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Original Article

Nutritional composition in the chia seed and its processing properties on restructured ham-like products

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ABSTRACT

Low-fat meat products always have harder texture, lower juiciness, and worse flavor. Due to their higher water-holding, water absorption, and organic molecule absorption, chia seeds (CHIA) have been applied in powders, nutrition bars, breads, and cookies. Hence, the objectives of this study were to: (1) analyze the nutritional compositions in CHIA; and (2) look for the possible application of CHIA on restructured ham-like products. CHIA has high amounts of α-linolenic acid, crude polysaccharides, and also contains essential amino acids, minerals, and polyphenols. Regarding processing properties of CHIA, a combination of CHIA and carrageenan (CA) increased ($p < 0.05$) production yield of restructured ham-like products. A scanning electron microscope observation indicated that CHIA and CA addition can assist an emulsification in this ham-like product. Addition of 0.5% CA and 1.0% CHIA in this ham-like product showed the similar overall acceptance as products with added fat. Following storage at 4°C, higher ($p < 0.05$) purge and centrifugation losses, as well as hardness of this ham-like product can be improved by adding CHIA and CA. CHIA addition also resulted in lower ($p < 0.05$) lipid and protein oxidation, especially a 1.0% addition. In summary, due to both nutritional addition and improvements on physicochemical and sensorial properties of restructured ham-like products, CHIA seeds have great potential on the development of healthy and good-quality meat products.

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1. Introduction

Generally, the fat content makes meat products creamy and delicious. However, saturated fatty acid intakes from meat products increase the occurrence of cardiovascular diseases. Hence, the development of low-fat meat products has received global attention. In the USA, the claim of low-fat is the fat content <6% in a small serving size food (<50 g) [1]. Ham is generally recognized as a low-fat meat product in Europe and America. Although the low-fat meat products are regarded as healthier than other meat products, they still have some textural, sensorial, and lower yield problems. In order to conquer these problems, fat replacers are candidates to improve the texture and sensorial properties of low-fat meat products.

Dietary fiber has hydration properties, as well as particle size, density, and surface characteristics; hence, it has been applied well in baked goods [2] or meat products [3]. Chia (*Salvia hispanica*) seed (CHIA) contains rich dietary fibers [4]. Due to the gum-like property of CHIA, their fiber-rich fraction had 56.4 g/100 g dietary fiber, where 53.45 g/100 g is insoluble dietary fiber and the remainder is soluble [5]. In comparison with other fiber sources (soybean, wheat, maze, wheat hulls), the fiber-rich fraction in CHIA has higher water holding, absorption, and organic-molecule absorption with high emulsifying activity (53.26 mL/100 mL) and emulsion stability (94.84 mL/100 mL) [5]. Therefore, it has been well applied in desserts or cookies [4,6].

Although CHIA is a potential ingredient in health and diet food products on its physicochemical properties [5,7], it is seldom used in meat products to our knowledge. Hence, the purposes of this study were: (1) to understand the nutritional compositions in CHIA; (2) to investigate the effects of CHIA on processing properties of restructured ham-like products; and (3) to look for the effects of CHIA on the physicochemical changes of restructured ham-like products after storage.

2. Methods

2.1. *Materials*

CHIA (The Chia Co., Ltd., Port Melbourne, Victoria, Australia) were purchased from a local market and ground to powder. Carrageenan (CA) was purchased from Gemfont Co., Ltd. (Taipei, Taiwan). Pork leg meat and back fat were purchased from Shang Lee Food Co., Ltd. (Nantou County, Taiwan), packaged with polyethylene bags under −20°C. All other chemicals used in this study were purchased from Sigma–Aldrich Co., LLC (St Louis, MO, USA).

2.2. *Nutritional compositions in CHIA*

2.2.1. *Fatty acid, amino acid, and mineral profiles of CHIA*

Lipid in CHIA powders was extracted by chloroform and methanol (2:1, v/v). based on the previous report [8], the fatty acid profile was analyzed by using a gas chromatograph (Model 6890N; Agilent, Santa Clara, CA, USA) and a flame ionization detector fitted with a highly polar stationary phase SP-2560 (100 m length, 0.25 mm inside diameter, 0.20 μm film) column from Supelco Inc. (Bellefonte, PA, USA). For the amino acid profile of CHIA, 1 g of CHIA powder was hydrolyzed in 2 mL methane sulfonic acid solution (4N) for 24 hours. Amino acids were quantified using the Hitachi L-8900 High Speed Amino acid Analyzer (Hitachi High-Technologies Co., Tokyo, Japan). The data were described as mg amino acid per 100-g CHIA. Regarding the mineral profile, the CHIA powder was ashed at 550°C for 6 hours. Two-mL nitric acid (70%) was added. Acidized samples were diluted in double distilled H_2O and then filtered. Filtrate was diluted to 50 mL volumetric bottle by double distilled H_2O. The mineral profile of CHIA was analyzed by Inductively Coupled Plasma-Optical Emission Spectrometer (ELEMENT 2*ICP-MS; Thermo Fisher Scientific Inc., Waltham, MA, USA).

2.2.2. *Crude polysaccharide and phytochemical contents, and polyphenolic profile of CHIA*

The crude polysaccharide content in CHIA was assayed according to the procedure of a previous report [9]. Regarding phytochemical analyses, 50 g CHIA powder was mixed with 1 L of n-hexane in a Waring Laboratory Blender (The Lab Depot, Inc., Dawsonville, GA, USA) for 3 minutes, and extracted for 24 hours in the dark. After filtration, the defatted reside was dried under nitrogen gas, and then extracted with 1 L of 80% ethanol for 24 hours in the dark. After filtration, the solvent was removed under vacuum at 40°C, followed by lyophilization in a freeze-dryer (Vastech Scientific Co., Ltd., Taipei, Taiwan) to obtain the phenolic extract. Total phenolic acid, flavonoid, and condensed tannin contents in CHIA were determined according to the methods of a previous report [10]. The polyphenolic profile in CHIA powders was analyzed by using high-performance liquid chromatography (Shimadzu SCL-10A system controller module; Shimadzu, Kyoto, Japan) is composed of a Shimadzu SCL-10AT pump system, a Shimadzu SPD-10A UV-vis detector, and a 20 μL loop (Rheodyne Inc., Cotati, CA, USA). A Inspire C_{18} column (250 mm × 4.6 mm, 5 μm; Dikma Technologies Inc., Lake Forest, CA, USA) and a gradient solvent system consisting of 2% glacial acetic acid (solvent A) and acetonitrile (solvent B; conditions: A/B = 2/98 (v/v) from 0 minutes to 25 minutes, A/B = 4/96 (v/v) from 25 minutes to 40 minutes; A/B = 10/90 (v/v) from 40 minutes to 50 minutes, A/B = 15/85 (v/v) from 50 minutes to 60 minutes, A/B = 20/80 (v/v) from 60 minutes to 115 minutes, A/B = 22/78 (v/v) from 115 minutes to 135 minutes, and A/B = 25/75 (v/v) from 135 minutes to 150 minutes; flow rate = 0.8 mL/min) were used for separation of components whose UV spectra were recorded at 280 nm. Those phenolic acid and flavonoid compounds in CHIA were identified via high-performance liquid chromatography based on UV absorbance and retention time compared with the standards for phenolic acid compounds (Sigma-Aldrich Co., LLC), and quantified using standard curves of authentic compounds.

2.3. *Preparation of restructured ham-like products*

Three individual batches in each formula ham-like product were made in this study and each time seven different products were manufactured on the same day. The same portion of pork leg meat from the meat packer (Shang Lee Food Co., Ltd, Nantou County, Taiwan) was minced (~0.2 cm length × width × height) by a high-shear emulsifying machine (Model#: 334, Talleres Cato, S. A., Barcelona, Spain) at <10°C and then mixed with sodium chloride (Taiyen Biotech Co., Ltd., Tainan City, Taiwan) and polyphosphate (Gemfont Co., Taipei, Taiwan). Pork back fat was added only in high-fat batch (fat added groups). The minced meat was blended with iced water and additives containing sodium nitrite/nitrate (Palatinata Cure PM; Gemfont Co., Taipei, Taiwan), sugar (Taiwan Sugar Co., Tainan City, Taiwan), ascorbic acid/sodium ascorbate (TARI Colpur 40S; Fibrisol Service Australia, Heatherton, Victoria, Australia), five-spice powder, and pepper powder, while CHIA and CA were added in groups except high-fat and control batches. The blended meat mixtures were assigned into seven treatment formula (Table 1). Mixtures were stuffed into vacuum-packs (110 mm diameter nylon casings; Ten Geniuses Enterprise Co., Ltd, Taipei, Taiwan). The restructured ham-like products were cooked in a water bath (85°C) until the core temperature reached 75°C, and then cooled in an ice water bath (4°C) for 20 minutes. After cooling, casings were removed, and restructured ham-like products were vacuum-packed in high-density polyethylene bags (Taipei Pack Industries Co., Taipei, Taiwan), and then stored at 4°C for further analyses.

2.4. Production yields, proximate compositions, microstructure, and sensory properties of restructured ham-like products

2.4.1. Production yield and proximate composition of restructured ham-like products

After stuffing the batters into the casings (initial weight) and cooking at 85°C for 40 minutes (processed weight), production yield (%) of restructured ham-like products was calculated as processed weight (g)/initial weight (g) × 100%. Moisture, ash, crude fat, and crude protein contents of restructured ham-like products were determined initially in duplicate for each sample [11].

2.4.2. Scanning electron microscope and sensory evaluation of restructured ham-like products

The microstructure of restructured ham-like products was analyzed by using scanning electron microscope, and the magnification was 1000× [8]. In the last set of product manufactures (7 different products), the sensory evaluation, which contained preference test (odor, color, texture, and flavor), sensorial test (juiciness), and overall acceptance, was performed 1 week after restructured ham-like products were manufactured and stored at 4°C. Forty panelists (age, 20–40 years; 20 women and 20 men) were recruited from staff, faculties, and students in the National Taiwan University, Taipei, Taiwan and pretrained for this panel assessment. The evaluation was done using a five-point scale (5 = very good and 1 = very bad). The restructured ham-like products stored at 4°C were prepared in hot water (100°C) for 10 minutes. After the nylon casings of products were peeled off and then cut into sizes of length = 3.0 cm, width = 3.0 cm, and thickness = 0.5 cm. The restructured ham-like products (2 slices per treatment) were prepared for tasting. The restructured ham-like products of each treatment were distributed on a white plate for evaluation, and water was provided for cleaning the palate. All sensory evaluations were conducted at room temperature (25°C).

2.5. Physicochemical changes of restructured ham-like products after storage

2.5.1. Texture profile analysis and color measurement of restructured ham-like products

Texture profile analysis indices of restructured ham-like products were determined using a texture analyzer (Model TA.XTplus Texture Analyzer; Stable Micro Systems, Godalming, UK) with a P/50 probe (50 mm diameter cylinder aluminum; Stable Micro Systems). The texture profile analysis values were calculated by graphing a curve using force and time plots. The units for hardness, adhesiveness, springiness, and cohesiveness of products are N, N × s, dimensionless, and dimensionless, respectively. Color measurements were taken in the section of restructured ham-like products immediately after opening the package. The following color coordinates were determined: lightness (L*), redness (a*), and yellowness (b*). CIE-L*, a*, and b* values were measured by a color checker (Model NR-11A, Nippon Denshoku Co., Japan).

Table 1 – Ingredient levels (g) for restructured ham-like products with different levels of chia seed (CHIA) and carrageenan (CA).

	HF	CON	CON+0.5CHIA	CON+1.0CHIA	CON+0.5CA	CON+0.5CA+0.5CHIA	CON+0.5CA+1.0CHIA
Minced pork leg meat (g)	1700	1700	1690	1680	1690	1680	1670
Pork back fat (g)	100	0	0	0	0	0	0
Water (g)	200	300	300	300	300	300	300
Chia seed (g)	0	0	10	20	0	10	20
Carrageenan (g)	0	0	0	0	10	10	10
Sodium chloride (g)	30	30	30	30	30	30	30
Polyphosphate (g)	4	4	4	4	4	4	4
Sodium nitrite (g)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sugar (g)	40	40	40	40	40	40	40
Five spices powder (g)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pepper powder (g)	6	6	6	6	6	6	6
Vitamin C (g)	1	1	1	1	1	1	1

CON = control (without addition of fat); HF = high fat (addition of 5% pork back fat).

2.5.2. Purge loss and centrifugation loss of restructured ham-like products

Water holding capacities of restructured ham-like products were determined as purge and centrifugation losses according to a previous method with a slight modification [12]. Purge loss was measured in 2- and 4-week storage intervals at 4°C and calculated as a percentage of the weight of each sample at each storage period compared to its initial weight. Centrifugation loss of restructured ham-like products was measured immediately after manufacturing (1000 *g*, 1 hour, 4°C), and in 2- and 4-week storage intervals at 4°C. The centrifugation loss (%) was calculated as the difference in weights before and after centrifugation.

2.5.3. Measurements of lipid and protein oxidation of restructured ham-like products

Regarding measurements of lipid and protein oxidation, samples (~50 g) of ham-like products from different groups stored at 4°C were picked up in each storage period (0 weeks, 2 weeks, and 4 weeks). The lipid oxidation of ham-like products was measured by previous method [8]. Protein oxidation was evaluated by a sulfhydryl content assay as described by Jia et al [13].

2.6. Statistical analysis

All analysis parameters, except sensory evaluation, were conducted on three independent batches of CHIA or restructured ham-like products ($n = 3$). Tested parameters in each batch per product were carried out with at least three analyses. The experiment was conducted by using a completely randomized design with subsampling. Due to the only one session of sensory evaluation performed, the completely randomized design was used, and the sample size on sensory evaluation was 40. Data were analyzed using analysis of variance. The significant differences were determined at 0.05 probability level, and differences between treatments were tested using the least significant difference test. All statistical analyses of data were performed using SAS 9.0 (SAS Institute Inc., Cary, NC, USA).

3. Results and discussion

3.1. Nutritional-composition profiles in CHIA

Regarding the fatty acid profile in CHIA (Table 2), α-linolenic acid (ALA) was in the highest amount, followed by linoleic acid (LA), oleic acid, and stearic acid. Meanwhile, the amount of unsaturated fatty acids was almost eight times than that of saturated fatty acids where the ratio of ω-3 fatty acids and ω-6 fatty acids was 2.65. Leucine was the highest content in essential amino acids of CHIA. Besides, glutamic acid, arginine, and aspartic acid made up more than 60% nonessential

Table 2 – Fatty acid and amino acid profiles in chia seeds.

	Content	Adult DIRs (male, female)[a]		Content	FAO/WHO/UNU(1985) adults (mg/kg BW/day)[b]
Fatty acid (g/100g oil)			Amino acid (mg/100 g)		
Myristic acid (C 14:0)	0.04 ± 0.01		Threonine	795.33 ± 6.58	7
Pentadecanoic acid (C 15:0)	0.03 ± 0.00		Valine	940.67 ± 19.84	10
Palmitic acid (C 16:0)	6.95 ± 0.26		Methionine	467.93 ± 8.82	13[c]
Palmitoleic acid (C 16:1)	0.07 ± 0.01		Isoleucine	775.25 ± 20.89	10
Margaric acid (C 17:0)	0.05 ± 0.01		Leucine	1514.48 ± 37.86	14
Stearic acid (C 18:0)	4.33 ± 0.34		Phenylalanine	1021.05 ± 39.21	14[d]
Oleic acid (C 18:1)	9.17 ± 0.08		Lysine	1183.91 ± 72.11	12
Linoleic acid (C 18:2 (ω-6))	21.51 ± 0.35	(12, 17) g/day	Histidine	663.35 ± 42.85	8–12
α-Linolenic acid (C 18:3 (ω-3))	56.98 ± 0.77	(1.1, 1.6) g/day	Arginine	2380.73 ± 176.40	
Arachidic acid (C 20:0)	0.30 ± 0.01		Aspartic acid	2068.83 ± 88.28	
Gadoleic acid (C 20:1)	0.23 ± 0.03		Serine	1197.13 ± 30.57	
Eicosadienoic acid (C 20:2)	0.04 ± 0.00		Glutamic acid	3761.49 ± 57.80	
cis-11,14,17-Eicosatrienoic acid (C 20:3 (ω-3))	0.04 ± 0.00		Glycine	1182.02 ± 29.07	
Behenic acid (C 22:0)	0.09 ± 0.00		Alanine	1163.09 ± 35.18	
Tricosanoic acid (C 23:0)	0.02 ± 0.00		Cysteine	380.35 ± 38.44	
Lignoceric acid (C 24:0)	0.08 ± 0.01		Tyrosine	893.33 ± 45.47	
Saturated fatty acid	11.90 ± 0.42		Proline	528.59 ± 14.70	
Unsaturated fatty acid	88.11 ± 0.47		Essential amino acids	7361.97 ± 55.76	
ω-3 fatty acid	57.02 ± 0.77		Nonessential amino acids	13555.57 ± 37.29	
ω-6 fatty acid	21.51 ± 0.35				
ω-3:ω-6	2.65 ± 0.08				

Data are mean ± standard error of the mean ($n = 3$).

DIR = daily reference intake.

[a] Values are based on people aged 19–50 years from USDA (2015).

[b] Values are based on people older than 12 years from FAO/WHO/UNU Expert Consultation (1985).

[c] Methionine + cysteine.

[d] Phenylalanine + tyrosine.

amino acids. The major minerals of CHIA were Mg, Ca, and K; Fe, Zn, Mn, Co, and Se were also found (Table 3). Total crude polysaccharide content reached 30.81 g per 100 g CHIA. The flavonoid content occupied 80.85% in the polyphenols of CHIA (Table 3) where both rutin and hesperidin (Figure 1) are major components.

According to the dietary reference intakes for LA and ALA per day, suggested by USDA (2015) [14], CHIA is a good choice for a daily supplementation. It was also reported that CHIA can decrease serum triglyceride and increase high-density lipoprotein contents in rats [15]. This benefit has been attributed to ALA contents in CHIA. The high ALA content (56.98 g/100 g oil) and a good ratio of ω-3 and ω-6 fatty acids (2.65) in CHIA should be good for the cardiovascular system in humans. Although the biological values of plant proteins are not as good as animal proteins, CHIA has complete essential amino acids. In a comparison of daily recommended values in essential amino acids from FAO/WHO/UNU Expert Consultation (1985) [16], CHIA should be a good amino-acid supplementation. According to the adult daily reference intakes in minerals from USDA (2013) [14], CHIA can be also a suggestive supplementation for the adults. CHIA improved the water holding capacity and emulsifying ability in cookies, bread, and other desserts due to their gum-like characteristic of polysaccharides mainly consisting of crude fiber and carbohydrate [4,6,17], but published reports relevant to their application on meat products seem lacking. Moreover, the application of plant polyphenols on prolonging the shelf life of meat products has been studied [12,18–21]. The application of rutin or hesperidin, major flavonoid compounds in CHIA, on food

Table 3 – Mineral and polyphenolic profiles in chia seeds.

	Content	Adult DIRs (male, female)[a]		Content
Mineral			Total crude polysaccharides (g/100g)	30.81 ± 1.44
Potassium (K; mg/100g)	13,477.61 ± 56.27	(4.7, 4.7) g/d		
Magnesium (Mg; mg/100g)	4963.81 ± 31.80	(420, 320) mg/d	Total polyphenols (mg GAE/100g extract)	239.02 ± 7.06
Calcium (Ca; mg/100g)	4221.89 ± 232.44	(1.0, 1.0) g/d	Total flavonoids (mg CE/100g extract)	193.24 ± 5.39
Sodium (Na; mg/100g)	11.55 ± 0.87	(2.3, 2.3) g/d	Condensed tannins (mg CE/100g extract)	31.15 ± 0.66
Iron (Fe; mg/100g)	131.12 ± 14.60	(45, 45) mg/d	Rutin (mg/100g extract)	98.56 ± 3.62
Zinc (Zn; mg/100g)	88.69 ± 5.24	(40, 40) mg	*p*-Anisic acid (mg/100g extract)	8.32 ± 0.36
Manganese (Mn; mg/100g)	71.01 ± 6.35	(2.3, 1.8) mg/d	Hesperidin (mg/100g extract)	56.79 ± 2.53
Copper (Cu; mg/100g)	26.67 ± 3.47	(10,000, 10,000) μg/d		
Cobalt (Co; mg/100g)	1.73 ± 0.07	NA		
Nickel (Ni; mg/100g)	4.09 ± 0.30	(1.0, 1.0) mg/d		
Selenium (Se; μg/100g)	45.33 ± 1.67	(55, 55) μg/d		

Data are given as mean ± standard error of the mean ($n = 3$).
DIR = daily reference intake; NA = not available.
[a] Values are based on people aged 19–70 years from USDA (2015).

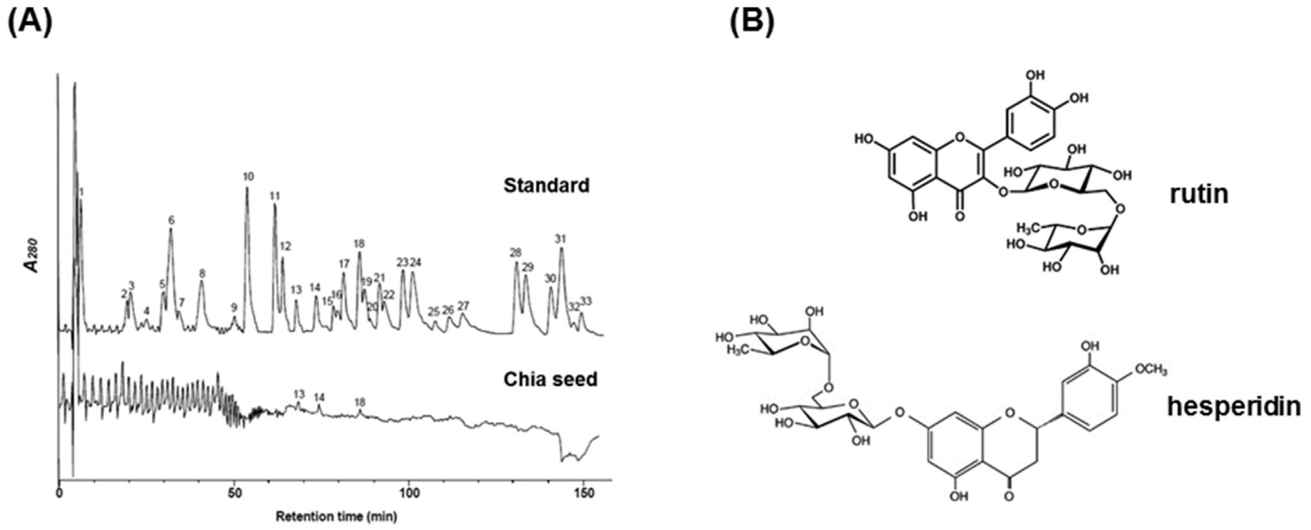


Figure 1 – (A) High-performance liquid chromatograms of flavonoids and phenolic acids in chia seed and standards. (B) The structures of rutin and hesperidin. Peaks: (1) gallic acid; (2) gentisic acid; (3) p-hydroxybezoic acid; (4) catechin; (5) chlorogenic acid; (6) vanillic acid; (7) caffeic acid; (8) syringic acid; (9) epicatechin; (10) p-coumaric acid; (11) ferulic acid; (12) sinapic acid; (13) rutin; (14) p-anisic acid; (15) quercitrin; (16) myricetin; (17) naringin; (18) hesperidin; (19) rosmarinic acid; (20) diosmin; (21) neohesperidin; (22) morin; (23) daidzein; (24) eriodictyol; (25) glycitein; (26) quercetin; (27) luteolin; (28) narigenin; (29) genistein; (30) apigenin; (31) kaempferol; (32) hesperetin; (33) isorhamnetin.

products has been characterized as oxidative stability of oil in water emulsions [22], a native stabilizer for protein emulsions [23], and improvements of meat quality (i.e., lipid/protein oxidation), water holding capacity for supplementing lambs [24] and broilers [25]. Hence, it is speculative that a CHIA addition not only adds nutritional value but also improves processing properties of low-fat meat products.

3.2. *Application of CHIA on manufacture of restricted ham-like products*

3.2.1. *Effects of CHIA on processing properties and sensorial evaluation of restructured ham-like products*

HF, CON+0.5CA+0.5CHIA, and CON+0.5CA+1.0CHIA products had higher ($p < 0.05$) production yields than other products; meanwhile, the HF group had the lowest ($p < 0.05$) moisture and the highest ($p < 0.05$) fat contents among all groups (Table 4). Generally, CON+1.0CHIA and CON+0.5CA+1.0CHIA products had higher crude protein and ash contents, respectively, among different-recipe products. Via the microstructural observation, HF product had the smallest fat globules uniformly, and CON product had the largest ones among groups (Figure 2A). The fat globule sizes in products with CHIA, CA, or CHIA + CA were smaller than that of CON products. Larger areas of rock-like cracks were also observed in CON+0.5CA+0.5CHIA and CON+0.5CA+1.0CHIA groups than others (Figure 2A). Overall, the HF group demonstrated the best ($p < 0.05$) odor, color, texture, flavor, and overall acceptance among groups while the CON group had the least ($p < 0.05$) scores in all parameters except color (Figure 2B). In a comparison of all sensorial parameters among products, CON+0.5CA+1.0CHIA product showed a similar acceptance to HF product, and even better juiciness than HF ones.

According to the recipes of restructured ham-like products (Table 1), the HF group includes additions of 5% pork back fat and 10% water compared to other groups with no additions of pork fat and addition of 15% water. Therefore, it is reasonable that HF products had the highest fat content but the lowest moisture content. In addition, the higher crude protein and ash contents in an extra 1.0% CHIA addition in the recipe may result from the amino acid and mineral contents in CHIA, accordingly. Emulsion stability and yield are similar concepts that indicate the abilities of holding water and oil when products being cooked [26]. A combination of 0.7% CA and pectin show the good yield on low-fat beef frankfurters [27]. They also reported that high-fat meat products own lower exudates and higher production yields because of lower or even no water addition. Similar observations were also demonstrated in our results (Figure 1). Overall, a combination of CHIA and CA in the recipe of restructured ham-like products showed the better water binding capacities. A better emulsifying ability is considered in that smaller fat globules disperse in the products homogeneously [28]. The inconsistent particle sizes of fat globule make worse mouth feel in meat and even dairy products [28]. The restructured ham-like products are emulsified products, and the fat globules do influence overall acceptance of products significantly. According to the results, CHIA and CA improved the emulsifying effect of ham-like products. The rock-like cracks in ham-like products depict the vacancy of water retention in products possibly due to the scanning electron microscopy dehydration process. Therefore, it corresponds to the better emulsifying status and production yields in ham-like products added with both CHIA and CA compared to others without fat addition (Figure 2A and 2B). Pork back fat (5.0%) in recipe of restructured ham-like products got the best overall acceptance because of its better emulsifying properties, water holding capacity, mouth feel, and aroma. Due to smaller fat globules (Figure 2A) and higher consumers' acceptance (Figure 2B), an extra addition of combination of 0.5% CA and 1.0% CHIA is recommended to the recipes of restructured ham-like products without the fat addition.

3.2.2. *Physicochemical properties of CHIA on restructured ham-like products during refrigerator storage (4°C)*

HF products had the highest ($p < 0.05$) hardness when products were tested immediately after manufacturing, as well as cohesiveness during 4 weeks of storage (Table 4). Generally, CHIA, CA, or a combination of CHIA and CA resulted in softer texture in restructured ham-like product without fat addition after storage. The patterns of adhesiveness and springiness of all products after storage did not seem to change greatly, whereas the CON+0.5CA+1.0CHIA product always kept the lowest ($p < 0.05$) springiness. In color measurements, HF products had the highest ($p < 0.05$) L^* value among groups during the storage (Figure 3A). Regarding the color parameters of products, the CON+0.5CA product had the lowest ($p < 0.05$) a^* value but the highest ($p < 0.05$) b^* value after storage. The purge losses (%) of products were not ($p > 0.05$) different after 2 weeks of storage, but after 4 weeks of storage the HF product had the lowest purge (Figure 3B). Although no ($p > 0.05$) differences on purge loss were detected among products without fat addition, there was a tendency towards lower purge loss in products added with CHIA or CA. Regarding centrifugation loss, CON products showed higher losses at any measurable time of storage. The HF, CON+1.0CHIA, CON+0.5CA+0.5CHIA, and CON+0.5CA+1.0CHIA products showed lower ($p < 0.05$) centrifugation loss after the 4 weeks of storage compared to CON product. Figure 3C illustrates that the HF group had the highest ($p < 0.05$) TBARS value and the lowest thiol group content during the storage period. CON+0.5CHIA, CON+1.0CHIA, CON+0.5CA+0.5CHIA, and CON+0.5CA+1.0CHIA products showed lower ($p < 0.05$) TBARS values after storage. Especially, CON+1.0CHIA and CON+0.5CA+1.0CHIA products showed the lowest ($p < 0.05$) TBARS values among products during the storage. Generally, the changes of thiol groups in the seven product groups during the refrigerator storage were in contrast with those of TBARS values in the products.

The ratio of protein, fat, and water is the major factor transforming the textural properties of meat products. If part of protein or fat is substituted by water in meat products, the texture of products becomes overly tender. Hence, the hardest texture of HF products possibly results from less water addition. An addition of CA increased water holding capacity in low-fat frankfurters, thus improving textural properties [29]. Upon storage, the lower hardness of restructured ham-like products added with CHIA, CA, or combination of CHIA and CA than that without them is possible due to CHIA and CA with a higher water holding capacity, which retains the water in the

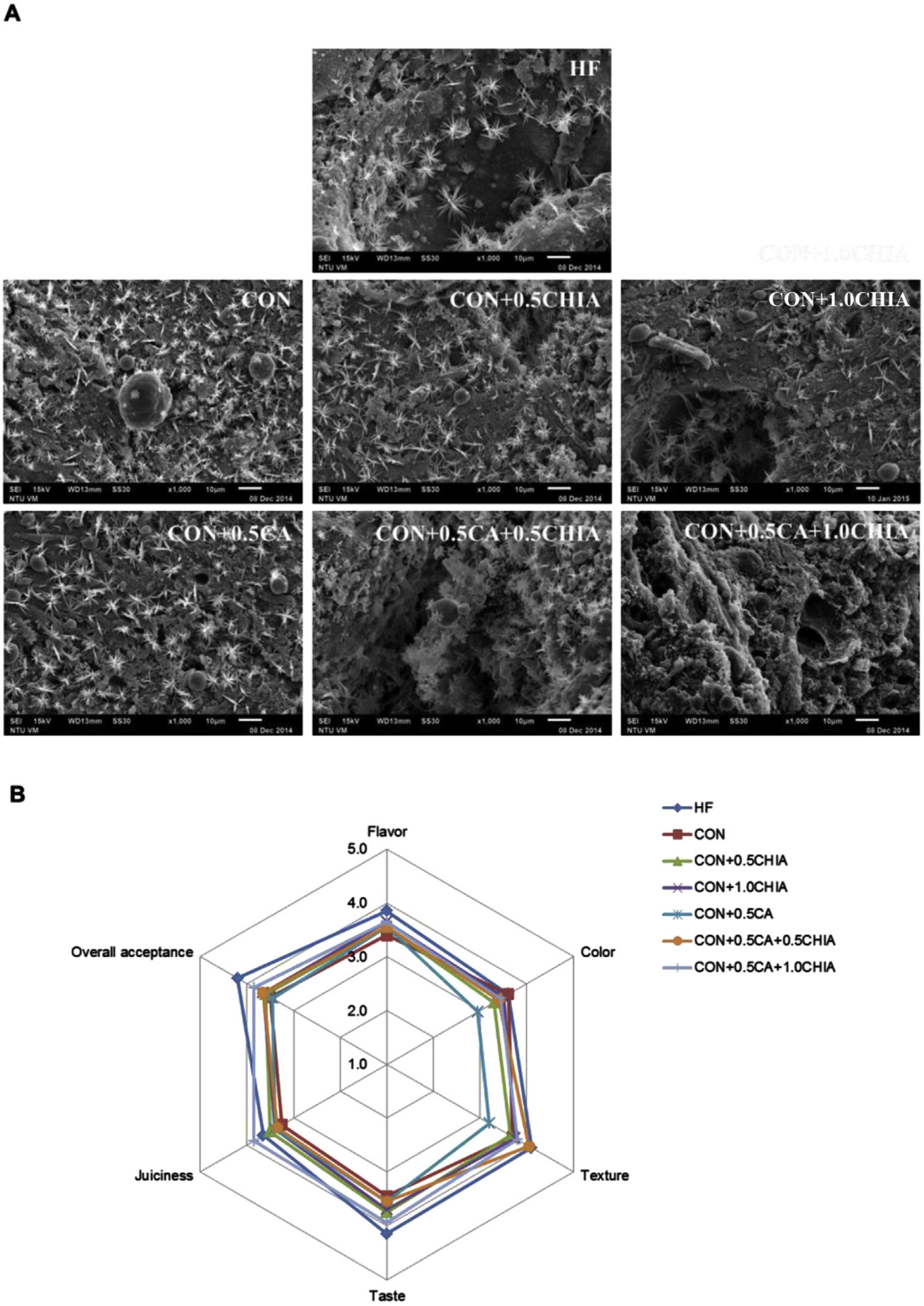
Table 4 – Effects of different levels of chia seeds (CHIA) and carrageenan (CA) on production yield and proximate composition of restructured ham-like products, and changes of textural profiles of restructured ham-like products during the storage period.

	HF	CON	CON+0.5CHIA	CON+1.0CHIA	CON+0.5CA	CON+0.5CA+0.5CHIA	CON+0.5CA+1.0CHIA
Production yield (%)	99.22 ± 0.04^{a}	96.57 ± 0.38^{bc}	97.05 ± 0.53^{b}	95.43 ± 1.55^{c}	96.87 ± 0.17^{b}	99.64 ± 0.21^{a}	98.94 ± 0.47^{a}
	Proximate compositions						
Moisture (%)	69.05 ± 0.32^{c}	73.79 ± 0.94^{a}	73.46 ± 0.90^{a}	71.79 ± 0.77^{ab}	73.14 ± 0.62^{a}	73.37 ± 0.43^{a}	70.35 ± 1.42^{bc}
Crude fat (%)	10.42 ± 0.29^{a}	5.55 ± 0.33^{c}	6.13 ± 0.33^{c}	6.82 ± 0.33^{bc}	6.41 ± 0.47^{c}	6.29 ± 0.10^{c}	8.31 ± 1.19^{b}
Crude protein (%)	15.86 ± 0.03^{ab}	16.21 ± 0.82^{ab}	15.90 ± 0.57^{ab}	16.99 ± 0.32^{a}	15.79 ± 0.28^{ab}	15.44 ± 0.37^{b}	16.27 ± 0.36^{ab}
Ash (%)	2.13 ± 0.03^{b}	2.12 ± 0.06^{b}	2.16 ± 0.08^{ab}	2.21 ± 0.03^{ab}	2.12 ± 0.07^{b}	2.21 ± 0.04^{ab}	2.29 ± 0.05^{a}
Storage period	Textural properties						
0 week							
Hardness (N)	18.17 ± 0.92^{a}	16.38 ± 0.57^{ab}	14.62 ± 1.52^{b}	16.47 ± 0.68^{ab}	14.89 ± 0.93^{b}	15.38 ± 0.39^{b}	14.79 ± 0.57^{b}
Adhesiveness (Nxs)	-0.05 ± 0.01^{a}	-0.06 ± 0.00^{a}	-0.05 ± 0.01^{a}	-0.04 ± 0.01^{a}	-0.04 ± 0.01^{a}	-0.04 ± 0.01^{a}	-0.04 ± 0.00^{a}
Springiness	0.93 ± 0.01^{a}	0.92 ± 0.01^{a}	0.91 ± 0.01^{ab}	0.88 ± 0.00^{bc}	0.86 ± 0.01^{c}	0.89 ± 0.00^{bc}	0.83 ± 0.01^{d}
Cohesiveness	0.70 ± 0.01^{a}	0.70 ± 0.00^{a}	0.70 ± 0.03^{a}	0.64 ± 0.01^{b}	0.59 ± 0.01^{b}	0.69 ± 0.01^{a}	0.62 ± 0.02^{b}
2 week							
Hardness (N)	16.92 ± 1.25^{a}	18.05 ± 1.98^{a}	15.35 ± 0.45^{a}	17.07 ± 0.59^{a}	15.47 ± 0.68^{a}	15.02 ± 1.05^{a}	15.22 ± 1.57^{a}
Adhesiveness (Nxs)	-0.05 ± 0.02^{ab}	-0.08 ± 0.01^{b}	-0.03 ± 0.01^{a}	-0.04 ± 0.01^{a}	-0.05 ± 0.01^{ab}	-0.05 ± 0.00^{a}	-0.04 ± 0.01^{a}
Springiness	0.86 ± 0.07^{a}	0.92 ± 0.00^{a}	0.91 ± 0.00^{a}	0.90 ± 0.00^{a}	0.87 ± 0.01^{a}	0.89 ± 0.01^{a}	0.86 ± 0.02^{a}
Cohesiveness	0.75 ± 0.02^{a}	0.70 ± 0.01^{bc}	0.72 ± 0.01^{ab}	0.65 ± 0.00^{d}	0.61 ± 0.02e	0.69 ± 0.01^{c}	0.64 ± 0.00^{d}e
4 *week*							
Hardness (N)	19.03 ± 0.89^{a}	17.75 ± 0.72^{ab}	16.26 ± 0.22^{bcd}	17.14 ± 0.67^{bc}	15.09 ± 0.58^{d}	15.68 ± 0.55^{cd}	14.70 ± 0.48^{d}
Adhesiveness (Nxs)	-0.06 ± 0.02^{b}	-0.03 ± 0.00^{a}	-0.05 ± 0.01^{ab}	-0.06 ± 0.01^{b}	-0.05 ± 0.01^{ab}	-0.04 ± 0.00^{ab}	-0.06 ± 0.00^{ab}
Springiness	0.91 ± 0.00^{ab}	0.91 ± 0.00^{ab}	0.93 ± 0.01^{a}	0.90 ± 0.02^{ab}	0.84 ± 0.02^{ab}	0.89 ± 0.01^{bc}	0.87 ± 0.01^{cd}
Cohesiveness	0.69 ± 0.01^{a}	0.64 ± 0.02^{bc}	0.68 ± 0.02^{ab}	0.67 ± 0.01^{ab}	0.60 ± 0.01^{cd}	0.63 ± 0.01^{cd}	0.59 ± 0.00^{d}

Data are given as mean ± standard error of the mean ($n = 3$).

[a–d] Mean values without the same letters in each testing parameter are significantly different by using least significant difference ($p < 0.05$).

CON = control (without addition of fat); HF = high fat (addition of 5% pork back fat).



	HF	CON	CON+ 0.5CHIA	CON+ 1.0CHIA	CON+ 0.5CA	CON+ 0.5CA+ 0.5CHIA	CON+ 0.5CA+ 1.0CHIA
Odor	3.88±0.14a	3.35±0.13b	3.55±0.11ab	3.65±0.13ab	3.55±0.15ab	3.55±0.13ab	3.65±0.16ab
Color	3.60±0.15a	3.60±0.12a	3.28±0.10ab	3.55±0.142a	2.90±0.13b	3.43±0.12a	3.45±0.15a
Texture	4.13±0.14a	3.73±0.14bc	3.65±0.15c	3.75±0.10abc	3.15±0.16d	4.08±0.12ab	3.80±0.14abc
Flavor	4.18±0.12a	3.43±0.12c	3.75±0.12bc	3.70±0.15bc	3.55±0.11c	3.58±0.11c	3.90±0.15ab
Juiciness	3.65±0.13ab	3.25±0.14b	3.50±0.15ab	3.40±0.13b	3.40±0.17b	3.40±0.13b	3.90±0.14a
Overall acceptance	4.18±0.11a	3.50±0.16c	3.68±0.14bc	3.68±0.13bc	3.43±0.14c	3.68±0.11bc	3.95±0.15ab

Figure 2 – Effects of different levels of chia seed (CHIA) and carrageenan (CA) on (A) changes in scanning electron micrographs (magnification, 1000×) and (B) sensorial attributes of restructured ham-like products. Data are given as mean ± standard error of the mean ($n = 40$ for sensory evaluation). $^{a-c}$ Mean values without the same letters in each testing parameter are significantly different by using least significant difference ($p < 0.05$). CON = control (without addition of fat); HF = high fat (addition of 5% pork back fat).

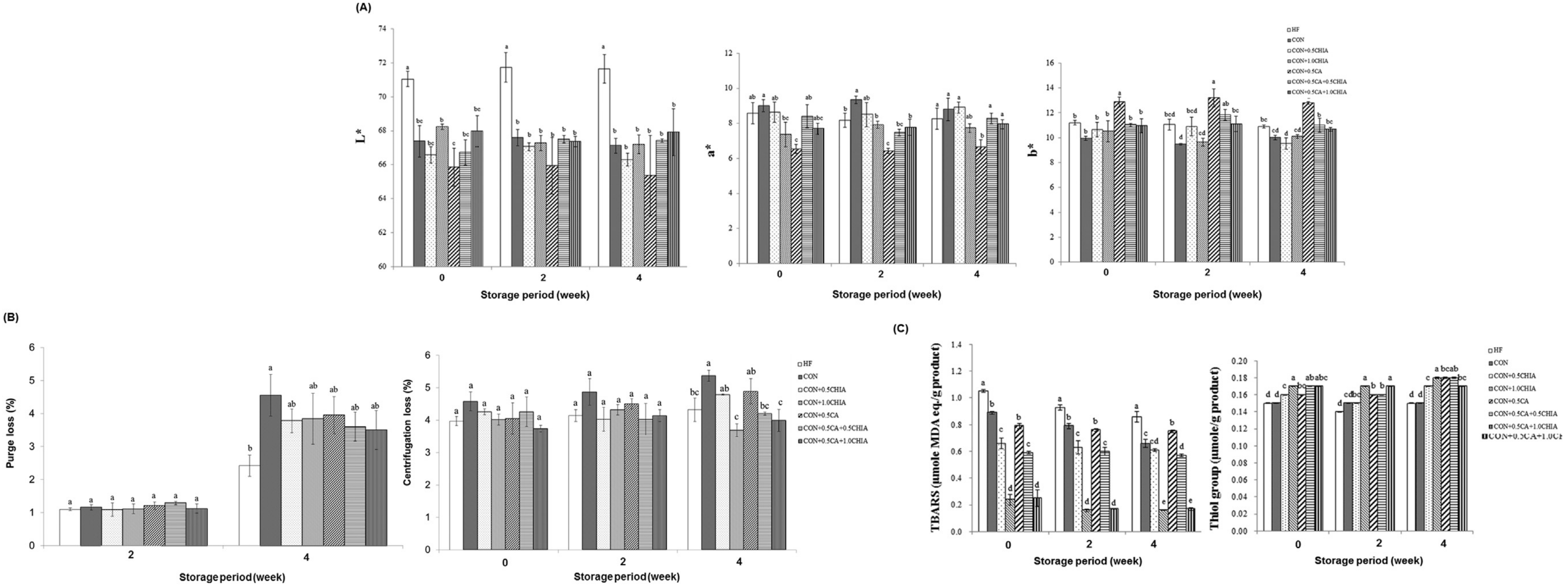


Figure 3 — Effect of different levels of chia seed (CHIA) and carrageenan (CA) on (A) color parameters (L*, a*, and b* value), (B) water holding capacities [purge and centrifugation (%)], and (C) lipid/protein oxidation levels (TBARS value and thiol-group contents) of restructured ham-like products during the storage period. Data are given as mean ± standard error of the mean ($n = 3$). $^{a-c}$ Mean values without the same letters on data bars in the same storage period are significantly different by using least significant difference ($p < 0.05$). CON = control (without addition of fat); HF = high fat (addition of 5% pork back fat); a* = greenness (-a*) to redness (a*), b* = blueness (-b*) to yellowness (b*); L* = lightness.

products (Figure 3B). Color plays an important role in both the quality and consumer's preference of meat products. Generally, the formations of metmyoglobin and lipid oxidation make meat discolor. The group with pork back fat added increased the lightness (L* value) of ham-like products (Figure 3A) which assumed that white pork fat brightens the products. The high ratio of pork fat makes the pork patties lighter and also has the better color preference to panelists [30]. Moreover, ham-like products with CA addition made the yellowness (b* value) lower to the value as similar as ham-like products in this experiment (Figure 3A). Purge and centrifugation losses are common indicators for water holding capacity of meat products [12]. According to the results, the CON group had the higher purge and centrifugation losses upon the refrigerator storage. The recipe added with 1.0% CHIA (CON+1.0CHIA and CON+0.5CA+1.0CHIA products) performed the lower centrifugation loss during the storage period (Figure 3B). Oxidation causes rancidity and deterioration in meat products. Many studies have been available for a retarded effect of plant extracts on lipid oxidation in meat products, such: as tea catechins in red meat, poultry, and fish patties [18]; rosemary and lemon balm extracts in pork patties or packaged beef [19]; grape seed flour in frankfurters [13]; and ethanolic grape-seed extract in dry cured sausage (*chorizo*) [20]. It was reported that rutin or hesperidin has a good effect against lipid oxidation [23–25]. Hence, the lower TBARS values in restructured ham-like products with CHIA partially results from their polyphenols, especially rutin and hesperidin (Table 3 and Figures 1 and 3C). Disulfide bonds were formed if protein was oxidized [13]; hence, the thiol-group contents of protein were reduced. Therefore, a higher TBARS value may results in the lower thiol-group content simultaneously [12]. According to our results, although the fat addition had the higher overall acceptance but it resulted in higher lipid and protein oxidation in restructured ham-like products than products without additional fat, CHIA addition indeed showed a retardation from lipid and protein oxidation in products without additional fat.

4. Conclusion

Regarding the fatty acid profile, CHIA had a high ratio (88%) of ω-3 unsaturated fatty acids where ALA (C18:3) is the majority. In addition, the abundant essential amino acids were also assayed in CHIA as well. In minerals, Mg, K, and Ca are major elements while Fe and Zn were also found in CHIA. Meanwhile, rutin, *p*-anisic acid, and hesperidin were the major polyphenolic compounds in CHIA. To overcome the defects of low-fat meat products, the recipe of restructured ham-like products with CHIA addition makes products with better processing properties. A 0.5% CA and 1.0% CHIA addition showed a similar overall acceptance as an extra 5.0% pork fat added restructured ham-like product. Moreover, 1.0% CHIA addition decreased lipid and protein oxidation of restructured ham-like products after refrigerator storage. Overall, CHIA improves not only physicochemical and sensorial properties but also add nutritional values on restructured ham-like products. Meanwhile, the polyphenols in CHIA may partially contribute to the prolongation of the shelf life on this ham-like product.

Conflicts of interest

All authors have no conflicts of interest to declare.

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