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The application of high-pressure processing in reduced sodium chloride and phosphate Kai-yor (Thai chicken sausage)

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Abstract The study found that decreasing sodium chloride (NaCl) and phosphate levels, particularly at 0.5% NaCl and 0% phosphate under high pressure, had an impact on the emulsion stability and cooking loss of sausages. Emulsion stability was not affected by HPP significantly ($p>0.05$), whereas cooking loss was significantly ($p\leq0.05$) increased when treated at 300 MPa. The pH value of the sausage was not significantly impacted by NaCl or HPP ($p>0.05$). However, high levels of phosphate gave the high pH value in sausage. The lightness (L*) and redness (a*) of sausage were not significantly ($p\leq0.05$) affected by HPP. Additionally, the lightness decreased with the reduction of NaCl and phosphate, while the redness and yellowness (b*) increased. Texture profile analysis indicated the hardness, springiness, cohesiveness, and chewiness were improved by high pressure. Chicken sausage with 0.75% NaCl and 0.1% phosphate at 300 MPa had not significantly different ($p>0.05$) in the hardness, springiness, and cohesiveness compared to the control (1% NaCl and 0.2% phosphate at 0.1 MPa).

Keywords: Chicken sausage, Emulsion stability, High pressure processing, Phosphate, Sodium chloride

Introduction

Sodium chloride (NaCl) is an additive in meat processing industry that has an essential function in the quality of meat products, e.g. water holding and juiciness. Typically, a NaCl content of 2-3% is required to myofibrillar proteins solubilization to accomplish the desired functional properties for meat products (Sun and Holly, 2011). There is a rising demand for healthier meat products with reduced NaCl content, as high NaCl intake has been associated with hypertension and cardiovascular disease, and the meat industry's focus is on lowering product salt content (Aburto *et al.*, 2013). However, a reduction in NaCl content may reduce the product quality, e.g. emulsion stability, textural

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properties, and water holding capacity of meat products, as myofibrillar proteins are not sufficiently solubilized (Cando *et al*., 2015).

Phosphates are an important additive in the meat processing industry for promoting the properties of meat products through their special functions. Phosphates fulfill several functions in meat products, including neutralizing the crosslink between actin and myosin and supporting the dissociation of actomyosin. Phosphate loosens the electrostatic forces within actomyosin, as it contributes greatly to the solubility of muscle protein (Feiner, 2006). In addition, polyphosphate is capable of increasing protein solubility and expose hydrophobic groups, resulting in improved water holding capacity, tenderness, and juiciness of meat products (Baublits *et al*., 2005). Traditional cooked sausages typically require 0.3- 0.5% phosphate to produce high quality meat products. However, excessive phosphate consumption may be harmful to human health, particularly in bone metabolism and cardiovascular and renal functions (Ritz *et al*., 2012).

Many methods have been used to reduce NaCl and polyphosphate content in meat products, e.g., the addition of enzymes, salt replacers, and the application of high-pressure processing (HPP). HPP is a non-thermal technology in which a packed product is treated at or above 100 MPa using a compression fluid (Chen *et al*., 2019). In the past decade, HPP has primarily been used for the inactivation of spoilage and pathogenic microorganisms, the extension of food's shelf life, and the improvement of product safety (Speroni *et al.*, 2014). Recently, HPP has received attention because of its ability to increase the solubilization of meat proteins and thus improve the binding properties of meat batters. HPP has been extensively used to modify the structure of myofibrillar proteins via protein denaturation, solubilization, aggregation, and gelation, primarily by influencing functional properties and producing novel products (Sun and Holly, 2011; Grossi *et al*., 2016). The increasing demand of consumer for nutritious and healthy products has stimulated the food industry towards the invention and application of new processes. HPP allows the formulation of customized meat products with reduced salt, phosphate, and/or fat (Inguglia *et al*., 2017). Many researchers focused on the modification in the formulations using HPP in order to develop meat products with acceptable functional and textural properties. The aim of this study was to determine the effect and interaction of HPP on physicochemical properties and textural properties in reduced NaCl and phosphate of Kai-yor, a Thai traditional chicken emulsion-type sausage.

Materials and methods

Materials

The chicken breast meat was purchased from a local grocery store (CP Fresh Mart, Bangkok, Thailand). The visible fat, skin, and connective tissue were removed from the meat. The trimmed meat was cut into 2×2×2 cm and minced twice through a 3-mm plate using a mincer (Kenwood, MG450, UK). Ground meat was packed into polyethylene (PE) bags and stored at-18 ℃ for 12h. The rice bran oil contains 8,000 ppm of oryzanol (King Rice Bran Oil, Thai Edible Oil Co. Ltd., Bangkok, Thailand) and was packaged in PE bags and stored at -18 ℃ for 12 h.

Preparation of Thai chicken batter

Raw chicken meat batters were prepared as follows: the ground meat (69%) was comminuted with NaCl (0.5, 0.75, and 1.0%) and sodium tripolyphosphate (0, 0.1, or 0.2%) for 3 min in a food processor (Bosch, MC812M844, Germany). In the next step, the mixture was chopped again for 4 min with ice water (6.5%) and frozen rice bran oil (20%). The seasonings were added, including sugar (1.2%), fish sauce (0.65%), pepper (0.65%), and monosodium glutamate (0.3%), and mixed for 3 min until the meat emulsion was formed. During the chopping process, the meat batter was maintained at a temperature below 12 ℃. The batter was stuffed into a 50-mm diameter polyamide casing (Xingda plastic, China) and linked at approximately 15 cm. Finally, the sausages were individually vacuum packed into polyamide or polyethylene bags. The sausages were stored at 4 ℃ for less than 24 h and then subjected to high-pressure processing.

High-pressure processing and cooking of batter

High-pressure processing of sausages was carried out in high-pressure equipment with a 5-L capacity (HPP600MPa, BaoTou KeFa High Pressure Technology Co., Ltd., China). Water was used as a pressure-transmitting medium, and the internal temperature was set at room temperature (25 ℃). The samples were subjected to HPP treatment at 300 MPa for 2 min. HPP-treated and untreated samples were cooked in hot water at 98 ℃ for 45 min and cooled in an iced water bath for 15 min. All samples were stored in a refrigerator (4 ℃) until further use.

Emulsion stability and cooking loss

The emulsion stability of chicken batter was measured in terms of total fluid release (TFR), according to the method of Yang *et al.* (2021). Briefly, approximately 25 g of batter was weighed and placed in a 50 mL centrifuge tube and centrifuged at 3,600 g for 1 min at 25 ℃. The batters were heated in a water bath for 30 min at 70 ℃, and cooled in an ice bath. Then, the samples were centrifuged again at 3,600 g for 1 min at 25 ℃. The supernatants were removed and weighed with the pellets and centrifuge tube. The percentage of TEF was calculated as follows:

$$\text{TFR (\%)} = \frac{\text{Weight}_{\text{sample and centrifuge tube}} - \text{Weight}_{\text{pellet and centrifuge tube}}}{\text{Weight}_{\text{sample}}} \times 100$$

Cooking loss was measured by calculating the weight difference of sausage before and after cooking, expressed as a percentage of the uncooked batter weight according to the following equation (Zheng *et al*., 2017). Before weighing, each sample was blotted with a paper towel to remove excess fluid.

$$\text{Cooking loss (\%)} = \frac{\text{Weight}_{\text{before cooking}} - \text{Weight}_{\text{after cooking}}}{\text{Weight}_{\text{before cooking}}} \times 100$$

pH and color

The pH values were measured with a pH meter (AMTAST, AMT620, USA). Ten grams of batter were mixed in 100 mL of distilled water and the pH of the mixture was recorded. The internal color of cooked sausages was measured using a color meter (Hunter Lab CX2687, USA), and the values were expressed as CIELab; L* (lightness), a* (redness), and b* (yellowness).

Texture profile analysis

Texture profile analysis of cooked chicken sausage was performed at room temperature using a texture analyser (TA-XT plus, Stable Micro Systems, UK) equipped with a 50-mm diameter aluminium cylindrical probe (P/50) as described by Thephuttee and Theprugsa (2020). The sausages were cut into 15×15×15 mm and compressed at 40% strain using a 50 kg load cell and test speed of 1 mm/s. Texture parameters of hardness (N), springiness, cohesiveness, and chewiness (N) were determined.

Statistical analysis

Analysis of variance (ANOVA) was used to determine the effects and interactions of factors (high pressure, % NaCl, and % phosphate) on the physicochemical and textural properties of chicken sausages. Significant main effects and interactions were verified using Duncan's multiple range test with a 95% confidence level.

Results

The significant interaction was shown in between NaCl, phosphate, and high pressure on physicochemical and textural properties including emulsion stability, cooking loss, pH, color, and texture of Kai-yor (Table 1). The results indicated that phosphate had a significant ($p \leq 0.05$) impact on all properties. NaCl also had a significant ($p \leq 0.05$) effect on physicochemical and textural properties except for pH value. The pressure affected cooking loss, b*, and textural characteristics but had no effect on the stability of the emulsion, pH, L*, and a*. The interaction between NaCl and phosphate had more impact on properties of Kai-yor than other interaction. The triple interaction between NaCl, phosphate, and pressure was significantly found for emulsion stability and cooking loss. However, it had no significantly ($p > 0.05$) affected on pH, color and texture.

Table 1. The effects and interactions of factors on the physicochemical and textural properties of Kai-yor (Thai chicken sausage)

Physical properties	Main effects/interactions						
	NaCl	Phosphate	Pressure	NaCl × Phosphate	NaCl × Pressure	Phosphate × Pressure	NaCl × Phosphate × Pressure
Emulsion stability	**	**	NS	**	*	**	**
Cooking loss	**	**	**	**	NS	NS	*
pH	NS	**	NS	NS	NS	NS	NS
L*	**	**	NS	**	NS	NS	NS
a*	**	**	NS	**	*	NS	NS
b*	**	**	**	**	NS	NS	NS
Hardness	**	**	**	**	NS	**	NS
Springiness	**	**	**	*	NS	NS	NS
Cohesiveness	**	**	**	**	NS	NS	NS
Chewiness	**	**	**	**	NS	NS	NS

NS: non-significant, * <0.05, ** < 0.01

Emulsion stability and cooking loss

Emulsion stability expressed as total fluid release and cooking loss of meat batters are shown in Table 2. The results showed that the total fluid release and cooking loss of chicken meat batters were decreased when NaCl was added at a concentration of 1%. Moreover, phosphate reduced the total fluid release and cooking loss of chicken meat batters. High pressure alone had no significant (p>0.05) effect on emulsion stability. On the other hand, HPP had affected on the cooking loss of chicken meat batters, which reduced cooking loss.

NaCl and phosphate had synergistic affected to reduce the total fluid release and cooking loss. Moreover, emulsion stability was affected by an interaction between salt and high pressure. According to the samples that contained 0.5 and 0.75% NaCl, high pressure increased total fluid release; however, at 1% NaCl, total fluid release decreased. In the same way, the interaction between phosphate and high pressure had significantly affected on emulsion stability. High pressure increased the total fluid release of samples without phosphate, but in the samples with phosphate (1 and 2%), total fluid release decreased. Nevertheless, the interaction between NaCl and pressure, phosphate and pressure had no significantly affected on the cooking loss.

The triple interaction between NaCl, phosphate, and high pressure was significant for emulsion stability and cooking loss. The effect of high pressure enhanced the synergistic effect of salt and phosphate to decrease the total fluid release. The meat batter treated at 300 MPa with 0.75% NaCl and 0.2% phosphate had no significant difference in the total fluid release compared with the control (0.1 MPa, 1% NaCl, and 0.2% phosphate).

Table 2. Emulsion stability and cooking loss of Kai-yor (Thai chicken sausage) after high-pressure processing at different NaCl and phosphate levels

NaCl (%)	**Phosphate (%)**	**Pressure (MPa)**	**Total fluid release (%)**	**Cooking loss (%)**
0.50	0.0	0.1	11.02±0.87^{b}	10.47±0.91^{b}
		300	14.07±0.89^{a}	11.81±1.23^{a}
	0.1	0.1	6.84±0.69^{c}	7.55±0.20^{cd}
		300	7.12±0.34^{c}	7.47±0.79^{cd}
	0.2	0.1	5.32±0.50^{d}	6.27±0.45^{de}
		300	3.70±1.27^{ef}	5.65±1.00^{e}
0.75	0.0	0.1	10.82±1.16^{b}	8.80±1.62^{c}
		300	13.58±0.96^{a}	11.10±0.94^{ab}
	0.1	0.1	4.43±0.78^{de}	5.74±0.36^{e}
		300	3.73±0.65^{ef}	5.79±0.77^{e}
	0.2	0.1	1.65±0.93^{h}	2.16±0.25^{hi}
		300	1.52±0.29^{h}	4.10±0.31^{f}
1.00	0.0	0.1	4.57±0.54^{de}	3.70±0.37^{fg}
		300	3.03±0.74^{fg}	3.87±0.37^{fg}
	0.1	0.1	1.40±0.28^{h}	1.61±0.06^{i}
		300	1.36±0.63^{h}	3.15±0.60^{fgh}
	0.2	0.1	1.98±0.68^{gh}	1.22±0.11^{i}
		300	1.22±0.59^{h}	2.57±1.04^{ghi}

$^{a-i}$ Different letters in the same column indicate significant differences ($p < 0.05$).

pH and color

The pH of meat batters is shown in Table 3. The results showed that the pH values of chicken batters ranged from 7.05 to 7.29. High pressure and NaCl had no significant (p>0.05) effect on the pH of meat batter. Phosphate increased the pH of meat batter at 0.1 and 0.2% phosphate. The highest pH was observed in the HPP- treated samples with 1.0% salt and 0.2% phosphate. However, there was no significant difference between samples with 0.5 and 0.75% salt and the same level of phosphate in HPP-treated and untreated.

Table 3. pH of Kai-yor (Thai chicken sausage) after high-pressure processing at different NaCl and phosphate levels

NaCl (%)	Phosphate (%)	Pressure (MPa)	pH
0.50	0.0	0.1	7.07 ± 0.02^{d}
		300	7.09 ± 0.06^{cd}
	0.1	0.1	7.18 ± 0.02^{b}
		300	7.16 ± 0.03^{b}
	0.2	0.1	7.23 ± 0.04^{a}
		300	7.28 ± 0.02^{a}
0.75	0.0	0.1	7.05 ± 0.06^{d}
		300	7.07 ± 0.02^{d}
	0.1	0.1	7.16 ± 0.03^{b}
		300	7.13 ± 0.02^{bc}
	0.2	0.1	7.24 ± 0.04^{a}
		300	7.27 ± 0.02^{a}
1.00	0.0	0.1	7.06 ± 0.03^{d}
		300	7.08 ± 0.04^{cd}
	0.1	0.1	7.13 ± 0.01^{bc}
		300	7.15 ± 0.03^{b}
	0.2	0.1	7.26 ± 0.02^{a}
		300	7.29 ± 0.03^{a}

$^{a-d}$ Different letters in the same column indicate significant differences ($p < 0.05$)

The lightness (L*), redness (a*), and yellowness (b*) of cooked sausages are shown in Table 4. High pressure alone decreased the yellowness and had no significant (p>0.05) effect on the lightness and redness of cooked sausages. In addition, NaCl increased the lightness of the sausages but decreased the redness and yellowness of cooked sausages. Like NaCl, phosphate also had an impact on the lightness, redness, and yellowness of cooked sausages.

The interaction between NaCl and phosphate is explained by the fact that NaCl acts synergistically with phosphate to increase the lightness and decrease the redness and yellowness of cooked sausages. The interaction between NaCl, phosphate, and high pressure had no significant effect on the color of cooked sausages. The HPP-untreated samples were slightly more yellow than the HPP-treated samples at the same salt and phosphate levels.

Table 4. Color of Kai-yor (Thai chicken sausage) after high-pressure processing at different NaCl and phosphate levels

NaCl (%)	Phosphate (%)	Pressure (MPa)	L*	a*	b*
0.50	0.0	0.1	73.53±0.25[f]	1.05±0.10[ab]	16.32±0.18[a]
		300	72.11±0.64[g]	1.16±0.02[a]	15.85±0.23[ab]
	0.1	0.1	75.89±0.19[e]	0.86±0.08[c]	15.96±0.21[ab]
		300	75.83±1.42[e]	0.91±0.09[bc]	15.11±0.20[bcd]
	0.2	0.1	76.18±0.70[de]	0.92±0.10[bc]	15.93±0.11[ab]
		300	75.96±0.79[e]	0.97±0.18[bc]	15.77±0.74[abc]
0.75	0.0	0.1	72.91±0.24[fg]	1.04±0.02[abc]	16.52±0.23[a]
		300	71.85±1.35[g]	0.97±0.14[bc]	16.07±1.48[a]
	0.1	0.1	77.96±0.15[c]	0.61±0.05[d]	15.08±0.19[bcd]
		300	77.49±0.99[cd]	0.59±0.12[de]	14.45±0.31[def]
	0.2	0.1	80.00±0.16[ab]	0.47±0.06[defg]	14.15±0.44[efg]
		300	80.69±0.13[a]	0.30±0.07[g]	13.43±0.51[g]
1.00	0.0	0.1	77.89±0.99[c]	0.56±0.06[def]	14.94±0.10[cde]
		300	78.72±1.44[bc]	0.42±0.06[efg]	14.12±0.58[efg]
	0.1	0.1	79.53±0.25[ab]	0.56±0.09[def]	14.68±0.35[de]
		300	80.43±1.08[a]	0.38±0.10[fg]	13.45±0.50[g]
	0.2	0.1	80.14±0.27[ab]	0.38±0.18[fg]	14.16±0.23[efg]
		300	80.51±0.63[a]	0.40±0.13[fg]	13.57±0.14[fg]

[a-g] Different letters in the same column indicate significant differences ($p < 0.05$)

Texture profile analysis

The hardness, springiness, cohesiveness, and chewiness of cooked sausages were shown in HPP-treated and untreated with different NaCl and phosphate concentrations (Table 5). The results of the texture profile analysis demonstrated that the effects and/or interactions between salt, phosphate, and high pressure had a significant impact on hardness, springiness, cohesiveness, and chewiness. NaCl significantly increased the hardness, springiness, cohesiveness, and chewiness of cooked sausages. The sausages at 1.0% salt concentration had the highest hardness and chewiness, while at 0.75 and 1% NaCl, there was no significant difference in springiness and cohesiveness. Phosphate also improved the texture of cooked sausages significantly. There were no significant differences in the hardness, springiness, and cohesiveness of cooked sausages with 0.1 and 0.2% phosphate. Moreover, high pressure also significantly increased all texture parameters. The interaction between NaCl and phosphate was significant synergistic to improve the texture of cooked sausages. There was no significant triple interaction between NaCl, phosphate, and high pressure on the textural qualities of cooked sausages. The sample with 0.75% salt and 0.1% phosphate treated at 300 MPa had no significant difference in hardness, springiness, and cohesiveness from the control. As a result, HPP could enhance the textural properties of chicken sausages by reducing salt and phosphate by 25% and 50%, respectively.

Table 5. Texture profile analysis of Kai-yor (Thai chicken sausage) after high-pressure processing at different NaCl and phosphate levels

NaCl (%)	Phosphate (%)	Pressure (MPa)	Hardness (N)	Springiness	Cohesiveness	Chewiness (N)
0.50	0.0	0.1	9.48 ±0.22^{i}	0.45 ±0.03^{i}	0.43 ±0.03^{g}	1.83 ±0.17^{j}
		300	13.24 ±0.39^{h}	0.52 ±0.03^{hi}	0.52 ±0.02^{def}	3.57 ±0.05^{i}
	0.1	0.1	18.04 ±0.77^{ef}	0.55 ±0.03f^{gh}	0.47 ±0.02^{fg}	4.68 ±0.21^{h}
		300	19.90 ±0.70^{cde}	0.63 ±0.08^{abcdef}	0.55 ±0.01^{bcdef}	6.80 ±0.42^{e}
	0.2	0.1	18.74 ±0.82^{de}	0.60 ±0.02^{cdefgh}	0.53 ±0.01^{cdef}	5.89 ±0.50^{f}
		300	20.09 ±0.76^{bcd}	0.65 ±0.06^{abcd}	0.55 ±0.04^{abcde}	7.22 ±0.32^{e}
0.75	0.0	0.1	9.97 ±0.75^{i}	0.56 ±0.05^{efgh}	0.51 ±0.03^{ef}	2.88 ±0.12^{i}
		300	15.54 ±0.46^{g}	0.64 ±0.02^{abcde}	0.58 ±0.03^{abcde}	5.74 ±0.47^{fg}
	0.1	0.1	19.90 ±1.18^{cde}	0.54 ±0.02^{gh}	0.56 ±0.09^{abcde}	5.95 ±0.43^{f}
		300	21.72 ±1.43^{abc}	0.67 ±0.03^{abc}	0.60 ±0.03^{ab}	8.75 ±0.56^{bc}
	0.2	0.1	21.87 ±0.64^{ab}	0.57 ±0.05^{efgh}	0.59 ±0.02^{abc}	7.33 ±0.64^{e}
		300	22.15 ±1.83^{a}	0.69 ±0.03^{ab}	0.61 ±0.01^{ab}	9.29 ±0.37^{b}
1.00	0.0	0.1	16.87 ±0.93^{fg}	0.58 ±0.04^{defgh}	0.51 ±0.07^{ef}	4.98 ±0.63^{gh}
		300	19.01 ±0.81^{de}	0.62 ±0.06^{bcdefg}	0.59 ±0.02^{abcd}	6.88 ±0.62^{e}
	0.1	0.1	22.49 ±1.32^{a}	0.61 ±0.06^{cdefgh}	0.57 ±0.05^{abcde}	7.70 ±0.89^{de}
		300	23.23 ±0.37^{a}	0.70 ±0.03^{a}	0.62 ±0.02^{a}	10.20 ±0.55^{a}
	0.2	0.1	22.75 ±2.20^{a}	0.60 ±0.05^{cdefgh}	0.60 ±0.02^{ab}	8.24 ±0.20^{cd}
		300	23.56 ±1.23^{a}	0.71 ±0.07^{a}	0.62 ±0.04^{a}	10.40 ±0.87^{a}

$^{a-i}$ Different letters in the same column indicate significant differences ($p < 0.05$).

Discussion

High-pressure processing before heating has been reported to be different effect on emulsion stability and cooking loss. This study demonstrates that high pressure at 300 MPa did not affect emulsion stability while affect on cooking loss of chicken meat batters. Both emulsion stability and cooking loss depended on NaCl and phosphate concentration. Similar results of previous study that reported that high pressure at 350 MPa had no significant impact on the water holding capacity, although had an impact on cooking loss of cooked pork meat batter (Villamonte *et al.*, 2013). Although, Yang *et al.* (2015) found that high pressure at 200 MPa increased the emulsion stability of reduced-salt pork sausages (1% salt) without phosphate. In addition, it has been reported that high pressure at 200 MPa improved the stability of reduced-salt pork meat batter (1% salt, 0% phosphate) by increasing the binding capacity of fat and water in the meat emulsion matrix (Yang *et al.*, 2021). However, this study found that the total fluid release and cooking loss of chicken batters were not different between the samples treated at 0.1 and 300 MPa at high NaCl (1%) and phosphate (0.2%) concentrations. Moreover, high pressure acts as a synergetic effect between NaCl and phosphate in appropriate concentrations to decrease the total fluid release and cooking loss of chicken meat batters. It could be due to emulsion stability and cooking loss related to the extraction and solubilization of myofibrillar proteins in meat products. Therefore, the suitable NaCl and phosphate concentrations in emulsion meat products enhanced a stable gel matrix, resulting in a reduced fluid release after HPP and heating (Carballo *et al*., 1995).

This study revealed that chicken meat batters had no significant difference in pH value due to NaCl and high pressure. However, the presence of phosphate in chicken meat batters significantly increased the pH value. Almost all the phosphates employed in meat manufacturing are alkaline phosphates, and the addition of alkaline phosphates to meat products leads to a rise in pH value. As a result, phosphates shifted the pH away from the isoelectric point and increased water binding capacity. This is because phosphates increase the gap between actin and myosin due to electrostatic repulsive forces, to which a larger amount of water can be bound (Feiner, 2006).

The results showed that the reduction of NaCl and/or phosphate increased the redness and yellowness of chicken sausages whereas the lightness decreased. This suggested that myofibrillar proteins in meat products could not be properly extracted and solubilized at a low concentration of salt and phosphate, leading to the insufficient emulsification between oil and proteins and formation a weak gel matrix. Therefore, when sausages were heated, water and oil could be released from gel matrix and color will be brown and darker. Moreover, high pressure changed the yellowness of cooked chicken sausages; however, the lightness and redness did not change under high pressure. Similar results were reported by O'Flynn *et al*. (2014a) who found that the yellowness decreased in reduced-phosphate pork sausages manufactured with meat treated at 300 MPa. Nevertheless, the lightness and redness of pork sausages increased when pork meat treated at 300 MPa. According to Villamonte *et al.* (2013), the yellowness of pork meat batters decreased when the proteins in the meat were denatured by the interaction of salt, phosphate, and high pressure. They suggested that the discoloration of meat products could be caused by denaturation of meat proteins and was possibly unrelated to myoglobin modification.

The textural properties of chicken sausages depended on the concentration of NaCl, phosphate, and high pressure. The hardness, springiness, cohesiveness, and chewiness of cooked sausages increased with a higher concentration of NaCl and phosphate under high pressure at 300 MPa. These results are partially similar to O'Flynn *et al*. (2014b), who reported that the texture attributes, including the hardness, springiness, adhesiveness, cohesiveness, gumminess, and chewiness, of pork sausages increased with higher salt concentrations. However, they reported only the adhesiveness and cohesiveness affected by high pressure at 150 MPa. Many researchers described high pressure enhanced gelation of myofibrillar proteins by induced depolymerization, denaturation, and aggregation, which produces a new structure resulting in texture modifications of meat products (Villamonte *et al*., 2013; Sikes *et al*., 2009; Cheftel and Culioli, 1997). Overall, the results indicated that the application of high pressure in Thai chicken sausages at 300 MPa has the potential for reducing NaCl and phosphate levels from the control by 25% and 50%, respectively, and also improved their texture with slightly changes in their qualities.

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