

Effects of Edible Seaweed on Physicochemical and Sensory Characteristics of Reduced-salt Frankfurters

Yun-Sang Choi, Jun-Seok Kum, Ki-Hong Jeon, Jong-Dae Park, Hyun-Wook Choi,
Ko-Eun Hwang¹, Tae-Jun Jeong¹, Young-Boong Kim*, and Cheon-Jei Kim^{1*}

Food Processing Research Center, Korean Food Research Institute, Seongnam 13539, Korea

¹Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea

Abstract

The effects of sea tangle, sea mustard, hijiki, and glasswort were investigated based on the proximate composition, salinity, cooking loss, emulsion stability, pH, color, texture profile analysis, apparent viscosity, and sensory characteristics of reduced-salt (NaCl) meat batter and frankfurters. The moisture content, salinity, lightness of the meat batter and frankfurter, hardness, gumminess, and chewiness of the reduced-salt frankfurters with sea weeds were lower than the control without seaweed ($p < 0.05$). The protein content, springiness, and cohesiveness of the reduced-salt frankfurters were not significantly different among the treatments ($p > 0.05$). The moisture content, salinity, cooking loss, lightness, redness, hardness, gumminess, and chewiness of treatments with sea tangle and with sea mustard were lower than the control ($p < 0.05$). Among the sensory traits, color was highest in the control ($p < 0.05$). The flavor was also highest in the control. The treatments with sea tangle and with sea mustard samples had high tenderness, juiciness, and overall acceptability scores similar to the control ($p < 0.05$). The results of this study show that the combination of low-salt and seaweed in the formulation successfully improved reduced-salt frankfurters, improving sensory characteristics to levels similar to the regular salt control (1.5%).

Keywords: reduced-salt frankfurters, sea tangle, sea mustard, hijiki, glasswort

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Introduction

Seaweed has been used as a drug in traditional Korean medicine for over a thousand years (Hur, 1999) and is traditionally consumed as a sea vegetable in Asia due to its high nutritional value (Choi *et al.*, 2012). According to Sohn (2009), there are 780 seaweed species in Korea, with 50 edible species such as brown algae (sea tangle, sea mustard, Hizikia fusiforme), green algae (green laver, gulfweed), and red algae (laver, seaweed fulvescens, agar seaweed). Also, seaweed contains biochemical that act as anti-oxidant, anti-inflammatory, anti-coagulation, anti-proliferation, and anti-biotic agents (Jaswir *et al.*, 2014). Especially, seaweed contains various bioactive compounds that possess potential health benefits such as dietary fib-

ers, vitamins, and minerals (Jeon and Choi, 2012; Kwak *et al.*, 2010). Seaweed contains major sources of dietary fiber such as alginic acid, fucoidan, and laminaran (Jeon and Choi, 2012).

Sea tangle (*Laminaria japonica*) is one of the most common brown marine algae used as a seasoning in East Asia. It consists of polysaccharides with alginates, fucoidan, fucoxanthin, laminarian, and insoluble cellulose, which is rich in dietary fiber (You *et al.*, 2009). Sea mustard (*Undaria pinnatifida*) is edible perennial brown algae in the Laminariaceae family and is usually found in the East Sea (Bang *et al.*, 2011; Hwang *et al.*, 1998). Jeon and Choi (2012) reported that sea mustard improved the quality characteristics of pork patties, but the utilization of sea mustard in low-salt meat products has not yet been studied for its effects on quality characteristics. The edible brown algae hijiki, *Hizikia fusiforme*, is widely consumed in Asia. In Western countries, it is consumed in soups, salads, and vegetable dishes in Asian restaurants (Wondimu *et al.*, 2007). The hijiki contains various bioactive compounds such as dietary fibers, vitamins, minerals, and proteins that possess potential health benefits (Jung *et al.*, 2001). Glasswort (*Salicornia herbacea* L.), a halophytic

*Corresponding authors: Young-Boong Kim, Food Processing Research Center, Korea Food Research Institute, Sungnam 13539, Korea. Tel: +82-31-780-9180, Fax: +82-31-780-9076, E-mail: kybaaa@kfri.re.kr

Cheon-Jei Kim, Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea. Tel: +82-2-450-3684, Fax: +82-2-444-6695, E-mail: kimej@konkuk.ac.kr

plant that grows naturally in mud flats and saltpan plains can be found in Korea (Kim *et al.*, 2014). Glasswort contains several bioactive compounds with anti-microbial, anti-cancer, and antioxidant activities that have various benefits to human health (Park *et al.*, 2011). Previous studies have investigated the effects of glasswort on the lipid oxidation of pork (Han *et al.*, 2003), but studies to determine the effects of glasswort on the quality characteristics of low-salt meat products have been limited. Also, research on low/reduced-salt meat products prepared with seaweed is limited, and no studies have reported on the comparison of seaweed in low/reduced-salt meat products.

Therefore, the objective of this study was to investigate the effects of sea tangle, sea mustard, hijiki, and glasswort on the proximate composition, cooking loss, pH, color, texture profile, and sensory properties of reduced-salt frankfurters.

Materials and Methods

Preparation and processing of sea tangle, sea mustard, hijiki, and glasswort

Dried sea tangle, sea mustard, hijiki, and glasswort were purchased from a market in Gwangingu, Seoul, Korea. They were each ground using a blender (KA-2610, Jworld Tech, Korea) for one minute and passed through a 35-mesh sieve (particle size of <0.5 mm). The sea tangle, sea mustard, hijiki, and glasswort were then placed in individual polyethylene bags, vacuum packaged using a vacuum packaging system (FJ-500XL, Fjtee Tech, Korea) and stored at -4°C until used for product manufacture. The chemical and physical properties of seaweed are given in Table 1.

Reduced-salt frankfurters 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, intermuscular fat and visible connective tissue were removed from the muscle. Lean materials and pork fat were initially ground using an 8-mm plate. The ground tissue was then placed in polyethylene bags, vacuum sealed using a vacuum packaging system (FJ-500XL, Fjtee Tech, Korea) and stored at 0°C until required for product manufacturing. Six different reduced-salt frankfurters were produced, and the experimental design and compositions are given in Table 2. The first frankfurters served as the control, with 1.5% NaCl and without seaweed. The following treatments with sea tangle, sea mustard, hijiki, or glasswort were used; T1: 1.0% NaCl, T2: 1.0% NaCl + 1.0% sea tangle; T3: 1.0% NaCl + 1.0% sea mustard; T4: 1.0% NaCl + 1.0% hijiki; T5: 1.0% NaCl + 1.0% glasswort. The lean materials were homogenized and ground for 1 min 30 sec in a silent cutter (Cutter Nr-963009, Hermann Scharfen GmbH & Co, Germany). Pork back fat, NaCl, and sodium tripolyphosphate (0.15%) were added to the meat and mixed for 1 min 30 s. The meat batters were homogenized for 3 min. A temperature probe (Kane-May, KM330, UK) was used to monitor the temperature of the batter, which was maintained below 10°C throughout batter preparation. After batter preparation, the meat batter was stuffed into collagen casings (#240, NIPPI Inc., Japan; approximate diameter, 25 mm) using a stuffer (Stuffer IS-8, Sirman, Italy). The meat batters were cooked to 80°C for 30 min in a chamber (Model MAXi3501, Kerres, Germany), and then the cooked meat batters were cooled (21°C) for 3 h. This procedure was performed in triplicate for each frankfurter (Choi *et al.*, 2014).

Proximate composition

Compositional properties of the reduced-salt frankfurt-

Table 1. Chemical and physical properties of seaweeds

Treatments ¹⁾	Sea tangle	Sea mustard	Hijiki	Glasswort
Moisture content (%)	6.49±0.08	6.65±0.03	5.71±0.34	4.21±0.23
Protein content (%)	4.17±0.12	7.57±0.52	10.40±0.59	4.83±0.10
Fat content (%)	1.44±0.15	6.65±0.55	1.38±0.08	6.30±0.20
Ash content (%)	22.28±0.44	13.32±1.37	17.89±0.05	16.80±0.19
pH	5.96±0.06	5.51±0.10	5.77±0.02	5.56±0.02
Salinity (%)	35.20±3.35	25.20±1.10	27.20±3.35	18.20±1.10
CIE <i>L</i> *	70.61±0.67	63.33±0.67	49.43±0.40	63.72±0.33
CIE <i>a</i> *	-2.93±0.05	-4.89±0.07	4.83±0.11	4.13±0.07
CIE <i>b</i> *	17.27±0.15	27.18±0.43	8.63±0.29	17.15±0.11

All values are mean±standard deviation of three replicates.

Table 2. Reduced-salt frankfurters formulations with various types of seaweed (units: g/100 g)

Ingredients	Treatments ¹⁾					
	Control	T1	T2	T3	T4	T5
Pork ham	50	50	50	50	50	50
Back fat	25	25	25	25	25	25
Ice	25	25	25	25	25	25
Total	100	100	100	100	100	100
NaCl	1.5	1.0	1.0	1.0	1.0	1.0
Sodium tripolyphosphate	0.15	0.15	0.15	0.15	0.15	0.15
Sea tangle	-	-	1.0	-	-	-
Sea mustard	-	-	-	1.0	-	-
Hijiki	-	-	-	-	1.0	-
Glasswort	-	-	-	-	-	1.0

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

ers were performed using AOAC (2007). 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 Kjeldahl method with an automatic Kjeldahl nitrogen analyzer (Kjeltec® 2300 Analyzer Unit, Foss Tecator AB, Sweden). Ash was determined according to AOAC method 920.153 (muffle furnace).

Salinity

The salinity of frankfurters (5 g) mixed with 20 mL distilled water for 60 s in a homogenizer (Ultra-Turrax T25, Janke and Kunkel, Germany) at 8,000 rpm speed was determined with a salimeter (TM-30D, Takemura Electric Works Ltd., Japan).

Cooking loss

The meat batters were stuffed into the casing (initial weight) and cooked to 80°C for 30 min in a chamber, 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 (%) = [(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 (%) = [(the water layer (mL) + the fat layer (mL)) / weight of raw meat batter (g)] × 100

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

pH

The pH values of reduced-salt batters and frankfurters 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

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

Texture profile analysis

Texture profile analysis (TPA) was performed at room

temperature with a texture analyzer (TA-XT2i, Stable Micro Systems Ltd., England). Prior to analysis, samples were allowed to equilibrate to room temperature. Reduced-salt frankfurters samples were taken from the central portion of each sample. 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 shear 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 ($18 \pm 1^\circ C$) of viscosity testing was also recorded (Shand, 2000).

Sensory evaluation

Trained thirty-members of panel group consisting of researchers of the Department of Food Sciences and Biotechnology of Animal Resources at Konkuk University in Korea was used to evaluate reduced-salt frankfurters at the time. Each reduced-salt frankfurter was evaluated in terms of color, flavor, juiciness, tenderness, and overall acceptability. The reduced-salt frankfurters were cooked to $80^\circ C$ for 30 min in a chamber (Model MAXi3501, Kerres, Germany), cooled to $21^\circ C$ for 3 h, cut into quarters (length \times diameter: 50×25 mm), and served to the panelists randomly. Each sample was coded with a randomly selected 3-digit number. Sensory evaluations were per-

formed under fluorescent lighting. Panelists were instructed to cleanse their palates between samples using water. The color (1 = extremely undesirable, 10 = extremely desirable), flavor (1 = extremely undesirable, 10 = extremely desirable), tenderness (1 = extremely tough, 10 = extremely tender), juiciness (1 = extremely dry, 10 = extremely juicy), and overall acceptability (1 = extremely undesirable, 10 = extremely desirable) of the cooked samples were evaluated using a 10-point descriptive scale. This analysis was conducted using the Hedonic test described by Choi *et al.* (2008).

Statistical analysis

All tests were done at 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 of the reduced-salt frankfurters formulated with sea tangle, sea mustard, hijiki, or glasswort are given in Table 3. The moisture content of the reduced-salt frankfurters were lower than the control ($p < 0.05$), and the moisture content was lowest in the treatment with 1.0% NaCl and without seaweed (T1) ($p < 0.05$). The reason for the reduction moisture content was lowered salinity by which ionic strength was weakened with lower water binding capacity. The protein content of the reduced-salt frankfurters was not significantly different among the treatments ($p > 0.05$). The fat content of the reduced-salt frankfurters was highest in T1 ($p < 0.05$), perhaps due to its lower relative moisture content. The ash

Table 3. Effect of proximate composition and salinity on reduced-salt frankfurters formulations with various types of seaweed

Treatments ¹⁾	Moisture content (%)	Protein content (%)	Fat content (%)	Ash content (%)	Salinity (%)
Control	61.51 \pm 0.37 ^a	14.07 \pm 0.93	23.28 \pm 0.14 ^d	1.52 \pm 0.12 ^c	1.93 \pm 0.06 ^a
T1	52.48 \pm 0.31 ^d	14.11 \pm 0.86	29.19 \pm 0.63 ^a	1.48 \pm 0.04 ^c	1.53 \pm 0.06 ^c
T2	60.49 \pm 0.10 ^b	13.51 \pm 0.47	24.64 \pm 0.73 ^d	1.87 \pm 0.02 ^a	1.74 \pm 0.05 ^b
T3	60.86 \pm 0.17 ^b	13.74 \pm 0.57	23.31 \pm 1.50 ^d	1.86 \pm 0.08 ^a	1.72 \pm 0.04 ^b
T4	55.31 \pm 0.02 ^c	13.70 \pm 0.47	28.84 \pm 0.21 ^b	1.66 \pm 0.11 ^b	1.71 \pm 0.05 ^b
T5	56.81 \pm 1.03 ^c	14.73 \pm 1.49	26.63 \pm 0.47 ^c	1.61 \pm 0.11 ^b	1.70 \pm 0.04 ^b

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

^{a-d}Means within a column with different letters are significantly different ($p < 0.05$).

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

content of the reduced-salt frankfurters with seaweed was higher than the control ($p<0.05$) because sea tangle, sea mustard, hijiki, and glasswort contain minerals and vitamins. These results were in agreement with those from Jeon and Choi (2012) who reported that the moisture and ash contents of patties with seaweed powder were affected by the addition of the seaweed powder, while the protein and fat contents were not significantly different. They reported that the ash content of the patties increased with increasing seaweed powder because seaweed contains minerals and vitamins. Similar trends in moisture content and ash content were reported in studies by Jimenez-Colmenero *et al.* (2010) when konjac and seaweed were added to low-salt frankfurters.

The salinity of reduced-salt frankfurters formulated with sea tangle, sea mustard, hijiki, and glasswort showed some significant differences (Table 3). The salinity of the reduced-salt frankfurters with seaweed were lower than the control ($p<0.05$), and the salinity was lowest in the treatment with 1.0% NaCl and without seaweed (T1) ($p<0.05$). Lopez-Lopez *et al.* (2009) reported that the addition of Sea Spaghetti accompanied by NaCl reduction produced a significant decrease in the sodium content of frankfurters. In general, seaweed includes salt because it grows in the sea. Therefore, the treatments with seaweed had higher salinity than those without seaweed.

Cooking loss and emulsion stability

The effects of salt replacement with sea tangle, sea mustard, hijiki, or glasswort on the cooking loss and emulsion stability of the reduced-salt meat batters are shown in Table 4. The cooking loss of the reduced-salt meat batters samples containing sea tangle (T2) and sea mustard (T3) was lower than the control without seaweed ($p<0.05$), while the cooking loss of the reduced-salt meat batters samples with hijiki (T4) and glasswort (T5) was higher

than the control ($p<0.05$). Also, the cooking loss of the treatment with 1.0% NaCl and without seaweed (T1) was higher than the control without seaweed ($p<0.05$), affected by salinity in meat emulsion. Similar results were reported by Jeon and Choi (2012) for the quality characteristics of pork patties containing seaweed powder. They reported that the treatment containing sea mustard showed the lowest cooking loss. These results were also in agreement with those of Choi *et al.* (2012) who reported decreased cooking loss in reduced-fat pork patties with increasing *Laminaria japonica*. Cofrades *et al.* (2011) reported that the meat products with seaweed had lower cooking loss and hence better water binding properties than the control. Kim *et al.* (2014) reported that the statistical results indicated that the increase in glasswort level in reduced-sodium frankfurter improved cooking loss. Thus, cooking loss of meat products is influenced by seaweeds containing salt content and dietary fiber.

Differences in the emulsion stability of meat batters formulated with sea tangle, sea mustard, hijiki, or glasswort were significant (Table 4). Total expressible fluid separation for the control, T2, and T3 had the lowest values ($p<0.05$), while total expressible fluid separation for the treatment with 1.0% NaCl (T1) had the highest value ($p<0.05$). Fat separation for the control samples was lower than for the reduced-salt meat batters with seaweed ($p<0.05$). Among the reduced-salt meat batters with seaweed, T2, and T3 had the lowest fat separation ($p<0.05$). Jimenez-Colmenero *et al.* (2010) reported that the quality of reduced/low-fat, low-salt frankfurters was affected by the addition of konjac and seaweed. Their report was similar to existing results showing that incorporation of a combination of seaweed and konjac gel increased emulsion stability such as total fluid release and fat release. Cofrades *et al.* (2008) observed that the protein and dietary fiber within seaweed improved water and fat binding proper-

Table 4. Effect of cooking loss and emulsion stability on reduced-salt frankfurters formulations with various types of seaweed

Treatments ¹⁾	Cooking loss (%)	Emulsion stability	
		Total expressible fluid separation (%)	Fat separation (%)
Control	8.12±0.21 ^d	19.40±0.87 ^d	1.55±0.02 ^c
T1	22.10±1.79 ^a	26.25±2.25 ^a	6.72±0.25 ^a
T2	6.98±0.68 ^c	20.12±1.53 ^d	3.09±0.05 ^d
T3	6.65±0.59 ^c	20.05±0.35 ^d	3.52±0.60 ^d
T4	19.75±0.94 ^b	24.89±0.54 ^b	4.94±0.55 ^c
T5	15.94±1.55 ^c	21.60±1.03 ^c	5.40±1.07 ^b

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

^{a-d}Means within a column with different letters are significantly different ($p<0.05$).

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

ties in low-salt meat emulsions formulated with 0.5% NaCl. Kim *et al.* (2014) reported that the amount of water and fat released decreased with increasing addition of glasswort in reduced-salt frankfurters. According to Sofos (1983), a weakened matrix structure in the meat emulsion system with reduced salt resulted in excessive water release because of its low ionic strength due to decreased protein solubility. In this study, it is generally assumed that the reason for the decreased emulsion stability of frankfurters formulated with 1.0% NaCl and sea tangle/sea mustard is the increased ionic strength and water binding capacity due to sea tangle/sea mustard containing salt content and dietary fiber. In particular, emulsion stability of the meat batters was higher emulsified with a low salt concentration, but utilizing seaweed containing salt and dietary fiber has resulted in lower emulsion stability.

pH and color

Table 5 shows the pH, L^* -values (lightness), a^* -values (redness), and b^* -values (yellowness) for reduced-salt batters and frankfurters formulated with sea tangle, sea mustard, hijiki, or glasswort. The pH of batters and frankfurters with seaweed treatments were higher than for the other treatments without seaweed ($p < 0.05$), due to affected by pH of seaweeds such as ranged 5.51-5.96 (Table 1). Cofrades *et al.* (2008) reported that the emulsion systems with seaweed presented slight differences in pH. Kim *et al.* (2010) reported that the pH values of breakfast sausages were different among different treatments with sea tangle levels, and Lopez-Lopez *et al.* (2009) indicated that such effect on pH in frankfurters was observed when addition of edible seaweed was added.

The lightness, redness, and yellowness of reduced-salt batters and frankfurters formulated with sea tangle, sea mustard, hijiki, or glasswort showed some significant differences in relation to the addition of various types of sea-

weed (Table 5). The lightness of control batters and frankfurters were higher than the treatments with seaweed ($p < 0.05$). Redness was highest for T1 batters and frankfurters ($p < 0.05$) while yellowness was highest in T3 batters and frankfurters ($p < 0.05$). These results were in agreement with those of Jeon and Choi (2012), who reported decreased lightness and redness in pork patties as the amount of seaweed powder increased. Similar results were obtained by Cofrades *et al.* (2008), who observed decreased lightness, redness and yellowness in low-salt gel/emulsion meat systems with edible seaweed. They reported that the lightness, redness, and yellowness of low-salt gel/emulsion meat systems samples were affected by sea spaghetti and wakame. Choi *et al.* (2012) reported that the lightness and redness of uncooked and cooked reduced-fat pork patties were lower in samples with *Laminaria japonica* than the control, and that increasing the *Laminaria japonica* levels decreased the lightness and redness of pork patties. Thus, the pH, lightness, redness, and yellowness for reduced-salt batters and frankfurters were affected by the pH and color of sea tangle, sea mustard, hijiki, and glasswort.

Texture profile analysis

Sea tangle, sea mustard, hijiki, and glasswort significantly affected the textural properties of the reduced-salt frankfurters (Table 6). Hardness, gumminess, and chewiness were higher in the control compared to the treatments ($p < 0.05$). T2 and T3 had the lowest hardness and chewiness in the experimental samples ($p < 0.05$). The springiness and cohesiveness of the reduced-salt frankfurters were not significantly different among the treatments ($p > 0.05$). Kim *et al.* (2014) reported that reduction in salt could weaken the gel matrix structure due to lower protein solubility, resulting in softer texture, and statistical analysis results showed that the textural properties of frankfurters formulated with 0.75% NaCl and glasswort

Table 5. Effects of pH and color (L^* -, a^* -, and b^* -values) on reduced-salt frankfurters formulations with various types of seaweed

Treatments ¹⁾	Batter				Frankfurter			
	pH	CIE L^*	CIE a^*	CIE b^*	pH	CIE L^*	CIE a^*	CIE b^*
Control	5.72±0.02 ^b	72.20±0.48 ^a	9.46±0.12 ^b	12.92±0.83 ^d	5.77±0.03 ^b	76.60±0.45 ^a	4.99±0.16 ^c	9.87±0.16 ^c
T1	5.75±0.03 ^b	68.73±0.64 ^b	11.23±0.17 ^a	12.72±0.56 ^d	5.79±0.02 ^b	74.13±0.28 ^b	5.93±0.13 ^a	9.69±0.19 ^c
T2	5.78±0.03 ^a	67.75±0.59 ^c	3.89±0.50 ^d	17.27±0.50 ^b	5.85±0.03 ^a	70.19±0.57 ^c	1.36±0.18 ^e	14.69±0.13 ^b
T3	5.80±0.03 ^a	69.63±1.11 ^b	3.84±0.55 ^d	20.50±1.31 ^a	5.85±0.02 ^a	74.31±0.26 ^b	1.26±0.23 ^e	16.64±0.33 ^a
T4	5.79±0.02 ^a	48.02±0.59 ^c	6.09±0.31 ^c	12.80±0.41 ^d	5.85±0.02 ^a	54.71±0.33 ^d	4.40±0.17 ^d	10.32±0.23 ^d
T5	5.79±0.03 ^a	64.81±0.69 ^d	9.94±0.51 ^b	16.13±0.51 ^c	5.83±0.02 ^a	69.97±0.28 ^c	5.63±0.19 ^b	11.10±0.05 ^c

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

^{a-c}Means within a column with different letters are significantly different ($p < 0.05$).

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

Table 6. Effects of textural attributes on reduced-salt frankfurters formulations with various types of seaweed

Treatments ¹⁾	Hardness (kg)	Springiness	Cohesiveness	Gumminess (kg)	Chewiness (kg)
Control	0.64±0.06 ^a	0.85±0.03	0.44±0.03	0.29±0.02 ^a	0.25±0.02 ^a
T1	0.46±0.04 ^c	0.82±0.03	0.44±0.03	0.21±0.03 ^c	0.17±0.03 ^c
T2	0.35±0.04 ^d	0.83±0.03	0.40±0.02	0.14±0.03 ^d	0.12±0.03 ^d
T3	0.37±0.05 ^d	0.85±0.04	0.43±0.03	0.16±0.02 ^d	0.13±0.02 ^d
T4	0.49±0.07 ^c	0.82±0.05	0.43±0.03	0.21±0.02 ^c	0.16±0.03 ^c
T5	0.58±0.05 ^b	0.82±0.03	0.46±0.04	0.26±0.03 ^b	0.22±0.03 ^b

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

^{a-d}Means within a column with different letters are significantly different ($p<0.05$).

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

powder were similar to those of the control. These findings agree with those reported by Hwang *et al.* (1998), who demonstrated that meat patties with sea mustard paste had reduced hardness. Choi *et al.* (2012) reported that the hardness of the control was higher than that of pork patties containing sea tangle and that the hardness increased as the concentration of sea tangle increased. Thus, the textural properties of reduced-salt frankfurters were affected by the addition of various types of seaweed. The decreased hardness, gumminess, and chewiness of frankfurters formulated with 1.0% NaCl and sea tangle/sea mustard increased water holding capacity due to the salt and/or dietary fiber in sea tangle/sea mustard.

Apparent viscosity

Different types of seaweed affected the apparent viscos-

ity of the reduced-salt frankfurter batters (Fig. 1). All the raw meat batters formulated with sea tangle, sea mustard, hijiki, or glasswort were thixotropic, with apparent viscosity values that decreased with rotation time. The apparent viscosity was higher in the control, T2, and T3 compared to the other treatments ($p<0.05$), and T2 had the lowest apparent viscosity ($p<0.05$). This agrees with the observations of Kim *et al.* (2014), who reported that the meat emulsion batters with glasswort displayed increased viscosity with increasing amounts of glasswort. Shand (2000) reported that an increase in emulsion viscosity is closely related with an increase in emulsion stability, and other researchers also reported that high apparent viscosity emulsions are not easily broken (Choi *et al.*, 2009; Lee *et al.*, 2008).

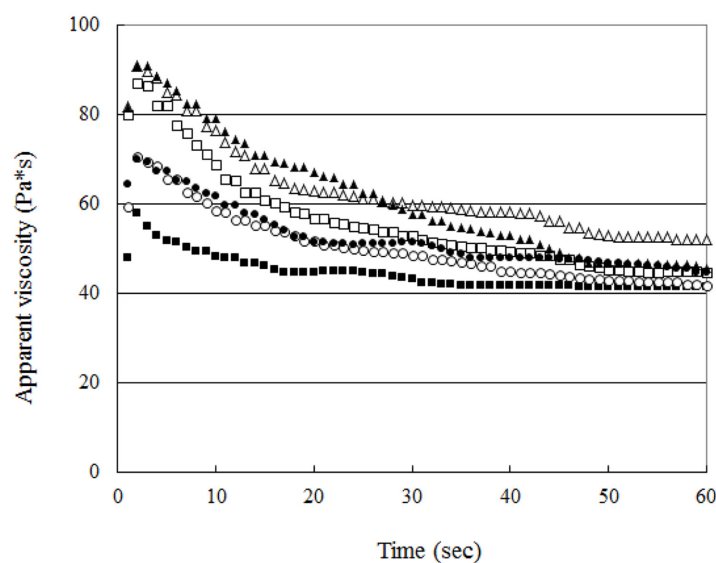


Fig. 1. Changes in apparent viscosity of frankfurter meat batters containing sea tangle, sea mustard, hijiki, or glasswort of added stirred for 60 s. (□) Control, frankfurter with 1.5% NaCl; (■) T1, frankfurter with 1.0% NaCl; (△) T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; (▲) T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; (○) T4, frankfurter with 1.0% NaCl + 1.0% hijiki; (●) T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

Table 7. Effects of sensory characteristics on reduced-salt frankfurters formulations with various types of seaweed

Treatments ¹⁾	Color	Flavor	Tenderness	Juiciness	Overall acceptability
Control	8.38±0.69 ^a	8.23±0.78 ^a	7.83±0.78 ^a	7.97±0.83 ^a	8.05±0.63 ^a
T1	7.45±0.98 ^b	7.65±0.83 ^b	6.13±0.83 ^c	6.21±0.74 ^c	5.92±0.72 ^c
T2	6.75±0.98 ^c	6.42±0.84 ^c	8.05±0.82 ^a	8.03±0.79 ^a	7.79±0.82 ^{ab}
T3	6.73±0.86 ^c	6.23±0.82 ^c	8.03±0.73 ^a	8.02±0.82 ^a	7.73±0.78 ^{ab}
T4	6.72±0.84 ^c	5.97±0.77 ^c	6.93±0.84 ^b	6.78±0.78 ^b	6.78±0.82 ^b
T5	6.83±0.81 ^c	6.29±0.83 ^c	6.98±0.78 ^b	6.83±0.45 ^b	6.37±0.63 ^b

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

^{a-c}Means within a column with different letters are significantly different ($p<0.05$).

¹⁾Control, frankfurter with 1.5% NaCl; T1, frankfurter with 1.0% NaCl; T2, frankfurter with 1.0% NaCl + 1.0% sea tangle; T3, frankfurter with 1.0% NaCl + 1.0% sea mustard; T4, frankfurter with 1.0% NaCl + 1.0% hijiki; T5, frankfurter with 1.0% NaCl + 1.0% glasswort.

Sensory evaluation

Table 7 shows the sensory characteristics for the reduced-salt frankfurters formulated with sea tangle, sea mustard, hijiki, and glasswort. The control had the highest color and flavor scores, while T1 had the lowest ($p<0.05$). The control, T2, and T3 samples had the highest tenderness and juiciness scores ($p<0.05$) due to the effects of sea tangle and sea mustard. The overall acceptability score was highest in the control ($p<0.05$). T2 and T3 did not differ significantly from the control ($p>0.05$), perhaps due to their tenderness and juiciness. Results obtained by Jeon and Choi (2012) for pork patties with seaweed indicated slightly lower flavor and overall acceptance scores, but the decrease did not affect statistical results. Hwang *et al.* (1998) reported that sensory attributes such as color, tenderness, and juiciness were generally enhanced by adding sea mustard paste. Kim *et al.* (2010) noted that breakfast sausages with 1% sea tangle had improved tenderness, juiciness, and overall acceptability. Choi *et al.* (2012) reported that the tenderness, juiciness, and overall acceptability scores of reduced-fat pork patties containing 1% and 3% *Laminaria japonica* were significantly higher than the control. Overall, the reduced-salt frankfurters produced with sea tangle and sea mustard had the highest scores for sensory characteristics because sea tangle and sea mustard increased the water holding capacity and water binding capacity.

Conclusion

Sea tangle, sea mustard, hijiki, and glasswort had important effects on the quality characteristics of reduced-salt frankfurters. Reduced-salt frankfurters with sea tangle and sea mustard demonstrated improved cooking loss and emulsion stability, as they have improved quality characteristics. The reduced-salt frankfurters formulated with sea tangle and sea mustard had improved sensory proper-

ties similar to the control with regular-salt. Therefore, the combination of low-NaCl and seaweed in the formulation of reduced-salt frankfurters was successful with sea tangle or sea mustard.

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