Physiochemical properties of reduced-fat duck meat emulsion systems: effects of preemulsification with vegetable oils and duck skin

Tae-Kyung Kim ,[*,1] Min Hyeock Lee ,[*,1] Se-Myung Kim,[*] Min Jung Kim,[†] Samooel Jung,[‡] Hae In Yong,[*] and Yun-Sang Choi[*,2]

*[*Research Group of Food Processing, Korea Food Research Institute, Wanju 55365, Republic of Korea;* [†]*Research Group of Natural Materials and Metabolism, Korea Food Research Institute, Wanju 55365, Republic of Korea; and* [‡]*Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Republic of Korea*

ABSTRACT The effects of commercial vegetable oils and duck skin on quality characteristics of a reduced-fat duck meat emulsion were examined. The cooking loss, emulsion stability, and hardness were lower for emulsions preemulsified with vegetable oils and duck skin ($P < 0.05$) than for the control. Storage modulus (G′) and loss modulus (G″) of reduced-fat duck meat emulsions treated with corn, grape seed, soy, and olive oils were similar to the values of control; the highest G′ and G″ values were reported for the reduced-fat duck meat emulsion treated with coconut oil. Myofibril protein solubility was the highest for the reduced-fat duck meat emulsion treated with coconut oil and duck skin ($P < 0.05$). Replacing of pork back fat with different vegetable oils for emulsification may impart superior quality to reduced-fat duck meat emulsion. We recommend preemulsion with vegetable oils and duck skin to enhance the quality characteristics of reduced-fat duck meat emulsion.

Key words: reduced-fat, emulsion, preemulsion, duck skin, vegetable oil

2021 Poultry Science 100:1291–1298
https://doi.org/10.1016/j.psj.2020.10.044

INTRODUCTION

Meat emulsion sausages are traditional meat products that are popular as general meat products rich in fats (normally up to 30% fat) (Kim et al., 2020b). Fats play an important role in maintaining water-holding capacity, emulsion capacity, and emulsion stability (Shin et al., 2019). Fats in meat emulsions also reduce cooking loss, improve textural and structural properties, and impart flavor and juiciness (Lee et al., 2020). Despite these advantages, high intake of animal saturated fatty acids is known to cause hypertension, obesity, coronary heart diseases, and cardiovascular diseases (Rahman et al., 2019). Hence, studies have concentrated on developing techniques for reducing the intake of animal fat (Choi et al., 2013). According to Kim et al. (2020b), consumers are increasingly attracted to emulsion meat products with reduced fat content but excellent overall acceptability and flavor. Because of these current trends, it is replaced pork back fat with vegetable oils to produce emulsified meat products.

In general, vegetable oil is known to exhibit higher contents of unsaturated fatty acids and lower cholesterol compared with animal fat (Kim et al., 2020b). However, vegetable oils have different processing properties rely on the characteristics of the raw materials; therefore, they require suitable processing techniques (Asuming-Bediako et al., 2014). In particular, the difference of melting point, fatty acid composition, color, and flavor of vegetable oil have unfamiliar quality when manufacturing emulsified meat products compared with animal fat meat products (Kim et al., 2020a). Vural et al. (2004) reported the interesterification process used to successfully reform the physical characteristics of vegetable oil. When pork back fat was replaced with interesterified vegetable oils in reduced-fat frankfurters, it could improve the product quality characteristics (Choi et al., 2010a). Thus, incorporation of vegetable oil in meat emulsions to substitute animal fat may improve quality characteristics.

Duck skin is a waste by-product in the duck meat industry and composed of fat, gelatin, and collagen (Shim

Received June 23, 2020.

Accepted October 27, 2020.

[1]These authors contributed equally to this work.

[2]Corresponding author: kcys0517@kfri.re.kr

et al., 2018; Shin et al., 2019). Kim et al. (2020a) suggested the use of duck skin as a potential alternative to and novel source of gelatin and collagen. Despite these advantages, its application in meat products has been limited (Kang et al., 2020). We suggest that the application of duck skin in meat products may not only increase its value but also help develop new meat products.

Thus, present study evaluate the influence of substituting pork back fat with different vegetable oils emulsified with duck skin on the physiochemical properties of reduced-fat duck meat emulsion.

MATERIALS AND METHODS

Processing of Duck Meat Emulsions

Six different duck meat emulsions were prepared in 5 kg batches, and all analyses were conducted in triplicates for each duck meat emulsion. Each duck tenderloin and pork back fat were chopped using a 6 mm plate. Five types of commercial vegetable oils were used to substitute pork back fat, including corn, grape seed, soybean, olive, and coconut oil. Preemulsification of all vegetable oils was conducted as described by Choi et al. (2010a). The preemulsion was mixed with vegetable oil (20%), duck skin (5%), and water (5%) for 30 s and treated with 1.0% alginate and 1.0% isolated soy protein homogenized for 3 min. The prepared preemulsion was used after an overnight incubation at 5°C. Control duck meat emulsion was prepared using 30% pork back fat. Other reduced-fat duck meat emulsions were prepared using preemulsified vegetable oil. Duck meat emulsions prepared were homogenized and emulsified for a total of 6 min using a silent cutter and mixed with salt (1.5%) and sodium tripolyphosphate (0.15%) in 10 s. Chilled dissolved water (2°C) was added by dividing samples twice (20 s and 60 s). After 3 min, preemulsified vegetable oil (pork back fat) was added, and the temperature of emulsions was monitored and maintained below 10°C. All meat emulsion systems were tested on the same day and maintained below 10°C during analysis.

Cooking Loss

Duck meat emulsions were weighed (initial weight), stuffed into a casing, and heat processed at 75°C for 30 min. After cooling (21°C, 3 h), cooked emulsions were weighed, and cooking loss was calculated from the calculated weights.

Emulsion Stability

Meat emulsions were analyzed for emulsion stability using the method of Choi et al. (2007). Emulsion stability was determined from total expressible fluid separation and fat separation. The emulsion stability in graduated glass tubes was measured and calculated.

Viscosity and Rheological Property

Apparent viscosity of reduced-fat duck meat emulsions was measured with a rotational viscometer (DV3T HB, Brookfield Engineering Labs Inc. Stoughton, MA). A standard cylinder sensor (SC4-29 standard spindle) was filled with reduced-fat duck meat emulsions and allowed to spin at a fixed share rate (s^{-1}) for 30 s. Dynamic viscosity was investigated as a function of frequency using a Physica MCR 101 Rheometer (Anton Paar Ltd., Graz, Austria). Measurements were conducted using a parallel plate with a diameter of 25 mm and a gap of 1 mm. Angular frequency was swept from 1 to 100 Hz at a strain of 1%, and the temperature was maintained at 25°C. Storage modulus (G'), loss modulus (G''), and loss factor ($\tan\delta = G''/G'$) were recorded using RheoCompass 1.19 software.

Differential Scanning Calorimetry

Differential scanning calorimetry (**DSC**) was performed on a DSC 4000 furnace (PerkinElmer, Waltham, MA). Reduced-fat duck meat emulsion samples (20 μg) were placed in an aluminum pan; an empty pan was used as reference. The temperature range was 10–120°C, and samples were heated at a rate of 5°C/min. Pyris data analysis software was used to calculate the data displayed as onset temperature (**To**), peak temperature (**Tp**), end temperature (**Tc**), and changes in enthalpy (**dH**) (Hwang et al., 2019).

Texture Profile Analysis

Texture profile analysis (**TPA**) was measured using a TA-XTplus texture analyzer (Stable Micro Systems Ltd., Surrey, England). The TPA values were determined as shown by Bourne (1978). Cooked emulsions were cooled to room temperature, and samples were obtained from the central portion of each duck meat emulsion (Kim et al., 2020a).

Protein Solubility

Protein solubility was determined in terms of sarcoplasmic protein solubility and myofibrillar protein solubility (Joo et al., 1999). In brief, sarcoplasmic protein solubility was determined by dissolving reduced-fat duck meat emulsions (2 g) in 25 mmol ice-cold potassium phosphate buffer (20 mL, pH 7.2). The homogenized mixtures of low-fat duck meat emulsions, and buffer were incubated for overnight on a shaker at 4°C. Protein concentrations in the supernatants were determined by the Biuret method (Gornall et al., 1949). Myofibrillar protein solubility was determined by measuring the difference between total and sarcoplasmic protein solubilities. Total protein solubility was analyzed by homogenizing reduced-fat duck meat emulsions (2 g) in ice-cold 1.1 mol/L potassium iodide in 100 mol/L phosphate buffer (20 mL, pH 7.2). The procedures for homogenization, shaking, centrifugation, and protein determination are described above.

2-Thiobarbituric Acid Reactive Substance

Lipid oxidation was assessed using thiobarbituric acid (**TBA**), as described by Tarladgis et al. (1960). In brief, 10 g samples were mixed with 50 mL distilled water and washed with 47.5 mL distilled water. Each sample was treated with 4 N hydrochloric acid (HCl; 2.5 mL), an antifoam agent, and a boiling stone in a distillation flask and distilled. A total of 50 mL distillate was sampled, and 5 mL of 0.02 M TBA reagent (2-TBA in 90% acetic acid) was added to a vial containing 5 mL distillate. The mixture was homogenized well, and the vials were capped and heated in a boiling water bath (100°C, 30 min) to generate the chromogen. The vials were cooled (24°C, 30 min), and the absorbance of the reaction product was determined at 538 nm wavelength using a UV spectrophotometer. The TBA values were calculated using the standard curve for malondialdehyde.

Fatty Acid Composition

The fatty acid composition of the reduced-fat duck meat emulsion systems was measured by Choi et al. (2016). Fatty acid methyl esters were separated by an HP-6890 Series gas chromatograph (Hewlett-Packard, Waldbronn, Germany) equipped with a split injector (75:1), fused silica capillary column (CP-SIL 88, Varian Inc., Cromapak, the Netherlands).

Statistical Analysis

All experimental data were analyzed using SPSS Ver. 20.0 (SPSS Inc.,) in a completely randomized study design. One-way analysis of variance was used to determine significant differences ($P < 0.05$) between the control and reduced-fat treatment groups, and Duncan's multiple range test was employed to analyze differences in the physicochemical characteristics of the reduced-fat duck meat emulsions.

RESULTS AND DISCUSSION

Cooking Loss and Emulsion Stability

The effects of different preemulsification conditions on the cooking loss and emulsion stability are presented in Table 1. The cooking loss of vegetable oil treatments was significantly lower than that of the control sample, and the lowest value was observed in coconut oil treatment ($P < 0.05$). These results are in line with those reported by Choi et al. (2013), who reported reduced cooking loss in reduced-fat frankfurters meat batters treated with sunflower seed oil and *makgeolli* lees fiber as compared with that in the control sample treated with pork back fat. Shim et al. (2018) also found that cooking loss in restructured ham was influenced by the preemulsified duck skin and that it reduced upon preemulsion with vegetable oils and duck skin, owing to the increase in the water-binding capacity of the meat emulsion. Reduced diameter size of fat or oil generally increase emulsion stability with high dispersion (Zayas, 2012). Duck skin and oil was homogenized before manufacturing sausage preemulsified processing, and these processing might affect positively cooking loss and emulsion stability.

The total expressible fluid separation and fat separation of vegetable oil treatments were lower ($P < 0.05$) than those of the control sample (Table 1). The total expressible fluid separation among vegetable oil treatments was not significantly different ($P > 0.05$). According to Choi et al. (2013), when sunflower seed oil at various levels was used in low-fat meat batters, no significant difference was found. These authors found that the increase in sunflower seed oil level from 0 to 20% led to a significant reduction in total expressible fluid separation and fat separation. Shim et al. (2018) observed that the emulsion stability of duck ham preemulsified with duck skin was lower than that of the control sample treated with pork back fat, owing to improvements in water-holding and fat-holding capacities. In general, emulsion stability may serve as a substantial indicator of the quality characteristics of meat products. Thus, replacement of pork back fat with preemulsified vegetable oils and duck skin may yield high-quality reduced-fat meat products.

Viscosity and Rheological Property

Figure 1 shows the changes in the apparent viscosity and dynamic viscosity of reduced-fat meat emulsions preemulsified with different vegetable oils and duck skin. The apparent viscosity values of vegetable oil treatments were lower ($P < 0.05$) than the values of the control, except for the sample treated with coconut oil and duck skin (Figure 1A). Similar results were obtained by Choi et al. (2009), who observed that reduced-fat meat emulsion treated with vegetable oil and dietary fiber had higher maximum apparent viscosity and that control meat batters with pork back fat had the lowest maximum apparent viscosity. Kim et al. (2018) showed that the apparent viscosity of the meat batter was influenced by the duck skin used for preemulsification. Some studies have reported that higher apparent viscosity was related to the increase in emulsion stability and that emulsions with high apparent viscosity have strong emulsion stability (Aktaş and Genccelep, 2006; Kim et al., 2020b).

Figure 1B illustrates the changes in the dynamic viscosity of vegetable oil treatment. The G′ and G″ values of vegetable oil treatments showed different trends. These values of corn, grape seed, soy, and olive oil treatments were similar to the value reported for the control; however, coconut oil treatment had higher G′ and G″ values than others. This observation might be attributable to a higher melting temperature of coconut oil than others oils. Corn oil (−11°C melting temperature), grape seed oil (10°C melting temperature), soy oil (−16°C melting temperature), and olive oil (−6°C melting temperature) exist in a liquid state, and coconut oil (25°C melting temperature) exists in a solid state at

Table 1. Effects of preemulsification with various vegetable oils and duck skin on the cooking loss and emulsion stability of reduced-fat duck meat emulsions.

Parameters	Pork fat	Corn oil[1]	Grapeseed oil	Soybean oil	Olive oil	Coconut oil
Cooking loss (%)	8.27 ± 0.21[a]	6.13 ± 0.16[d,e]	7.00 ± 0.22[b]	6.78 ± 0.54[b,c]	6.48 ± 0.30[c,d]	5.67 ± 0.16[e]
Emulsion stability (%)						
Total fluid separation	5.32 ± 1.15[a]	1.66 ± 0.58[b]	1.33 ± 0.29[b]	1.16 ± 0.29[b]	1.16 ± 0.58[b]	1.50 ± 0.25[b]
Fat separation	1.05 ± 0.29[a]	0.83 ± 0.15[b]	0.67 ± 0.17[b,c]	0.51 ± 0.13[c]	0.42 ± 0.14[c]	0.50 ± 0.15[c]

[a-e]Means within a row with different letters are significantly different ($P < 0.05$).
All values are mean ± standard deviation of 3 replicates.
[1]Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

23 to 25°C (room temperature). The fatty acid compositions of vegetable oils were differentiated depending on the length of the hydrocarbon chain and the degree of unsaturation, both of which define their physical properties such as viscoelasticity and melting temperature. In general, the melting temperature of cooking oil increases, whereas the unsaturation of fatty acid content decreases (Wagh and Martini, 2017). Coconut oil is composed of approximately 92% of saturated fatty acids, 6% of monounsaturated fatty acids, and 2% of polyunsaturated fatty acids, whereas the composition of unsaturated fatty acids of other vegetable oils used in this study is more than 85%. Therefore, coconut oil treatment had higher G′ and G″ values than those of other samples. As shown in Figure 1C, the loss factors for corn, grape seed, soy, and olive oil treatments were similar, but the value reported for coconut oil treatment was higher than the values reported for the others. Loss factor value smaller or greater than 1 is indicative of gel-like behavior and sol-like behavior, respectively (Lee et al., 2018). Although loss factors for all samples in the present study were lower than 1, indicative of their gel-like behavior, the value of coconut oil treatment was close to 1. This is attributed to the shorter chain length of fatty acids in coconut oil than that in other oils. Vegetable oils used in the present study (except for coconut oil) comprise linoleic acid (C18:2) and oleic acid (C18:1), whereas coconut oil in general comprises lauric acid (C12:0), myristic acid (C14:0), and palmitic acid (C16:0). The viscosity of the oil phase decreases as the hydrocarbon chain length of fatty acids decreases, resulting in high G″ value and loss factor (Gomes et al., 2018).

DSC Analysis

Table 2 shows the changes in DSC values of reduced-fat meat emulsions treated with different vegetable oils and duck skin. Four types of endothermic reactions were observed in this study. We divided the reactions into 2 major parts as follows: the endothermic reaction from 10°C to 50°C is known as fat/oil phase (peak 1) and protein denaturation after heating was observed in the range from 40°C to 90°C (peaks 2–4) (Fernández-Martín et al., 2009). Except for samples treated with pork fat and coconut oil, other samples showed no endothermic reactions in the range from 10°C to 50°C. This observation may be related to the lower melting points of vegetable oils (corn oil, grape seed oil, soy bean oil, and olive oil) than the range of temperature employed (10°C–100°C). Pork fat and coconut oil showed similar thermal denaturation temperatures (peak 1) and endothermic enthalpy changes ($P > 0.05$); this result suggests that coconut oil may be used to replace pork fat when focused on the thermal stability. Meat protein denatured by heat treatment showed 3 major components in DSC. Thermal denaturation of myosin (43°C–67°C), sarcoplasmic protein (65°C–70°C), and actin (71°C–83°C) was gradually detected as peak 2, peak 3, and peak 4, respectively, and the endothermic peak temperatures of these proteins could change depending on their solubility (Kazemi et al., 2011; Li et al., 2019). Each peak indicates the thermal stability of meat proteins, whereas enthalpy changes (ΔH) indicate the degree of protein denaturation (Chen et al., 2007). According to Table 2, peaks 2 and 3 of vegetable-meat emulsion were lower than those observed for pork fat-meat emulsion, indicating that the oil phase decreased the thermal stability of myosin and sarcoplasmic protein. However, no specific difference was observed in peaks 3 and 4 among the different treatment groups. In conclusion, the stability of myosin and sarcoplasmic protein could be lower in the presence of vegetable oil than in the presence of the pork fat-meat emulsion, resulting in a decrease in the thermal denaturation of myosin.

Texture Profile Analysis

In Table 3, the effect of the addition of vegetable oils and duck skin on the textural profiles of reduced-fat meat emulsions is shown. The hardness of control duck meat emulsion showed significantly higher value ($P < 0.05$) than that of the samples preemulsified with vegetable oils and duck skin. The springiness and cohesiveness of reduced-fat duck meat emulsions preemulsified with coconut oils and duck skin was the lowest ($P < 0.05$). In addition, gumminess and chewiness was the highest for the control sample ($P < 0.05$) and lowest for the sample preemulsified with coconut oil and duck skin ($P < 0.05$). Meat emulsion manufactured with vegetable oil had a higher value in hardness when replaced animal fat (Choi et al., 2009). Kim et al. (2020b) also reported the highest values of hardness, cohesiveness, and gumminess for meat emulsions preemulsified with grape seed oil without hydrocolloids. Substitution of back fat with vegetable oil in meat emulsion products resulted in firmed meat emulsions. Therefore, hydrocolloids were combined with vegetable oils to improve textural

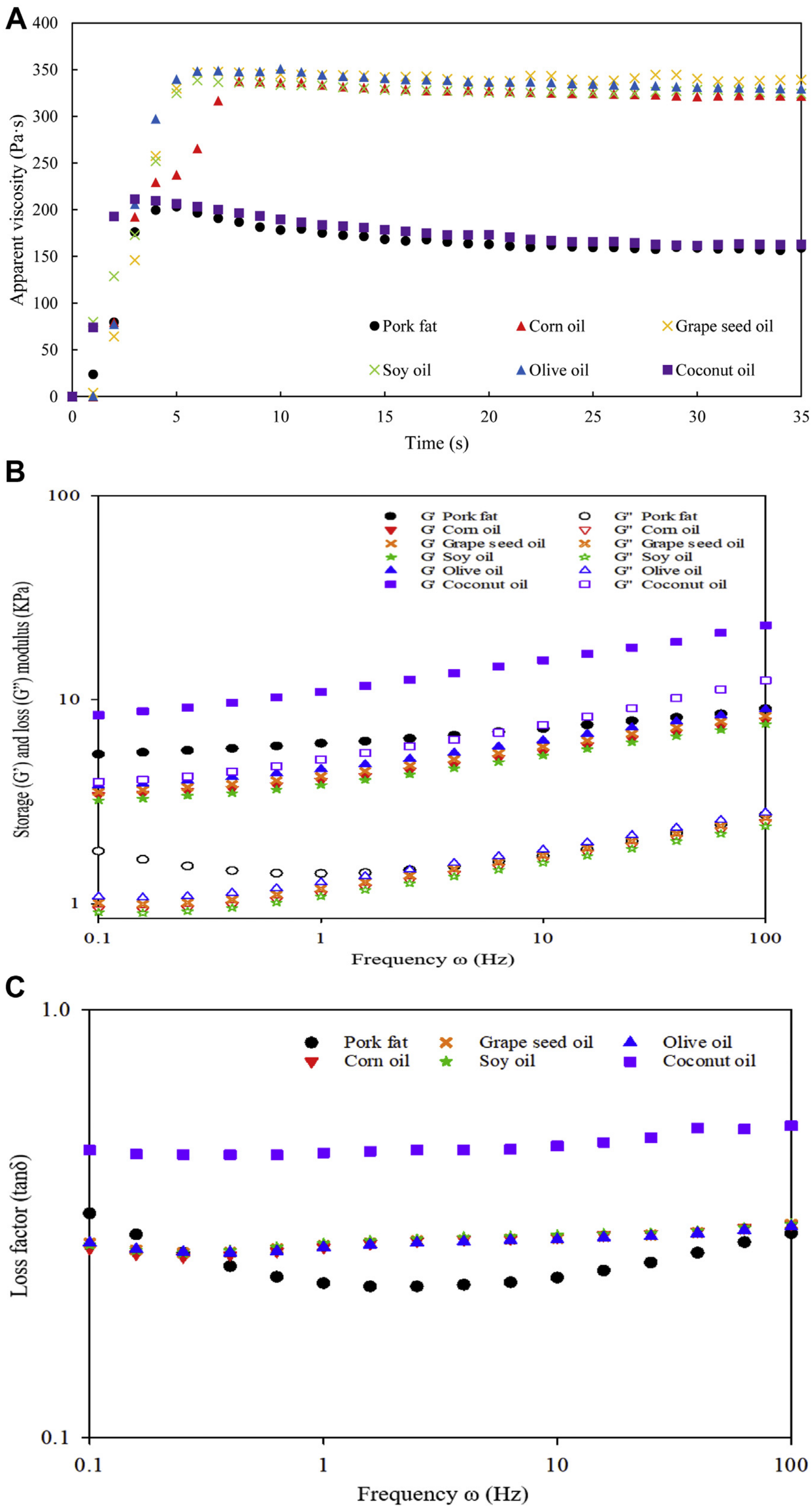

Figure 1. Apparent viscosity (A) and dynamic viscosity (B) storage [G′] modulus and loss modulus [G″], and (C) loss factor [tanδ] of reduced-fat duck meat emulsions preemulsified with various vegetable oils and duck skin. Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

properties of meat emulsion, and the hardness was decreased owing to high water holding capacity of hydrocolloids (Shim et al., 2018; Kim et al., 2020b). Thus, preemulsified vegetable oil and duck skin contents need to be controlled to obtain reduced-fat meat products with soft texture properties.

Table 2. Effects of preemulsification with various vegetable oils and duck skin on the thermal properties of reduced-fat duck meat emulsions.

Parameters	Pork fat	Corn oil[2]	Grapeseed oil	Soybean oil	Olive oil	Coconut oil
Peak 1[1]	31.29 ± 1.07	ND	ND	ND	ND	31.04 ± 0.82
ΔH of peak 1	0.37 ± 0.06	ND	ND	ND	ND	0.29 ± 0.11
Peak 2	64.60 ± 0.29^{a}	51.34 ± 0.30^{b,c}	51.64 ± 0.26^{b,c}	51.25 ± 0.06^{b,c}	52.25 ± 0.65^{b}	50.67 ± 1.00^{c}
ΔH of peak 2	0.10 ± 0.01^{a}	0.08 ± 0.00^{a,b}	0.05 ± 0.01^{c}	0.06 ± 0.02^{b,c}	0.09 ± 0.01^{a}	0.05 ± 0.00^{c}
Peak 3	68.13 ± 1.18^{a}	63.67 ± 0.30^{b}	62.52 ± 0.39^{b,c}	62.14 ± 0.01^{c}	63.63 ± 0.35^{b}	63.63 ± 0.36^{b}
ΔH of peak 3	0.02 ± 0.02	0.06 ± 0.01	0.09 ± 0.02	0.05 ± 0.07	0.09 ± 0.02	0.08 ± 0.00
Peak 4	70.76 ± 2.18	71.30 ± 0.35	71.39 ± 0.21	71.80 ± 0.47	72.09 ± 0.41	71.75 ± 0.41
ΔH of peak 4	0.07 ± 0.05	0.03 ± 0.00	0.03 ± 0.00	0.01 ± 0.01	0.05 ± 0.00	0.03 ± 0.00

[a-c]Means within a row with different letters are significantly different ($P < 0.05$).
All values are mean ± standard deviation of 3 replicates.
[1]Peak and ΔH of peak units are °C and J/g.
[2]Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

Protein Solubility and Thiobarbituric Acid Reactive Substance

The effects of the various vegetable oils on protein solubility and thiobarbituric acid reactive substance (**TBARS**) values of reduced-fat meat emulsion are shown in Table 4. The solubility of sarcoplasmic proteins of reduced-fat duck meat emulsions preemulsified with vegetable oils and duck skin was higher ($P < 0.05$) than that of the control, except for the sample treated with coconut oil. The solubility of myofibril proteins of reduced-fat duck meat emulsions treated with coconut oil and duck skin was the highest ($P < 0.05$). These results in current study are in agreement with the data reported by Choi et al. (2010b) who found higher sarcoplasmic protein solubility for reduced-fat meat emulsion batters treated with grape seed oil than for control samples treated with 30% pork back fat; the myofibril protein solubility of reduced-fat meat emulsion batters increased with an increase in grape seed oil concentration. Kim et al. (2017) found that the protein solubility of duck ham meat batter was affected by duck skin concentration. Some studies revealed myofibril protein solubility as the most important index for improving emulsifying capacity and texture properties of emulsion meat products (Kim et al., 2019; Noh et al., 2019). In our study, increased myofibril solubility might increase emulsion stability and cooking loss of meat emulsion. There are various factors which can affect protein solubility such as pH, ionic strength, temperature, protein type, and oxidation. Lipid oxidation of meat emulsion has a negative effect on protein solubility of meat emulsion (Zayas, 2012). Antioxidant capacity of natural oil might inhibit the lipid oxidation and increase protein solubility of myofibril protein.

The TBARS values of cooked reduced-fat meat emulsions were significantly different (Table 4). Lipid oxidation is one of the important factors affecting meat product quality, especially, when it stored. The TBARS values for reduced-fat duck meat emulsions preemulsified with vegetable oil and duck skin samples were significantly ($P < 0.05$) lower than those for the control, treated with 30% pork back fat, excepted to treatments with soy bean oil. This seems to be because of the higher fat content in the control and because of the fact that added vegetable oils executed different fatty acid composition. These results are in line with those reported by Choi et al. (2010a), who found that the TBARS of reduced-fat frankfurters formulated with vegetable oil and dietary fiber was significantly higher than that of control sample without vegetable oil. The highest TBARS value was reported for samples treated with soybean oil. Woo (1995) reported that the emulsion-type sausage manufactured with cottonseed oil had significantly higher TBARS than control sample with pork back fat. However, some researchers showed that the biggest drawback of using vegetable oils in emulsion meat products was the chance of rancidity owing to high contents of unsaturated fatty acids (Yıldız-Turp and Serdaroğlu, 2008).

Fatty Acid Composition

The fatty acid composition of reduced-fat meat emulsions formulated with various vegetable oils and duck skin is shown in Table 5. Palmitic acid (C 16:0), stearic

Table 3. Effects of pre-emulsification with various vegetable oils and duck skin on the textural profile analysis of reduced-fat duck meat emulsions.

Parameters	Pork fat	Corn oil[1]	Grapeseed oil	Soybean oil	Olive oil	Coconut oil
Hardness (kg)	5.95 ± 0.35^{a}	4.27 ± 0.42^{c}	5.20 ± 0.77^{b}	5.15 ± 0.46^{b}	4.68 ± 1.28^{b,c}	4.43 ± 0.87^{b,c}
Springiness	0.90 ± 0.03^{a}	0.91 ± 0.04^{a}	0.91 ± 0.04^{a}	0.91 ± 0.05^{a}	0.90 ± 0.03^{a}	0.81 ± 0.04^{b}
Cohesiveness	0.43 ± 0.06^{a}	0.42 ± 0.06^{a}	0.35 ± 0.07^{b,c}	0.38 ± 0.07^{a,b}	0.43 ± 0.06^{a}	0.31 ± 0.03^{c}
Gumminess (kg)	2.54 ± 0.23^{a}	1.80 ± 0.28^{c}	2.22 ± 0.37^{a,b}	1.97 ± 0.31^{b,c}	1.65 ± 0.61^{c,d}	1.36 ± 0.29^{d}
Chewiness (kg)	2.30 ± 0.26^{a}	1.63 ± 0.23^{c}	1.47 ± 0.52^{c}	1.78 ± 0.28^{b,c}	2.02 ± 0.34^{a,b}	1.11 ± 0.23^{d}

[a-d]Means within a row with different letters are significantly different ($P < 0.05$).
All values are mean ± standard deviation of 3 replicates.
[1]Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

Table 4. Effects of preemulsification with various vegetable oils and duck skin on the protein solubility and TBARS values of reduced-fat duck meat emulsions.

Parameters	Pork fat	Corn oil[1]	Grapeseed oil	Soybean oil	Olive oil	Coconut oil
Sarcoplasmic protein (mg/mL)	16.04 ± 1.09^{c}	20.97 ± 1.97^{b}	27.77 ± 2.50^{a}	25.58 ± 1.63^{a}	20.72 ± 1.92^{b}	15.52 ± 1.27^{c}
Myofibril protein (mg/mL)	29.72 ± 1.19^{d}	32.06 ± 3.55^{d}	35.58 ± 1.58^{c}	29.17 ± 1.07^{d}	43.87 ± 1.19^{b}	50.26 ± 2.21^{a}
TBARS (mg/kg)	1.08 ± 0.04^{b}	0.42 ± 0.03^{d}	0.19 ± 0.02^{f}	1.35 ± 0.07^{a}	0.50 ± 0.02^{c}	0.25 ± 0.02^{e}

[a-f]Means within a row with different letters are significantly different ($P < 0.05$).
All values are mean ± standard deviation of 3 replicates.
Abbreviation: TBARS, thiobarbituric acid reactive substance.
[1]Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

acid (C 18:0), oleic acid (C 18:1), and linoleic acid (C 18:2) were the most abundant fatty acids in control samples with pork back fat and those preemulsified with vegetable oils and duck skin. When compared with pork back fat control, vegetable oil treatment had lower saturated fatty acids and higher unsaturated fatty acids ($P < 0.05$) except for coconut oil treatment. These results are similar to those reported by Choi et al. (2010a) who substituted pork back fat with vegetable oils to formulate reduced-fat frankfurters. These authors reported higher contents of saturated fatty acids in control sample treated with 30% pork back fat and higher unsaturated fatty acids for samples preemulsified with vegetable oils and rice bran fiber. Wood et al. (2004) recommended that a meal should have a polyunsaturated fatty acids/saturated fatty acids ratio higher than 0.45 because values lower than 0.45 may correlate with a higher incidence of cardiovascular disease. In this study, this ratio was 0.45 or more for all reduced-fat duck meat emulsions preemulsified with vegetable oils and duck skin but not for the treatment sample with coconut oil. Thus, lipid reformulation of reduced-fat duck meat emulsions preemulsified with vegetable oils and duck skin could enhance the nutritional quality of products.

CONCLUSION

Preemulsification with vegetable oils and duck skin was performed to replace pork back fat in the manufacturing of reduced-fat duck meat emulsions. Reduced-fat duck meat emulsions offer health benefits owing to their low saturated fatty acid levels except for coconut oil. The results of present study demonstrate the use of preemulsified vegetable oils and duck skin as a replacement for pork back fat to produce reduced-fat duck meat emulsions with superior quality. Cooking losses and emulsion stability were improved with addition of preemulsified vegetable oil with duck skin. Although thermal stability of vegetable oil treatments was lower than control, they have softer texture than pork fat control with increase of protein solubility and apparent viscosity and decrease of lipid oxidation. Our data indicate that vegetable oils and duck skin may be used to replace pork back fat in reduced-fat

Table 5. Effects of preemulsification with various vegetable oils and duck skin on the fatty acid composition of reduced-fat duck meat emulsions.

Parameters	Pork fat	Corn oil[1]	Grapeseed oil	Soybean oil	Olive oil	Coconut oil
C6:0	-	-	-	-	-	0.51 ± 0.00
C8:0	-	-	-	-	-	6.50 ± 0.01
C10:0	-	-	-	-	-	5.34 ± 0.02
C12:0	0.11 ± 0.00^{c}	0.12 ± 0.00^{c}	0.11 ± 0.01^{c}	0.21 ± 0.01^{c}	0.55 ± 0.00^{b}	42.42 ± 0.17^{a}
C14:0	1.32 ± 0.00^{b}	0.22 ± 0.00^{d}	0.23 ± 0.01^{d}	0.23 ± 0.01^{d}	0.32 ± 0.00^{c}	16.93 ± 0.00^{a}
C16:0	20.01 ± 0.04^{a}	11.93 ± 0.00^{d}	9.34 ± 0.01^{f}	12.27 ± 0.03^{b}	12.06 ± 0.05^{c}	10.32 ± 0.03^{e}
C18:0	9.61 ± 0.03^{a}	4.25 ± 0.00^{c}	4.46 ± 0.00^{b}	2.17 ± 0.01^{f}	3.84 ± 0.01^{d}	2.84 ± 0.03^{e}
C20:0	0.10 ± 0.00^{b}	0.10 ± 0.01^{b}	0.08 ± 0.00^{b}	0.20 ± 0.00^{a}	0.20 ± 0.00^{a}	0.05 ± 0.07^{b}
C22:0	-	0.20 ± 0.00^{a}	0.04 ± 0.00^{b}	0.10 ± 0.00^{b}	0.05 ± 0.07^{b}	-
C14:1	0.12 ± 0.00	-	-	-	0.12 ± 0.01	-
C16:1	1.90 ± 0.00^{a}	0.65 ± 0.07^{d}	0.60 ± 0.01^{d}	0.60 ± 0.00^{d}	1.10 ± 0.00^{b}	0.40 ± 0.00^{d}
C18:1	41.25 ± 0.07^{b}	26.25 ± 0.07^{d}	22.27 ± 0.00^{e}	29.75 ± 0.07^{c}	71.40 ± 0.14^{a}	11.05 ± 0.07^{f}
C18:2	20.15 ± 0.07^{d}	47.60 ± 0.00^{c}	61.42 ± 0.01^{a}	51.50 ± 0.00^{b}	7.95 ± 0.07^{e}	3.30 ± 0.00^{f}
C18:3	0.95 ± 0.02^{c}	5.92 ± 0.00^{a}	0.52 ± 0.00^{e}	1.16 ± 0.00^{b}	0.86 ± 0.00^{d}	0.13 ± 0.01^{f}
C20:1	1.54 ± 0.00^{a}	1.23 ± 0.02^{b}	0.43 ± 0.00^{d}	0.55 ± 0.05^{c}	0.50 ± 0.00^{c}	0.21 ± 0.01^{e}
C20:2	0.83 ± 0.00^{a}	0.12 ± 0.00^{b}	0.12 ± 0.01^{b}	0.11 ± 0.02^{b}	-	-
C20:3	0.22 ± 0.00^{a}	0.11 ± 0.00^{b}	-	-	0.12 ± 0.02^{b}	-
$\sum$ SFA	31.10 ± 0.00^{b}	16.70 ± 0.00^{d}	14.10 ± 0.02^{f}	15.00 ± 0.00^{e}	16.90 ± 0.14^{c}	84.25 ± 0.07^{a}
$\sum$ MUFA	44.75 ± 0.07^{b}	28.10 ± 0.00^{d}	23.31 ± 0.00^{e}	30.90 ± 0.00^{c}	73.05 ± 0.21^{a}	11.65 ± 0.07^{f}
$\sum$ PUFA	22.00 ± 0.00^{d}	53.65 ± 0.07^{b}	61.99 ± 0.01^{a}	52.65 ± 0.07^{c}	8.80 ± 0.00^{e}	3.40 ± 0.00^{f}
$\sum$ UFA	66.75 ± 0.07^{d}	81.75 ± 0.07^{c}	85.29 ± 0.01^{a}	83.55 ± 0.07^{b}	81.85 ± 0.21^{c}	15.05 ± 0.07^{e}
SFA/UFA	0.47 ± 0.00^{b}	0.20 ± 0.00^{c}	0.17 ± 0.00^{d}	$0.18 \pm 0.00^{c,d}$	0.21 ± 0.00^{c}	5.60 ± 0.03^{a}
PUFA/SFA	0.71 ± 0.00^{d}	3.21 ± 0.00^{c}	4.40 ± 0.01^{a}	3.51 ± 0.00^{b}	0.52 ± 0.00^{e}	0.04 ± 0.00^{f}

[a-f]Means within a row with different letters are significantly different ($P < 0.05$).
Abbreviations: MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; UFA, unsaturated fatty acids.
[1]Each vegetable oil was preemulsified with duck skin, alginate, and isolated soy protein.

duck meat emulsion to successfully manufacture high-quality meat products.

ACKNOWLEDGMENT

This research was supported by Main Research Program [E0187000-03] of the Korea Food Research Institute (KFRI) funded by the Ministry of Science and ICT (Korea).

DISCLOSURES

The authors declare no conflicts of interest.

REFERENCES

Aktaş, N., and H. Genccelep. 2006. Effect of starch type and its modifications on physicochemical properties of bologna-type sausage produced with sheep tail fat. Meat Sci. 74:404–408.

Asuming-Bediako, N., M. Jaspal, K. Hallett, J. Bayntun, A. Baker, and P. Sheard. 2014. Effects of replacing pork backfat with emulsified vegetable oil on fatty acid composition and quality of UK-style sausages. Meat Sci. 96:187–194.

Bourne, M. C. 1978. Texture profile analysis. Food Technol. 32:62–66.

Chen, H. H., S. Y. Xu, and Z. Wang. 2007. Interaction between flaxseed gum and meat protein. J. Food Eng. 80:1051–1059.

Choi, Y. S., J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, J. Y. Jeong, H. J. Chung, and C. J. Kim. 2010a. Effects of replacing pork back fat with vegetable oils and rice bran fiber on the quality of reduced-fat frankfurters. Meat Sci. 84:557–563.

Choi, Y. S., J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, H. W. Kim, J. Y. Jeong, and C. J. Kim. 2009. Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. Meat Sci. 82:266–271.

Choi, Y. S., J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, H. W. Kim, J. W. Lee, H. J. Chung, and C. J. Kim. 2010b. Optimization of replacing pork back fat with grape seed oil and rice bran fiber for reduced-fat meat emulsion systems. Meat Sci. 84:212–218.

Choi, Y. S., J. Y. Jeong, J. H. Choi, D. J. Han, H. Y. Kim, M. A. Lee, S. Y. Shim, H. D. Paik, and C. J. Kim. 2007. Quality characteristics of meat batters containing dietary fiber extracted from rice bran. Food Sci. Anim. Resour. 27:228–234.

Choi, Y. S., K. S. Park, H. W. Kim, K. E. Hwang, D. H. Song, M. S. Choi, S. Y. Lee, H. D. Paik, and C. J. Kim. 2013. Quality characteristics of reduced-fat frankfurters with pork fat replaced by sunflower seed oils and dietary fiber extracted from makgeolli lees. Meat Sci. 93:652–658.

Choi, Y. S., S. K. Ku, H. J. Lee, J. M. Sung, K. H. Jeon, H. W. Kim, T. K. Kim, and Y. B. Kim. 2016. Study on processing quality of different parts of pork and beef. Korean J. Food Cookery Sci. 32:157–167.

Fernández-Martín, F., I. López-López, S. Cofrades, and F. J. Colmenero. 2009. Influence of adding Sea Spaghetti seaweed and replacing the animal fat with olive oil or a konjac gel on pork meat batter gelation. Potential protein/alginate association. Meat Sci. 83:209–217.

Gomes, A., A. L. R. Costa, and R. L. Cunha. 2018. Impact of oil type and WPI/Tween 80 ratio at the oil-water interface: Adsorption, interfacial rheology and emulsion features. Colloids Surf. B. Biointerfaces 164:272–280.

Gornall, A. G., C. J. Bardawill, and M. M. David. 1949. Determination of serum proteins by means of biuret reaction. J. Biol. Chem. 177:751–766.

Hwang, S. I., E. J. Lee, and G. P. Hong. 2019. Effects of temperature and time on the cookery properties of sous-vide processed pork loin. Food Sci. Anim. Res. 39:65–72.

Joo, S. T., R. G. Kauffman, B. C. Kim, and G. B. Park. 1999. The relationship of sarcoplasmic and myofibrillar protein solubility to colour and water-holding capacity in porcine longissimus muscle. Meat Sci. 52:291–297.

Kang, E. S., H. J. Kim, S. G. Han, and H. G. Seo. 2020. Duck oil-loaded nanoemulsion inhibits senescence of angiotensin II-treated vascular smooth muscle cells by upregulating SIRT1. Food Sci. Anim. Res. 40:106–117.

Kazemi, S., M. O. Ngadi, and C. Gariépy. 2011. Protein denaturation in pork longissimus muscle of different quality groups. Food Bioproc. Tech. 4:102–106.

Kim, T. K., Y. K. Ham, D. M. Shin, H. W. Kim, H. W. Jang, Y. B. Kim, and Y. S. Choi. 2020a. Extraction of crude gelatin from duck skin: effects of heating methods on gelatin yield. Poult. Sci. 99:590–596.

Kim, D. H., T. K. Kim, Y. B. Kim, J. M. Sung, Y. J. Jang, J. Y. Shim, S. G. Han, and Y. S. Choi. 2017. Effect of the duck skin on quality characteristics of duck hams. Korean J. Food Sci. Anim. Resour. 37:360–367.

Kim, T. K., J. Y. Shim, K. E. Hwang, Y. B. Kim, J. M. Sung, H. D. Paik, and Y. S. Choi. 2018. Effect of hydrocolloids on the quality of restructured hams with duck skin. Poult. Sci. 97:4442–4449.

Kim, T. K., H. I. Yong, C. H. Jeong, S. G. Han, Y. B. Kim, H. D. Paik, and Y. S. Choi. 2019. Technical functional properties of water-and salt-soluble proteins extracted from edible insects. Food Sci. Anim. Resour. 39:643–654.

Kim, T. K., H. I. Yong, S. Jung, Y. B. Kim, and Y. S. Choi. 2020b. Effects of replacing pork fat with grape seed oil and gelatine/alginate for meat emulsions. Meat Sci. 163:108079.

Lee, J. S., H. G. Kim, M. J. Choi, and Y. J. Cho. 2020. Improved physicochemical properties of pork patty supplemented with oil-in-water nanoemulsion. Food Sci. Anim. Resour. 40:262–273.

Lee, M. H., G. H. Shin, and H. J. Park. 2018. Solid lipid nanoparticles loaded thermoresponsive pluronic–xanthan gum hydrogel as a transdermal delivery system. J. Appl. Polym. Sci. 135:46004.

Li, K., J. Y. Liu, Y. H. Bai, Y. Y. Zhao, Y. Y. Zhang, J. G. Li, H. Zhang, and D. B. Zhao. 2019. Effect of bamboo shoot dietary fiber on gel quality, thermal stability and secondary structure changes of pork salt-soluble proteins. CYTA J. Food 17:706–715.

Noh, S. W., D. H. Song, Y. K. Ham, T. K. Kim, Y. S. Choi, and H. W. Kim. 2019. Interaction of porcine myofibrillar proteins and various gelatins: impacts on gel properties. Food Sci. Anim. Res. 39:229–239.

Rahman, M. S., J. K. Seo, M. A. Zahid, J. Y. Park, S. G. Choi, and H. S. Yang. 2019. Physicochemical properties, sensory traits and storage stability of reduced-fat frankfurters formulated by replacing beef tallow with defatted bovine heart. Meat Sci. 151:89–97.

Shim, J. Y., T. K. Kim, Y. B. Kim, K. H. Jeon, K. I. Ahn, H. D. Paik, and Y. S. Choi. 2018. The ratios of pre-emulsified duck skin for optimized processing of restructured ham. Korean J. Food Sci. Anim. Resour. 38:162–171.

Shin, D. M., D. H. Kim, J. H. Yune, H. C. Kwon, H. J. Kim, H. G. Seo, and S. G. Han. 2019. Oxidative stability and quality characteristics of duck, chicken, swine and bovine skin fats extracted by pressurized hot water extraction. Food Sci. Anim. Res. 39:446–458.

Tarladgis, B. G., B. M. Watts, M. T. Younathan, and L. Dugan, Jr. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. J. Am. Oil Chem. Soc. 37:44–48.

Vural, H., I. Javidipour, and O. O. Ozbas. 2004. Effects of interesterified vegetable oils and sugarbeet fiber on the quality of frankfurters. Meat Sci. 67:65–72.

Wagh, A., and S. Martini. 2017. Crystallization behavior of fats: effects of processing conditions. Pages 327–348 in Food Lipids: Chemistry, Nutrition, and Biotechnology. C. C. Akoh, ed. CRC Press, Cleveland, OH.

Woo, M. J. 1995. Quality characteristics of emulsion-type sausages manufactured with cottonseed oil. Korean J. Food Sci. Anim. Resour. 15:187–191.

Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2004. Effects of fatty acids on meat quality: a review. Meat Sci. 66:21–32.

Yıldız-Turp, G., and M. Serdaroğlu. 2008. Effect of replacing beef fat with hazelnut oil on quality characteristics of sucuk–A Turkish fermented sausage. Meat Sci. 78:447–454.

Zayas, J. F. 2012. Functionality of Proteins in Food. Springer Science & Business Media, Berlin, Germany.