Lipid oxidation-related characteristics of gim bugak (Korean fried cuisine with *Porphyra*) affected by frying oil

Leejin Jung¹ · Eunok Choe¹

Received: 3 January 2017 / Revised: 11 March 2017 / Accepted: 17 March 2017 / Published online: 29 May 2017
© The Korean Society of Food Science and Technology and Springer Science+Business Media Dordrecht 2017

Abstract The effect of frying oil on the lipid oxidation, antioxidants, and in vitro antioxidant activity of gim bugak was studied. Bugak was prepared by pan-frying at 180 °C in unroasted sesame, soybean, extra virgin olive, or palm oil. The degree of lipid oxidation based on conjugated dienoic acid and *p*-anisidine values was higher in the bugak fried in soybean or sesame oil with high contents of polyunsaturated fatty acids and tocopherols. However, the oil oxidation was lower in olive and palm oils, which showed higher degradation of tocopherols and polyphenols than in sesame or soybean oil during frying. Although the bugak fried in palm oil contained less antioxidants than that fried in soybean or sesame oil, the in vitro antioxidant activity was not different ($p > 0.05$). Results suggest that palm oil can replace unroasted sesame oil for the preparation of gim bugak with improved lipid oxidative stability and health functionality.

Keywords Gim bugak · Frying oil · Lipid oxidation · Antioxidant · Pigment

Introduction

Bugak, a Korean fried cuisine, is prepared by frying rice- or flour-battered vegetables, or seaweeds after drying, and perilla leaf and gim (dried laver, *Porphyra*) are the frequently used food materials for bugak. Bugak has been consumed as a snack or side dish in Korea owing to its crispiness.

Although it is a common way to cover all the surfaces of food materials with batter for frying, bugak is battered just enough to keep the shape (appearance) of the food materials with fragile texture, resulting in minimal oil absorption [1]. Bugak was an important lipid source for Koreans many years ago; however, it is not rare to find bugak in the markets of western countries nowadays. The most frequently found bugak in the market is gim bugak, possibly owing to consumer familiarity compared to other bugaks. Gim contains high amounts of antioxidants as well as protein and dietary fiber [2]. Antioxidants present in gim include polyphenols, porphyrin, and tocopherols, which showed radical scavenging activities [2–4]. Consumption of gim helps to decrease the levels of serum cholesterol and neutral lipids [5] and prevent cardiovascular diseases [6].

Frying during bugak preparation can cause losses of the naturally present antioxidants and pigments [1] and increase lipid oxidation. Because there was little oil source for cooking in the past, the traditional bugak preparation process included frying in a shallow pan with a small amount of sesame oil instead of deep-fat frying. However, currently, there are many choices of edible oils for domestic and industrial uses, and consumers are more demanding the oil to have benefits in health as well as oxidative stability during cooking and storage. Extra virgin olive oil is a good example, however, it is not usually refined, just like unroasted sesame oil, resulting in lower smoking point than refined oils such as soybean and palm oils, which makes less use in frying. There are many reports on bugak [7–12], and most of them reported the antioxidant activity and quality improvement of bugak through the addition of colored food materials such as green tea and mulberry leaf. It is not easy to find a study that evaluates the plausibility of various edible oils for the preparation of bugak having improved health and food

✉ Eunok Choe
eochoe@inha.ac.kr

¹ Department of Food and Nutrition, Inha University, Incheon 22212, Korea

functionality. Therefore, this study was performed to investigate the effect of frying oil on the lipid oxidation, antioxidants, and in vitro antioxidant activity of gim bugak. Oxidation of frying oil during bugak preparation was also monitored.

Materials and methods

Materials and reagents

Gim in thin sheets without any added salt and toasting and glutinous rice were purchased from Eochonsaramdle Co. (Hwasung, Korea) and Hansalim Co. (Seoul, Korea), respectively. Unroasted sesame oil was a product of Dubio Co., Ltd. (Eumsung, Korea), and extra virgin olive and soybean oils were purchased from CJ Co., Ltd. (Seoul, Korea). Palm oil was generously donated by Nongshim Co. Ltd. (Seoul, Korea). Caffeic acid, Folin–Ciocalteu's phenol reagent, *p*-anisidine, chlorophylls *a* and *b*, β -carotene, lutein, α -, γ -, and δ -tocopherol and tocotrienol, and standard fatty acid methyl esters were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA). *n*-Hexane, isopropanol, ethyl acetate, toluene, ethanol, acetone, methanol, and water in HPLC grade were purchased from J. T. Baker Ltd. (Phillipsburg, NJ, USA). All other reagents were of analytical grade.

Preparation of gim bugak

Gim bugak was prepared using fermented glutinous rice batter and pan-frying according to the method of Jung et al. [1]. One piece of gim (9 × 6.7 cm) was rice-battered on both sides and then stacked with another piece of rice-battered gim, which was then air-dried at room temperature for 3 days in the dark. Dried gim pieces with rice batter (3 pieces, ~8.5 g) were fried in a shallow pan (28 cm diameter and 2.41 cm height) with unroasted sesame, soybean, extra virgin olive, or palm oil (520 mL) at 180 °C for 3 s on each side. The total frying time for 15 batches was less than 20 min, including waiting time between batches, and no oil replenishment was required. Smoke point of all oils used was higher than 190 (195, 245, 200, and 230 °C for unroasted sesame, soybean, extra virgin olive, and palm oils, respectively). The frying oil before frying when the oil temperature reached 180 °C and then after final frying was collected for analysis.

Determination of fatty acid composition of frying oil and gim bugak

The fatty acid compositions of the vegetable oils (frying medium) were analyzed using a GC with a flame ionization detector (Younglin M600D, Younglin Co., Ltd., Anyang,

Korea) after methylation with 14% BF₃ in methanol [13]. An HP-Innowax column (30 m × 0.53 mm, 1.0 μm thick; Agilent, Böblingen, Germany) was used. The temperatures of the oven, injector, and detector were 200, 270, and 280 °C, respectively. The nitrogen flow rate was 5 mL/min, and the split ratio was 33:1. Each fatty acid in the chromatogram was identified by comparing their retention times with those of standard fatty acid methyl esters and quantified by the peak areas. The fatty acid composition of gim bugak was determined with the same method as the analysis of frying oil but after extracting lipids from bugak by the Folch method [1] using chloroform and methanol mixture (2:1, v/v).

Determination of antioxidants and pigments of frying oil and bugak

Antioxidants and pigments determined included tocopherols, polyphenols, chlorophylls, and carotenoids. Tocopherol contents of frying oil were determined using the calibration curves of standards using a YL 9100 HPLC (Younglin Co. Ltd.) with a μ-porasilTM column (3.9 × 300 mm, 10 μm i.d., Waters Co., Milford, MA, USA) and a fluorescence detector (excitation 290 nm, emission 330 nm). The eluent was a mixture of *n*-hexane and isopropanol (99.8:0.2, v/v) at 2 mL/min [12]. Polyphenol contents were determined by the Folin–Ciocalteu method at 725 nm [12] and represented as caffeic acid equivalent. Chlorophyll and carotenoid contents were quantified using calibration curves of standards using a YL 9100 HPLC (Younglin Co., Ltd.) [12]. Chlorophylls were determined using a symmetry C18 column (5.0 μm, 4.6 × 250 mm; Waters Co.) with an eluting solvent of 3% isopropanol in *n*-hexane (v/v) at 1 mL/min and a UV detector at 436 nm. A μ-porasil column (10 μm, 3.9 × 300 mm; Waters Co.) with an eluent of ethyl acetate–methanol–water (50:37.5:12.5, v/v/v) mixture at 1.5 mL/min was used for carotenoid determination, and the wavelength of the UV detector was 438 nm.

The contents of tocopherols, polyphenols, chlorophylls, and carotenoids of *bugak* were determined using the same method as that used in the analysis of frying oil but after extracting lipids from bugak by the Folch method [1] using chloroform and methanol mixture (2:1, v/v).

Evaluation of lipid oxidation of frying oil and bugak

The degree of frying oil oxidation was evaluated on the basis of the conjugated dienoic acid and *p*-anisidine values by the AOCS method [14] Ti 1a-64 and Cd 18-90, respectively. Lipid oxidation of *bugak* was evaluated using the same AOCS method [14] after lipid extraction by the Folch method [1] and represented based on the bugak lipid.

Evaluation of in vitro antioxidant activity of gim bugak

The DPPH radical scavenging activity and reducing power of gim bugak were evaluated after obtaining the bugak extract with 80% ethanol [10]. α -Tocopherol and L-ascorbic acid as a positive control, and bugak extract (2 g each) were dissolved in 80% ethanol (30 mL), and 0.1 and 1 mL of each solution were used for the determination of the DPPH radical scavenging activity and reducing power, respectively. The DPPH radical scavenging activity was calculated from the absorbance at 517 nm (A_{517}) using a UV–Vis spectrophotometer (HP 8453, Hewlett Packard, Wilmington, DE, USA) as follows [10]:

$$\text{DPPH radical scavenging activity (\%)} = 100 \times (A_{517} \text{ of samples without bugak extract} / A_{517} \text{ of samples with bugak extract})$$

For determination of reducing power, the bugak extract was mixed with a mixture of 0.2 M phosphate buffer (pH 6.6) and 1% potassium ferricyanide solution for 30 min, and then 10% trichloroacetic acid was added, followed by centrifugation. Water and 0.1% ferrous chloride solution (5:1, v/v) were added to the upper layer, and finally, the reducing power was represented with absorbances at 700 nm [10].

Statistical analysis

All samples were prepared in duplicate, and the measurement for each sample was replicated. Data were statistically analyzed using SAS/PC (SAS version 9.2; SAS Institute Inc., Cary, NC, USA) including *t* test and Duncan's multiple range test.

Results and discussion

Initial composition of frying oil and gim

Fatty acid compositions and the contents of antioxidants and pigments of unroasted sesame, soybean, extra virgin olive, and palm oils are shown in Table 1. Sesame and soybean oils contained linoleic acid at the highest concentration (45.72 and 49.91%, respectively), followed by oleic (36.66 and 25.73%, respectively) and palmitic (10.65 and 11.37%, respectively) acids. Stearic acid was detected at 5.57 and 5.25% in sesame and soybean oils, respectively. Linolenic acid was present in soybean oil (7.27%), but it was hardly detected in sesame oil (0.47%). Oleic acid was a major fatty acid in extra virgin olive oil (76.01%), followed by palmitic (11.67%), linoleic (5.55%), and stearic (4.23%) acids. Palm oil contained a similar amount of

saturated (palmitic and stearic acids of 42.99 and 5.08%, respectively) and unsaturated fatty acids (oleic and linoleic acids of 38.64 and 10.85%, respectively). Results of the fatty acid composition of these oils were similar to those of previous studies [15, 16].

Tocopherols were present in all oils; sesame (1446.47 mg/kg) and soybean (1221.36 mg/kg) oils contained higher concentrations of tocopherols than extra virgin olive (158.09 mg/kg) and palm (464.88 mg/kg) oils. Among tocopherol isomers, only γ -isomer was detected in unroasted sesame oil, whereas only α -tocopherol was detected in extra virgin olive oil. Soybean oil contained α - (98.57 mg/kg), γ - (812.11 mg/kg), and δ -tocopherols (310.68 mg/kg). Palm oil contained α - (129.31 mg/kg), γ - (179.36 mg/kg), and δ -tocotrienols (56.48 mg/kg) in addition to α -tocopherol (99.73 mg/kg). Polyphenols were detected in unroasted sesame and extra virgin olive oils at 17.13 and 191.48 mg/kg, respectively. Results of the contents and composition of tocopherols and polyphenols of these oils were similar to those of previous studies [15, 16]. Carotenoids were detected in all oils and the contents were at a higher concentration in extra virgin olive oil (132.73 mg/kg) than in sesame (23.05 mg/kg), soybean (15.09 mg/kg), and palm (19.73 mg/kg) oils. No chlorophyll was detected in any oil.

Gim contained chlorophyll *a* (403.76 ± 17.11 mg/kg), β -carotene (15.18 ± 0.20 g/kg), and lutein (0.30 ± 0.01 g/kg), which is similar to or shows a difference from previous reports [2, 17–20]. Pigment contents of seaweeds are largely dependent on the cultivating environment [18, 19]. Tocopherol (only α -isomer) content was 6.70 ± 0.81 mg/kg, and polyphenols were present at 2548.10 ± 123.73 mg/kg. Results of the contents of polyphenols and tocopherols were similar to those of Farvin and Jacobsen [21].

Fatty acid composition and degree of lipid oxidation of gim bugak and frying oil

Lipid contents of gim bugak fried in extra virgin olive, unroasted sesame, soybean, and palm oils were 47.99, 35.75, 36.04, and 33.79%, respectively. Because gim and rice batter hardly contain lipids (<1%) [2, 22], the lipid in the bugak must be absorbed from the frying oil. Higher viscosity and/or lower surface tension of sesame and extra virgin olive oils might have caused them to adhere to bugak's surface and flow into the center of bugak during cooling [23]. Viscosity of sesame, soybean, and olive oils was reported to be 41.14, 38.63, and 46.29 mPa s, respectively, at 35 °C [24]. Fatty acid compositions of gim bugak, as shown in Table 2, were similar to those of the respective frying oils, as was expected, owing to the very low amount of lipid in gim and rice powder compared to

Table 1 Initial composition of frying oils

	Unroasted sesame oil	Soybean oil	Extra virgin olive oil	Palm oil
Fatty acid composition (relative %)				
C14:0	n.d. ¹	n.d.	n.d.	1.25 ± 0.01
C16:0	10.65 ± 0.52	11.37 ± 0.06	11.67 ± 0.05	42.99 ± 0.21
C16:1	0.24 ± 0.01	n.d.	1.15 ± 0.00	0.32 ± 0.01
C18:0	5.57 ± 0.06	5.25 ± 0.07	4.23 ± 0.03	5.08 ± 0.04
C18:1	36.66 ± 0.03	25.73 ± 0.69	76.01 ± 0.08	38.64 ± 0.29
C18:2	45.72 ± 0.45	49.91 ± 0.66	5.55 ± 0.04	10.85 ± 0.51
C18:3	0.47 ± 0.00	7.27 ± 0.02	0.85 ± 0.03	0.37 ± 0.00
C20:0	0.69 ± 0.02	0.47 ± 0.01	0.54 ± 0.01	0.51 ± 0.02
Tocopherol content (mg/kg)				
α-Tocopherol	n.d.	98.57 ± 0.08	158.09 ± 0.55	99.73 ± 5.86
γ-Tocopherol	1446.47 ± 97.85	812.11 ± 4.29	n.d.	n.d.
δ-Tocopherol	n.d.	310.68 ± 20.99	n.d.	n.d.
α-Tocotrienol	n.d.	n.d.	n.d.	129.31 ± 7.55
γ-Tocotrienol	n.d.	n.d.	n.d.	179.36 ± 1.89
δ-Tocotrienol	n.d.	n.d.	n.d.	56.48 ± 4.92
Total	1446.47 ± 97.85	1221.36 ± 25.36	158.09 ± 0.55	464.88 ± 20.23
Polyphenol content (mg/kg)	17.13 ± 2.27	n.d.	191.48 ± 2.24	1.67 ± 0.20
Carotenoid content (mg/kg)				
β-Carotene	23.05 ± 0.18	15.09 ± 0.46	131.51 ± 1.56	19.73 ± 1.10
Lutein	n.d.	n.d.	1.21 ± 0.02	n.d.
Total	23.05 ± 0.18	15.09 ± 0.46	132.73 ± 0.46	19.73 ± 1.10
Chlorophyll content (mg/kg)	n.d.	n.d.	n.d.	n.d.

¹ Not detected

that of absorbed frying oil. Similar fatty acid composition of fried products to that of frying oil has been reported previously [25].

The CDA value of the gim bugak lipid when fried in soybean oil (26.00 ± 0.47%) was the highest ($p < 0.05$), followed by bugak fried in unroasted sesame oil (20.93 ± 0.67%), palm oil (14.64 ± 0.54%), and extra virgin olive oil (10.90 ± 0.32%) as shown in Fig. 1. The *p*-anisidine values of the lipid in gim bugak fried in unroasted sesame, soybean, extra virgin olive, or palm oils were 8.80 ± 0.24, 16.33 ± 0.73, 11.96 ± 0.43, and 11.34 ± 0.52, respectively. High

CDA and *p*-anisidine values of the gim bugak lipid when fried in soybean oil are considered to be partly due to the high content of polyunsaturated fatty acids, which produce CDA and aldehydes upon oxidation of oil during frying.

The CDA and *p*-anisidine values of heated unroasted sesame, soybean, extra virgin olive, and palm oils to 180 °C before frying were 16.53% and 4.16, 18.67% and 9.22, 10.03% and 13.90, and 11.13% and 3.45, respectively (Fig. 2). After frying for bugak, the CDA and *p*-anisidine values of unroasted sesame, soybean, extra virgin olive, and palm oils significantly ($p < 0.05$) increased to 23.90% and

Table 2 Fatty acid composition (relative content, %) of gim bugak lipid with different frying oils

	Unroasted sesame oil	Soybean oil	Extra virgin olive oil	Palm oil
C14:0	n.d. ¹	n.d.	n.d.	1.27 ± 0.01
C16:0	10.66 ± 0.08	11.14 ± 0.03	11.81 ± 0.05	42.50 ± 0.26
C16:1	0.20 ± 0.00	0.16 ± 0.02	1.24 ± 0.00	0.31 ± 0.01
C18:0	5.47 ± 0.10	4.86 ± 0.01	4.24 ± 0.03	5.10 ± 0.08
C18:1	36.37 ± 0.11	26.04 ± 0.06	75.39 ± 0.07	39.15 ± 0.13
C18:2	46.15 ± 0.27	50.03 ± 0.05	5.93 ± 0.04	10.94 ± 0.09
C18:3	0.48 ± 0.01	7.29 ± 0.03	0.88 ± 0.01	0.24 ± 0.03
C20:0	0.66 ± 0.01	0.48 ± 0.01	0.51 ± 0.01	0.48 ± 0.01

¹ Not detected

Fig. 1 Conjugated dienoic acid and *p*-anisidine values of gim bugak fried in different oils at 180 °C for 3 s (Different letter on the bar means a significantly different value among bugaks fried in different oils by Duncan's multiple range test at 5%)

Fig. 2 Conjugated dienoic acid and *p*-anisidine values of oil after frying for gim bugak (*square with line*; before frying and *square*; after frying) The asterisk on the bar means significant difference by *t* test between oils before and after frying, **p* < 0.05; ***p* < 0.01; ****p* < 0.001

20.71, 25.93% and 30.93, 10.28% and 20.50, and 13.33% and 21.60, respectively, indicating the oxidation of oil during frying. Soybean and unroasted sesame oils showed higher increase in the CDA and *p*-anisidine values after frying than extra virgin olive and palm oils, despite their higher tocopherol contents. This could be because of their higher content

of polyunsaturated fatty acids; this confirmed that fatty acid composition is more critical than the concentration of antioxidants in frying oil [26]. Our results suggest that extra virgin olive or palm oil can be a good substitute for sesame oil as a frying medium for gim bugak based on the fatty acid composition and antioxidant contents.

Table 3 Antioxidant and pigment contents (mg/kg lipid) of gim bugak and its respective frying oil

	Gim bugak fried in					
	Unroasted sesame oil		Soybean oil		Extra virgin olive oil	
	Before	After	Before	After	Before	After
Tocopherols						
α -Tocopherol	n.d. ¹	n.d.	20.71 $\pm$ 0.37 ^{ab3}	20.71 $\pm$ 0.37 ^{ab3}	7.99 $\pm$ 0.31 ^b	20.85 $\pm$ 0.97 ^a
γ -Tocopherol	354.00 $\pm$ 19.14	483.76 $\pm$ 3.13	549.11 $\pm$ 8.93	600.27 $\pm$ 3.04	n.d.	n.d.
δ -Tocopherol	n.d.	n.d.	235.29 $\pm$ 3.50	235.08 $\pm$ 0.84	n.d.	n.d.
α -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	4.65 $\pm$ 0.54
γ -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	89.61 $\pm$ 5.91
δ -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	49.16 $\pm$ 3.75
Total	354.00 $\pm$ 19.14 ^b	483.76 $\pm$ 3.13	819.16 $\pm$ 13.88 ^a	932.08 $\pm$ 4.16 ^{***}	7.99 $\pm$ 0.31 ^d	74.67 $\pm$ 2.99 ^c
Polyphenols	25.79 $\pm$ 1.21 ^b	19.91 $\pm$ 1.75	1.13 $\pm$ 0.10 ^d	n.d.	71.21 $\pm$ 5.24 ^a	8.57 $\pm$ 0.94 ^c
Chlorophylls						
Chlorophyll <i>a</i>	22.70 $\pm$ 0.90 ^{b1}	n.d.	29.01 $\pm$ 4.39 ^a	n.d.	23.68 $\pm$ 0.69 ^b	22.89 $\pm$ 1.41 ^b
Chlorophyll <i>b</i>	84.51 $\pm$ 4.40 ^a	n.d.	55.02 $\pm$ 1.76 ^b	n.d.	56.77 $\pm$ 3.19 ^b	55.02 $\pm$ 2.81 ^b
Total	107.22 $\pm$ 5.11 ^a	n.d.	84.02 $\pm$ 2.97 ^b	n.d.	80.45 $\pm$ 3.23 ^{bc}	77.91 $\pm$ 2.78 ^c
Carotenoids						
β -Carotene	8165.48 $\pm$ 839.18 ^a	n.d.	3016.01 $\pm$ 230.19 ^b	n.d.	3189.93 $\pm$ 201.06 ^b	3382.87 $\pm$ 157.9 ^b
Lutein	82.57 $\pm$ 6.93 ^a	n.d.	11.94 $\pm$ 1.26 ^b	n.d.	14.24 $\pm$ 1.09 ^b	14.37 $\pm$ 1.17 ^b
Total	8248.05 $\pm$ 845.90 ^a	n.d.	3027.95 $\pm$ 231.34 ^b	n.d.	3204.16 $\pm$ 201.98 ^b	3397.25 $\pm$ 158.90 ^b
Frying oil after frying						
	Unroasted sesame oil		Soybean oil		Extra virgin olive oil	
	Before	After	Before	After	Before	After
Tocopherols						
α -Tocopherol	n.d.	n.d.	96.74 $\pm$ 0.28 ^{***2}	76.07 $\pm$ 0.68	96.40 $\pm$ 0.81 ^{***2}	87.48 $\pm$ 3.93 ^{***2}
γ -Tocopherol	624.38 $\pm$ 0.56 ^{***2}	483.76 $\pm$ 3.13	600.27 $\pm$ 3.04	600.62 $\pm$ 1.45	n.d.	n.d.
δ -Tocopherol	n.d.	n.d.	235.08 $\pm$ 0.84	235.29 $\pm$ 1.07	n.d.	n.d.
α -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	104.59 $\pm$ 3.59 ^{***2}
γ -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	165.84 $\pm$ 4.57 ^{***2}
δ -Tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	100.82 $\pm$ 2.97
Total	624.38 $\pm$ 0.56 ^{***2}	483.76 $\pm$ 3.13	932.08 $\pm$ 4.16 ^{***}	911.98 $\pm$ 1.06	96.40 $\pm$ 0.81 ^{***2}	242.87 $\pm$ 9.38 ^{***2}
Polyphenols	16.96 $\pm$ 0.69	19.91 $\pm$ 1.75	n.d.	n.d.	113.37 $\pm$ 9.82 [*]	79.33 $\pm$ 3.51
Chlorophylls						
Chlorophyll <i>a</i>	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Chlorophyll <i>b</i>	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 3 continued

	Frying oil after frying							
	Unroasted sesame oil		Soybean oil		Extra virgin olive oil		Palm oil	
	Before	After	Before	After	Before	After	Before	After
Carotenoids								
β-Carotene	20.57 ± 1.03 ^{*2}	16.35 ± 0.10	15.01 ± 0.23 ^{*2}	14.16 ± 0.03	85.89 ± 1.20 ^{**2}	47.65 ± 1.28	17.72 ± 1.12	18.79 ± 1.50
Lutein	n.d.	n.d.	n.d.	n.d.	0.57 ± 0.08 [*]	0.24 ± 0.01	n.d.	n.d.
Total	20.57 ± 1.03 ^{*2}	16.35 ± 0.10	15.01 ± 0.23 [*]	14.16 ± 0.03	86.47 ± 1.12 ^{**2}	47.89 ± 1.29	17.72 ± 1.12	18.79 ± 1.50

¹ Not detected² Significant difference between oils before and after frying in each sample by *t* test; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ ³ Different superscript means significant difference among bugaks by Duncan's multiple range test at 5%

Antioxidant and pigment contents of gim bugak and frying oil

The contents of antioxidants and pigments of gim bugak and frying oil are shown in Table 3. Tocopherol contents were 354.0, 819.16, 7.99, and 74.67 mg/kg in gim bugak fried in unroasted sesame, soybean, extra virgin olive, and palm oils, respectively. Tocopherol composition of gim bugak was similar to that of the frying oil. Gim bugak fried in unroasted sesame and extra virgin olive oils contained only γ - and α -tocopherol, respectively, and α -, γ -, and δ -tocopherols and tocotrienols were detected in the bugak fried in soybean and palm oils, respectively. These results suggest that tocopherols in the bugak were mainly transferred from their respective frying oils. Tocopherols were detected in all heated frying oils, unroasted sesame (624.38 mg/kg), soybean (932.08 mg/kg), extra virgin olive (96.40 mg/kg), and palm (242.87 mg/kg) oils, at a lower concentration than that of the respective oils before heating. Frying for the bugak further significantly ($p < 0.01$) decreased tocopherol contents in unroasted sesame, soybean, olive, and palm oils to 483.76 (77.5% of the level before frying), 911.98 (97.8%), 44.48 (46.1%), and 106.19 mg/kg (43.7%), respectively. The results clearly indicate the degradation of tocopherols in oils during heating to 180 °C and during frying for bugak, with higher degradation in extra virgin olive and palm oils. Lower degradation of tocopherols in soybean oil than in palm oil during frying of steamed noodles was reported previously [27].

Polyphenols were detected at 25.79, 1.13, 71.21, and 8.57 mg/kg in gim bugak fried in unroasted sesame, soybean, extra virgin olive, and palm oils, respectively. Lower content of polyphenols in the bugak compared to gim itself suggests their degradation during frying. Polyphenols are not stable at high temperature [20]. Soybean and palm oils, which are refined oils, did not contain polyphenols after heating to 180 °C as was expected, whereas sesame and extra virgin olive oil heated to 180 °C contained polyphenols at 16.96 and 113.37 mg/kg, respectively. The content of polyphenols in heated extra virgin olive oil was significantly ($p < 0.05$) lower than that of oil before heating, but this was not observed in unroasted sesame oil. After frying for bugak, extra virgin olive oil showed much more decrease in the level of polyphenols to 79.33 mg/kg ($p < 0.05$), indicating degradation of polyphenols during frying. There was no significant change in polyphenols during frying for bugak in unroasted sesame oil ($p > 0.05$), which was similar to heating to 180 °C. The results suggest that tocopherols in the unroasted sesame oil protect polyphenols from degradation during heating and frying, but polyphenols play a major role during frying for bugak

Fig. 3 DPPH radical scavenging activity and reducing power of gim bugak fried in different oils (Different letter on the bar means a significantly different value among bugaks fried in different oils by Duncan's multiple range test at 5%)

in decreasing the oxidation of the extra virgin olive oil, which contains tocopherols at a lower concentration.

Total chlorophyll contents of gim bugak fried in unroasted sesame, soybean, extra virgin olive, and palm oils was 107.22, 84.02, 80.45, and 77.91 mg/kg, respectively, and carotenoids were present at 8248.05, 3027.95, 3204.16, and 3397.25 mg/kg, respectively. Considering the chlorophyll and carotenoid contents of gim before bugak preparation, it was possible that the pigments present in gim were degraded or some of the oil-soluble pigments migrated to the frying oil during frying. Chlorophylls and carotenoids in gim (546.9 and 7424.8 mg/kg, respectively) are easily decomposed by heating at a high temperature [20]. Unlike bugak, chlorophylls were not detected in any of the heated frying oils before and after frying; however, carotenoids were detected in all oils and the concentration significantly ($p < 0.05$) decreased after frying, except in palm oil, compared to the level before frying. Heated extra virgin olive oil contained carotenoids at 86.47 mg/kg before frying, but the content significantly ($p < 0.01$) decreased to 47.89 mg/kg after frying. Because carotenoid content of unheated olive oil was 132.73 mg/kg, the results indicate degradation of carotenoids present in extra virgin olive oil during heating to 180 °C and frying for the bugak preparation. Some carotenoid degradation products can accelerate lipid oxidation by increasing radical production [28]. Significant decrease in carotenoid content during frying was also observed during frying in unroasted sesame and soybean oils ($p < 0.05$) but at a lower degree, possibly owing to protection of carotenoids from degradation by other antioxidants such as tocopherols at high concentration. Tocopherols help the regeneration of carotenoids to provide hydrogens to carotenoid radicals, which might decrease the oxidation of oil during frying [29]. There was

no significant change in the carotenoid content of palm oil during frying.

In vitro antioxidant activity of gim bugak

The DPPH radical scavenging activity was significantly ($p < 0.05$) higher in the 80% ethanol extract of gim bugak fried in palm (15.53%) or soybean (15.10%) oil than in the 80% ethanol extract of that fried in unroasted sesame (11.93%) or olive (13.83%) oil (Fig. 3). Reducing power of the 80% ethanol extract of gim bugak fried in palm or unroasted sesame oil ($A_{700} = 0.26$) was higher than that of the bugak fried in soybean ($A_{700} = 0.23$) and olive ($A_{700} = 0.21$) oils ($p < 0.05$). The in vitro antioxidant activities of the gim bugak extract were lower (12–25%) as compared with those of L-ascorbic acid or α -tocopherol, which suggests that gim bugak needs the addition of antioxidative food materials for high health functionality. Jung et al. [11] reported improvement in the antioxidative activity of lotus root bugak by the addition of gardenia seed, green tea, or *Opuntia* powder to the rice batter.

In conclusion, frying oil affected the chemical quality of bugak through its oxidation and antioxidants. Although polyphenol and tocopherol contents were the highest in the gim bugak fried in extra virgin olive and soybean oils, respectively, the in vitro antioxidant activity was the highest in the bugak fried in palm oil. These results suggest that palm oil can be an alternative for unroasted sesame oil for the preparation of bugak with the improvement of lipid oxidative stability and health functionality.

Acknowledgements This research was supported by the Superiority and Functionality of Hansik (Korean Food) Research Program (No. 913003-1), iPET (Korea Institute of Planning and Evaluation for

Technology in Food, Agriculture, Forestry and Fisheries), and the Ministry of Agriculture, Food and Rural Affairs.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

References

- Jung L, Song Y, Chung L, Choe E. Characteristics on lipid and pigments of lotus root, dried laver, and perilla leaf bugak (Korean fried cuisine) made by Korean traditional recipe. *Korean J. Food Cook. Sci.* 29: 805–814 (2013)
- Oh S, Kim J, Kim H, Son S, Choe E. Composition and antioxidant activity of dried laver, dolgim. *Korean J. Food Sci. Technol.* 45: 403–408 (2013)
- Choe EO, Min DB. Mechanisms and factors for edible oil oxidation. *Compr. Rev. Food Sci. Food Saf.* 5: 169–186 (2006)
- Zhang Z, Zhang Q, Wang J, Song H, Zhang H, Niu X. Chemical modification and influence of function groups on the in vitro antioxidant activities of porphyran from *Porphyra haitanensis*. *Carbohydr. Polym.* 79: 290–295 (2010)
- Son HS, Kim HS, Ju JS. Effect of seaweed intake on the absorption of sodium, calcium, potassium and hypolipidemic mechanism in healthy male subjects. *J. Korean Soc. Food Sci. Nutr.* 21: 471–477 (1992)
- Cornish ML, Garbary DJ. Antioxidants from macroalgae: Potential application in human health and nutrition. *Algae* 25: 155–171 (2010)
- Park BH, Choi HK, Cho HS. A study on the oxidative stability and quality characteristics of *kimbugak* made of aqueous green tea. *J. Korean Soc. Food Sci. Nutr.* 30: 557–564 (2001)
- Lee JM, Kim JA, Lee JM. Sensory and physicochemical attributes of *Boogags* using mulberry leaf. *Korean J. Dietary Culture.* 17: 103–110 (2002)
- Choi HM, Sim CH, Shin TS, Bing DJ, Chun SS. Quality characteristics of *Kimbugak* with sea tangle powder. *Korean J. Food Nutr.* 24: 434–441 (2011)
- Jung L, Song Y, Chung L, Choe E. *In Vitro* antioxidative activity and polyphenol and tocopherol contents of *bugak* with lotus root, dried laver, or perilla leaf. *Korean J. Food Cook. Sci.* 30: 767–773 (2014)
- Kim M, Hong SH, Chung L, Choe E, Song Y-O. Development of lotus root bugak with plasma lipid reduction capacity by addition of *Opuntia ficus-indica* var. saboten or green tea as a coloring agent. *J. Korean Soc. Food Sci. Nutr.* 43: 333–340 (2014)
- Jung L, Song Y-O, Choe E. Effects of gardenia seed, green tea, and cactus pear in rice batter on the chemical quality of lotus root bugak and frying oil. *Food Sci. Biotechnol.* 25: 1029–1034 (2016)
- Jung L, Lee E, Choe E. Effects of catechin and α -tocopherol addition on the autoxidative stability of diacylglycerol oil derived from an olive oil and perilla oil mixture. *Food Sci. Biotechnol.* 23: 1793–1798 (2014)
- AOCS. Official Methods and Recommended Practices of the American Oil Chemists' Society. 4th ed. Methods Ti la-64 and Cd 18–90. AOCS Press. Champaign. IL. USA (2008)
- Lee J, Lee Y, Choe E. Temperature dependence of the autoxidation and antioxidants of soybean, sunflower, and olive oil. *Eur. Food Res. Technol.* 226: 239–246 (2007)
- Lee Y, Choe E. Effects of fatty acid composition and β -carotene on the chlorophyll-photosensitized oxidation of W/O emulsion affected by phosphatidylcholine. *J. Food Sci.* 78: C31–C36 (2013)
- Mizuta H, Shirakura Y, Yasui H. Relationship between phycoerythrin and nitrogen content in *Gloiopeltis furcata* and *Porphyra yezoensis*. *Algae* 17: 89–93 (2002)
- Ishihara K, Oyamada C, Sato Y, Danno H, Kimiya T, Kaneniwa M, Kunitake H, Muraoka T. Relationships between quality parameters and content of glycerol galactoside and porphyra in dried laver nori *Porphyra yezoensis*. *Fisheries Sci.* 74: 167–173 (2008)
- Kim JB, Lee W-C, Hong S, Shim JH, Park J-I, Park J, Lee EG. Relationship between environmental characteristics and pigment composition and concentrations of *Porphyra yezoensis* Ueda in the southwestern coast of the Korean peninsula. *Korean J. Environ. Biol.* 30: 200–209 (2012)
- Son S, Choe E. Toasting effects on the lipid oxidation, antioxidants, and pigments of dried laver (*Porphyra* spp.). *Korean J. Food Sci. Technol.* 46: 677–681 (2014)
- Farvin KHS, Jacobsen C. Phenolic compounds and antioxidant activities of selected species of seaweeds from Danish coast. *Food Chem.* 138: 1670–1681 (2013)
- Zhou Z, Blanchard C, Helliwell S, Robardsa K. Fatty acid composition of three rice varieties following storage. *J. Cereal Sci.* 37: 327–335 (2003)
- Moreira RG, Sun X, Chen Y. Factors affecting oil uptake in tortilla chips in deep-fat frying. *J. Food Engineering* 31: 485–498 (1997)
- Fasina OO, Colley Z. Viscosity and specific heat of vegetable oils as a function of temperature: 35°C to 180°C. *Int. J. Food Prop.* 11: 738–746 (2008)
- Chung J, Lee Y, Choe E. Effects of sesame oil addition to soybean oil during frying on the lipid oxidative stability and antioxidants contents of the fried products during storage in the dark. *J. Food Sci.* 71: C222–226 (2006)
- Alireza S, Tan CP, Hamed M, Che Man YB. Effect of frying process on fatty acid composition and iodine value of selected vegetable oils and their blends. *Int. Food Res. J.* 17: 295–302 (2010)
- Choe E, Lee J. Thermooxidative stability of soybean oil, beef tallow, and palm oil during frying of steamed noodles. *Korean J. Food Sci. Technol.* 30: 288–292 (1998)
- Ha D-O, Park CU, Kim M-J, Lee JH. Antioxidant and prooxidant activities of β -carotene in accelerated autoxidation and photosensitized model systems. *Food Sci. Biotechnol.* 21: 607–611 (2012)
- Schroeder MT, Becker EM, Skibsted LH. Molecular mechanism of antioxidant synergism of tocotrienols and carotenoids in palm oil. *J. Agric. Food Chem.* 54: 3445–3453 (2006)