Combined effects of processing method and black garlic extract on quality characteristics, antioxidative, and fatty acid profile of chicken breast

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ABSTRACT The combined effects of pretreated black garlic (**BG**) extract and various cooking methods were investigated. The chicken breast was prepared at a uniform size of 5 × 5 × 1.5 cm and randomly allocated into 12 treatment groups that were placed in solutions containing fresh BG extract (1:4, w/v) (positive control), distilled water (negative control), oven-dried BG, and encapsulated BG extract. They were subjected to cooking via sous-vide (**SV**), boiling, and retorting, for 1 h. Both the BG extract and the different cooking methods modified the physicochemical, antioxidative, and fatty acid profiles of the chicken breast. The antioxidative value was 1.83 to 11.59 times higher than the negative control, with extensive protection from lipid oxidation observed in the oven-dried BG extract, compared the fresh BG treatment. The maltodextrin-encapsulated extract prolonged the protection of the antioxidant BG compounds under high-temperature cooking, and thus, produced the highest antioxidative values. The increase in SFA percentage is a consequence of high-temperature cooking, mainly from the increased proportion of palmitic and stearic acids. A higher percentage of monounsaturated fatty acids and polyunsaturated fatty acids was observed under the SV cooking treatments that had BG extract prepared at any pretreatments. The BG lightly protected the linoleic acid during the retorting process. The BG extract treatment improved meat quality by lowering cooking loss (**CL**), improving water holding capacity (**WHC**), and provided better visual attributes. This study suggests that an appropriate cooking method, together with the addition of oven-dried BG extract in an either raw or encapsulated form, can improve the functional quality of chicken breast.

Key words: chicken breast, black garlic, antioxidative status, fatty acid profile, meat quality

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INTRODUCTION

In the midst of steadily increasing poultry meat consumption worldwide, meat products enriched with natural health-promoting materials have gained increasing attention and a surge of development, to meet consumer demands for functional foods. The pivotal characteristic of functional foods is that consumption of these benefit human health, without any side effects (Utama et al., 2019). In recent decades, the meat industry has moved toward fulfilling healthy food objectives by functionality enhancing commonly consumed meat products with natural materials that are rich in carotenoids, polyphenols, or polysaccharides; to improve antioxidative properties, lower potential health risks, and include health-promoting factors such as anti-inflammation, antidiabetic, and anticancer components (Hathwar et al., 2012; Barido et al., 2020; Frasao et al., 2021). In addition to health benefits, the direct incorporation of natural antioxidants to meat helps to maintain a protective effect against lipid oxidation, thus reducing its deteriorative effects and extending shelf life (Huang et al., 2011; Packer et al., 2015; Menegali et al., 2020).

Black garlic (**BG**) is a product with excellent antioxidant properties. It is manufactured from garlic (*Allium sativum*) under controlled temperature (60−90°C), humidity (60−80%), and airflow, over specific durations (21−72 d) (Lee et al., 2010; Lei et al., 2012). These process change the consistency and nutritional content, reducing the odors, and enhancing the sweetness and has stronger antioxidative properties than fresh garlic (Zhang et al., 2016; Kimura et al., 2016). Studies on both cell and animal models have revealed that the strong antioxidative properties of BG extract can be attributed to the upregulation of reducing power, DPPH, ABTS, hydroxyl radical, and nitrite scavenging activities (Ryu et al., 2017). The bioactive compounds

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altered from fresh garlic include allicin, alliin, and deoxidized alliin; which are transformed into sulfur-containing substances such as S-allyl cysteine and S-allyl mercapto cysteine—responsible for the properties described above (Corzo-martinez and Villamiel, 2007; Yuan et al., 2016). In addition, the Maillard reaction, which takes place during processing, increases the concentrations of total phenolic acid, flavonoids, 5-hydroxymethylfurfural, melanoidins, and thiosulfinate in BG (Choi et al., 2014; Zhang et al., 2016). Despite all these health-promoting benefits, literature on the direct incorporation of BG extract with poultry products, especially chicken, is still limited.

Ready-to-eat (**RTE**) products have been introduced to modern society as an innovation that solves the problem of excessive meal preparation times. The increasing economic growth in developed and developing countries urges people to adapt to a rapidly prepared meal culture that requires less preparation time (Lee et al., 2014). Sous-vide (**SV**) cooking and retorting are among the cooking methods adopted by the meat industry for the preparation of RTE products. Sous-vide utilizes vacuum-sealing to cook raw meat under precisely controlled temperatures, generally in the low-temperature range of 60 to 80°C at the determined time (Baldwin, 2012). While retorting utilizes a retort pouch that is subjected to high temperature-high pressure cooking at 121.1°C and 1.5 kgf/cm^2 for specific durations (Kang et al., 2010). Studies have been conducted to evaluate the nutritional content, organoleptic properties, and quality of poultry meat products after subjecting them to different cooking methods and comparing the results with those of conventional methods (Jeong et al., 2020; Kim et al., 2020; Park et al., 2020). Each cooking method produced chicken meat with specific advantageous and disadvantageous characteristics.

The combined effect of cooking and antioxidant-rich spices on the fatty acid profile and antioxidative status of chicken breast is still uncertain because of variations in experimental results (Janiszewski et al., 2016; Werenska et al., 2021). To provide sufficient information concerning direct incorporation of chicken meat which is high in protein level, lower fat content and high polyunsaturated fatty acid (**PUFA**) (Park et al., 2020) with natural antioxidants, this study proposed the utilization of pretreated BG extract with different cooking methods, determining their combined effects on the characteristic quality, fatty acid profile, and antioxidative status of chicken breast. The results of the current study are expected to provide an overview of the cooking methods that optimize the antioxidative effects of BG extract.

MATERIALS AND METHODS

Phenolic Extract Preparation

Black garlic with 66.70 ± 0.13% moisture content was obtained from Haenafood Co.(Seoul, South Korea)—product serial number: 20160506929-1. Antioxidant activity and phenolic compounds were measured and are presented in Table 2. The phenolic extract preparation from BG was performed according to the method described by Kimura et al. (2016), with minor modifications. After peeling and grinding, predetermined dry base weights of BG were mixed with 10 volumes of distilled water, blended, and subjected to hot water extraction in a water bath at 80°C for 1 h. The solutions were allowed to stand in a chill room at 4 ± 2°C for another 1 h and subsequently filtered using Whatman filter paper number 1. The solution containing the phenolic extract of BG was used as a positive control in subsequent analysis. Oven-dried BG (180°C, 15 min) was selected for its better antioxidative profiles and phenolic compounds, compared to that of freeze-dried BG—analyzed during a pilot experiment (data not shown). In addition, considering the vulnerability of phenolic extracts to oxidation and high temperatures (Ray et al., 2016), encapsulation was performed, wherein maltodextrin was chosen as the coating material, due to its extensive capacity to protect the antioxidative compounds of the BG extract (data not shown). The encapsulation method was based on a method by Ballesteros et al. (2017). Briefly, 100 mL of BG extract solution was mixed with 20 g of maltodextrin (5:1, v/w) in a homogenizer at 6,500 rpm for 1 min. Homogenized solutions were then subjected to gradual freezing at −24°C for 6 h, −70°C for another 18 h to dry into powder.

Sample Preparation

Skinless chicken breasts, the *pectoralis major* muscle (Ross, 4-wk-old, 24 h postmortem), were prepared in three batches of three replicates, to investigate the effect of each treatment. A total of 86 samples were cut into a uniform size of 5 × 5 × 1.5 cm with a weight of (53 ± 2 cm) in the chill room at 4 ± 2°C. Prepared chicken breasts were randomly allocated into 12 treatment groups of pretreated BG extract and different cooking methods as seen in Table 1. To investigate the effect of pretreated BG extract, each breast sample was randomly assigned to one of four treatment solutions (1:4, w/v): a negative control with distilled water, a positive control with fresh BG extract solution, or an oven-dried and encapsulated BG extract. Each treatment group consisted of nine chicken breast samples. For the cooking method, the conventional boiling method at 100°C for 1

Table 1. Experimental design and total sample number for each treatment.

		Cooking method		
Sample	Black garlic	Sous-vide	Boiling	Retorting
Chicken breast	NC	9	9	9
	PC	9	9	9
	ODBG	9	9	9
	MEBG	9	9	9

Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.

h was used as the control, and SV and retorting were set as treatments. In SV cooking, after the chicken breast samples were packed into a nylon-polyethylene bag, they were vacuum-packed and cooked in a water bath at 80°C for 1 h. In the retorting treatment, chicken breast samples were inserted into a retort pouch made from polyethylene terephthalate and cooked at 121.1°C and 1.5 kgf/cm^2 for 1 h.

Proximate Composition

The Association of Official Analytical Chemists (**AOAC,** 2012) method was used to determine the proximate composition of chicken breast samples. The moisture content was determined from a 1 g sample by calculating weight loss after oven drying at 105°C for 24 h. Crude protein percentage was measured according to the Kjeltec system procedure (2200 Kjeltec Auto Distillation Unit, Foss, Hillerød, Denmark). Crude fat was extracted through a dietary ether solution and Soxhlet extraction for 48 h. Crude ash content was determined after burning in a muffle furnace (LEF-115S, Daihan Labtech Co., Ltd., Namyangju, Korea) at 550°C. All analyses were performed in triplicate.

Meat Surface Color

Meat color was determined at five different locations throughout the unfilmed chicken breast surface after cooling in the chill room at 4 ± 2°C for 30 min using a Chroma meter (CR-400, Konica Minolta Sensing, Osaka, Japan). The Chroma meter (8-mm aperture size) calibration was set according to the protocol of Commission International de l'Eclairage (1978) for lightness (CIE L∗), redness (CIE a∗), and yellowness (CIE b∗), using a white plate (2° observer; Illuminant C: Y = 93.6, x = 0.3134, y = 0.3194).

pH

The pH value was measured in triplicate on chicken breast slurry samples, after homogenization of 5 g with 45 mL of distilled water in a homogenizer (PH91; SMT Co., Ltd., Tokyo, Japan). Steadily stirred slurry samples were measured using a pH meter probe (Seven Easy pH; Mettler-Toledo GmbH, Schwerzenbach, Switzerland) that had previously been calibrated.

Water Holding Capacity

A centrifugation method (Kristensen and Purslow, 2001) was used to determine the percentage of water holding capacity (**WHC**) after treatment. Thrity minutes after cooking, five grams of the sample was placed in a centrifuge tube set with a wire mesh and heated in a water bath at 75°C for 30 min. The samples were directly immersed in ice water for another 10 min and centrifuged (CS-6R Centrifuge; Beckman Instruments Inc., Hialeah, FL) at 980 × g for 10 min. The WHC percentage was obtained by calculating the ratio of the total moisture content to the remaining water volume recorded.

Cooking Loss

Cooking loss represents the product yield after cooking and was determined by calculating the sample weight before and after being subjected to the cooking ((W1-W2)-W1). Cooking loss analyses were conducted in triplicate.

Shear Force Value

After adding phenolic extract to the chicken breast samples in plastic bags and letting them stand for 45 min, they were subjected to different processing methods, as previously described. The shear force value analysis was performed in triplicate using a TA-XT2i Plus (Stable Micro Systems, Surrey, UK). Briefly, cooked samples were prepared at the uniform size of 1.5 × 1.5 cm, placed under the V blade parallel with the myofibrils orientation. In order to avoid the high variety of measurement due to the possible hardening that occurs toward the outside cooked edge of the sample, the assay was performed once on the interior of each samples. The cooked breast sample was subsequently cut with a constant speed (assay parameters were: pretest speed: 2.0 mm/s; test speed: 1.0 mm/s; posttest speed: 10 mm/s).

Lipid Oxidation

The 2-thiobarbituric acid reactive substances (**TBARS**) method was used to quantify the malondialdehyde concentration at the same day following treatments. Briefly, after 30 min resting in the chill room at 4 ± 2°C chicken breast samples (0.5 g) were prepared in triplicate in a 25-mL TBARS test tube, with the addition of antioxidant mixture (0.1 g). Three milliliters of 1% TBA in 0.3% NaOH was added to the mixture, it was then vortexed, followed by the addition of 17 mL of 2.5% trichloroacetic acid in 36 mM HCl. After the tubes were sealed, they were heated in a water bath (BW-20G, Biotechnical Services, North Little Rock, AR) at a temperature of 100°C for 30 min. The tubes were directly immersed in ice water once heating was completed. Every 5 mL of aqueous sample was moved to a new 15 mL conical tube and mixed with 3 mL of chloroform. The mixtures were subsequently subjected to centrifugation at 2,400 × g for 30 min at 4°C (1248R, Labogene, Lynge, Denmark), and the absorbance was recorded at 532 nm using a UV spectrophotometer (UV-mini 1240 PC, Shimadzu, Kyoto, Japan) and compared against a blank.

Antioxidant Activities

The antioxidant activities of chicken breast samples were evaluated in triplicate using DPPH and ABTS assays, according to the method described by

Islam et al. (2016). Trolox was used as a standard and the results were expressed as a scavenging percentage.

Fatty Acid Composition

A gas chromatography (**GC**)/flame-ionization detection instrument (6890 N, Agilent Technologies, CA) with an autosampler (7683, Agilent Technologies) was used to determine the fatty acid composition in the present study. Initially, finely ground samples (20 g) were extracted in duplicate according to Folch et al. (1957) with a chloroform-methanol (2:1 v/v) solution. Methylation to convert fatty acids into methyl esters was performed using 25% boron trifluoride in methanol at 80°C for 1 h. Fatty acid methyl esters were subsequently mixed with 1.5 mL hexane and 1 μL of the sample was injected into the GC port using an autosampler. The injector temperature was set at 250°C with a 100:1 split ratio. Fatty acid methyl esters were separated using a WCOT-fused silica capillary column (100 m × 0.25 mm i.d., 0.20-μm film thickness; Varian Inc., CA) with a 1.0 mL/min helium flow. The detailed program of the oven was: 150°C/1 min, 150 to 200°C at 7°C/min, 200°C/5 min, 200 to 250°C at 5°C/min, and 250°C/10 min. The detector temperature was 275°C. Fatty acids were identified by comparing the identified peaks with the retention time of fatty acid standards (47,015-U, Sigma-Aldrich, MO). The peak area of each identified fatty acid was used to calculate the proportion (%) of the total identified peak area.

Statistical Analysis and Experimental Design

To compare the effect from different processing method and black garlic extracts, this study utilized the factorial design, wherein the obtained data were analized using two-way multivariate analysis of variance (**MANOVA**) using R-version 3.6.1 (The R-foundation for Statistical Computing, Vienna, Austria), with respect to treatments and cooking methods. The significant mean value of each group was continuously analyzed using Duncan's multiple range test, with significance considered significant at *P*-values lower than 0.05.

RESULTS AND DISCUSSION

Antioxidant Activity of BG Extract

The antioxidant activity and total phenolic compounds were measured and are presented in Table 2. The DPPH assay were utilized to measure the antioxidant activity of BG extract, and its suppressing activities were ranging from 42.39 to 63.29%, with the order of antioxidant activities from highest to lowest were oven dried BG, fresh BG and encapsulated BG, respectively. Accordingly, the concentration of phenolic compounds obtained by this study showed similar pattern, wherein oven dried BG had the highest value, followed by fresh BG and encapsulated BG. The phenolic compounds were ranging from 10.30 to 14.40 GAE mg/g. In addition, the moisture content in fresh BG was observed at 66.70% and after subjected to oven drying, its value was declined to 44.99%. The moisture content after encapsulation was at 9.77%. Furthermore, the pH value did not markedly different among pretreatment groups and its value were ranging from 4.67 in oven dried BG to 4.74 in fresh BG and encapsulated BG groups.

The decrease in antioxidant activity was observed after encapsulation with maltodextrin when compare to that of fresh BG extract. It possibly caused by the lower quantity of phenolic compounds exist in maltodextrin encapsulated sample at normal temperature (Lavelli, Harsha and Spigno, 2016). The result of present study confirms finding by Ballesteros et al. (2017), in which the antioxidant activities of phenolic extract from spent ground coffe was decreased after subjected to encapsulation with maltodextrin and gum arabic. However, after exposure to high temperature, the antioxidant compounds could be retained at 63 to 72% from its initial concentration. The encapsulation efficiency is also strongly depending on the coating material used (Mahdavee, Jafari, Ghorbani and Kakhki, 2014; Ray et al., 2016).

Proximate Composition

The moisture content was strongly influenced by both the cooking method and BG treatment ($P < 0.001$). As shown in Table 3, the addition of BG extracts, regardless of pretreatment, significantly modified the moisture content by increasing its percentage in all processing methods except the retorting group. Although a slight effect of encapsulated BG extract on moisture content was observed, compared to the negative control in the SV and boiling groups, the encapsulated BG extract treatment retained the highest moisture content among treatments during retorting ($P < 0.001$). No marked difference in moisture content was found between the fresh and oven-dried BG extract treatments with any processing method ($P > 0.05$). In addition, with respect to the

Table 2. Antioxidant activities and phenolic acids of black garlic extract subjected to different pretreatments.

	Fresh black garlic	Oven dried black garlic	Encapsulated black garlic	SEM[1)]
Moisture (%)	66.70	44.99	9.77	0.08
Ph	4.74	4.67	4.74	0.02
TPC (GAE mg/g)	14.4	15.34	10.30	0.51
DPPH (%)	60.83	63.29	42.39	2.21

Abbreviations: TPC, total phenolic compounds expressed as gallic acid equivalent mg/g.
[1]SEM, standard error of the mean

Table 3. Proximate composition of chicken breast subjected to black garlic and different cooking method

Variable	BG	Cooking method			*P*-value		
		Sous-vide	Boiling	Retorting	BG	Cooking	BG × cooking
Mositure (%)	NC	69.40^{b,A}	67.05^{b,B}	65.24^{c,C}	<0.001	<0.001	<0.001
	PC	70.18^{a,A}	68.60^{a,B}	65.35^{b,c,C}			
	ODBG	70.23^{a,A}	69.23^{a,A}	65.73^{b,C}			
	MEBG	69.91^{a,b,A}	68.34^{a,b,B}	66.31^{a,C}			
Crude fat (%)	NC	2.39^{C}	3.03^{B}	3.20^{A}	<0.001	<0.001	<0.001
	PC	2.43^{B}	2.81^{A}	2.92^{A}			
	ODBG	2.34^{C}	3.41^{B}	3.85^{A}			
	MEBG	2.15^{C}	3.38^{B}	4.83^{A}			
Crude ash (%)	NC	0.80	0.79	0.81	0.45	0.38	0.41
	PC	0.78	0.79	0.80			
	ODBG	0.79	0.80	0.79			
	MEBG	0.82	0.81	0.81			
Crude protein (%)	NC	26.91	27.78	27.63	0.09	0.07	0.08
	PC	26.70	27.76	27.13			
	ODBG	26.55	27.16	27.76			
	MEBG	26.62	27.81	27.47			

Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.
$^{a-c}$Means within the same column are significantly different among BG treatment ($P < 0.05$).
$^{A-C}$Means within the same row are significantly different among cooking methods ($P < 0.05$).

cooking method, SV cooking produced a chicken breast with significantly higher moisture content than that of the boiling and retorting groups ($P < 0.001$); with the lowest moisture percentage observed in chicken breast samples cooked under retorting. Conversely, high-temperature and high-pressure cooking produced chicken breast with a higher fat percentage than low temperature cooking ($P < 0.001$). No remarkable differences were found in crude protein and crude ash percentages after cooking or BG treatments. The cooking method plays a significant role during the processing stages, by altering the physicochemical composition and the inner meat environment. It determines the evaporation rate of moisture, degradation of proteins and lipids through heating, and the Maillard reaction (Werenska et al., 2021). A significant increase in moisture content is congruent with the results in Dominguez-Hernandez et al. (2018), who utilized vacuum-sealed and low-cooking temperatures to inhibit water loss from evaporation. On the other hand, high-temperature cooking may lead to higher water loss and the degradation of lipids and proteins, which consequently modifies the nutritional content of chicken breast (Suleman et al., 2020).

Meat Surface Color

The different cooking methods applied resulted in the distinct appearance of meat surface colors, as presented in Table 4. The lightness value was highest in the chicken breast group cooked under SV conditions, followed by boiling and retorting ($P < 0.001$). Retorting produced the lowest lightness values among the samples. In contrast, chicken breast samples cooked under high-temperature conditions showed significantly more intensely red and yellow surface color profiles ($P < 0.001$). Regarding BG extract additions, chicken breast samples were shown to be darker in color after treatment with any cooking method, regardless of pretreatment (P

Table 4. Meat surface color of black garlic chicken breast affected by encapsulation and processing stage.

Variable	BG	Cooking method			*P*-value		
		Sous-vide	Boiling	Retorting	BG	Cooking	BG × cooking
CIE L*	NC	81.45^{a,A}	79.05^{a,B}	74.92^{a,C}	<0.001	<0.001	<0.001
	PC	78.87^{b,A}	74.55^{b,B}	69.36^{b,C}			
	ODBG	76.06^{c,A}	74.64^{b,B}	70.37^{b,C}			
	MEBG	76.07^{c,A}	74.65^{b,B}	70.08^{b,C}			
CIE a*	NC	2.52^{b,B}	2.45^{c,B}	3.01^{c,A}	<0.001	<0.001	<0.001
	PC	3.71^{a,B}	3.74^{b,B}	4.61^{b,A}			
	ODBG	3.52^{a,B}	3.06^{b,C}	4.12^{b,A}			
	MEBG	3.81^{a,C}	4.66^{a,B}	5.66^{a,A}			
CIE b*	NC	2.52^{b,C}	15.66^{c,B}	21.87^{c,A}	<0.001	<0.001	<0.001
	PC	3.71^{a,C}	20.85^{b,B}	28.01^{b,A}			
	ODBG	4.12^{a,C}	20.56^{b,B}	26.62^{b,A}			
	MEBG	3.81^{a,C}	26.42^{a,B}	30.71^{a,A}			

Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.
$^{a-c}$Means within the same column are significantly different among BG treatment ($P < 0.05$).
$^{A-C}$Means within the same row are significantly different among cooking methods ($P < 0.05$).

< 0.001). In contrast, BG extract additions to chicken breast resulted in a significantly higher redness and yellowness values under SV-cooking, while its value was highest in the encapsulation group under boiling and retorting conditions ($P < 0.001$). There was a significant interaction between the BG extract and cooking methods ($P < 0.001$).

The lightness value of the negative control was within the range of a previous study by Park et al. (2020), at 81.2 to 83.5, for chicken breast cooked by SV. In the retorting treatment, the value was within the range of a previous study by Kim et al. (2020). The color of white meat changes differently than that of red meat, where an increase in cooking temperature alters the myoglobin profile, thus resulting in lower red and higher yellow values (Suleman et al., 2020). In white meat, due to the lower myoglobin pigment, the Maillard reaction plays a more significant role in determining the meat surface color, creating a brownish red color through the biochemical interactions that take place under high temperatures (Hunt et al., 1999; King and Whyte, 2006). The lower lightness value in the BG-treated groups might have been caused by the brown-black color of the phenolic extract solution that penetrated the meat. In addition to its potential for improving food functionality, the unique color of the phenolic extract solution from plants and spices may affect the visual attributes of the meat (Jin et al., 2015)

pH Value

The pH values after treatment are presented in Table 5—all samples of the chicken breast were considered normal (Barido et al., 2020). Meat samples subjected to treatment with BG extract, regardless of pretreatment, had significantly lower pH value than that of the negative control for all cooking methods ($P <$ 0.01). In addition, under conventional boiling and retorting, the pH values in chicken breast samples treated with encapsulation were the lowest, followed by those in the positive control, oven-dried, and negative control. Under the conventional boiling treatment, the pH value of the negative control group was 6.63, and its value did not differ much from that of the SV cooking treatment, in which it was 6.67. The pH was the highest in the retorting treatment, at 6.79. In addition, a slightly different pattern was observed in the BG-treated groups, in which the order of pH value was highest in the negative control, followed by SV cooking, boiling, and retorting ($P < 0.001$).

The lower pH value after treatment with the BG extract can be attributed to the low pH value of the BG extract solution. After being subjected to several pretreatments, the pH value of the black garlic extract used in this study ranged from 4.67 to 4.74. In terms of cooking method, this study confirms the findings of Lee et al. (2021), who did not find any significant differences between conventional cooking and SV cooking. However, the pH for the negative control in the boiling treatment was slightly higher than that of Park et al.'s (2020), who applied a convection oven cooking method as a control. Generally, pH values are indicative of the biochemical reactions that occur within the meat environment (Juncher et al., 2001; Lonergan et al., 2005). It is the first indicator of meat quality attributes, including water retention ability (Barbut et al., 2005), visual attributes, texture properties, and the physicochemical state inside the meat (Honikel et al., 1986). Low pH values are unfavorable for the meat industry. It is a sign of excessive protein denaturation (Huff-Lonergan and Lonergan, 2005), and is associated with meats with low water retention capacity, tougher textures, and lower cooking yields after cooking (Barido et al., 2021).

Table 5. Quality charactestics of chicken breast subjected to black garlic and different cooking method.

Variable	BG	Cooking method			*P*-value		
		Sous-vide	Boiling	Retorting	BG	Cooking	BG × cooking
pH	NC	$6.67^{a,B}$	$6.63^{a,B}$	$6.79^{a,A}$	<0.01	<0.001	<0.001
	PC	$6.55^{b,B}$	$6.54^{b,B}$	$6.75^{b,A}$			
	ODBG	$6.56^{b,B}$	$6.52^{c,B}$	$6.75^{b,A}$			
	MEBG	$6.50^{b,B}$	$6.49^{c,B}$	$6.71^{c,A}$			
WHC (%)	NC	80.49^{A}	67.51^{B}	$66.49^{b,B}$	0.09	<0.01	0.25
	PC	81.55^{A}	70.87^{B}	$76.93^{a,B}$			
	ODBG	82.16^{A}	69.69^{B}	$75.23^{a,B}$			
	MEBG	84.29^{A}	74.00^{B}	71.98^{AB}			
Cooking loss (%)	NC	21.12^{C}	29.05^{B}	$35.03^{a,A}$	<0.05	<0.05	0.41
	PC	21.98^{C}	28.79^{B}	$32.88^{b,A}$			
	ODBG	19.87^{C}	28.70^{B}	$32.01^{b,A}$			
	MEBG	19.82^{C}	29.01^{B}	$31.97^{b,A}$			
Shear force value (kgf)	NC	1.82^{B}	2.01^{A}	1.47^{C}	0.09	<0.05	0.08
	PC	1.81^{B}	1.99^{A}	1.45^{C}			
	ODBG	1.83^{B}	1.97^{A}	1.44^{C}			
	MEBG	1.82^{B}	1.96^{A}	1.46^{C}			

Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.

$^{a-d}$Means within the same column are significantly different among BG treatment ($P < 0.05$).

$^{A-C}$Means within the same row are significantly different among cooking methods ($P < 0.05$).

Cooking Loss, Water Holding Content, and Shear Force Values

A greater WHC after treatment with BG extract was not observed in the retorting group, wherein the BG-treated groups possessed a distinctly higher WHC compared to the negative control ($P < 0.05$). The WHC in the negative control ranged from 66.49 to 80.49%, with a higher percentage recorded in the chicken samples cooked under SV conditions, and the lowest values from both boiled and retorted samples ($P < 0.01$). A similar trend was observed for cooking loss, as presented in Table 5, in which chicken breast samples with BG extract and cooked by retorting had a significantly lower CL percentages compared to that of the negative control ($P < 0.05$), regardless of pretreatment. Regarding the cooking method, as expected, chicken breast samples cooked under SV conditions resulted in a significantly lower CL than the other cooking methods, with the highest cooking loss observed from retorting ($P < 0.05$).

The shear force measurements of the chicken breast samples used in this study were in agreement with those reported by Lee et al. (2021) for breast meat cooked under SV conditions. Similarly, the shear force values from retorted meat ranged from 1.44 kgf to 1.47 kgf, within the normal range reported by Kim et al. (2020), and slightly higher than those reported by Jeong et al. (2020) for breast meat of Korean chicken soup. In addition, chicken breast cooked under retorting conditions was significantly more tender; followed by SV, cooking, and boiling ($P < 0.05$). Chicken breasts cooked using the conventional boiling method had the highest shear force values, indicating a tougher texture. Furthermore, there was no significant improvement in tenderness after the addition of BG extract, for any cooking method, compared to the negative control. Tenderness is an important attribute that the meat industry is trying to maintain, due to its role in providing satisfaction from eating; along with flavor and nutritional content (Barido et al., 2020).

In addition, meat tenderness is highly correlated with other economically important attributes, such as CL and WHC. The significantly lower CL and higher WHC in the SV-treated groups can be explained as an effect of vacuum-sealed cooking, which reduces any unwanted water evaporation and thus retains more water within the meat (Dominguez-Hernandez et al., 2018). In addition, it is another mechanism by which low-temperature cooking inhibits rapid protein coagulation, which creates a tough texture and reduces cooking yield (Choi et al., 2019). On the other hand, higher tenderness after high-temperature processing might be due to the breakdown of actomyosin linkages that form postmortem (Spudich, 2001), thus releasing free actin (Okitani et al., 2009) and altering the structure of protein in beneficial ways (Barido et al., 2021). Chicken meat with greater WHC, lower CL, and more tender characteristics, but less developed flavors are mostly produced by SV cooking. Retort cooking develops flavor through the Maillard reaction (Tornberg et al., 2005; Warner et al., 2017).

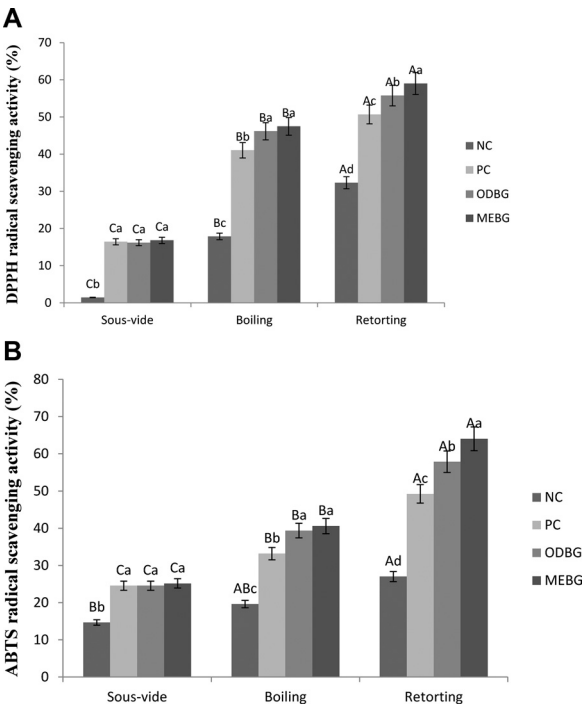

Figure 1. (A) 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity of chicken breast subjected to black garlic and different cooking method. (B) 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging activity of chicken breast subjected to black garlic and different cooking method. Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.

Addition of BG extract into meat products were studied and reported to not impart adverse effects on textural, flavor and overall acceptance of the pork meatbalss (Jin et al., 2010), pork sausage (Shin et al., 2011), and duck nuggets (Lishianawati et al., 2021). However, the basic dark-brown color from the BG extract could penetrate into muscle, causing the dark surface color and thereby lower color acceptances (Ryu and Kang, 2017; Lishianawati et al., 2021).

Antioxidant Activities and Lipid Oxidation

Figure 1 presents the antioxidant activity measured by DPPH and the ABTS radical scavenging activity on the chicken breast samples, to which BG extract was added before cooking. Treatment of meat samples with BG extract, regardless of pretreatment, significantly improved the antioxidant potential measured by DPPH assay for all cooking methods ($P < 0.001$). The antioxidant activity of BG treated groups was 1.83 to 11.59 times higher than the negative control, while SV cooking had the greatest improvement. Meanwhile, the highest antioxidant activity, measured by the DPPH assay, found 59.00% scavenging activity in the maltodextrin-encapsulated group after retort cooking. A similar pattern was confirmed using the ABTS assay. The antioxidant activity was increased up to 1.71 to 2.37 times higher than the negative control ($P < 0.01$),

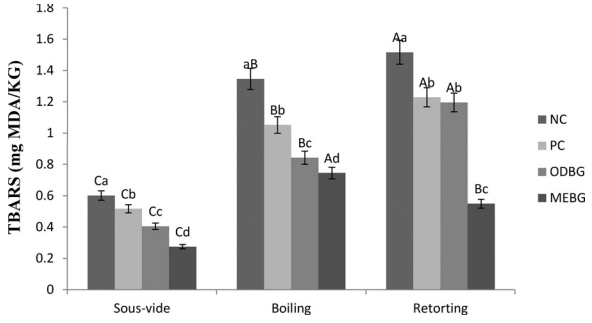

Figure 2. Lipid oxidation rate of chicken breast subjected to black garlic and different cooking method. Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.

with the highest scavenging activity recorded in the maltodextrin encapsulated group subjected to retorting, with 64.05% scavenging activity. The oven-dried group had significantly higher antioxidant activity compared to the positive control using fresh garlic extract measured by both DPPH and ABTS assays at any cooking time except SV.

The malondialdehyde (**MDA**) content quantified by the TBARS assay on the chicken breast samples used in this study were significantly affected by the addition of the BG extract, cooking method, and the interaction between the BG extract and cooking method ($P < 0.01$). As seen in Figure 2, regarding BG treatments, the MDA content was significantly suppressed by the addition of extract, regardless of pretreatment for any cooking method, compared to the negative control ($P < 0.05$). Throughout the cooking process, the formation of lipid oxidation products was lowest in the maltodextrin-encapsulated group, followed by the oven-dried, positive control, and negative control groups ($P < 0.001$). The limited effect was recorded between oven-dried and positive controls during retort cooking ($P > 0.05$). On the other hand, higher cooking temperatures seemed to increase the lipid oxidation rate in chicken breast, wherein the lowest TBARS value was observed for SV cooking, followed by boiling and retorting, respectively ($P < 0.01$). Black garlic has excellent antioxidative properties. It is manufactured from garlic (*Allium sativum*) under controlled temperature, humidity, and airflow over a specific duration (Lee et al., 2010; Lei et al., 2012), thus changing its consistency and nutritional content and enhancing its antioxidative properties, compared to fresh garlic (Zhang et al., 2016; Kimura et al., 2016). Studies have revealed that BG extract has strong antioxidative properties through the upregulation of reducing power, DPPH, ABTS, hydroxyl radical, and nitrite scavenging activities, making it promising for direct incorporation into meat products (Ryu and Kang, 2017; Sun and Wang, 2018). The stronger suppression properties of lipid oxidation and higher antioxidative status may also be attributed to the presence of phytochemicals, especially phenols, due to their prominent scavenging activities (Barido et al., 2020; Domínguez et al., 2019).

Fatty Acid Profile

Table 6 displays the fatty acid profiles after treatment with black garlic extract and different cooking methods. The major fatty acids from high to low were C18:1n9 (oleic acid), C16:0 (palmitic acid), C18:2n6 (linoleic acid), C18:0 (stearic acid), and C16:1 (palmitoleic acid). The percentage of monounsaturated fatty acids (**MUFAs**) was the highest, followed by saturated fatty acids (**SFA**), and polyunsaturated fatty acids (**PUFA**s), in the chicken breast samples used in this study. There were significant differences in the fatty acid content of the chicken breast as a result of the different cooking methods, as shown in Table 5 ($P < 0.05$). The SFA percentage was significantly higher with higher cooking temperature, whereas the SV-cooked samples had the lowest SFA among the samples ($P < 0.05$). The

Table 6. Fatty acid profile of chicken breast subjected to black garlic and different cooking method,

	Sous-vide				Boiling				Retorting				*P*-value		
Fatty acids	NC	PC	ODBG	MEBG	NC	PC	ODBG	MEBG	NC	PC	ODBG	MEBG	BG	Cooking	BG × cooking
C14:0	0.92	0.98	0.93	0.92	1.08	1.01	0.98	0.99	1.02	1.02	1.05	1.02	0.16	0.24	0.17
C16:0	23.18^{B}	23.58^{B}	22.87^{B}	22.52^{B}	22.74^{B}	24.37^{B}	23.65^{B}	23.66^{B}	27.22^{A}	25.37^{A}	24.47^{A}	25.68^{A}	0.08	<0.05	0.59
C16:1	4.13	4.52	4.90	4.88	4.73	4.90	4.87	4.90	4.52	5.18	5.24	5.42	0.31	0.12	0.18
C18:0	6.21^{B}	6.18^{B}	6.02^{B}	6.23^{B}	7.59^{A}	7.32^{A}	7.33^{A}	7.30^{A}	7.71^{A}	7.39^{A}	7.48^{A}	7.88^{A}	0.25	<0.05	0.72
C18:1n9	43.22^{A}	43.59^{A}	44.05^{A}	44.10^{A}	42.23^{AB}	42.22^{AB}	41.55^{B}	41.48^{B}	40.92^{B}	41.24^{B}	41.72^{B}	40.17^{B}	0.56	<0.05	0.55
C18:2n6	19.76^{A}	19.02^{A}	19.00^{A}	19.02^{A}	19.46^{A}	18.98^{A}	19.33^{A}	19.35^{A}	$16.19^{b,B}$	$17.31^{a,B}$	$17.40^{a,B}$	$17.35^{a,B}$	0.06	<0.05	0.22
C18:3n6	1.09	1.00	1.02	1.02	1.06	1.03	1.05	1.01	1.24	1.30	1.39	1.22	0.06	0.09	011
C18:3n3	0.68	0.60	0.60	0.57	0.63	0.62	0.64	0.67	0.63	0.66	0.68	0.68	0.45	0.08	0.42
C20:4n6	0.49	0.32	0.38	0.47	0.36	0.30	0.35	0.37	0.35	0.36	0.36	0.36	0.36	0.11	0.39
C22:4n6	0.22	0.21	0.23	0.27	0.23	0.25	0.25	0.27	0.21	0.20	0.25	0.25	0.75	0.66	0.37
SFA	30.31^{B}	30.74^{B}	29.82^{B}	29.67^{B}	31.41^{B}	32.7^{B}	31.96^{B}	31.95^{B}	35.95^{A}	33.78^{A}	33.00^{A}	34.58	0.08	<0.05	0.15
MUFA	47.35^{A}	48.11^{A}	48.95^{A}	48.98^{A}	46.96^{B}	47.12^{B}	46.42^{B}	46.38^{B}	45.44^{B}	46.42^{B}	46.96^{B}	45.59^{B}	0.13	<0.05	0.11
PUFA	22.24^{A}	21.15^{A}	21.23^{A}	21.35^{A}	21.74^{A}	21.18^{A}	21.62^{A}	21.67^{A}	18.62^{B}	19.83^{B}	20.08^{B}	19.86^{B}	0.07	<0.05	0.06

Abbreviations: MEBG, maltodextrin encapsulated black garlic extract; NC, negative control or chicken breast cooked without black garlic extract; ODBG, oven dried black garlic extract; PC, positive control or chicken breast cooked with the addition of fresh black garlic extract.

[a-d]Means within the same column are significantly different among BG treatment ($P < 0.05$).

[A-C]Means within the same row are significantly different among cooking methods ($P < 0.05$).

SFA percentage did not differ between samples cooked by retorting and boiling. The increase in the SFA percentage was mainly due to the increased concentrations of palmitic and stearic acid. This confirms a previous study by Werenska et al. (2021), who found an increase in SFA concentration in goose meat, caused by heat treatment, mainly by an altered proportion of stearic acid. Similarly, a study on Korean chicken soup also revealed increases in stearic acid as a result of extended exposure to high-temperature cooking (Kim et al., 2020). The concentration of C14:0 (myristic acid) SFA was found to be low across treatments. Its high concentration is unfavorable due to its role in cholesterol-raising activity, thus causing hypercholesterolemia (Werenska et al., 2021).

Total MUFA content in SV cooked samples (47.35−48.98%) was markedly higher than that in the boiling (46.38−47.12%) and retorting group (45.44−46.96%; $P < 0.05$). Likewise, the total PUFA in chicken breast samples was significantly higher (21.12−22.24%), along with samples cooked by boiling (21.18−21.74%), compared to that from retorting (18.62−20.08%). The decrease in the percentage of total PUFA was predominantly due to the lower proportion of individual PUFAs, mainly linoleic acid. The change in MUFA was caused by a decreasing percentage of oleic acid during the high-temperature cooking ($P < 0.05$). In terms of BG extract, linoleic acid was observed to have been slightly protected in retort cooking, provided by the addition of BG extract during pretreatment. The linoleic acid concentration was significantly higher in the black garlic treated groups than in the negative control ($P < 0.05$). No other significant effects were observed on the fatty acid profile, after the addition of BG extract to the chicken breast samples used in this study ($P > 0.05$).

The higher percentage of MUFA and PUFA retained under SV cooking might be caused by the lower rates of water evaporation, as SV cooking utilizes vacuum-sealed packaging to cook meat at low temperatures. This confirms the findings of Dal Bosco et al. (2001) and Alfaia et al. (2010), in which fatty acid changes were maintained throughout cooking. Because of water loss, biochemical reactions occur within the meat environment, and lipid oxidation determines fatty acid alterations. The lower proportion of unsaturated fatty acids after high-temperature cooking is mainly a consequence of the higher lipid oxidation rate (Jin et al., 2015), thus altering its carbon chain formation and changing it into other compounds such as benzaldehyde, 2-heptanal, 2-nonenal, and 2-octenal (Kim et al., 2020). Unsaturated fatty acids are more susceptible to heat, as the higher the degree of unsaturation, the less stable they would be, making PUFA the most unstable fatty acid (Larsen et al., 2010). Therefore, the addition of plants and spices rich in antioxidants can sustain the protective effect of unsaturated fatty acids, through the inhibition of lipid oxidation rate (Castroman et al., 2013; Dominguez et al., 2019; Frasao et al., 2021) as has been found in the present study for BG extract.

CONCLUSIONS

The incorporation of BG extract and different cooking conditions modified the physicochemical, antioxidative, and fatty acid profiles of chicken breast. The extensive protection from lipid oxidation was observed to be the most effective in the maltodextrin-encapsulated extract through the prolonged protection of antioxidant compounds under high-temperature cooking when compared to fresh BG extract. The BG extract in all the pretreatments applied also lightly protected the linoleic acid under the retorting conditions, whereas the SV group maintained the higher percentage of MUFA and PUFA that might be due to less water loss and the suppression of the lipid oxidation rate. In addition, in terms of cooking methods, the meat samples cooked under SV conditions in this study exhibited lower CL and higher WHC and produced cooked meat with a lighter color. A higher cooking temperature tended to increase the antioxidative status of chicken breast, but reduced WHC, which resulted in lower moisture and cooking yield. Taken together, this study suggests that the addition of BG extract either in a oven dried or encapsulated form, together with an appropriate cooking method, could be an option to improve the functionality of chicken breast.

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DISCLOSURES

The authors no conflicts of interest to report.

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