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ARTICLE

Effects of Replacing Pork with Tuna Levels on the Quality Characteristics of Frankfurters

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Abstract The aim of this study was to evaluate the effects of pork and tuna levels on the quality characteristics of frankfurters and to establish a suitable percentage of added tuna. The levels of pork meat (PM) and yellow-fin tuna (YFT) in the test frankfurters were as follows: 100% PM (control), 90% PM+10% YFT (T1), 80% PM+20% YFT (T2), 70% PM+30% YFT (T3), 60% PM+40% YFT (T4), and 50% PM+50% YFT (T5). The pH of the frankfurter batters significantly decreased with increasing tuna levels, because the pH of the tuna is lower than that of the pork. The water holding capacity did not differ significantly in frankfurters containing up to 30% tuna, whereas that of the 40% tuna-containing frankfurter was significantly lower than the control. Cooking loss did not differ significantly. At up to 10% tuna, apparent viscosity did not differ significantly, whereas at 20% tuna, it was significantly lower than the control. Fat separation and total expressible fluid separation at up to 30% tuna did not differ from the control; however, when more than 30% was added, higher losses were observed. The hardness of frankfurters containing more than 40% tuna was lower than that of the control, but there was no significant difference in springiness. The overall acceptability of frankfurters manufactured with up to 30% tuna did not differ significantly from the control. These results suggest that the addition of 30% tuna does not affect the quality of frankfurters made from pork.

Keywords tuna, pork, frankfurter, quality characteristics, emulsion stability

Introduction

With the recent westernization of dietary patterns in Korea, the intake of animal-based foods has increased (Kim et al., 2017). This change has led to increased serum cholesterol levels, hypertension, atherosclerosis, and an increased incidence of cardiovascular diseases, such as heart disease (Choi et al., 2010; Kim et al., 2018). The idea that diet is closely related to health is widely accepted by the general public; thus, interest in functional foods is growing (Choi et al., 2014; Hwang et al., 2018). Research on functional meat products is also actively progressing. In recent years, the inclusion of rice bran dietary fiber in low-fat sausages has been studied extensively (Choi et al., 2015b; Choi et al., 2016; Choi et al., 2017). In most of these studies, dietary fiber, water, non-meat protein, and vegetable oil were used to replace the animal fat (Choi et al., 2009; Shim et al., 2018). If pork, which contains saturated fatty acids, could be replaced with fish meat, which contains unsaturated fatty acids, new functional meat products could be developed.

Tuna is a typical red meat that is widely used in the domestic market in Korea. In particular, the ω-3 polyunsaturated fatty acid (PUFA) contents of tuna, which contains eicosapentaenoic acid (EPA, C20:5 ω-3) and docosahexaenoic acid (DHA, C22:6 ω-3), have attracted much attention (Klomklao et al., 2016). DHA is found in the phospholipids in the frontal lobe grey matter of the human brain and the retina. Thus, DHA has unique biological activities in the brain and retina, and has been found to be effective for improving learning ability and vision (Howe et al., 2002). Therefore, functional foods supplemented with DHA are already popular, and DHA is found in a variety of food products. In addition, both EPA and DHA have been reported to decrease serum cholesterol, have hypotensive effects and antitumor activity, and reduce the incidence of various diseases, such as heart disease (Liu et al., 2006). Thus, tuna, with its PUFA content, has many advantages for the development of functional foods. In addition, the efficacy of the DHA and EPA in tuna is greater; thus, functional meat products containing tuna may be superior in terms of nutritional quality. Therefore, this study was conducted to evaluate the effects of varying pork and yellow-fin tuna (YFT) levels on the quality characteristics of frankfurters, and to establish an appropriate percentage of tuna meat.

Material and Methods

Frankfurter preparation and processing

Fresh pork ham (*Musculus biceps femoris*, *M. semitendinosus*, and *M. semimembranosus*) was purchased and transforted to a pilot plant of the Department of Food Science & Biotechnology of Animal Resources, Konkuk University (Seoul, Korea) at 48 h postmortem. Pork back fat was also collected. All subcutaneous fat and visible connective tissue were removed from the muscles. Yellow-fin tuna (*Thunnus albacares*, 14–15 kg, 70–75 cm in length) was purchased from a commercial tuna processing plant (DongWon F&B Co., Ltd., Changwon, Korea). The scale, fin, and bone of the tuna were removed. The pH of the pork was 5.64, and the pH of the YFT was 5.77. Six different meat batters were produced depending on the ratios of pork meat (PM) and tuna, and the experimental design and batter compositions are shown in Table 1. The lean muscles of the pork and tuna were initially ground through a Ø-8 mm plate, and the pork back fat was ground through a Ø-8 mm plate using a grinder (PA-82, Maincam Spain). The compositions of all batters were as follows: lean meat 60%, back fat 20%, ice water 20% (2℃), NaCl 1.5%, and sodium tripolyphosphate 0.3%. The levels of lean PM andYFT in the batters were as follows: Control (100% PM), T1 (90% PM+10% YFT), T2 (80% PM+20% YFT), T3 (70% PM+30% YFT), T4 (60% PM+40% YFT), and T5 (50% PM+50% YFT). The ground PM and YFT were homogenized in a silent cutter (Cutter Nr-963009, Hermann Scharfen GmbH & Co., Postfach, Germany) for 1 min and chilled with ice water (2℃). Then, NaCl and sodium tripolyphosphate were added to the meat and mixed for 1 min. Finally, pork fat was added to the mixture and mixed for 5 min. A temperature probe (Kane-May, KM330, UK) was used to monitor the temperature of the meat batter, which was maintained below 10℃. Meat batter was stuffed into collagen casings of 25 mm diameter (#240, NIPPI Inc., Tokyo, Japan) using a stuffer (IS-8, Sirman, Marsango, Italy). The stuffed meat batters were then heated at 75℃ for 30 min in a water bath (M10-101, Dae Han Co., Seoul, Korea). The cooked meat batters were cooled with 15℃ cold water. Then, the manufactured meat batter and frankfurter were analyzed.

Table 1. **Frankfurter formulations with different ratio of pork meat (PM) and yellow-fin tuna (YFT)**

Traits (g/100 g)	Treatments (PM/YFT levels, %)					
	Control (100/0)	T1 (90/10)	T2 (80/20)	T3 (70/30)	T4 (60/40)	T5 (50/50)
Pork ham	60	54	48	42	36	30
Yellow fin tuna	-	6	12	18	24	30
Pork back fat	20	20	20	20	20	20
Ice water	20	20	20	20	20	20
Total	100	100	100	100	100	100
Salt	1.5	1.5	1.5	1.5	1.5	1.5
Phosphate	0.3	0.3	0.3	0.3	0.3	0.3

pH

The pH value of each sample was measured as a homogenate prepared with 5 g of sample and 20 mL of distilled water using a pH meter (Model 340, Mettler-Toledo GmbH, Switzerland).

Color

The color of each sample was determined using a colorimeter (Minolta Chroma meter CR-210; Minolta, Ltd., Japan; illuminate C, calibrated with a white plate, L*=+97.83, a*=–0.43, b*=+1.98). The CIE L* (lightness), a* (redness), and b* (yellowness) values were recorded.

Water holding capacity

Water holding capacity (WHC) was measured according to the procedure of Grau and Hamm (1953), with some modifications. Briefly, a 300-mg sample was placed between two plexiglasses and compressed for 3 min. Then, WHC was calculated as the ratio of the pressed meat area to the total area (Choi et al., 2007).

Cooking loss

The stuffed frankfurter meat batters were heated at 75℃ for 30 min, and then cooled to room temperature (21℃) for 3 h. After cooling, the cooked frankfurter samples were weighed, and the cooking loss was calculated.

Apparent viscosity

The apparent viscosity of the meat batter was measured in triplicate with a rotational viscometer (HAKKE Viscotester® 550; Thermo Electron Corporation, Karlsruhe, Germany) set at 10 rpm. The standard cylinder sensor (SV-2) was positioned in a 25 mL metal cup filled with meat batter and allowed to rotate under a constant shear rate (s^{-1}) for 60 s before each reading was taken. Maximum apparent viscosity values in Pa·s were obtained.

Emulsion stability

The meat batter samples were analyzed for emulsion stability using the method of Bloukas and Honikel (1992), with the following modifications: total expressible fluid and fat separated at the bottom of each graduated glass tube were measured and calculated (Choi et al., 2007).

Total expressible fluid separation (mL/g) = [(the water layer (mL) + the fat layer (mL)] / weight of raw meat batter (g)] × 100

Fat separation (mL/g) = [the fat layer (mL) / weight of raw meat batter (g)] × 100

Texture profile analysis

The texture profile analysis (TPA) was conducted at room temperature with a texture analyzer (TA-XT2*i*, Stable Micro Systems, Ltd., Surrey, England). The meat mixtures were stuffed into collagen casings and then heated at 75℃ (30 min) and cooled to room temperature (21℃) for 30 h. Samples were taken from the central portion of each frankfurter. TPA values (pre-test speed, 2.0 mm/s; post-test speed, 5.0 mm/s; maximum load, 50 kg; head speed, 2.0 mm/s; distance, 8.0 mm, and trigger force, 5.0 g) were obtained. Hardness (kg), springiness, cohesiveness, gumminess (kg), and chewiness (kg) were determined as described by Bourne (1978).

Sensory evaluation

A trained 12-member panel from the Department of Food Science & Biotechnology of Animal Resources of Konkuk University (Seoul, Korea) evaluated the frankfurters. Each frankfurter was evaluated for color, flavor, tenderness, juiciness, and overall acceptability. The frankfurters were heated at 75℃ for 30 min, cooled to 21℃ for 3 h, cut into quarters, and randomly served to the panelists. The panelists were instructed to cleanse their palates with warm water between samples. The qualities of the cooked samples were evaluated using a 9-point descriptive scale (from 1 [very undesirable] to 9 [very desirable]). This analysis was conducted using the Hedonic test described by Choi et al. (2009).

Statistical analysis

All tests were conducted at least three times for each experimental condition (1 batch=3 kg), and the mean values were reported. The statistical analysis was performed by using Statistical Analysis System software (version 8.0, SAS Institute, Cary, NC, USA) to calculate the mean and standard deviation. When using Duncan's multiple range test, the significance test ($p<0.05$) was carried out through multiple tests.

Results and Discussion

pH, color, water holding capacity (WHC), and cooking loss

The pH of the frankfurter batters formulated with different ratios of PM and YFT is shown in Table 2. The pH of batters was significantly decreased with increasing tuna content ($p<0.05$), because the pH of the tuna is lower than pH of the pork. According to a report by Kung et al. (2012), the pH of sausage product ranged from 5.7 to 7.0 by addition amount of tuna, and the pH decreased as the YFT content increased. According to previous studies, the lower pH value of meat product had the lower quality characteristics of meat product such as WHC, emulsion stability, and cooking loss because of decreased ionic strength between myofibrillar in meat protein (Huff-Lonergan and Lonergan, 2005; Kim et al., 2017). In this study, lower pH value of tuna than pork caused pH value decrease of final product.

Table 2 shows the color values of frankfurter batters according to PM and YFT content. The lightness and yellowness values of the frankfurter batters did not differ significantly across all samples. However, although the redness values did not

Table 2. Comparison on physicochemical properties of frankfurter batter with combined pork meat (PM) and yellow-fin tuna (YFT) levels

Traits	Treatments (PM/YFT levels, %)					
	Control (100/0)	T1 (90/10)	T2 (80/20)	T3 (70/30)	T4 (60/40)	T5 (50/50)
pH	6.00±0.01^{A}	5.97±0.01^{B}	5.95±0.01^{BC}	5.95±0.01^{BC}	5.93±0.03^{CD}	5.91±0.02^{D}
CIE L*-value	74.92±3.21	74.18±3.79	75.19±4.43	74.57±3.69	73.75±3.80	72.53±4.32
CIE a*-value	11.75±1.34^{A}	11.85±0.69^{A}	11.46±1.04^{A}	11.25±0.91^{AB}	10.53±0.75^{BC}	10.43±0.55^{C}
CIE b*-value	11.99±1.43	12.05±0.60	11.87±1.49	11.35±1.38	11.85±1.07	11.43±0.94
WHC (%)	98.31±0.62^{A}	97.87±0.66^{A}	97.63±0.44^{A}	96.72±1.08^{A}	92.83±1.76^{B}	88.10±1.48^{C}
Cooking loss (%)	12.86±1.23^{B}	14.87±1.42^{AB}	14.77±1.12^{AB}	14.31±1.23^{AB}	15.70±1.42^{A}	16.76±1.17^{A}

All values are mean±SD of three replicates (n=9).
$^{A–D}$ Means within a row with different letters are significantly different (p<0.05).

differ significantly up to 30% tuna meat, the redness value of the T4 (60/40) and T5 (50/50) treatment was significantly lower than that of the control (p<0.05). Murphy et al. (2004) reported that the lightness and yellowness values of sausage were not significantly different regardless of addition of fish meat protein or fat. Cardoso et al. (2008) reported that the redness values of low-fat fish sausage showed a significant descending trend with increasing PM replacement content. Thus, the color values of the frankfurter batters were affected by adding tuna.

The WHC values of frankfurter batters manufactured with different levels of PM and YFT are shown in Table 2. There were no significant differences in the WHC of frankfurters containing up to 30% tuna meat (p>0.05), and frankfurters with 50% tuna (T5) had the lowest WHC. Huff-Lonergan and Lonergan (2005) reported that the ability of meat to retain moisture is arguably one of the most important quality characteristics. Thus, the WHC can be a key factor to understand how changes in emulsion structure affect emulsion stability.

The cooking loss of the frankfurters batters was evaluated (Table 2). Frankfurters containing 0% tuna showed the lowest cooking loss, while frankfurters containing 40% and 50% tuna showed the highest cooking losses (p<0.05). Huda et al. (2012) reported that the cooking loss of fish sausage depends on its WHC, and concluded that protein content was the variable with the greatest influence on WHC. Generally, cooking loss is dependent on formulation, emulsion stability, and WHC (Choi et al., 2013).

Apparent viscosity and emulsion stability

The changes in the apparent viscosity of the frankfurter meat batters according to the percentages of PM and YFT are presented in Table 3. Choi et al. (2014) reported that apparent viscosity is influenced by WHC, protein solubility, and emulsion stability, which is the effects of the interactions among the fat, protein, and moisture. Apparent viscosity did not differ significantly in frankfurter meat batters containing up to 10% tuna (p>0.05), whereas the apparent viscosity of formulations containing more than 20% tuna was significantly lower than the control (p<0.05). In addition, the apparent viscosity of the frankfurter meat batters containing YFT tended to decrease as the tuna level increased (p<0.05). Jin et al. (2008) reported that the gel and jelly strength of sausages were significantly lower in formulations containing chicken meat than those containing Alaskan Pollack surimi. Ramírez et al. (2011) observed that interactions among the two proteins lead to more structured fish products, influence water binding, and modify the viscosity. It is reasonable to consider that the formulation could affect the capacity of myofibrillar proteins. Choi et al. (2015a) reported that the apparent viscosity of

Table 3. Comparison on apparent viscosity and emulsion stability of frankfurters with combined pork meat (PM) and yellow-fin tuna (YFT) levels

Traits	Treatments (PM/YFT levels, %)					
	Control (100/0)	T1 (90/10)	T2 (80/20)	T3 (70/30)	T4 (60/40)	T5 (50/50)
AV (Pa·S)	95.95±3.69^{A}	92.75±3.65^{AB}	89.79±4.19^{B}	87.42±3.60^{B}	70.52±4.12^{C}	63.15±3.12^{D}
Emulsion stability						
Fat separation (mL/g)	1.27±0.12^{C}	1.33±0.10^{BC}	1.35±0.12^{BC}	1.45±0.12^{BC}	1.56±0.17^{AB}	1.73±0.15^{A}
Total expressible fluid separation (mL/g)	7.38±0.74^{B}	7.71±0.65^{B}	8.21±0.95^{B}	8.31±0.77^{B}	10.54±0.81^{A}	11.22±1.01^{A}

All values are mean±SD of three replicates (n=9).
$^{A–D}$ Means within a row with different letters are significantly different (p<0.05).
AV, apparent viscosity.

formulations with high resistance is high due to the presence of irregular arrays, and higher stability emulsions showed higher apparent viscosity.

Table 3 shows the emulsion stability values of frankfurter meat batters containing different ratios of PM and YFT. Fat separation and total expressible fluid separation increased with increasing YFT levels (p<0.05). Thus, the emulsion stability of meat batter tended to be poor as the amount of added tuna increased. Choi et al. (2015b) reported that emulsion stability was important for understanding the interrelationships among cooking loss, apparent viscosity, and textural properties, due to their association with the final quality of emulsion meat products. Thus, from the viewpoint of emulsion stability, up to 30% YFT does not seem to affect quality.

Texture profile analysis (TPA)

Table 4 shows the texture profiles of the frankfurters with different levels of the PM and YFT, including the hardness, springiness, cohesiveness, gumminess, and chewiness. The hardness of the frankfurters decreased with increasing percentages of YFT (p<0.05), whereas the springiness of the frankfurters did not differ significantly (p>0.05). Control frankfurters without YFT showed the highest cohesiveness, gumminess, and chewiness (p>0.05), and these characteristics showed a tendency to decrease with increasing amounts of YFT. This tendency was considered to be due to the destruction of micelle structure of emulsified meat batter. This result agreed with the findings in a study by Cardoso et al. (2008), in which the hardness, gumminess, and chewiness of sausages decreased as the PM was replaced with increasing percentages of fish. In

Table 4. Comparison on textural properties of frankfurter with combined pork meat (PM) and yellow-fin tuna (YFT) levels

Traits	Treatments (PM/YFT levels, %)					
	Control (100/0)	T1 (90/10)	T2 (80/20)	T3 (70/30)	T4 (60/40)	T5 (50/50)
Hardness (kg)	0.56±0.07^{A}	0.54±0.05^{A}	0.53±0.04^{A}	0.52±0.07^{A}	0.47±0.05^{B}	0.41±0.04^{C}
Springiness	0.93±0.02	0.92±0.03	0.93±0.03	0.93±0.02	0.93±0.03	0.91±0.05
Cohesiveness	0.62±0.06^{A}	0.57±0.04^{B}	0.56±0.06^{B}	0.58±0.04^{B}	0.58±0.04^{B}	0.57±0.02^{B}
Gumminess (kg)	0.35±0.07^{A}	0.30±0.04^{BC}	0.30±0.03^{BC}	0.30±0.04^{BC}	0.27±0.03^{C}	0.24±0.03^{D}
Chewiness (kg)	0.32±0.06^{A}	0.28±0.04^{BC}	0.28±0.03^{BC}	0.28±0.04^{BC}	0.26±0.03^{C}	0.22±0.03^{D}

All values are mean±SD of three replicates (n=9).
$^{A–D}$ Means within a row with different letters are significantly different (p<0.05).

agreement with the textural properties of sausage containing Alaska Pollack surimi reported by Jin et al. (2008), the hardness, gumminess, and chewiness of sausage were significantly lower in formulations containing higher concentrations of Alaska Pollack surimi. Nithin et al. (2015) reported that TPA is an important quality characteristic that determines the acceptability of fishery products. Based on the above results, the texture profiles of frankfurters containing PM and YFT vary depending on the amount of YFT added.

Sensory analysis

Table 5 shows the results of the sensory evaluation of frankfurters containing varying percentages of PM and YFT. The color and flavor scores of frankfurters containing up to 30% YFT did not differ significantly ($p>0.05$). The control frankfurters had similar ($p>0.05$) tenderness scores to T1 (90/10), T2 (80/20), and T4 (60/40). Juiciness scores were not significantly different among all test samples ($p>0.05$). Thus, the overall acceptability values of test frankfurters containing PM and up to 30% YFT did not differ significantly ($p>0.05$). Thus, according to the sensory analysis results, frankfurters containing up to 30% YFT did not differ from control frankfurters without YFT. In agreement with the sensory properties of fish emulsion sausages reported by Intarasirisawat et al. (2014), there were no differences in all analyzed attributes, including color, odor, appearance, and overall acceptability among tested samples. In this previous report, the fish protein hydrolysate did not affect the sensory properties of fish emulsion sausages. Similar results were obtained by Jin et al. (2008), in which the sensory characteristics of crab-flavored sausage were retained when prepared with 20% Alaskan Pollack surimi.

Conclusion

The study was conducted to evaluate the effects of varying percentages of PM and YFT on the quality characteristics of frankfurters. Evaluation of emulsion stability and the textural profile analysis showed no differences compared to the control for frankfurters containing up to 30% tuna, and higher losses in frankfurters containing more than 30% YFT. The overall acceptability of frankfurters containing up to 30% YFT did not differ significantly from the control. These results suggest that the addition of 30% tuna meat does not affect the quality of an emulsion-type frankfurter made of pork.

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Table 5. Comparison on sensorial properties of frankfurters with combined pork meat (PM) and yellow-fin tuna (YFT) levels

Traits	Treatments (PM/YFT levels, %)					
	Control (100/0)	T1 (90/10)	T2 (80/20)	T3 (70/30)	T4 (60/40)	T5 (50/50)
Color[1)]	8.50±0.53^{A}	8.50±0.76^{A}	8.38±0.52^{A}	8.00±0.53^{AB}	7.38±0.52^{B}	7.38±0.74^{B}
Flavor	8.25±0.46^{A}	8.38±0.52^{A}	8.25±0.46^{A}	8.13±0.64^{A}	7.50±0.53^{B}	7.50±0.53^{B}
Tenderness	7.75±0.71^{B}	8.25±0.46^{AB}	8.13±0.35^{AB}	8.63±0.52^{A}	8.38±0.92^{AB}	8.63±0.92^{A}
Juiciness	8.13±0.83	8.38±0.74	8.38±0.52	8.50±0.76	7.88±0.83	7.63±0.92
Overall acceptability	8.38±0.74^{A}	8.38±0.74^{A}	8.13±0.35^{A}	8.50±0.53^{A}	7.44±0.50^{B}	7.38±0.92^{B}

All values are mean±SD of three replicates (n=9).
^{A,B} Means within a row with different letters are significantly different ($p<0.05$).
[1)] 9-point descriptive scale (1, very undesirable; 9, very desirable) was used to evaluate sensory properties of frankfurters.

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