oils decreased the redness of emulsion-type sausages from spent layer meat. The yellowness was also found to be higher in pork sausages formulated with RBO-substituted PBF than the controls ($p<0.05$). Previous studies have reported that yellowness could be increased in meat batters by adding vegetable oils (Koo et al., 2009). This effect may be due to the high-density yellow color of RBO itself.

The texture attributes of emulsified pork sausages formulated with PBF substituted with different concentrations of RBO are shown in Table 3. No significant differences were observed in the cohesiveness, springiness, and chewiness of

the test and control sausages ($p>0.05$). However, in all RBO-substituted samples, the softness-increased the concentration of RBO decreased. Therefore, the hardness values decreased as the concentration of RBO in the sausage increased, with the values being 0.26 for T1, 0.24 for T2, 0.24 for T3, and 0.22 for T4, compared to the control (hardness values=0.27). Selani et al. (2016) had demonstrated that the substitution of animal fats with vegetable oils increased the hardness of burgers. Youssef and Barbut (2009) had also noted that substituting fats with canola oil increased the hardness of meat products. This effect may be because vegetable oils contain lower amounts of fat globules than animal fats, resulting in higher protein-protein and protein-lipid interactions. Consistent with these results, Khalil (2000) reported that the hardness of beef patties significantly decreased when its moisture content increased. This apparent discrepancy in hardness is related to moisture content and cooking loss (Table 2). Xiong et al. (2016) reported that substitution of back fat with pre-emulsified plant oils developed the properties of water- and fat-binding, thus decreasing the fluid reduction in chicken liver paste. These results indicated that oil/water emulsions could be stabilized using RBO, and that using pre-emulsified meat batters produced firmer emulsion-type pork sausages than directly adding RBO to the emulsion. Therefore, RBO substituted PBF could be used to make sausages with softer texture. These results were also important for sensory attributes of the sausages.

Fatty acid composition

The composition of fatty acid in raw and cooked emulsion-type pork sausages from PBF substituted with different concentrations of RBO is shown Table 4. Palmitic acid (C16:0) and stearic acid (C18:0) were the main saturated fatty acids (SFAs) found in emulsion-type pork sausages, while oleic acid (C18:1) and linoleic acid (C18:2) were the richest monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA), respectively. Significant changes in the percentages of SFA, MUFA, and PUFA were observed in the raw and cooked pork sausages. The substitution of PBF with RBO decreased the percentage of SFA and MUFA in the raw and cooked pork sausages ($p<0.05$). The PUFA content in RBO-substituted samples was significantly higher ($p<0.05$) than that in the control samples. This may be attributed to the high amounts of linoleic acids. In addition, RBO (purchased from local market) contained 17.48% saturated fatty acid, 43.83% monounsaturated fatty acid and 38.86% polyunsaturated fatty acid.

In general, the substitution of vegetable oils significantly increases the content of UFA and decreases that of SFA in meat products. Choi et al. (2010) had reported that replacing PBF with different vegetable oils significantly increased the content of linoleic acid in reduced-fat frankfurters. Back et al. (2008) had reported that the PUFA content of spent-layer sausages with substituted flaxseed oil was higher than that of sausages that underwent other treatments; most of the PUFAs comprised linoleic acid. In addition, the ratios of UFA/SFA and PUFA/SFA were larger in RBO-substituted samples than in control sausages ($p<0.05$). Cheong et al. (2010) reported that replacing lard with enzymatic interesterified rapeseed oil increased the UFA/SFA ratio from 1.47 to 2.84, which effectively reduced the risk of cardiovascular disease. The ratio of PUFA/SFA is a vital indicator of coronary heart diseases (CHD); lower PUFA/SFA ratios indicate a higher risk of CHD (Jakobsen et al., 2009). Therefore, lipid reformulation with vegetable oils could improve the nutritional quality of emulsion-type pork sausages. CHD risk could be reduced by replacing SFAs with MUFAs and PUFAs.

Table 4. Composition of fatty acid in raw and cooked pork sausages formulated by partially substituting pork back fat with rice bran oil

	Treatments (raw condition) ¹⁾					P-value	Treatments (cooked condition)					P-value
	C	T1	T2	T3	T4		C	T1	T2	T3	T4	
C14:0	1.43 ± 0.14 ^A	1.01 ± 0.01 ^D	1.07 ± 0.01 ^{CD}	1.12 ± 0.01 ^{BC}	1.14 ± 0.01 ^B	<0.0001	1.49 ± 0.00 ^A	1.18 ± 0.24 ^B	1.07 ^B	1.14 ^B	1.15 ± 0.01 ^B	<0.0001
C16:0	23.04 ± 0.93 ^A	20.16 ± 0.05 ^C	20.46 ± 0.04 ^C	21.10 ± 0.01 ^B	21.41 ± 0.02 ^B	<0.0001	23.58 ± 0.02 ^A	21.44 ± 1.59 ^{BC}	20.71 ± 0.07 ^C	21.36 ± 0.04 ^{BC}	21.56 ± 0.06 ^B	<0.0001
C16:1	2.35 ± 0.28 ^A	1.53 ± 0.02 ^D	1.61 ± 0.01 ^{CD}	1.67 ± 0.01 ^{BC}	1.78 ± 0.01 ^B	<0.0001	2.42 ± 0.04 ^A	1.76 ± 0.50 ^B	1.53 ± 0.06 ^B	1.57 ± 0.05 ^B	1.70 ± 0.06 ^B	<0.0001
C17:0	0.41 ± 0.05 ^A	0.26 ^D	0.28 ^{CD}	0.29 ^{BC}	0.31 ^B	<0.0001	0.43 ^A	0.17 ± 0.21 ^B	0.06 ± 0.12 ^B	0.06 ± 0.12 ^B	0.13 ± 0.16 ^B	<0.0001
C18:0	10.46 ± 1.16 ^A	6.93 ± 0.05 ^C	7.20 ± 0.09 ^C	7.98 ± 0.02 ^B	8.50 ± 0.02 ^B	<0.0001	10.98 ± 0.02 ^A	8.33 ± 1.97 ^B	7.40 ± 0.02 ^C	8.09 ± 0.04 ^{BC}	8.56 ± 0.04 ^B	<0.0001
C18:1	43.50 ± 0.03 ^A	43.15 ± 0.07 ^B	43.21 ± 0.09 ^B	43.20 ± 0.02 ^B	42.75 ± 0.04 ^C	<0.0001	43.81 ± 0.01 ^A	43.56 ± 0.21 ^B	43.41 ± 0.11 ^C	43.55 ± 0.07 ^B	43.01 ± 0.15 ^C	<0.0001
C18:2	16.39 ± 2.70 ^C	24.67 ± 0.19 ^A	23.87 ± 0.06 ^A	22.34 ± 0.05 ^B	21.77 ± 0.04 ^B	<0.0001	15.68 ± 0.01 ^B	21.84 ± 4.60 ^A	23.99 ± 0.10 ^A	22.34 ± 0.19 ^A	22.05 ± 0.11 ^A	<0.0001
C18:3	0.94 ± 0.03 ^A	0.89 ± 0.01 ^C	0.89 ^C	0.91 ± 0.01 ^B	0.89 ± 0.01 ^C	<0.0001	0.95 ^A	0.91 ± 0.03 ^{BC}	0.90 ± 0.01 ^{CD}	0.92 ^B	0.90 ^D	<0.0001
C20:0	0.24 ± 0.05 ^C	0.37 ^A	0.36 ± 0.01 ^A	0.35 ^{AB}	0.33 ^B	<0.0001	0.00 ^C	0.12 ± 0.18 ^{BC}	0.24 ± 0.18 ^B	0.31 ± 0.11 ^A	0.25 ± 0.14 ^{AB}	0.0006
C20:1	0.67 ± 0.02 ^B	0.71 ± 0.01 ^A	0.70 ^A	0.68 ^B	0.70 ± 0.01 ^A	<0.0001	0.66 ^B	0.69 ± 0.02 ^A	0.70 ^A	0.66 ± 0.01 ^B	0.69 ± 0.01 ^A	<0.0001
C22:0	0.57 ± 0.17 ^A	0.30 ^B	0.36 ^B	0.37 ^B	0.41 ^B	<0.0001	-	-	-	-	-	-
ΣSFA	36.15 ± 2.41 ^A	29.06 ± 0.11 ^C	29.73 ± 0.14 ^C	31.21 ± 0.03 ^B	32.11 ± 0.03 ^B	<0.0001	36.48 ± 0.04 ^A	31.24 ± 3.91 ^{BC}	29.48 ± 0.15 ^C	30.96 ± 0.20 ^{BC}	31.66 ± 0.22 ^B	<0.0001
ΣMUFA	46.52 ± 0.28 ^A	45.38 ± 0.08 ^C	45.52 ± 0.10 ^B	45.54 ± 0.02 ^B	45.23 ± 0.04 ^D	<0.0001	46.89 ± 0.04 ^A	46.01 ± 0.67 ^B	45.64 ± 0.05 ^{BC}	45.78 ± 0.05 ^{BC}	45.40 ± 0.11 ^C	<0.0001
ΣPUFA	17.33 ± 2.68 ^C	25.55 ± 0.19 ^A	24.76 ± 0.07 ^A	23.25 ± 0.05 ^B	22.66 ± 0.04 ^B	<0.0001	16.63 ± 0.01 ^D	22.75 ± 4.57 ^C	24.88 ± 0.10 ^A	23.26 ± 0.18 ^B	22.95 ± 0.12 ^{BC}	<0.0001
ΣUFA	63.85 ± 2.41 ^C	70.94 ± 0.11 ^A	70.27 ± 0.14 ^A	68.79 ± 0.03 ^B	67.89 ± 0.03 ^B	<0.0001	63.52 ± 0.04 ^C	68.76 ± 3.91 ^{AB}	70.52 ± 0.15 ^A	69.04 ± 0.20 ^{AB}	68.34 ± 0.22 ^B	<0.0001
UFA/SFA	1.78 ± 0.22 ^C	2.44 ± 0.01 ^A	2.36 ± 0.02 ^A	2.20 ± 0.01 ^B	2.11 ± 0.01 ^B	<0.0001	1.74 ^C	2.24 ± 0.37 ^{BC}	2.39 ± 0.02 ^A	2.23 ± 0.02 ^{BC}	2.16 ± 0.02 ^B	<0.0001
PUFA/SFA	0.49 ± 0.13 ^C	0.88 ± 0.01 ^A	0.83 ± 0.01 ^A	0.75 ± 0.01 ^B	0.71 ± 0.01 ^B	<0.0001	0.46 ^C	0.75 ± 0.22 ^{AB}	0.84 ± 0.01 ^A	0.75 ± 0.01 ^{AB}	0.72 ± 0.01 ^B	<0.0001

All values are mean ± standard deviation. n=3. ^{A-B} Means within each row with different superscripts are significantly different ($p < 0.05$).

SFA: saturated fatty acid, UFA: unsaturated fatty acid, MUFA: monounsaturated fatty acid, PUFA: polyunsaturated fatty acid.

¹⁾Control: 100% pork back fat, T1: 50% pork back fat substitution by rice bran oil, T2: 45% pork back fat substitution by rice bran oil, T3: 40% pork back fat substitution by rice bran oil, and T4: 35% pork back fat substitution by rice bran oil.

Sensory evaluations

Table 5 shows the sensory evaluation of emulsion-type pork sausages in which PBF was substituted with different concentrations of RBO. No differences were observed in the juiciness, saltiness, and overall acceptability score of the controls and all treated samples ($p > 0.05$). The color scores of emulsion-type pork sausages made from PBF substituted with 50% RBO (T1) were significantly lower ($p < 0.05$) than those of other samples. Regarding sensory evaluation, the flavor score decreased as the concentration of RBO decreased; T1 had more intense flavor than other samples, but no significant differences were perceived among any of other. The tenderness scores were higher in the samples made from

Table 5. Sensory evaluation of pork sausages formulated by partially substituting pork back fat with rice bran oil

	Treatments ¹⁾					P-value
	Control	T1	T2	T3	T4	
Color ²⁾	4.63 ± 1.41 ^{AB}	3.25 ± 0.68 ^C	4.25 ± 1.81 ^{BC}	5.38 ± 1.67 ^A	5.19 ± 1.42 ^{AB}	0.0007
Flavor	5.63 ± 1.75 ^{AB}	5.81 ± 1.68 ^A	4.44 ± 1.46 ^{BC}	4.38 ± 1.50 ^{BC}	3.44 ± 2.22 ^C	0.0011
Saltiness	4.94 ± 1.65	4.88 ± 1.63	4.19 ± 2.37	4.19 ± 1.80	4.69 ± 2.02	0.6759
Tenderness	4.50 ± 1.51 ^C	4.75 ± 1.18 ^{BC}	5.81 ± 1.38 ^A	5.56 ± 1.21 ^{AB}	4.88 ± 1.45 ^{ABC}	0.0345
Juiciness	5.31 ± 1.85	5.19 ± 1.33	5.00 ± 1.26	5.13 ± 1.41	4.93 ± 1.59	0.7431
Overall acceptability	4.56 ± 1.97	5.50 ± 1.37	5.25 ± 1.69	4.94 ± 1.44	5.33 ± 1.11	0.4597

All values are mean ± standard deviation. n=8.

^{A-B} Means within each row with different superscripts are significantly different ($p < 0.05$).

¹⁾Control: 100% pork back fat, T1: 50% pork back fat substitution by rice bran oil, T2: 45% pork back fat substitution by rice bran oil, T3: 40% pork back fat substitution by rice bran oil, and T4: 35% pork back fat substitution by rice bran oil.

²⁾Based on a 9-point intensity scale (1=dislike extremely or extremely light/bland/tasteless/tough/dry; and 9=like extremely or extremely dark/intense/salty/tender/juice).

PBF substituted with 45% RBO (T2) and 40% RBO (T3) than in the control samples ($p < 0.05$). Choi et al. (2010) had reported that replacing PBF with vegetable oils decreased the flavor, juiciness, and tenderness of frankfurters, although no significant differences were observed between the control and treated samples. Alejandre et al. (2016) also reported that, in terms of sensory attributes for taste and juiciness, no significant differences were observed between control and treated dry-fermented sausages made after replacing PBF with 32.8% linseed oil. Thus, substitution with RBO did not affect the intensity of “flavor” in emulsion-type pork sausages. However, RBO-substitution was more effective than the control for obtaining favorable tenderness ($p < 0.05$).

Conclusion

The nutritional value of meat products can be improved by increasing the degree of unsaturation in fats used in pork sausages. RBO was found to be effective for increasing the UFA content in fatty acid profile of emulsion-type pork sausages. In addition, RBO-substitution could provide a healthy PUFA/SFA. Substituting PBF with RBO in sausages did not deteriorate its emulsion stability. Sausages substituted with RBO showed lower cooking loss and lower hardness values. Compared to the control samples, RBO-substituted sausages were found to have a more favorable tenderness score. Therefore, emulsion-type pork sausages prepared from PBF-substituted with RBO had no apparent fat and water excretion, but was softer in texture.

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