Korean J. Food Sci. An. Vol. 35, No. 4, pp. 515~523 (2015)
© 2015 Korean Society for Food Science of Animal Recources
DOI http://dx.doi.org/10.5851/kosfa.2015.35.4.515
ISSN 1225-8563 eISSN 2234-246X

ARTICLE

Optimization for Reduced-Fat / Low-NaCl Meat Emulsion Systems with Sea Mustard (*Undaria pinnatifida*) and Phosphate

Cheon-Jei Kim[1], Ko-Eun Hwang[1], Dong-Heon Song[1], Tae-Jun Jeong[1], Hyun-Wook Kim[2], Young-Boong Kim, Ki-Hong Jeon, and Yun-Sang Choi*

Food Processing Research Center, Korean Food Research Institute, Seongnam 463-746, Korea
[1]*Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 143-701, Korea*
[2]*Meat Science and Muscle Biology Lab, Purdue University, West Lafayette, IN 47907, USA*

Abstract

The effects of reducing fat levels from 30% to 20% and salt concentrations from 1.5% to 1.0% by partially substituting incorporated phosphate and sea mustard were investigated based on physicochemical properties of reduced-fat / low-NaCl meat emulsion systems. Cooking loss and emulsion stability, hardness, springiness, and cohesiveness for reduced-fat / low-NaCl meat emulsion systems with 20% pork back fat and 1.2% sodium chloride samples with incorporation of phosphate and sea mustard were similar to the control with 30% pork back fat and 1.5% sodium chloride. Results showed that reduced-fat / low-NaCl meat emulsion system samples containing phosphate and sea mustard had higher apparent viscosity. The results of this study show that the incorporation of phosphate and sea mustard in the formulation will successfully reduce fat and salt in the final meat products.

Keywords: reduced-fat, low-NaCl, meat emulsion systems, phosphate, sea mustard

Received January 12, 2015; Revised March 4, 2015; Accepted March 5, 2015

Introduction

Fat and salt are some of the main components of meat products. In recent years, we have seen a rapid expansion of knowledge about the influence of diet on health. Meat product based potential functional foods have been formulated both by reducing the fat and sodium contents and by promoting the presence of healthy compounds (Jimenez-Colmenero *et al*., 2010).

The addition of fat to meat products has played important roles in stabilizing meat emulsions, reducing cooking loss, improving water holding capacity and providing juiciness and hardness (Choi *et al*., 2009; Woo *et al*., 1995). Some researchers have found that fats have considerable effects on the binding, rheological and structural properties of meat products (Bloukas *et al*., 1997; Crehan *et al*., 2000). However, high fat diets are linked to obesity, hypertension, cardiovascular diseases and coronary heart diseases (Choi *et al*., 2014; Ozvural and Vural, 2008). Thus, the reduced fat content in meat products should result in healthier products.

Added salt in meat products has become a major issue for the processed meat industry (Desmond, 2006). Common salt has a flavor enhancing effect in meat products and one of the main functions of salt in processed meats is the solubilisation of the functional myofibrillar proteins in meat (Lee and Chin, 2010; Pappa *et al*., 2000; Ruusunen *et al*., 2005). This activates the proteins to increase hydration and water holding capacity, ultimately increasing the binding properties of proteins to improve texture. Salt is a critical component in contributing to the texture and shelf life of processed meat products (Ruusunen and Puolanne, 2005). However, excessive intake of sodium has been linked to hypertension. High blood pressure may in turn increase the risk of stroke and premature death from cardiovascular diseases (Jimenez-Colmenero *et al*., 2010). Thus, salt reduction is a prime concern in meat industry.

Sea mustard (*Undaria pinnatifida*) is originally found in Korea and East Asian countries. It is a marine vegetable and the growing conditions depend on geography and temperature (Boulom *et al*., 2014). In general, nutritional

*Corresponding author: Yun-Sang Choi, Food Processing Research Center, Division of Strategic Research, Korean Food Research Institute, Sungnam 463-746, Korea. Tel.: +82-31-780-9387; Fax: +82-31-780-9059, E-mail: kcys0517@kfri.re.kr

composition of sea mustard is varying depending with location and seasonal changes. Furthermore, *Undaria pinnatifida* is an excellent source of dietary fiber, vitamins, minerals, and phytosterols (MacArtain *et al*., 2007). In particular, *Undaria pinnatifida* is a major source of dietary fiber such as alginic acid, fucoidan, and laminaran, all of which are beneficial to human health (Fung *et al*., 2013; Urbano and Gorii, 2002). Dietary fiber has been added to different meat products to counteract the problems caused by fat and salt reduction (Kim *et al*., 2014; Turhan *et al*., 2005). Some studies have been carried out on low-fat or low-salt meat products with fat or salt partially replaced by dietary fiber, which helps to improve rheological properties and emulsion stability (Tobin *et al*., 2012). However, application in meat products with dietary fiber both low-fat and low-salt have so far been limited research.

Sodium tripolyphosphate (STPP) is commonly used in the production of value added meat products (Detienne and Wicker, 1999) and it imparts improved sensory characteristics to the meat products. Also, STPP has demonstrated improved yield, tenderness, water holding capacity and extractable protein (Cannon *et al*., 1993; Murphy and Zerby, 2004). A well known, but not well understood, interaction has been reported among NaCl, STPP and sea mustard. A clear understanding of this interaction could lead to more effective methods for commercial meat emulsion systems.

Therefore, the objective of this study is to evaluate the effect of replacing fat and salt with various levels of sea mustard (*Undaria pinnatifida)* fiber and phosphate on optimized proximate composition, pH, color, cooking loss, emulsion stability, protein solubility, textural profile analysis and apparent viscosity of reduced-fat and reduced-salt meat emulsion systems.

Materials and Methods

Preparation and processing of sea mustard (*Undaria pinnatifida*)

The dietary fiber was extracted using the modified AOAC enzymatic-gravimetric method (AOAC, 2000). The sea mustard, purchased from a market in Seongnam-si, Gyeonggi-do, Korea, was ground in a mill and passed through a 25-mesh sieve. The sea mustard powder (moisture content: 8.54 g/100 g, protein content: 17.72 g/100 g, fat content: 1.42 g/100 g, ash content: 24.95 g/100 g, dietary fiber content: 54.32 g/100 g, salinity: 3.4%, pH: 6.43, lightness (*L**-value): 41.37, redness (*a**-value): -1.46, yellowness (*b**-value): 1.35) was placed in polyethylene bags and vacuum-sealed using a vacuum packaging system (FJ-500XL, Fujee Tech., Korea). It was then stored at 4°C until it was used for product manufacturing.

Meat batter preparation and processing

Fresh pork ham (castrated boars; Landrace × Yorkshire × Duroc; approximately 110 kg, *M. biceps femoris, M. semitendinosus, M. semimembranosus*) and pork back fat (moisture 12.61%, fat 85.64%) were purchased from a local processor 48 h postmortem. All subcutaneous, intramuscular fat and visible connective tissue were removed from muscle. Lean materials and the pork fat were initially ground through an 8-mm plate. The ground tissue was then placed in polyethylene bags, vacuum sealed using a vacuum packaging system (FJ-500XL, Fujee Tech, Korea) and stored at 0°C until required for product manufacturing. Seven different meat batters were produced and the experimental design and compositions are given in Table 1. The first meat batter served as the control and was prepared with 30% pork back fat and 1.5% sodium chloride. The second meat batter (T1) was prepared with

Table 1. Reduced-fat meat emulsion systems formulation with varying sodium chloride, sodium tripolyphosphate and sea mustard levels (units: g/100 g)

Ingredients	Treatments[1)]						
	Control	T1	T2	T3	T4	T5	T6
Pork meat	50	50	50	50	50	50	50
Back fat	30	20	20	20	20	20	20
Ice	20	30	30	30	30	30	30
Total	100	100	100	100	100	100	100
Sodium chloride	1.5	1.2	1.2	1.2	1.0	1.0	1.0
Sodium tripolyphosphate	-	-	0.1	0.1	-	0.1	0.1
Sea mustard	-	-	-	2.0	-	-	2.0

[1)]Control: pork back fat (30%) + sodium chloride (1.5%), T1: pork back fat (20%) + sodium chloride (1.2%), T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), T4: pork back fat (20%) + sodium chloride (1.0%), T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

20% pork back fat and 1.2% sodium chloride. Meat batter T2 was prepared with 20% pork back fat, 1.2% sodium chloride and 0.1% sodium tripolyphosphate. Meat batter T3 was prepared with 20% pork back fat, 1.2% sodium chloride, 0.1% sodium tripolyphosphate, and 2.0% sea mustard. The concentration of the sea mustard was based on recommendations by Choi *et al*. (2009). The next three meat batters were prepared with 1.0% sodium chloride. The following combination of back fat, sodium chloride, sodium tripolyphosphate and sea mustard were used; T4: pork back fat 20% + sodium chloride 1.0%; T5: pork back fat 20% + sodium chloride 1.0%+ sodium tripolyphosphate 0.1%; T6: pork back fat 20% + sodium chloride 1.0% + sodium tripolyphosphate 0.1% + sea mustard 2%. Pork meat was homogenized, ground for 1 min in a silent cutter (Cutter Nr-963009, Hermann Scharfen GmbH & Co, Germany) then chilled in iced water (2°C). Sodium chloride and sodium tripolyphosphate were added to the meat and mixed for 1 min. 2% sea mustard was used for the samples and pork back fat was added after 3 min. The meat batters were homogenized for 6 min. A temperature probe (Kane-May, KM330, UK) was used to monitor the temperature of the emulsion, and the temperature was maintained below 10°C during batter preparation. Meat batter processing was carried out thrice for each treatment (each meat batter was processed in a 10 kg batch). All analyses were carried out in triplicate for each meat batter formulation.

Proximate composition

Compositional properties of the meat batters were performed using AOAC (2000) procedures. Moisture content (950.46B) was determined by weight loss after 12 h of drying at 105°C in a drying oven (SW-90D, Sang Woo Scientific Co., Korea). Fat content (960.69) was determined by the Soxhlet method with a solvent extraction system (Soxtec® Avanti 2050 Auto System, Foss Tecator AB, Sweden) and protein content (981.10) was determined by the Kjeldahl method with an automatic Kjeldahl nitrogen analyzer (Kjeltec® 2300Analyzer Unit, Foss Tecator AB, Sweden). Ash was determined according to AOAC method 920.153 (muffle furnace).

Salinity

Mohr's titration was carried out according to Chen *et al*. (2005). The salinity of the sample was calculated according to the amount of titrated chloride ion. Means with standard deviations of triplicate determinations were reported.

pH

The pH values of meat batters were measured in a homogenate prepared with 5 g of sample and distilled water (20 mL) using a pH meter (Model 340, Mettler-Toledo GmbH, Switzerland). All determinations were performed in triplicate.

Color measurements

The color of each meat batter was determined using a colorimeter (Minolta Chroma meter CR-210, Minolta Ltd., Osaka, Japan; illuminate C, calibrated with a white plate, L^*=+97.83, a^*=-0.43, b^*=+1.98). Six measurements for each of five replicates were taken. Lightness (CIE L^*-value), redness (CIE a^*- value), and yellowness (CIE b^*-value) values were recorded.

Cooking loss

The meat batters were stuffed into the casing (initial weight) and after heat processing at 75°C for 30 min, cooked samples were cooled to room temperature at 21°C for 3 h. After cooling, cooked meat batters were weighed and a cooking loss was calculated from the weights.

Cooking loss (g/100g) =
[(weight of raw meat batter (g) − weight of cooked meat batter (g)) / weight of raw meat batter (g)] × 100

Emulsion stability

The meat batters were analyzed for emulsion stability using the method of Blouka and Honikel (1992) with the following modifications. At the middle of a 15 mesh sieve, pre-weighed graduated glass tubes were filled with batter. The glass tubes were closed and heated for 30 min in a boiling water bath to a core temperature of 75±1°C. After cooling to approximately 4±1°C to facilitate fat and water layer separation, the total expressible fluid and fat separated in 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

Texture profile analysis (TPA) was performed at room temperature with a texture analyzer (TA-XT2*i*, Stable Micro Systems Ltd., England). The meat batters were stuffed into casings followed by heating (75°C for 30 min), and the cooked samples were cooled to room temperature at 21°C for 3 h. Prior to analysis, samples were allowed to equilibrate to room temperature. Cooked meat batter samples were taken from the central portion of each meat batter. The conditions of texture analysis were as follows: pre-test speed 2.0 mm/s, post-test speed 5.0 mm/s, maximum load 2 kg, head speed 2.0 mm/s, distance 8.0 mm, force 5 g. The calculation of TPA values was obtained by graphing a curve using force and time plots. Values for hardness (kg), springiness, cohesiveness, gumminess (kg), and chewiness (kg) were determined as described by Bourne (1978).

Apparent viscosity

Meat batter viscosity was measured in triplicate with a rotational viscometer (HAKKE Viscotester® 550, Thermo Electron Corporation, Germany) set at 10 rpm. The standard cylinder sensor (SV-2) was positioned in a 25 mL metal cup filled with batter and allowed to rotate under a constant share rate (s^{-1}) for 60 s before each reading was taken. Apparent viscosity values in centipoises were obtained. The temperature of each sample at the time (18±1°C) of viscosity testing was also recorded.

Statistical analysis

All tests were done at least three times for each experimental condition and mean values were reported. An analysis of variance was performed on all the variables measured using the general linear model (GLM) procedure of the SAS statistical package (2008). Duncan's multiple range test ($p<0.05$) was used to determine the differences among treatments.

Results and Discussion

Proximate composition and salinity

The proximate composition and salinity of reduced-fat/low-salt meat emulsion systems formulated with different amounts of phosphate and sea mustard are given in Table 2. The differences in moisture, fat and ash contents of the reduced-fat/low-salt cooked meat emulsion systems are shown to be significant statistically compared to control ($p<0.05$), but protein content shows no statistically significant difference ($p>0.05$). The moisture content of the control was lower than that of the treatment samples, due to the fact that the treatment samples had 10% more water added to make up for the replaced back fat (Table 2). The moisture contents of emulsion systems with same sodium chloride were higher for treatments with sodium tripolyphosphate and sea mustard than for treatment without ($p<0.05$). The control had higher fat content than the treatment samples ($p<0.05$) and the fat levels for the reduced-fat/low-salt meat batters were close to the target value of 20%. The highest ash content for the reduced-fat/low-salt cooked meat emulsion systems were obtained for sea mustard treatment samples ($p<0.05$). The sea mustard used for the treatment contained mineral and vitamin. Similar trends of proximate composition were observed in studies by Choi *et al*. (2012) when different amounts of *Laminaria japonica* were added to reduced-fat pork patties. These results agree with Jimenez-Colmenero *et al*. (2010) who reported similar quality characteristics for reduced/low-fat, low-salt frankfurters supplemented with konjac and seaweed. Differences in proximate analysis are likely due to differences in formulation conditions.

The differences in salinity of reduced-fat/low-salt meat emulsion systems with phosphate and sea mustard are

Table 2. Proximate composition of cooked reduced-fat meat batters formulation with varying sodium chloride, sodium tripolyphosphate and sea mustard levels

Treatments[1)]	Moisture (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Ash (g/100 g)	Salinity (%)
Control	$53.71±1.26^{e}$	12.19±0.53	$31.65±0.99^{a}$	$1.80±0.15^{b}$	$1.54±0.04^{a}$
T1	$61.40±1.23^{b}$	12.79±0.67	$23.93±0.91^{b}$	$1.61±0.27^{c}$	$1.30±0.03^{d}$
T2	$64.09±0.69^{a}$	11.58±0.62	$21.94±0.98^{b}$	$1.78±0.10^{b}$	$1.36±0.03^{c}$
T3	$64.15±0.83^{a}$	11.44±0.75	$22.18±0.83^{b}$	$1.98±0.11^{a}$	$1.42±0.05^{b}$
T4	$57.84±0.36^{d}$	12.19±0.78	$20.48±1.11^{b}$	$1.44±0.12^{d}$	$1.15±0.02^{e}$
T5	$60.53±1.26^{c}$	11.46±0.72	$21.20±0.98^{b}$	$1.62±0.10^{c}$	$1.17±0.03^{e}$
T6	$63.98±1.21^{ab}$	11.91±0.85	$20.55±1.05^{b}$	$1.97±0.11^{a}$	$1.28±0.02^{d}$

All values are mean±standard deviation of three replicates (n=9).

[a-e]Means within a column with different letters are significantly different ($p<0.05$).

[1)]Control: pork back fat (30%) + sodium chloride (1.5%), T1: pork back fat (20%) + sodium chloride (1.2%), T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), T4: pork back fat (20%) + sodium chloride (1.0%), T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

shown to be significant (Table 2). The salinity for the control with 1.5% NaCl was the highest. By decreasing the sodium chloride levels from 1.5% to 1.0%, the salinity of reduced-fat/low-salt meat emulsion systems significantly decreased (p<0.05). Also, the treatments adding the phosphate and sea mustard increased salinity, due to phosphate and sea mustard contains sodium components. Thus, the salinity of reduced-fat/low-salt meat emulsion systems is shown to be positive related to the amount of salt, phosphate and sea mustard added.

pH and color

Table 3 gives the pH, L*-value (lightness), a*-value (redness), and b^*-value (yellowness) values for uncooked and cooked reduced-fat/low-salt meat emulsion systems formulated with incorporated phosphate and sea mustard. Increasing sodium chloride levels yielded lower pH values for both uncooked and cooked meat emulsion systems (p<0.05). Also, the pH values for uncooked and cooked reduced-fat/low-salt meat emulsion systems were higher for batters formulated with phosphate and sea mustard. According to Puolanne *et al*. (2001), the pH of cooked sausages tended to decrease when phosphate or salt level was increased. Jimenez-Colmenero *et al*. (2010) reported that the pH of low-fat frankfurters with konjac gel were higher than the control with regular fat and salt. Detienne and Wicker (1999) observed that the pH of pork loin injected with 0.5% NaCl increased with increasing sodium tripolyphosphate levels. Jung and Lee (2011) reported that the pH of cookies containing sea mustard decreased as the sea mustard powder level increased. Puolanne *et al*. (2001) reported similar results for the combined effects of NaCl and phosphate in cooked sausage.

The differences in lightness, redness and yellowness values of uncooked and cooked reduced-fat/low-salt meat emulsion systems are shown to be significant (Table 3). The highest lightness value for uncooked reduced-fat/low-salt meat emulsion systems was obtained for the control sample (p<0.05), due to affect by adding salt and phosphate levels, and sea mustard. By adding sea mustard, the redness of uncooked and cooked reduced-fat/low-salt meat emulsion systems decreased significantly when compared to treatments without sea mustard (p<0.05). The yellowness of uncooked and cooked reduced-fat/low-salt meat emulsion systems with added sea mustard was significantly higher than that for treatments without sea mustard (p<0.05). Jung and Lee (2011) reported that yellowness of cookies prepared significantly increased, while lightness and redness decreased with higher sea mustard levels. These results were also in agreement with Jimenez-Colmenero *et al*. (2010) who reported that reduced/low-fat, low-salt frankfurters prepared with added konjac and seaweed had similar color values. Also, by decreasing the sodium chloride levels from 1.5% to 1.0%, the lightness and redness of uncooked reduced-fat/low-salt meat emulsion systems significantly decreased (p<0.05), while the lightness of cooked reduced-fat/low-salt meat emulsion systems increased. However, the redness of cooked reduced-fat/low-salt meat emulsion systems was not affected by sodium chloride levels. Similar results of decreased lightness as a function of reducing salt levels were reported by O'Flynn *et al*. (2014b) for reduced-phosphate breakfast sausages. Thus, the color of reduced-fat/low-salt meat emulsion systems is shown to be affected by the amount of salt and phosphate levels, and sea mustard added.

Table 3. Effects of pH and color (CIE L*-, a*- and b*-values) of reduced-fat meat batters formulated with varying sodium chloride, sodium tripolyphosphate and sea mustard levels

Treatments[1)]	Uncooked				Cooked			
	pH	L*-value	a*-value	b*-value	pH	L*-value	a*-value	b*-value
Control	$5.93±0.03^{d}$	$73.23±2.13^{a}$	$7.90±0.52^{d}$	$11.68±0.46^{b}$	$6.08±0.02^{e}$	$73.91±0.65^{c}$	$4.19±0.16^{a}$	$10.44±0.23^{b}$
T1	$5.95±0.05^{c}$	$68.20±2.12^{b}$	$10.02±0.35^{b}$	$11.84±0.83^{b}$	$6.14±0.03^{d}$	$74.50±0.87^{bc}$	$4.50±0.25^{a}$	$10.63±0.10^{b}$
T2	$6.06±0.03^{b}$	$67.01±1.16^{b}$	$8.17±0.46^{c}$	$11.06±0.81^{b}$	$6.17±0.03^{c}$	$75.95±0.45^{b}$	$3.25±0.23^{b}$	$9.89±0.28^{c}$
T3	$6.10±0.02^{ab}$	$50.71±1.69^{d}$	$-8.14±0.31^{e}$	$20.02±0.96^{a}$	$6.23±0.04^{b}$	$58.12±0.82^{d}$	$-9.04±0.23^{c}$	$19.91±0.32^{a}$
T4	$5.97±0.02^{c}$	$65.91±1.23^{bc}$	$10.42±0.38^{a}$	$11.27±0.88^{b}$	$6.16±0.03^{c}$	$75.86±0.28^{b}$	$4.20±0.22^{a}$	$10.91±0.15^{b}$
T5	$6.12±0.02^{a}$	$61.20±2.03^{c}$	$7.65±0.48^{d}$	$11.56±0.65^{b}$	$6.26±0.03^{a}$	$77.44±0.36^{a}$	$2.92±0.18^{b}$	$10.29±0.13^{b}$
T6	$6.14±0.03^{a}$	$50.86±0.98^{d}$	$-8.72±0.29^{f}$	$20.79±0.87^{a}$	$6.27±0.02^{a}$	$59.59±0.94^{d}$	$-9.13±0.15^{c}$	$20.24±0.19^{a}$

All values are mean±standard deviation of three replicates (n=9).

[a-f]Means within a column with different letters are significantly different (p<0.05).

[1)]Control: pork back fat (30%) + sodium chloride (1.5%), T1: pork back fat (20%) + sodium chloride (1.2%), T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), T4: pork back fat (20%) + sodium chloride (1.0%), T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

Cooking loss and emulsion stability

The effects of incorporated phosphate and sea mustard on the cooking loss and emulsion stability of the reduced-fat/low-salt meat emulsion systems are shown in Table 4. The cooking loss for the control, T3 and T6 samples had the lowest values ($p<0.05$). Decreasing the sodium chloride from 1.5% to 1.0% significantly increased the cooking loss and significant differences in cooking loss were observed among the treatments with sodium tripolyphosphate and sea mustard added ($p<0.05$). Tobin *et al*. (2012) indicated that lowering the salt and fat levels increased the cooking loss of frankfurter. Jimenez-Colmenero *et al*. (2010) reported that cooking loss in reduced-fat or low-fat frankfurter samples having only konjac gel was similar to that of the control samples, while reduced/low-fat and low-salt frankfurters samples with konjac gel had higher cooking loss than the control. Kim *et al*. (2014) reported that the most difficult challenge to reducing salt addition is the technological function of salt, contributing to water and fat retention and impacting cooking loss of meat products. They reported that reduced-salt frankfurter with glasswort caused the increased cooking loss. According to O'Flynn *et al*. (2014b), salt content decreased cooking loss, and the decrease was directly related to salt concentrations up to 2%. These results agree with Detienne and Wicker (1999) who showed that sodium chloride and tripolyphosphate levels in meat product samples resulted in cooking loss. Therefore, the cooking loss of reduced-fat/low-salt meat emulsion systems can be similar to the control by adding phosphate and sea mustard.

The differences in emulsion stability of reduced-fat/low-salt emulsion systems formulated with incorporated phosphate and sea mustard at different concentrations were significant (Table 4). The reduced-fat/low-salt emulsion systems with control and T3 resulted in lower total expressible fluid and fat loss compared to other treatment samples ($p<0.05$). Total expressible fluid and fat loss also exhibited similar trends to cooking loss. Jimenez-Colmenero *et al*. (2010) reported that emulsion stability of the different meat batters was affected by the formulation. Their results showed that the effect of substituting konjac gel for back fat was dependent on the level of substitution. O'Flynn *et al*. (2014a) reported similar results that increasing the salt content added to breakfast sausages decreased the total expressible fluid and fat loss. According to O'Flynn *et al*. (2014b), the phosphates are employed in the manufacture of breakfast sausages to increase the extraction and solubilisation of proteins. Thus, a stable gel matrix leads to a smaller release of water and fat and helps to improve the binding properties of emulsion systems. Cofrades *et al*. (2008) reported that incorporation of sea *spaghetti* and *wakame* led to a decrease in total fluid and fat release in the gel/emulsion systems and in general, the emulsion stability of these samples was improved when the amount of added seaweed was increased.

Texture profile analysis

Textural properties are the most important factor in the arrangement of emulsion meat products. The effects of incorporated phosphate and sea mustard on the textural properties of reduced-fat/low-salt meat emulsion systems are presented in Table 5. The control with general fat and sodium chloride had the highest value for all textural parameters ($p<0.05$), and a reduction in fat and sodium chloride levels led to decreased hardness, cohesiveness, gumminess and chewiness. Also, the addition of phos-

Table 4. Effects of cooking loss and emulsion stability of reduced-fat meat batters formulated with varying sodium chloride, sodium tripolyphosphate and sea mustard levels

Treatments[1)]	Cooking loss (g/100 g)	Emulsion stability	
		Total expressible fluid (mL/100 g)	Fat loss (mL/100 g)
Control	15.97±0.81^{d}	10.23±0.66^{e}	1.71±0.25^{e}
T1	35.11±0.84^{b}	19.21±0.92^{b}	3.28±0.35^{b}
T2	29.58±1.08^{c}	16.08±0.98^{c}	1.75±0.09^{de}
T3	16.54±0.15^{d}	9.89±0.86^{e}	1.68±0.12^{e}
T4	40.55±1.20^{a}	24.86±1.09^{a}	3.82±0.16^{a}
T5	36.71±1.08^{b}	19.96±0.99^{b}	2.69±0.19^{c}
T6	16.92±1.64^{d}	11.92±0.87^{d}	1.98±0.08^{d}

All values are mean±standard deviation of three replicates (n=9).

[a-e]Means within a column with different letters are significantly different ($p<0.05$).

[1)]Control: pork back fat (30%) + sodium chloride (1.5%), T1: pork back fat (20%) + sodium chloride (1.2%), T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), T4: pork back fat (20%) + sodium chloride (1.0%), T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

Table 5. Effects of the textural attributes of cooked meat batters formulated with varying sodium chloride, sodium tripolyphosphate and sea mustard levels

Treatments[1)]	Hardness (kg)	Springiness	Cohesiveness	Gumminess (kg)	Chewiness (kg)
Control	2.51 ± 0.12^{a}	0.92 ± 0.03^{a}	0.42 ± 0.02^{a}	1.05 ± 0.12^{a}	0.97 ± 0.12^{a}
T1	1.63 ± 0.12^{de}	0.79 ± 0.04^{d}	0.34 ± 0.03^{d}	0.56 ± 0.14^{e}	0.44 ± 0.13^{e}
T2	2.26 ± 0.28^{b}	0.83 ± 0.04^{c}	0.41 ± 0.03^{ab}	0.94 ± 0.27^{b}	0.78 ± 0.19^{c}
T3	2.32 ± 0.32^{ab}	0.89 ± 0.03^{ab}	0.41 ± 0.04^{ab}	0.96 ± 0.19^{b}	0.85 ± 0.20^{b}
T4	1.10 ± 0.29^{e}	0.81 ± 0.04^{c}	0.32 ± 0.03^{e}	0.35 ± 0.21^{f}	0.28 ± 0.20^{f}
T5	1.83 ± 0.12^{d}	0.86 ± 0.02^{b}	0.38 ± 0.04^{c}	0.70 ± 0.15^{d}	0.60 ± 0.16^{d}
T6	2.06 ± 0.19^{c}	0.91 ± 0.03^{a}	0.40 ± 0.03^{b}	0.82 ± 0.17^{c}	0.74 ± 0.14^{c}

All values are mean±standard deviation of three replicates (n=9).

[a-f]Means within a column with different letters are significantly different ($p<0.05$).

[1)]Control: pork back fat (30%) + sodium chloride (1.5%), T1: pork back fat (20%) + sodium chloride (1.2%), T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), T4: pork back fat (20%) + sodium chloride (1.0%), T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

phate and sea mustard to the reduced-fat/low-salt meat emulsion systems led to significant increases in all textural parameters ($p<0.05$). This is in agreement with the results reported by O'Flynn *et al*. (2014a) where textural properties were affected when salt contents in frankfurters were reduced from 2.5 to 0.5%. Kim *et al*. (2014) reported that sausage batters with lower salt concentrations implies less solubilized protein and decreased water holding capacity, and hence there may be enough protein aggregation to form a strong protein network. According to related studies, Jimenez-Colmenero *et al*. (2010), the seaweed and/or konjac is largely responsible for the increase in the hardness and chewiness of low-fat/reduced-salt frankfurter. Also, Cofrades *et al*. (2008) showed that low-salt gel/emulsion meat systems with edible seaweed added have improved textural properties and this may be due to the enhanced binding capacity of the emulsion systems. O'Flynn *et al*. (2014a) found that the effect of phosphate levels on the texture profile attributes of breakfast sausages was not affected by reductions in the range of 0.5 to 0%. Thus, this study showed that utilizing dietary fiber from sea mustard and phosphate in systems with worsening texture profiles due to reduced fat and salt levels results in significant improvements in the textural profiles.

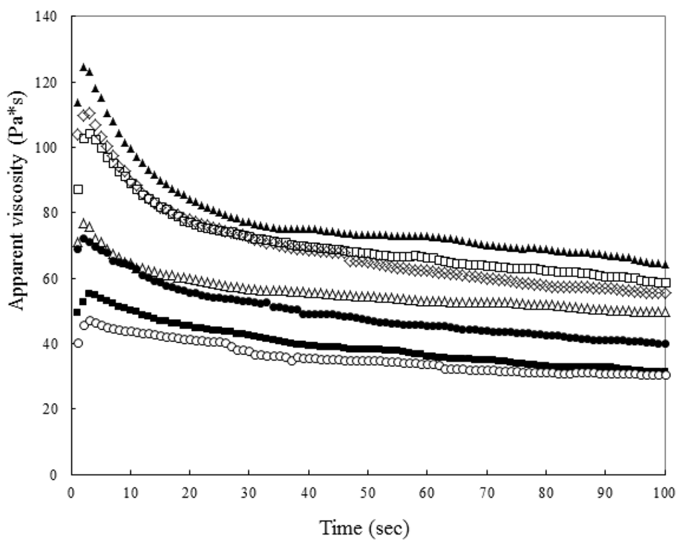

Fig. 1. Change of apparent viscosity on reduced-fat meat batters formulated with varying sodium chloride, sodium tripolyphosphate and sea mustard levels stirred for 100 s. (□) Control: pork back fat (30%) + sodium chloride (1.5%), (■) T1: pork back fat (20%) + sodium chloride (1.2%), (△) T2: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%), (▲) T3: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%), (○) T4: pork back fat (20%) + sodium chloride (1.0%), (●) T5: pork back fat (20%) + sodium chloride (1.0%) + sodium tripolyphosphate (0.1%), (◇) T6: pork back fat (20%) + sodium chloride (1.2%) + sodium tripolyphosphate (0.1%) + sea mustard (2%).

Apparent viscosity

Fig. 1 shows the apparent viscosity for reduced-fat/low-salt meat emulsion systems formulated with incorporated phosphate and sea mustard. All the reduced-fat/low-salt meat emulsion systems samples exhibited thixotropic behavior with apparent values that decreased with an increase in rotation time. According to some researchers, the meat emulsion samples had significantly decreased apparent viscosity with increased rotation time (Choi *et al*., 2009; Lee *et al*., 2008; Sariçoba *et al*., 2008; Yapar *et al*., 2006). The significant changes in higher apparent viscosity that were observed for reduced-fat/low-salt meat emulsion systems were due to the lower fat and salt concentrations found in the T3 and T6 samples with incorporated phosphate and sea mustard compared to control. The reduced-fat/low-salt meat emulsion systems without phosphate and sea mustard (T1 and T4) had the lowest values for apparent viscosity. This result agrees with the results of Choi *et al*. (2009) that showed the effects of dietary fiber extracted form rice bran on the apparent viscosity of low-fat meat batters. Similar results were found by Yapar *et al*. (2006) who reported that increasing emulsion viscosity is desirable in high-fat emulsion meat products since the higher emulsion viscosity imparts increased elasticity to emulsion meat products. Sariçoba *et al*. (2008) showed that an increase in viscosity of samples at different rotation speeds with respect to albedo levels proves that the albedo effect increases emulsion viscosity. Also, Kim *et al*. (2014) reported that effects of apparent viscosity of meat batter formulated with reduced salt (a half) and added glasswort powder resulted in an increase in apparent viscosity. Terrell (1983) reported that salt reduction reduced the apparent viscosity of meat batters. Normally, the increase in the apparent viscosity of meat emulsion is one of the reasons for the attributed stable emulsion (Choi *et al*., 2009; Kim *et al*., 2014, Lee *et al*., 2008; Shand, 2000). Thus, viscosity is an indicator of the valuable criteria of quality characteristics in emulsion meat products. In this study, increasing the apparent viscosity of reduced-fat/low-salt meat emulsion systems contributed to the observed improvements resulting from incorporating phosphate and sea mustard into the systems.

Conclusion

In this study we showed that the combination of reduced fat levels (from 30% to 20%), reduced salt concentrations (from 1.5% to 1.0%) and the addition of phosphate and sea mustard has an important effect on the quality of reduced-fat/low-salt meat emulsion systems. The results of this study showed that reducing pork back fat and salt with incorporated phosphate and sea mustard in reduced-fat/low-salt meat emulsion system formulations results in optimized food characteristics. The incorporation of phosphate and sea mustard in the formulation successfully reduced fat and salt in reduced-fat/low-salt meat emulsion systems.

Acknowledgements

This research was supported (2014-314068-3) by the Ministry of Agriculture, Food and Rural Afffairs (Republic of Korea). The authors were also partially supported by the Commercialization of Processed Foods and Materialization Technology Project (E0156404-01) from Korean Food Research Institute.

References

1. AOAC (2000) Official methods of analysis. 17th ed, Association of Official Analytical Chemists, Washington, DC, USA.
2. Bloukas, I. and Honikel, K. O. (1992) The influence of additives on the oxidation of pork back fat and its effect on water and fat binding in finely comminuted batters. *Meat Sci.* **32**, 31-43.
3. Bloukas, J. G., Paneras, E. D., and Fournitzis, G. C. (1997) Effect of replacing pork backfat with olive oil on processing and quality characteristics of fermented sausages. *Meat Sci.* **45**, 133-144.
4. Boulom, S., Robertson, J., Hamid, N., Ma, Q., and Lu, J. (2014) Seasonal changes in lipid, fatty acid, α-tocopherol and phytosterol contents of seaweed, Undarin pinnatifida, in the Marlborough sounds, New Zealand. *Food Chem*. **161**, 261-269.
5. Bourne, M. C. (1978) Texture profile analysis. *Food Technol.* **32**, 62-66.
6. Cannon, J. E., McKeith, F. K., Martin, S. E., Novakofski, J., and Carr, T. R. (1993) Acceptability and shelf-life of marinated fresh and precooked pork. *J. Food Sci.* **58**, 1249-1253.
7. Chen, M. J., Hsieh, Y. T., Weng, Y. M., and Chiou, R. Y. Y. (2005) Flame photometric determination of salinity in processed foods. *Food Chem*. **91**, 765-770.
8. Choi, Y. S., Choi, J. H., Han, D. J., Kim, H. Y., Kim, H. W., Lee, M. A., Chung, H. J., and Kim, C. J. (2012) Effects of *Laminaria japonica* on the physico-chemical and sensory characteristics of reduced-fat pork patties. *Meat Sci*. **91**, 1-7.
9. Choi, Y. S., Choi, J. H., Han, D. J., Kim, H. Y., Lee, M. A., Kim, H. W., and Kim, C. J. (2009) Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. *Meat Sci*. **82**, 266-271.
10. Choi, Y. S., Jeong, J. Y., Choi, J. H., Han, D. J., Kim, H. Y., Lee, M. A., Shim, S. Y., Paik, H. D., and Kim, C. J. (2007)

Quality characteristics of meat batters containing dietary fiber extracted from rice bran. *Korean J. Food Sci. An.* **27**, 228-234.

11. Choi, Y. S., Kim, H. W., Hwang, K. E., Song, D. H., Choi, J. H., Lee, M. A., Chung, H. J., and Kim, C. J. (2014) Physicochemical properties and sensory characteristics of reduced-fat frankfurters with pork back fat replaced by dietary fiber extracted from *makgeolli* lees. *Meat Sci*. **96**, 892-900.
12. Cofrades, S., Lopez-Lopez, I., Solas, M. T., Bravo, L., and Jimenez-Colmenero, F. (2008) Influence of different types and proportions of added edible seaweeds on characteristic of low-salt gel/emulsion meat systems. *Meat Sci*. **79**, 767-776.
13. Crehan, C. M., Jughes, E., Troy, D. J., and Buckley, D. J. (2000) Effects of fat level and maltodextrin on the functional properties of frankfurter formulated with 5, 12 and 30% fat. *Meat Sci*. **55**, 463-469.
14. Desmond, E. (2006) Reducing salt: A challenge for the meat industry. *Meat Sci*. **74**, 188-196.
15. Detienne, N. A. and Wicker, L. (1999) Sodium chloride and tripolyphosphate effects on physical and quality characteristics of injected pork loins. *J. Food Sci.* **64**, 1042-1047.
16. Fung, A., Hamid, N., and Lu, J. (2013) Fucoxanthin content and antioxidant properties of *Undaria pinnafifida*. *Food Chem*. **136**, 1055-1062.
17. Jimenez-Colmenero, F., Cofrades, S., Lopez-Lopez, I., Ruiz-Capillas, C., Pintado, T., and Solas, M. T. (2010) Technological and sensory characteristics of reduced/low-fat, low-salt frankfurters as affected by the addition of konjac and seaweed. *Meat Sci*. **84**, 356-363.
18. Jung, K. J. and Lee, S. J. (2011) Quality characteristics of rice cookies prepared with sea mustard (*Undaria pinnatifida Suringer*) powder. *J. Korean Soc. Food Sci. Nutr.* **40**, 1453-1459.
19. Kim, H. W., Hwang, K. E., Song, D. H., Kim, Y. J., Lim, Y. B., Ham, Y. K., Yeo, E. J., Chang, S. J., Choi, Y. S., and Kim, C. J. (2014) Effect of glasswort (*Salicornia herbacea* L.) on the texture of frankfurters. *Meat Sci*. **97**, 513-517.
20. Lee, H. C. and Chin, K. B. (2010) Application of microbial trasglutaminase and functional ingredients for the healthier low-fat/salt meat products: A review. *Korean J. Food Sci. An*. **30**, 886-895.
21. Lee, M. A., Han, D. J., Jeong, J. Y., Choi, J. H., Choi, Y. S., Kim, H. Y., Paik, H. D., and Kim, C. J. (2008) Effect of *kimchi* powder level and drying methods on quality characteristics of breakfast sausage. *Meat Sci.* **80**, 708-714.
22. MacArtain, P., Gill, C. I. R., Brooks, M., Campbell, R., and Rowland, I. R. (2007) Nutritional value of edible seaweeds. *Nutr. Rev.* **65**, 535-543.
23. Murphy, M. A. and Zerby, H. N. (2004) Prerigor infusion of lamb with sodium chloride, phosphate, and dextrose solutions to improve tenderness. *Meat Sci.* **66**, 343-349.
24. O'Flynn, C. C., Cruz-Romero, M. C., Troy, D., Mullen, A., and Kerry, J. P. (2014a) The application of high-pressure treatment in the reduction of salt levels in reduced-phosphate breakfast sausages. *Meat Sci*. **96**, 1266-1274.
25. O'Flynn, C. C., Cruz-Romero, M. C., Troy, D., Mullen, A., and Kerry, J. P. (2014b) The application of high-pressure treatment in the reduction of phosphate levels in breakfast sausages. *Meat Sci*. **96**, 633-639.
26. Ozvural, E. B. and Vural, H. (2008) Utilization of interesterified oil blends in the production of frankfurters. *Meat Sci.* **78**, 211-216.
27. Pappa, I. C., Bloukas, J. G., and Arvanitoyannis, I. S. (2000) Optimization of salt, olive oil and pectin level for low-fat frankfurters produced by replacing pork backfat with olive oil. *Meat Sci.* **56**, 81-88.
28. Puolanne, E. J., Ruusunen, M. H., and Vainionpaa, J. I. (2001) Combined effects of NaCl and raw meat pH on water-holding in cooked sausage with and without added phosphate. *Meat Sci*. **58**, 1-7.
29. Ruusunen, M. and Puolanne, E. (2005) Reducing sodium intake from meat products. *Meat Sci.* **70**, 531-541.
30. Ruusunen, M., Vainionpaa, J., Lyly, M., Lahteenmaki, L., Niemisto, M., Ahvenainen, R., and Puolanne, E. (2005) Reducing the sodium content in meat products: the effect of the formulaion in low-sodium ground meat patties. *Meat Sci*. **69**, 53-60.
31. Sariçoba, C., Özalp, B., Yýlmaz, M. T., Özen, G., Karakaya, M., and Akbulut, M. (2008) Characteristics of meat emulsion systems as influenced by different level of lemon albode. *Meat Sci.* **80**, 599-606.
32. SAS (2008) SAS/STAT software for PC. Release 9.2, SAS Institute Inc., Cary, NC, USA.
33. Shand, P. J. (2000) Textural, water holding, and sensory properties of low-fat pork bologna with normal and waxy starch hull-less barley. *J. Food Sci*. **65**, 101-107.
34. Terrell, R. N. (1983) Reducing the sodium content of processed meats. Food Technology (July), 66-71.
35. Tobin, B., O'Sullivan. M. G., Hamill, R. M., and Kerry, J. P. (2012) Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Sci*. **92**, 659-666.
36. Turhan, S., Sagir, I., and Ustun, N. S. (2005) Utilization of hazelnut pellicle in low-fat beef burgers. *Meat Sci*. **71**, 312-316.
37. Woo, M. J., Lee, K. T., and Kim, C. J. (1995) Quality characteristics of emulsion-type sausages manufactured with cottonseed oil. *J. Korean Soc. Food Sci. An.* **15**, 187-191.
38. Urbano, M. G. and Gorii, I. (2002) Bioavailability of nutrients in rats fed on edible seaweeds, Nori (*Porphyra tenera*) and Wakame (*Undaria pinnatifida*), as a source of dietary fibre. *Food Chem*. **76**, 281-286.
39. Yapar, A., Atay, S., Kayacier, A., and Yetim, H. (2006) Effects of different levels of salt and phosphate on some emulsion attributes of the common carp (*Cyprinus carpio* L., 1758). *Food Hydrocolloid.* **20**, 825-830.