*Food Sci. Biotechnol. Vol. 17, No. 2, pp. 396 ~ 401 (2008)*

Food Science and Biotechnology



# Effects of Replacing Backfat with Fat Replacers and Olive Oil on the Quality Characteristics and Lipid Oxidation of Low-fat Sausage During Storage

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**Abstract** Effects of replacing pork backfat with a combination (ICM) of isolated soy protein (ISP), carrageenan, and maltodextrin, or with ICM+olive oil, on the quality characteristics of sausages were investigated. Both treatments had lower fat content ($p<0.05$), but higher protein and moisture contents than the control ($p<0.05$). The fat content of low-fat sausage containing the ICM was increased on day 30 compared to day 1 and 15 ($p<0.05$), and that of ICM+olive oil was increased after day 15. The water holding capacity of ICM was lower than the control through day 30 ($p<0.05$). The ICM+olive oil had a lower cooking loss than ICM on day 1 and 15 ($p<0.05$). On day 1, the ICM had lower lightness and higher redness values than the control ($p<0.05$), and the ICM+olive oil had a higher yellowness value than the control and ICM ($p<0.05$). Both treatments presented higher hardness, cohesiveness, gumminess, and chewiness values than the control ($p<0.05$). The lipid oxidation values of both treatments were lower than the control on day 15 and 30 ($p<0.05$), and those were affected by the addition of olive oil. The ICM was rated higher for sensory color and overall acceptability than the ICM+olive oil ($p<0.05$).

**Keywords:** fat replacer, sausage, quality characteristic, lipid oxidation, olive oil

## Introduction

Health organizations have promoted lowering the intake of total dietary fat, particularly saturated fatty acids and cholesterol, as a means of preventing cardiovascular heart disease (1-4). Relative to this, consumers have been demanding low or reduced-fat products (5). Moreover, consumers are not only interested in the palatability of meat products, but are also concerned with nutritional quality.

Fat is a major determinant of eating quality, including the texture, flavor, and mouthfeel of meat products (6); thus, reducing fat content is not merely a matter of using less fat in the formulation. A reduction of fat content in meat products to ≤20% can lead to unacceptable product texture, flavor, and appearance (7). The total substitution of fat with water produces an unacceptably soft and rubbery product with an increased moisture loss (8-10). These problems, however, can be minimized by replacing animal fat with fat replacers (6,10-12).

Several studies have demonstrated the effects of replacing animal fat with small amounts of isolated soy protein (ISP) (13-16) and/or carbohydrates (17-19), such as maltodextrin and carrageenan, on the textural and sensory attributes of low-fat products. ISP has been used successfully to reduce fat, as a binder for improving yields, and also as a gelling agent to enhance emulsion stability. Carrageenan increases yield, consistency, sliceability, and cohesiveness, while simultaneously decreasing purge in low-fat products (20-22). Maltodextrin, which is a digestive by-product of starch, is widely used in the food industry as a functional biopolymer ingredient to provide desirable texture, stability, appearance, and flavor (23-25). Olive oil is a vegetable oil with very high monounsaturated fatty acid content. It is also rich in tocopherols and phenolic substances that act as antioxidants (26).

Although many studies have investigated the effects of fat replacers on food quality characteristics, little work has been carried out in meat products for utilizing a combination of whey protein concentrate and/or ISP and carrageenan as a 100% fat replacer (5,27,28). Also, the effect of fat replacers on the shelf-life of low-fat sausages was not sufficiently investigated. And no research has been carried out utilizing a combination of ISP, carrageenan, and maltodextrin, along with the addition of olive oil, for 100% fat replacement, in terms of quality, microbiological characteristics, and lipid oxidation during storage.

Therefore, the objectives of this study were to assess the quality, microbiological characteristics, and lipid oxidation of low-fat emulsified sausages during storage, which were produced by 100% fat replacement using a combination of ISP, carrageenan, and maltodextrin, as well as the addition of olive oil.

## Materials and Methods

**Sausage preparation** Fresh pork *semimembranosus* muscles (20 kg) and backfat (2 kg) were purchased from a local meat market at 24 hr post-mortem. The muscles were trimmed of visible fat and epimysial connective tissue, and the pork backfat was trimmed of adhering skin. Both the fat and lean were ground through a 5 mm-plate to obtain homogeneous samples. The ground lean pork (approximately

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Received September 7, 2007; accepted October 22, 2007

**Table 1. Formulation for emulsion-type sausages manufactured with and without fat replacers**

| Ingredients (%) | | Control | ICM | ICM+olive oil |
|---|---|---|---|---|
| Pork ham | | 68.95 | 73.24 | 71.57 |
| Pork backfat | | 19.25 | - | - |
| Ice/water | | 9.75 | 7.71 | 9.38 |
| Fat replacer | ICM[1)] | - | 17.00 | 12.00 |
| | Olive oil | - | - | 5.00 |
| NPS[2)] | | 1.30 | 1.30 | 1.30 |
| Phosphate | | 0.20 | 0.20 | 0.20 |
| Sugar | | 0.50 | 0.50 | 0.50 |
| Monosodium glutamate | | 0.05 | 0.05 | 0.05 |
| Total | | 100 | 100 | 100 |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20.
[2)]NaCl : $NaNO_2$ = 99:1.

3% fat content) and backfat were pre-weighed in appropriate amounts according to the formulation shown in Table 1. All preparations were carried out at approximately 10°C. The pork and backfat were vacuum-packed and stored at –20°C until needed. The fat replacers, which included ISP (EX-33l; Dupont, Protein Technologies International, St. Louis, MO, USA), maltodextrin (MD-1520; Corn Products Korea, Inc., Seoul, Korea), and carrageenan (WG, MSC Co., Seoul, Korea), were weighed separately and mixed in a 2:1:1 ratio of ISP, carrageenan, and maltodextrin, respectively, followed by hydration in 10 L of distilled water (ICM) and blending for approximately 5-10 sec. The pre-hydrated fat replacers were then stored at 2°C for no more than 2 hr. Commercial pure liquid olive oil was obtained from a local market. The ISP was emulsified with olive oil for 3 min (ICM+olive oil) according to the procedure of Hoogenkamp (29), which was then mixed with the carrageenan and maltodextrin at the same rate as in the ICM treatment. The target fat levels were 20, 3, and 8% for the control, ICM, and ICM+olive oil treatments, respectively. To substitute the fat in the sausages, protein, and water levels were modified.

The lean pork and backfat were tempered overnight at 4°C. The lean pork was placed into a bowl chopper (MGB-32; Korea Fuji Co., Suwon, Korea) and chopped for 30 sec. The ingredients and half of the ice water were then added and mixed for 3 min to extract salt soluble proteins. The backfat (for control) or the pre-hydrated fat replacers (for treatments) and remaining ice water were added and emulsified with the meat mixture for 3 min. The final chopping temperature was 9-11°C. The 3 batters (5 kg for each treatment) were vacuum stuffed into 46 mm diameter polyvinylidene chloride casings (PVDC, D-755R; 40 micron gauge, Dongbang Co., Busan, Korea). The sausages were hand-linked and cooked in a 100-L autoclave (JS-AC-100; Johnsam Co., Busan, Korea) for 75 min at 78°C to obtain a core temperature of 72°C. They were then showered in cold water and stored overnight at 4°C. The sausages used to examine cooking loss and water holding capacity (WHC) were not cooked at this time. Samples from the control and each treatment were taken for analysis at day 1, 15, and 30. The samples used for the sensory analysis were taken on day 1.

**Chemical composition and WHC** The moisture, fat (ether-extractable), and protein contents were determined according to standard AOAC procedures (30). All analyses were performed in duplicate. The WHC was determined according to the method of Hughes *et al.* (31) with slight modification. Two g of each sample were put into 15 mL-tubes, heated at 70°C for 30 min, cooled to 25°C for 10 min, centrifuged at 168×g for 10 min at ambient temperature, and then the free liquid was measured. The WHC was expressed as the percentage (w/w) of moisture content in each sample.

**Cooking loss and color** To examine cooking loss, the sausages were cut to 2 cm-thickness, weighed, and cooked in Cryovac cooking bags in a water bath for 30 min at 70°C (core temperature). After cooling, the samples were re-weighed and cooking loss was calculated as a percentage of the raw weight. The color of the sausages was measured using a chromameter (CR-400; Minolta Co., Osaka, Japan). The measurements were taken on 9 locations (3 replicates) per sample and averaged. Before each measurement, the apparatus was standardized against a white tile ($L^*$=89.2, $a^*$=0.92, and $b^*$=0.78). Colors were expressed as $L^*$-, $a^*$-, and $b^*$-values for lightness, redness, and yellowness, respectively.

**Texture profile analysis** The sausage texture was determined using an Instron Universal Testing Machine (model 4464; Instron Engineering Corp., Canton, MA, USA) as described by Bourne (32). After measuring for cooking loss, 5 slices (2 cm-thickness) were taken from each treatment. Five cores (diameter 2.5 cm×length 2 cm) per sample were compressed at a crosshead speed of 50 mm/min to 50% of their original height in a 2 cycle compression, using a 2.5 cm circular flat disk attached to a 100 kg load cell. The sample measurements were carried out at room temperature. The following texture parameters were measured from the force/deformation curves: hardness (kg), springiness (mm), gumminess (g), cohesiveness (dimensionless), and chewiness (g × mm). The attributes were calculated as follows: hardness = peak force required for the first compression; cohesiveness = ratio of the positive force area during the second compression to that during the first compression; springiness = distance the sample recovers after the first compression; chewiness = hardness multiplied by cohesiveness multiplied by springiness.

**Thiobarbituric acid reactive substances (TBARS) and volatile basic nitrogen (VBN)** Lipid oxidation was examined by the TBARS method. Using the method of Buege and Aust (33), 5 g of each sausage were weighed into a 50-mL test tube and homogenized with 15 mL of distilled water using a Polytron homogenizer (T25B; IKA Sdn., Bhd., Malaysia) for 10 sec at the highest speed. One mL of homogenate was transferred to a disposable test tube (13×100 mm), and butylated hydroxyanisole (50 μL, 10% in ethanol) and 2 mL of thiobarbituric acid/trichloroacetic acid (TBA/TCA) (20 mM TBA and 15%, w/v, TCA) were added. The mixture was vortexed and then incubated in a boiling water bath for 15 min to develop color. The sample was cooled in cold water for 10 min, vortexed again, and centrifuged for 15 min at 2,000×g. The absorbance of the

resulting supernatant solution was determined at 531 nm against a blank, which contained 1 mL of distilled water and 2 mL of TBA/TCA solution. The TBARS amounts were expressed as mg of malonaldehyde per kg of sample. The content of VBN was determined by Conway's micro-diffusion method (34).

**Microbiological analysis** The samples were subjected to microbiological analysis according to standard procedures (35). Briefly, 10 g of sausage were blended with 90 mL of sterile peptone water in a stomacher (Masticator-silver Panoramic, IUL, Spain), and subsequent dilutions were made using recovery diluent. Each dilution was spread-plated in duplicate on plate count agar. The plates were incubated at 32°C for 48 hr before counting. The total viable counts were expressed as log numbers of CFU/g.

**Sensory evaluation** Taste testing was carried out by an experienced, 10-member sensory panel. The panelists had participated on other meat sensory panels previously, and were trained/selected for this project by following the procedures of the American Meat Science Association (36) and Cross *et al.* (37).

The evaluations were performed in individual booths under white fluorescent lights, with the temperature of the product approximately ambient. Each of the 10 panelists received 3 coded sausages in a random order on a white plate. The sensory method was a hedonic test where panelists were asked to record their opinions on color (9 point verbal scale, 9 = extremely red, 1 = extremely brown), aroma and flavor (9 = extremely intense, 1 = extremely bland), tenderness and juiciness (after 3 to 5 chews, 9 = extremely tough and juicy, 1 = extremely tender and dry), and overall acceptability (9 = extremely acceptable, 1 = non acceptable) (35). The scores were subsequently converted to a numeric scale (1 to 9) for analysis. The scores from individual panelists for each attribute were averaged after each sensory analysis session. The sensory assessments were performed in 5 replicates for each treatment group.

**Statistical analysis** The experiment was designed as a 2 factorial with 5 replicates (sausages). All data obtained were expressed as means and standard errors. Two-way analysis of variance (ANOVA) was carried out in order to determine the significant differences among sausages depending on the type of formulation and storage. Significant interactions were found, thus independent 1-way ANOVA was performed on each variable. Tukey's multiple range test was carried out to compare differences in mean values ($p<0.05$) using the SAS program package (38).

## Results and Discussion

**Chemical composition, cooking loss, and WHC** Chemical composition analysis of the sausages indicated that fat content was reduced by replacing the pork backfat with ICM ($p<0.05$), but it increased with the added olive oil ($p<0.05$) (Table 2). As expected, the fat contents (%) of both treatments ranged from 3.21-8.65%, which was targeted in the formulation. Replacing the backfat with the fat replacers resulted in increased fat content (%) at day 30 of storage for ICM ($p<0.05$), and at day 15 and 30 for the ICM+olive oil treatment; however, the control did not differ in fat content (%) with increasing storage days. These results might have been due to increases in moisture loss (%) with increasing storage days. Both treatments had moisture contents (%) in the range of 71.08-74.58%, which was higher than the control ($p<0.05$). These results agree with the findings of Crehan *et al.* (39) who reported that increases in fat content could be related to moisture loss; and of Kayaardi and Gök (40) who reported that fat contents significantly increased during storage as a result of moisture loss. Protein levels ranged from 15.06-18.38% in the control as well as in both treatments. As expected, protein content was affected by adding the fat replacers to the formulation. And protein content was higher in the ICM treatment than in the control and ICM+olive oil treatments due to the higher lean content and ISP ($p<0.05$). This agrees with the findings of Pietrasik and Duda (5) who demonstrated that the protein content of sausages was affected by the amount of lean and added ISP.

**Table 2. Mean chemical composition values of low-fat sausages manufactured with fat replacers**

| Treatment (day) | Fat (%) | Protein (%) | Moisture (%) |
|---|---|---|---|
| Control | | | |
| 1 | 19.72±1.56[a] | 15.06±0.71[d] | 61.96±1.78[d] |
| 15 | 19.36±1.34[a] | 15.16±0.49[d] | 61.34±1.40[d] |
| 30 | 19.62±1.44[a] | 15.34±0.70[d] | 61.15±1.46[d] |
| ICM[1)] | | | |
| 1 | 3.34±0.63[e] | 18.38±0.96[a] | 74.58±1.15[a] |
| 15 | 3.21±0.59[e] | 18.23±0.84[a] | 74.24±1.06[a] |
| 30 | 4.63±0.46[d] | 17.79±0.52[ab] | 72.77±0.58[b] |
| ICM+olive oil | | | |
| 1 | 7.35±0.19[c] | 16.70±0.75[bc] | 73.24±0.75[ab] |
| 15 | 8.65±0.29[b] | 17.27±0.50[ab] | 71.08±0.95[c] |
| 30 | 8.58±0.42[b] | 16.60±0.49[bc] | 71.12±1.06[c] |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-e]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

The WHC of ICM was lower than that of the control on day 1 and 30 ($p<0.05$), but there was no difference on day 15 (Table 3). No significant differences in WHC were found between the control and the ICM+olive oil treatment on any storage day; although there was a difference in fat content. WHC is the ratio of moisture retained in a sample to its initial moisture content. In the present study, the ICM and ICM+olive oil treatments had higher moisture contents than the control. The lower WHC for ICM as compared to the control might have been attributed to its lower fat level and higher moisture content (%), as well as to a less stable emulsion in the ICM treatment. A number of studies have investigated the effect of fat content on the WHC of meat products, reporting an inverse relationship between fat content and the amount of water released (31,41,42). Crehan *et al.* (39) reported a less stable emulsion in the presence of maltodextrin.

The results indicate that ICM had higher cooking losses than the ICM+olive oil treatment on day 1 and 15 of

**Table 3. Mean values for water holding capacity (WHC), and cooking loss in low-fat sausages manufactured with fat replacers**

| Treatment (day) | WHC (%) | Cooking loss (%) |
|---|---|---|
| Control | | |
| 1 | 71.02±1.17$^{a}$ | 13.30±0.37$^{cd}$ |
| 15 | 69.52±0.89$^{ab}$ | 13.18±0.53$^{d}$ |
| 30 | 68.33±0.93$^{b}$ | 13.86±0.52$^{bcd}$ |
| ICM[1)] | | |
| 1 | 68.32±0.59$^{b}$ | 14.37±0.82$^{bc}$ |
| 15 | 67.95±0.95$^{bc}$ | 14.78±0.48$^{a}$ |
| 30 | 66.77±0.59$^{c}$ | 14.90±0.40$^{a}$ |
| ICM+olive oil | | |
| 1 | 69.79±0.43$^{ab}$ | 13.13±0.54$^{d}$ |
| 15 | 69.12±1.18$^{ab}$ | 14.01±0.34$^{bc}$ |
| 30 | 68.28±0.82$^{b}$ | 14.61±0.52$^{ab}$ |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-d]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

**Table 4. Mean CIE $L^*$, $a^*$, and $b^*$ values of low-fat sausages manufactured with fat replacers**

| Treatment (day) | Lightness ($L^*$) | Redness ($a^*$) | Yellowness ($b^*$) |
|---|---|---|---|
| Control | | | |
| 1 | 78.39±0.37$^{a}$ | 11.06±0.21$^{b}$ | 3.45±0.17$^{b}$ |
| 15 | 77.25±0.64$^{ab}$ | 10.41±0.19$^{b}$ | 2.34±0.24$^{c}$ |
| 30 | 76.41±0.88$^{b}$ | 10.22±0.09$^{b}$ | 2.49±0.61$^{bc}$ |
| ICM[1)] | | | |
| 1 | 74.95±0.69$^{c}$ | 12.13±0.40$^{a}$ | 3.30±0.16$^{b}$ |
| 15 | 73.48±0.98$^{cde}$ | 10.42±0.07$^{b}$ | 2.42±0.24$^{bc}$ |
| 30 | 71.69±1.31$^{e}$ | 10.29±0.13$^{b}$ | 2.20±0.05$^{c}$ |
| ICM+olive oil | | | |
| 1 | 73.45±0.18$^{de}$ | 11.80±0.64$^{ab}$ | 4.04±0.13$^{a}$ |
| 15 | 72.49±0.17$^{e}$ | 10.46±0.25$^{b}$ | 2.44±0.15$^{bc}$ |
| 30 | 72.01±0.65$^{e}$ | 10.31±0.06$^{b}$ | 2.79±0.13$^{bc}$ |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-d]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

**Table 5. Mean values for the textural attributes of low-fat sausages manufactured with fat replacers**

| Parameter | Control | ICM[1)] | ICM+olive oil |
|---|---|---|---|
| Hardness (kg) | 0.33±0.04$^{b}$ | 0.42±0.02$^{a}$ | 0.40±0.03$^{a}$ |
| Cohesiveness | 60.85±1.52$^{b}$ | 66.47±0.90$^{a}$ | 66.09±0.54$^{a}$ |
| Springiness | 13.11±0.27 | 13.53±0.04 | 13.23±0.24 |
| Gumminess (g) | 19.26±0.88$^{b}$ | 22.09±0.65$^{a}$ | 21.74±0.30$^{a}$ |
| Chewiness (g) | 228.70±6.02$^{b}$ | 271.28±6.30$^{a}$ | 268.11±8.55$^{a}$ |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-d]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

storage, and higher cooking losses than the control on days 15 and 30 ($p<0.05$); but there was no difference between ICM and the control on day 1. The results agree with the findings of Lyons *et al.* (28) who reported that 3% low-fat sausages, which were produced by fat replacement with a mixture of whey protein concentrate, carrageenan, and tapioca starch, had no significant differences in cooking loss as compared to 20% full-fat sausages. Both treatments tended to have increases in cooking loss with increasing storage days ($p<0.05$); however, no significant difference was found between cooking loss and storage days in the control. These results may be related to differences in fat content as well as emulsion stability and soy protein solubility. Crehan *et al.* (39) found that reducing the fat content of sausages caused a significant increase in cooking loss. Ahmed *et al.* (9) and Hughes *et al.* (31) also found that cooking loss was affected by changing the fat and water contents. Dexter *et al.* (43) and He and Sebranek (44) found decreases in cooking loss with increasing soy protein or carrageenan levels. Pietrasik and Duda (5) reported that cooking losses decreased in sausages with increasing levels of soy protein or carrageenan and fat; however, cooking losses were higher in sausages containing a soy protein and carrageenan mix than in 20% high fat sausages. Soy protein stability is affected by pH and ionic strength (45), and at pH 6, soy protein solubility decreased when sodium chloride concentration ranged from 0 to 0.25 M, but it increased at above 0.25 M. Further studies are required to examine the effects of fat replacers on emulsion stability and soy protein solubility.

**Color, lipid oxidation, VBN, TPC, and textural and sensory attributes** As shown in Table 4, the control had higher lightness ($L^*$) values than the two other treatments over the 30 day storage period ($p<0.05$). The overall highest redness ($a^*$) value occurred with ICM on day 1, which was greater than the other treatments over all storage days($p<0.05$); ICM+olive oil showed a high redness value on day 1 as well. The ICM+olive oil treatment had the overall highest yellowness ($b^*$) value on day 1 as compared to the other storage days ($p<0.05$), while the other treatments were not different on each respective storage day. These results may be attributed to lean content, where higher myoglobin content is contained in low-fat sausages than in high-fat sausages. This agrees with the findings of Chin *et al.* (45) and Claus *et al.* (8) who reported that redness and lightness values were more affected by fat and lean contents and the myoglobin concentration of the lean. The yellowness results agree with the findings of Muguerza *et al.* (46) and Bloukas *et al.* (47) who found that partially replacing backfat with olive oil produced more yellow sausages.

The fat replacers used in both treatments caused significant changes in the textural attributes of the sausages ($p<0.05$) (Table 5). Both treatments had higher hardness, cohesiveness, gumminess, and chewiness values than the control ($p<0.05$). This might have been due to the lower fat contents of both treatments. Muguerza *et al.* (46) found that the reducing the fat level of sausages increased hardness. These results were supported by the findings of Chin *et al.* (45) who reported higher hardness values when animal fat was replaced with a mixture of ISP and carrageenan in 30% fat bologna sausages. And these results are similar to the findings of Crehan *et al.* (39) who reported that adding maltodextrin as a fat replacer produced higher hardness, gumminess, and chewiness in 12% fat sausages. The present study was also supported by

**Table 6. Mean Thiobarbituric acid reactive substances (TBARS), volatile basic nitrogen (VBN), and total plate count (TPC) values for low-fat sausages manufactured with fat replacers**

| Treatment (day) | TBARS (mg of malonaldehyde/kg) | VBN (mg%) | TPC (log CFU/cm$^2$) |
|---|---|---|---|
| Control | | | |
| 1 | 0.16±0.03$^{c}$ | 20.47±0.79 | 3.52±0.05 |
| 15 | 0.22±0.03$^{b}$ | 21.44±0.86 | 3.54±0.03 |
| 30 | 0.32±0.05$^{a}$ | 21.62±0.37 | 3.80±0.04 |
| ICM[1)] | | | |
| 1 | 0.16±0.02$^{c}$ | 21.16±0.47 | 3.51±0.03 |
| 15 | 0.14±0.04$^{cd}$ | 21.10±0.53 | 3.52±0.03 |
| 30 | 0.24±0.02$^{b}$ | 21.49±0.12 | 3.65±0.02 |
| ICM+olive oil | | | |
| 1 | 0.17±0.02$^{c}$ | 21.04±0.52 | 3.51±0.03 |
| 15 | 0.15±0.04$^{cd}$ | 21.56±0.16 | 3.53±0.02 |
| 30 | 0.20±0.03$^{bc}$ | 21.55±0.11 | 3.63±0.03 |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-d]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

**Table 7. Sensory attributes of low-fat sausages manufactured with fat replacers**

| Sensory attributes | Control | ICM[1)] | ICM+olive oil |
|---|---|---|---|
| Color | 6.10±0.88$^{a}$ | 6.50±0.97$^{a}$ | 4.60±0.70$^{b}$ |
| Aroma | 5.60±0.70 | 5.90±0.48 | 5.50±0.53 |
| Flavor | 5.90±0.88 | 6.10±0.74 | 5.50±1.08 |
| Tenderness | 5.36±0.42$^{b}$ | 6.10±0.37$^{a}$ | 5.87±0.64$^{ab}$ |
| Juiciness | 5.90±0.74 | 6.00±0.94 | 6.00±1.05 |
| Overall acceptability | 6.10±0.74$^{ab}$ | 6.25±0.79$^{a}$ | 5.50±0.85$^{b}$ |

[1)]Isolated soy protein : carrageenan : maltodextrin : water = 2:1:1:20;
[a-d]means±SE with different letters in the same column indicate significant differences ($p<0.05$).

the findings of Pietrasik and Duda (5), where the replacement of backfat with a mixture of carrageenan and ISP was positively correlated with hardness, cohesiveness, gumminess, and chewiness.

The shelf-life of meat products is often limited by the stability of fat. Lipid oxidation can cause changes in meat quality such as color, flavor, odor, texture, and even nutritional value, and is therefore a major cause of quality deterioration (48,51). The TBARS values of both treatments were lower than those of the control on day 15 and 30 ($p<0.05$) (Table 6). The TBARS values for the ICM+olive oil treatment remained constant through 30 days of storage as compared to the control and ICM, which showed increased values from day 15 to 30 ($p<0.05$). The higher TBARS values that presented for the control sausage on each respective storage day might have been due to their high fat content. When comparing the TBARS values of the ICM and ICM+olive oil treatments, even though no significant differences were found, the values are meaningful considering that the ICM+olive oil treatment had a higher fat content than the ICM treatment. The results are supported by the findings of Muguerza *et al.* (46) who reported that olive oil and ISP have antioxidant properties. The present study is in agreement with the findings of Kayaardi and Gök (40), Bloukas *et al.* (47), and Ansorena and Astiasarán (49), where lipid oxidation increased in samples during the fermentation and ripening period. These studies also found that replacing animal fat with olive oil was effective at inhibiting lipid oxidation during storage. No significant differences in VBN (volatile basic nitrogen) and TPC (total plate counts) were found between the control and both treatments over 30 days of storage.

In the sensory evaluations, the ICM+olive oil treatment was rated lowest for color and overall acceptability ($p<0.05$) (Table 7). However, the panelists did not notice sensory attribute differences between the control and ICM treatment, except for tenderness. These results agree with the findings of Muguerza *et al.* (46) who reported that sausages, where 30 or 20% of the backfat was replaced with 20% olive oil, were rated lower for color, odor, and taste than those without added olive oil. The present study is similar to that of Lyons *et al.* (28) in which a combination of whey protein concentrate, carrageenan, and starch resulted in low-fat sausages with mechanical and sensory characteristics similar to those of 20% full-fat sausages.

In conclusion, replacing pork backfat with a mixture of carrageenan, maltodextrin, and ISP, as a 100% fat replacer, was found to significantly affect quality by decreasing fat content and TBARS values, and increasing darkness and redness. The addition of olive oil to the fat replacement mixture resulted in poorer color and overall acceptability; although lipid oxidation was inhibited at this relatively higher fat content as compared to the ICM treatment. It is probable that 100% fat replacement, with the combination of carrageenan, maltodextrin, and ISP, could be utilized, in part, to minimize quality problems and lipid oxidation, and to additionally reduce the caloric density of sausages. However, further research is needed in order to isolate the ideal fat replacer and its addition level.

## Acknowledgments

This work was supported by the Ministry of Commerce, Industry, and Energy (MOCIE)/Korea Institute of Industrial Technology Evalluation and Planning (ITEP) through the Regional Animal Industry Center at Jinju National University, Jinju, Korea.

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