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Physicochemical and Storage Characteristics of Pork Tteokgalbi Treated with *Boesenbergia pandurata* (Roxb.) Powder

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Abstract: This study investigates the physicochemical and storage characteristics of Tteokgalbi treated with various concentrations of *Boesenbergia pandurata* (Roxb.) powder (BP). BP is constituted mainly of carbohydrates (77.9%), possesses free-radical scavenging activity due to the presence of polyphenol and flavonoids, and is slightly acidic (pH 5.99). Five Tteokgalbi samples were treated with 0 (CON), 0.5% (B1), 1.0% (B2), or 2.0% (B3) of BP or 0.05% of ascorbic acid (REF). Compared to CON, BP-treated Tteokgalbi demonstrated significantly higher carbohydrate content and water-holding capacity and decreased cooking loss (%). BP-treated Tteokgalbi had significantly altered Hunter color properties, with decreased L* and increased b* values. Additionally, BP treatment significantly changed the textural properties by increasing the hardness (B3) and chewiness (B2 and B3) and decreasing the springiness (B3) of Tteokgalbi. Owing to the increased total polyphenol and flavonoid content, BP addition significantly enhanced the DPPH and ABTS radical scavenging activities of Tteokgalbi during vacuum-packed cold storage (0–14 days) at 5 °C. BP-treated Tteokgalbi maintained a higher pH compared to CON, and BP-treatment significantly suppressed 2-thiobarbituric acid, volatile basic nitrogen, and total microbial count during the cold storage period (7 and 14 days). Therefore, BP is a natural, edible antioxidant that may be applied to Tteokgalbi.

Keywords: *Boesenbergia pandurata* (Roxb.); Tteokgalbi; physicochemical characteristics; storage characteristics

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1. Introduction

The environmental, social, and governance (ESG) strategy is as an emerging management strategy in the food industry [1]. In addition, ESG management is expected to increase the use of sustainable ingredients for manufacturing and selling food products. In the food industry, antioxidants are widely used to maintain product value by preventing changes to flavor, decolorization, and rancidity of food during manufacturing, processing, and storage [2]. Synthetic antioxidants, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and propyl gallate, are frequently used in food products to maximize industrial profits [3]. However, consumers have recently tended to pay more attention to the concept of ESG in the food industry, and there is an increasing demand for the use of natural antioxidative components in food products rather than artificial preservatives.

The main differences between natural and synthetic antioxidants are their source and components [4]. Natural antioxidative materials are generally derived from edible plants that possess multiple medicinal and free radical scavenging components such as ascorbic acid, flavonoids, and polyphenols [4–6]. The consumption of naturally edible antioxidants inherently mitigates biological oxidative stress at the cellular level by managing singlet oxygen molecules, hydroxyl radicals, superoxide anions, and hydrogen peroxide [4]. Moreover, plant-based antioxidants possess nutraceutical components, such as polyphenols and flavonoids, which may promote health effects that are not expected with the consumption

of synthetic antioxidants. For example, the consumption of polyphenols (i.e., ellagic acid, quercetin, myricetin, and kaempferol) may alleviate pathological cellular responses in mammals [7], in addition to their innate antioxidative capacities.

Boesenbergia pandurata (Roxb.), also known as *Boesenbergia rotunda* or fingerroot, is a culinary herb that grows in the tropical rainforests of Southeast Asia. *Boesenbergia pandurata* (Roxb.) is generally compared to ginger (*Zingiber officinale*) because of the similarity in classification under identical *Zingiberaceae* families. Both *Boesenbergia pandurata* (Roxb.) and *Zingiber officinale* have antioxidative and antimicrobial properties, and *Boesenbergia pandurata* (Roxb.) has superior antimicrobial activities by suppressing the growth of *Staphylococcus aureus* and *Bacillus cereus* [8]. *Boesenbergia pandurata* (Roxb.) is traditionally used as a folk nutraceutical component in Korea, Thailand, China, and Myanmar [9]. Recently, novel biological functions of *Boesenbergia pandurata* (Roxb.) have been intensively studied, and this has revealed that in addition to its antioxidative properties [8] it has protective effects against weight gain [10] and acute inflammation [11], as well as bacterial [12] and viral infections [13]. The biological functions of *Boesenbergia pandurata* (Roxb.) may be due to innate specific components such as panduratatin A, alpinetin, cardamonin, pinostrobin, pinocembrin, quercetin, naringin, and kaempferol [14,15]. Therefore, *Boesenbergia pandurata* (Roxb.) is a strong natural antioxidant candidate to meet the new demand for ESG management in the food industry.

Tteokgalbi is a traditional meat-based Korean royal court dish. Tteokgalbi is a compound word from "tteok" (meaning rice cake) and "galbi" (meaning rib). The overall manufacturing process, texture, and appearance of Tteokgalbi are similar to those of rice cakes. As with other meat-based products, such as sausages and processed ham, the addition of antioxidants is key to its storage. In the food industry, artificial preservatives, such as nitrite and nitrate, are widely used to maintain the physicochemical properties and lengthen the storage periods of meat products [16]. However, the consumption of artificial preservatives may increase the chances of carcinogenic and/or mutagenic effects in humans [16,17]. By increasing consumer awareness of the side effects of artificial preservatives in meat products, the food industry is seeking to replace artificial preservatives with natural components [18].

Therefore, in the present study, *Boesenbergia pandurata* (Roxb.) powder (BP) was applied to porcine Tteokgalbi as a natural preservative, and its resulting effects on the physicochemical properties and cold storage characteristics were investigated.

2. Materials and Methods

2.1. Preparation of Boesenbergia pandurata (Roxb.)

Boesenbergia pandurata (Roxb.) were purchased in March 2020 from an artificial tropical farm (Jajak Farm, Siheung, Korea). *Boesenbergia pandurata* (Roxb.) was washed with distilled water, and the water was removed using a salad spinner (Windax, Seoul, Korea). The washed *Boesenbergia pandurata* (Roxb.) was cut into ~3 cm in length and frozen quickly in a deep freezer at approximately −70 °C (MDF-U52V, Sanyo, Osaka, Japan). Cut *Boesenbergia pandurata* (Roxb.) was freeze-dried using a freeze dryer (ED 8512, Ilshin, Yangju, Korea) at approximately −70 °C for 72 h. Freeze-dried *Boesenbergia pandurata* (Roxb.) was powdered using an electric grinder (HR2904; Philips Co., Amsterdam, The Netherlands) and BP was stored in a deep freezer at approximately −70 °C. Dried and cut Boesenbergia pandurata (Roxb.) were extracted with 70% ethanol and concentrated by evaporation three consecutive times. After the 3rd concentration, freeze-dried *Boesenbergia pandurata* (Roxb.) were carefully collected and aliquoted in 50 mL conical tubes (SPL, Seoul, Korea) and stored in a deep freezer at approximately −70 °C for further experiments.

2.2. Proximate Composition, Quality Characteristics, and Hunter's Color Properties of Boesenbergia pandurata (Roxb.)

To understand the basic properties of BP, its proximate composition, pH, Brix, and color were measured. The moisture, crude protein, crude fat, and crude ash contents of

BP were assessed according to standard methods [19]. The carbohydrate content (%) was estimated using the following equation:

$$\text{Carbohydrate content (\%)} = 100 - (\text{moisture} + \text{crude protein} + \text{crude fat} + \text{crude ash})$$

Ten grams of BP was dissolved in 100 mL of three-times distilled water and mixed with a stomacher (Stomacher 400 Circulator, Seward, London, UK) for 2 min, and the pH was measured using a pH meter (Mettler Delta 340, Mettler Toledo GmbH, Greifensee, Switzerland). BP color was assessed using previously described methods [20]. The BP solution was filtered using Whatman No.1 filter paper, and the Brix was measured using a saccharometer (PAL-3, Atago Co., Ltd., Tokyo, Japan). The L* (lightness), a* (redness), and b* (yellowness) values of BP were measured using a validated colorimeter (JX-777, Color Techno System Co., Yamato, Japan), as previously reported [19,20].

2.3. Formulation and Preparation of Tteokgalbi

Tteokgalbi was produced using a previously reported method [21], with minor modifications. Boneless fresh pork shoulder meat was purchased from a market (e-mart, Cheongju, Korea), and following removal of the connective tissue and excess fat, the meat was ground using a processor equipped with 8 mm diameter holes (M-12S, Hankook Fujee Industries Co., Hwaseong, Korea). The control (CON) Tteokgalbi was ground pork meat mixed with 2.2% soy sauce, 0.5% tuna liquid, 0.6% salt, 2.2% minced garlic, 0.4% ginger, 3.7% onion, 2.4% white sugar, 3.6% green onion, 3.0% honey, 3.7% apple juice, 0.2% pepper, and 3.5% sesame oil. All ingredients in the CON, except pork, were obtained from CJ Cheiljedang, Seoul, Korea. The reference (REF) and experimental samples were prepared with the addition of ascorbic acid (Sigma-Aldrich, St. Louis, MO, USA) or 0.5, 1.0, or 2.0% of BP (Table 1). All the ingredients for Tteokgalbi were vigorously mixed for ~20 min in a cold room (~4 °C) by hand. Mixtures of Tteokgalbi were molded to a round shape (diameter of 10.0 cm, thickness of 1.2 cm, and weight ~100 g), vacuum packed in nylon/polyethylene film, and stored in cold storage (5 °C) for further designated storage periods (0, 7, and 14 days).

Table 1. Formula of Tteokgalbi treated with *Boesenbergia pandurata* (Roxb.) powder.

Ingredients	Treatments [1] (%)				
	CON	REF	B1	B2	B3
Pork	74.00	73.95	73.50	73.00	72.00
Soy sauce	2.20	2.20	2.20	2.20	2.20
Tuna liquid	0.50	0.50	0.50	0.50	0.50
Salt	0.60	0.60	0.60	0.60	0.60
Garlic	2.20	2.20	2.20	2.20	2.20
Ginger	0.40	0.40	0.40	0.40	0.40
Onion	3.70	3.70	3.70	3.70	3.70
White sugar	2.40	2.40	2.40	2.40	2.40
Green onion	3.60	3.60	3.60	3.60	3.60
Honey	3.00	3.00	3.00	3.00	3.00
Apple juice	3.70	3.70	3.70	3.70	3.70
Black pepper	0.20	0.20	0.20	0.20	0.20
Sesame oil	3.50	3.50	3.50	3.50	3.50
Ascorbic acid	-	0.05	-	-	-
Boesenbergia pandurata (Roxb.) powder	-	-	0.50	1.00	2.00

[1] CON, 0% *Boesenbergia pandurata* (Roxb.) powder; REF, Tteokgalbi with ascorbic acid 0.05% as a positive reference; B1, 0.5% *Boesenbergia pandurata* (Roxb.) powder; B2, 1% *Boesenbergia pandurata* (Roxb.) powder; B3, 2% *Boesenbergia pandurata* (Roxb.) powder.

2.4. Antioxidative Properties of Boesenbergia pandurata (Roxb.) and Tteokgalbi

To determine the antioxidative properties of BP, BP was dissolved in 70% ethanol as 1000, 2000, 4000, and 8000 μg/mL of three-times distilled water and ten grams of each mixed Tteokgalbi sample was dissolved in 100 mL of three-times distilled water and mixed with a stomacher (Stomacher 400 Circulator, Seward, London, UK) for 2 min, and the total polyphenol and flavonoid contents and 2,2-diphenyl-1-pictylhydrazyl (DPPH) and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (ABTS) radical scavenging activities were measured as described previously [4].

2.5. Proximate Compositions of Tteokgalbi

Ten grams of each Tteokgalbi sample was dissolved in 100 mL of three-times distilled water and mixed with a stomacher (Stomacher 400 Circulator). The moisture, crude protein, crude fat, and crude ash contents of the five different formulations of Tteokgalbi were assessed as previously described [20].

2.6. Water-Holding Capacity (WHC) and Cooking Loss of Tteokgalbi

The WHC of five different Tteokgalbi samples was analyzed as described in a previous report [20]. In brief, ~0.5 g from each condition was placed in a filter unit embedded in a conical tube, maintained for 20 min at 80 °C by heating, and then cooled for 10 min at room temperature. Analytical samples were spun at 2000× *g* for 10 min at 4 °C, and subsequently, WHC was calculated based on the altered analytical sample weight. To determine the cooking loss of Tteokgalbi, a ~4 × 4 × 4 cm^3 cube of each analytical sample was vacuum sealed into a polypropylene bag, and then heated in a water bath at 70 °C for 40 min. After cooking, samples were maintained at room temperature for 30 min to determine cooking loss (%). The cooking loss (%) was calculated using the following equation:

$$\text{Cooking loss (\%)} = [(\text{Initial Tteokgalbi sample weight} - \text{Tteokgalbi weight after cooking})/\text{initial Tteokgalbi sample weight}] \times 100$$

2.7. Color of Tteokgalbi before and after Cooking

Colorimetric values of both uncooked and cooked Tteokgalbi were assessed using a previously described method [20]. To minimize bloom time effects, freshly prepared Tteokgalbi had a 20 min bloom time at room temperature. Tteokgalbi was cooked in a pan for 10 min at ~70 °C by rotating front and back at 1 min intervals, and colorimetric parameters (L*, a*, and b*) were measured from the surface of Tteokgalbi.

2.8. Texture Profile Analysis (TPA)

For the TPA analysis, each Tteokgalbi sample was cooked and cooled, as described in the section on cooking loss. TPA values (hardness, springiness, cohesiveness, and chewiness) were determined from the minced ~1 cm^3 cubes using a rheometer (Sun Scientific Co., Ltd., Tokyo, Japan, v 3.0) at a constant table speed of 60 mm/min.

2.9. Storage Characteristics of Tteokgalbi

Ten grams of each Tteokgalbi sample was dissolved in 100 mL of three-times distilled water and homogenized using a stomacher (400 Lab blender, Seward, London, UK). pH values were measured using a calibrated pH meter (WTW InoLab pH 720, Weilheim, Germany). 2-thiobarbituric acid reactive substances (TBA), volatile basic nitrogen (VBN), and total microbial count (TMC) values were measured using well-established in-house methods [20] at 0, 7, and 14 days after storage at 4 °C.

2.10. Statistical Analysis

The data were tested by analysis of variance using the SAS program (2012) with a general linear model, and the differences between treatments or storage periods were analyzed using Duncan's multiple range test. The difference before and after cooking was analyzed using Student's *t*-test.

3. Results and Discussion

3.1. Proximate Composition, pH, Brix, and Colorimetric Properties of BP

The general properties of BP, such as its proximate composition, pH, Brix, and colorimetric properties, are summarized in Table 2. The proximate composition of BP included 2.51 ± 0.05%, 8.90 ± 0.13%, 3.24 ± 0.16%, 4.94 ± 0.17%, and 77.9 ± 0.51% of moisture, crude protein, crude fat, crude ash, and carbohydrates, respectively. Therefore, the main proximate component of BP was carbohydrate; crude protein, ash, and fat were the second, third, and fourth major components, respectively. BP contained 1.67 ± 0.06 g of sugars in 100 g of solution, and the pH of the solution was slightly acidic (5.99 ± 0.06). The colorimetric properties of BP were determined by observing the lightness (L*), redness (a), and yellowness (b), and the observed results were 31.99 ± 7.12, 7.12 ± 0.06, and 17.64 ± 0.26, respectively.

Table 2. Proximate composition, quality characteristics, and Hunter color properties of *Boesenbergia pandurata* (Roxb.) powder.

		***Boesenbergia pandurata* (Roxb.) Powder**
Proximate composition	Moisture	2.51 ± 0.05 [3]
	Crude protein	8.90 ± 0.13
	Crude fat	3.24 ± 0.16
	Crude ash	4.94 ± 0.17
	Carbohydrate [1]	77.9 ± 0.51
pH [4]		5.99 ± 0.07
Brix		1.67 ± 0.06
Color	L* [2]	31.99 ± 7.12
	a* [2]	7.12 ± 0.06
	b* [2]	17.64 ± 0.26

[1] Carbohydrate = 100 − (moisture + crude protein + crude fat + crude ash). [2] L*: lightness, a*: redness, b*: yellowness. [3] Values are expressed as mean ± standard deviation (n = 3). [4] pH and Brix were measured from 10% BP solution.

3.2. Antioxidative Properties of BP

Several edible plants inherently possess radical scavenging activities because they are rich in antioxidative compounds, including vitamin C and polyphenols. To examine the antioxidative capacity of BP, the total polyphenol content (TPC), total flavonoid content (TFC), DPPH radical scavenging, and ABTS radical scavenging activities were assessed. The TPC and TFC of the ethanol extract of BP are presented in Table 3. BP was dissolved in 70% ethanol; therefore, all solution was prepared with the identical vehicle (70% ethanol). BP contained TPC of 172.09 ± 2.43 mg gallic acid equivalent (GAE)/g and TFC of 28.97 ± 1.20 quercetin equivalent (QE)/g. The DPPH and ABTS radical scavenging activities of the ethanol extracts are shown in Tables 4 and 5, respectively. To verify the DPPH and ABTS radical scavenging activities, BHA, BHT, and ascorbic acid were used as positive controls. BHA (1000 μg/mL) scavenged DPPH at 72.32 ± 0.15 and ABTS at 77.51 ± 5.66 %. BHT (1000 μg/mL) also scavenged DPPH at 72.78 ± 0.67 and ABTS at 83.52 ± 2.47 %. Furthermore, 1000 μg/mL of ascorbic acid scavenged 85.03 ± 0.36 of DPPH and 89.25 ± 5.55 % of ABTS radical. BP scavenged DPPH radicals at 13.63 ± 0.69, 20.25 ± 0.39, 32.14 ± 0.93, and 53.31 ± 0.58 in a dose-dependent manner at 1000, 2000, 4000, and 8000 μg/mL, respectively; therefore, the IC_{50} of BP for DPPH radical scavenging activities was estimated as 7367.02 μg/mL. Moreover, BP scavenged ABTS radicals 38.22 ± 1.21, 48.45 ± 0.88, 62.39 ± 0.65, and 82.16 ± 7.17 in a dose-dependent manner at 1000, 2000, 4000, and 8000 μg/mL, respectively; therefore, IC50 of BP for ABTS radical scavenging activities was estimated as 308.15 μg/mL. The extraction solvent for natural materials is important for antioxidative activity. In a previous study, *Boesenbergia pandurata* (Roxb.) had lower antioxidative capacities than *Zingiber officinale Roscoe* by water extraction owing to less elution of polyphenols, flavonoids, and ascorbic acid [8]. However, when an organic

solvent such as ethanol was used for extraction, *Boesenbergia pandurata* (Roxb.) exhibited relatively higher antioxidative capacities than *Zingiber officinale* [8]. In this study, we also used ethanol as an extraction solvent; therefore, our method is suitable for maintaining the higher antioxidative capacities of *Boesenbergia pandurata* (Roxb.).

Table 3. Total polyphenol and flavonoid contents in ethanol extract of *Boesenbergia pandurata* (Roxb.) powder.

	Total Polyphenol Content (mg GAE1 [1]/g)	Total Flavonoid Content (mg QE [2]/g)
Boesenbergia pandurata (Roxb.) extracts	172.09 ± 2.43 [3]	28.97 ± 1.20

[1] GAE: Gallic acid equivalent. [2] QE: Quercertin equivalent. [3] Values are expressed as mean ± standard deviation (n = 3).

Table 4. DPPH radical scavenging activity of ethanol extracts of *Boesenbergia pandurata* (Roxb.) powder.

Sample	Concentration (μg/mL)	DPPH Radical Scavenging Activity (%)	IC_{50} [1] (μg/mL)
Boesenbergia pandurata (Roxb.) extracts	1000	13.63 ± 0.69 [3f4C5]	7367.02
	2000	20.25 ± 0.39 [e]	
	4000	32.14 ± 0.93 [d]	
	8000	53.31 ± 0.58 [3c4]	
BHA [2]	1000	72.32 ± 0.15 [bB]	N/A
BHT [2]	1000	72.78 ± 0.67 [bB]	N/A
Ascorbic acid	1000	85.03 ± 0.36 [aA]	N/A

[1] IC_{50}: Concentration required to reduce 50% of the DPPH radical scavenging activity. [2] BHT: butylated hydroxytoluene; BHA: butylated hydroxyanisole. [3] Values are expressed as mean ± standard deviation (n = 3). [4] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [5] Means ± standard deviation with different superscript capital letters within the same concentration (column) differ significantly by Duncan's multiple range test ($p < 0.05$).

Table 5. ABTS radical scavenging activity of ethanol extracts of *Boesenbergia pandurata* (Roxb.) powder.

Sample	Concentration (μg/mL)	ABTS Radical Scavenging Activity (%)	IC_{50} [1] (μg/mL)
Boesenbergia pandurata (Roxb.) extracts	125	38.22 ± 1.21 [3d4]	308.15
	250	48.45 ± 0.88 [c]	
	500	62.39 ± 0.65 [b]	
	1000	82.16 ± 7.17 [3A5]	
BHA [2]	1000	77.51 ± 5.66 [abA]	N/A
BHT [2]	1000	83.52 ± 2.47 [aA]	N/A
Ascorbic acid	1000	89.25 ± 5.55 [aA]	N/A

[1] IC_{50}: Concentration required to reduce 50% of the DPPH radical scavenging activity. [2] BHT: butylated hydroxytoluene; BHA: butylated hydroxyanisole. [3] Values are expressed as mean ± standard deviation (n = 3). [4] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [5] Means ± standard deviation with different superscript capital letters within the same concentration (column) differ significantly by Duncan's multiple range test ($p < 0.05$).

3.3. Proximate Composition of Tteokgalbi

The proximate composition of Tteokgalbi prepared with different concentrations of BP is presented in Table 6. The moisture content of CON Tteokgalbi was high, and ascorbic acid or BP treatment significantly decreased the moisture content (CON > B1, B2, B3 > REF). The crude protein content in Tteokgalbi was slightly lower in REF and B3 than in the other cultivars. Remarkably, crude fat was lowest in the highest BP group (B3). The reduction of crude protein and fat may be due to the altered recipe of Tteokgalbi since the BP was substituted for pork in the treated groups. Crude ash content was increased in REF and all BP-treated groups compared to CON. The carbohydrate content was lower in

the CON group than in the REF-or BP-treated Tteokgalbi. The increased crude ash and carbohydrate content may be due to the higher amount of crude ash and carbohydrate in BP than in CON.

Table 6. Proximate compositions of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder.

Proximate Compositions	Treatments [1] (%)				
	CON	REF	B1	B2	B3
Moisture	69.89 ± 0.24 [3a4]	63.27 ± 0.40 [c]	67.23 ± 0.78 [b]	67.01 ± 0.36 [b]	65.14 ± 1.02 [bc]
Crude protein	12.08 ± 0.13 [a]	11.85 ± 0.13 [b]	12.20 ± 0.15 [a]	12.22 ± 0.33 [a]	11.88 ± 0.39 [b]
Crude fat	10.73 ± 0.14 [a]	10.15 ± 0.25 [a]	10.70 ± 0.24 [a]	10.56 ± 0.13 [a]	9.75 ± 0.26 [b]
Crude ash	1.38 ± 0.02 [b]	1.94 ± 0.10 [a]	1.79 ± 0.01 [a]	1.86 ± 0.03 [a]	1.91 ± 0.05 [a]
Carbohydrate [2]	5.92 ± 0.14 [d]	12.82 ± 0.30 [a]	8.08 ± 0.11 [c]	8.35 ± 0.17 [c]	11.32 ± 0.48 [b]

[1] Treatments are shown in Table 1. [2] 100 − (moisture + crude protein + crude fat + crude ash). [3] Values are expressed as mean ± standard deviation (n = 3). [4] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$).

3.4. WHC and Cooking Loss of Tteokgalbi

The WHC and cooking loss characteristics of BP-treated Tteokgalbi are presented in Table 7. WHC was gradually elevated by increasing the BP concentration in Tteokgalbi (CON, REF, B1 < B2 < B3); therefore, BP treatment may enhance the retention of extra water in Tteokgalbi. In general, WHC is negatively correlated with cooking loss [22]. As expected, increasing the BP content in Tteokgalbi gradually decreased cooking loss (CON > REF > B1 > B2 > B3). The mechanism by which addition of *Boesenbergia pandurata* (Roxb.) affects the WHC of food products has not been widely studied. However, some studies have reported that ginger (classified in the same family, *Zingiberaceae*) powder treatments increase WHC in the ginger powder itself [23] and when added to hen meat [24]. Generally, in meat products, lower WHC and pH may induce higher cooking loss and vice versa [25]. In addition, the addition of ginger to chicken meat [24] and camel meat [26] significantly attenuated cooking loss in meat products. Moreover, ginger extract treatment also elevates WHC in camel meat [26]. In this study, we confirm that BP treatment increased WHC but decreased cooking loss in Tteokgalbi.

Table 7. Water-holding capacity (WHC) and cooking loss of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder.

Proximate Compositions	Treatments [1]				
	CON	REF	B1	B2	B3
WHC (%)	70.58 ± 1.73 [2c]	70.94 ± 4.78 [c]	70.76 ± 6.22 [c]	72.99 ± 1.90 [b]	74.05 ± 3.31 [a]
Cooking loss (%)	26.32 ± 1.24 [a]	22.96 ± 0.67 [b]	22.47 ± 1.52 [b]	19.51 ± 2.06 [c]	14.35 ± 1.54 [d]

[1] Treatments are shown Table 1. [2] Values are expressed as mean ± standard deviation (n = 3). [a–d] Means in row with different letters are significantly different ($p < 0.05$) by Duncan's multiple range test.

3.5. Tteokgalbi Color

The measurement of color change before and after cooking BP-treated Tteokgalbi is shown in Table 8. Overall lightness (L*) values of Tteokgalbi decreased remarkably (became darker) due to cooking, regardless of BP concentration. ($p < 0.01$–0.001), as verified in another Tteokgalbi study [27]. Both before and after the cooking of Tteokgalbi, the addition of ascorbic acid (REF) increased L* compared to CON and all BP-treated groups, irrespective of concentration. However, BP addition to Tteokgalbi significantly decreased L* compared to CON both before and after cooking. This may be because BP itself has a lower L* value than CON, as reported in the garlic powder treatment of pork patty [28]. In general, the values of redness (a*) in Tteokgalbi after cooking were significantly higher than those

before cooking (except B1). The addition of ascorbic acid to Tteokgalbi (REF) increased a*, regardless of cooking. BP treatment dynamically altered a* values of Tteokgalbi. A low concentration of BP (0.5%) in Tteokgalbi, regardless of cooking, significantly decreased a* compared to CON; however, higher BP concentration (2.0%) generally increased a* compared to CON. In a previous report, ginger addition to beef products significantly increased a* value compared with that of the control [28,29], as is seen in our B2 group. In general, the yellowness (b*) values of Tteokgalbi after cooking were significantly lower than those of Tteokgalbi before cooking (except B1; $p < 0.05$). B3 exhibited the highest b* value, regardless of cooking, as shown in another study [28], and the elevation of the b* value may be related to the yellowness components in BP. Overall, L, a*, and b* values were significantly decreased in Tteokgalbi after cooking, regardless of whether the treatments affected meat color by heating. The reduction in the L* value by cooking may be caused by the browning reaction of amino acids and reducing sugars in conjunction with meat proteins.

Table 8. Hunter color properties of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder.

		Treatments [1]				
		CON	**REF**	**B1**	**B2**	**B3**
Tteokgalbi color before cooking	L* [2]	60.10 ± 1.85 [3b4**5]	68.24 ± 1.53 [a**]	59.19 ± 0.92 [b**]	60.68 ± 2.39 [b***]	56.45 ± 1.09 [c***]
	a* [2]	10.06 ± 0.23 [a5**]	11.96 ± 0.79 [a*]	7.65 ± 2.41 [c]	10.91 ± 0.55 [ab*]	13.12 ± 0.64 [a***]
	b* [2]	17.40 ± 0.47 [b*]	17.57 ± 0.53 [b*]	17.40 ± 1.20 [b]	18.55 ± 0.88 [ab*]	19.18 ± 0.94 [a*]
Tteokgalbi color after cooking	L* [2]	53.03 ± 0.66 [b]	60.33 ± 1.07 [a]	52.36 ± 2.08 [b]	47.18 ± 1.68 [c]	45.68 ± 2.55 [c]
	a* [2]	8.08 ± 0.57 [b]	9.63 ± 0.66 [a]	7.34 ± 0.64 [b]	8.43 ± 1.32 [b]	8.83 ± 0.38 [ab]
	b* [2]	15.28 ± 1.35 [b]	15.73 ± 0.88 [b]	16.43 ± 2.15 [ab]	16.46 ± 1.95 [ab]	17.98 ± 0.97 [a]

[1] Treatments are shown in Table 1. [2] L*: lightness, a*: redness, b*: yellowness. [3] Values are expressed as mean ± standard deviation (n = 3). [4] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [5] Significant differences between raw and cooked Tteokgalbi by Student's *t*-test at * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

3.6. Textural Properties of Tteokgalbi

The textural properties of Tteokgalbi treated with BP are listed in Table 9. The addition of BP to Tteokgalbi increased its hardness in a dose-dependent manner; therefore, B3 exhibited the highest hardness. In addition, BP treatment of Tteokgalbi increased chewiness in a dose-dependent manner (CON, REF, B1 < B2, B3). However, springiness steadily decreased with increasing BP concentration in Tteokgalbi; therefore, B3 showed the lowest springiness. The cohesiveness value, which is the level of difficulty in breaking down Tteokgalbi, did not vary by treatment. In a study of pork patties treated with garlic powder, similar trends were reported as garlic addition increased hardness and chewiness in a dose-dependent manner [28]. In addition, there was no significant difference reported in springiness related to garlic powder content [28].

Table 9. Textural properties of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder during storage at 5 °C for 14 days.

Items	Treatments [1]				
	CON	**REF**	**B1**	**B2**	**B3**
Hardness (g)	2009.51 ± 515.23 [2b3]	2040.29 ± 707.00 [b]	2115.42 ± 355.05 [b]	2566.06 ± 838.67 [ab]	3784.52 ± 869.62 [a]
Springiness (%)	85.39 ± 4.02 [a]	89.64 ± 5.69 [a]	82.69 ± 6.21 [a]	72.39 ± 7.22 [ab]	70.78 ± 4.33 [b]
Cohesiveness (%)	76.82 ± 7.02 [NS]	72.99 ± 7.01	73.33 ± 6.02	70.99 ± 9.01	75.23 ± 5.55
Chewiness (g)	599.43 ± 70.59 [b]	564.21 ± 77.70 [b]	598.01 ± 95.07 [b]	639.23 ± 35.32 [a]	699.34 ± 88.80 [a]

[1] Treatments are shown in Table 1. [2] Values are expressed as mean ± standard deviation (n = 3). [3] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). NS; not siginificant.

3.7. Alterations in Antioxidative Properties during Storage of Tteokgalbi

TPC and TFC in the BP-treated Tteokgalbi after 14 days of cold storage at 5 °C are presented in Table 10. TPC after BP-treatment was significantly higher than in CON or REF. Among the BP-treated Tteokgalbi, the B3 sample had the highest polyphenol content. In all treatments, the TPC was intact after 7 days of cold storage; however, it was significantly decreased after 14 days of cold storage. In addition, the TFC after BP-treatment showed a similar trend as the TPC during 14 days of cold storage, as previously reported [30,31]. TFC was significantly higher in BP treatments in a dose-dependent manner at all storage time points, and B3 contained the highest proportion of total flavonoids. Freshly prepared Tteokgalbi had the highest TFC, which gradually decreased with increasing storage time. However, after 7 days of cold storage, TFC was decreased by ~50% compared to the initial Tteokgalbi samples. Moreover, TFC gradually decreased and was the lowest after 14 days of cold storage as previously studied [30,31]. It has been reported that increasing the storage period length decreases the antioxidative properties of ginger [32]; therefore, cold storage of BP-treated meats may result in reduced antioxidative activity.

Table 10. Total polyphenol and flavonoid contents of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder during storage at 5 °C for 14 days.

	Storage Days	Treatments [1]				
		CON	REF	B1	B2	B3
Total polyphenol (mg GAE [2]/g)	0	138.23 ± 5.70 ^{4c5A6}	140.67 ± 4.73 ^{cA}	150.99 ± 5.10 ^{bA}	153.68 ± 6.64 ^{bA}	169.09 ± 4.30 ^{aA}
	7	139.70 ± 3.31 ^{cA}	141.81 ± 4.77 ^{cA}	152.16 ± 1.57 ^{bA}	155.56 ± 3.26 ^{bA}	164.59 ± 2.73 ^{aA}
	14	130.65 ± 1.23 ^{dB}	132.56 ± 2.03 ^{dB}	138.23 ± 2.23 ^{cB}	142.32 ± 1.36 ^{bB}	153.63 ± 2.18 ^{aB}
Total flavonoid (mg QE [3]/g)	0	7.05 ± 0.31 ^{cA}	7.25 ± 0.53 ^{cA}	11.16 ± 0.18 ^{bA}	11.25 ± 0.46 ^{bA}	19.56 ± 0.95 ^{aA}
	7	4.25 ± 0.18 ^{dB}	4.22 ± 0.27 ^{dB}	5.77 ± 0.24 ^{cB}	6.96 ± 0.16 ^{bB}	9.70 ± 0.16 ^{aB}
	14	3.23 ± 0.12 ^{dC}	3.59 ± 0.09 ^{dC}	4.69 ± 0.17 ^{cC}	5.69 ± 0.59 ^{bC}	8.88 ± 0.23 ^{aC}

[1] Treatments are shown in Table 1. [2] GAE: Gallic acid equivalent. [3] QE: Quercertin equivalent. [4] Values are expressed as mean ± standard deviation (n = 3). [5] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [6] Means ± standard deviation with different superscripted capital letters within the same column differ significantly by Duncan's multiple range test ($p < 0.05$).

DPPH radical and ABTS radical scavenging activities of BP-treated Tteokgalbi during 14 days of cold storage at 5 °C are presented in Table 11. The DPPH radical scavenging activity of REF and B3 was significantly higher than that of the other treatments, regardless of the storage period. B1 and B2 had higher DPPH radical scavenging activity than CON, regardless of the length of storage. Intriguingly, DPPH radical scavenging activity was maintained in all treated groups after seven days of cold storage, except for CON. After 14 days of cold storage, DPPH radical scavenging activity decreased in all groups compared to activity level at days 0 and 7; however, after 14 days of cold storage, CON showed the greatest loss of DPPH radical scavenging activity.

ABTS radical scavenging activity in REF and B3 samples was significantly higher than that of all other treatments regardless of the storage period. B1 and B2 had higher ABTS radical scavenging activity than CON. ABTS radical scavenging activity gradually decreased with increased length of cold storage. Radical scavenging activities are closely correlated with phenolic and flavonoid components [33]; therefore, BP may effect changes in the antioxidative activities of BP-treated Tteokgalbi.

3.8. Changes in pH, TBARS, VBN, and TMC during Storage of Tteokgalbi

Changes in the pH, TBARS, VBN, and TMC in Tteokgalbi samples during 14 days of cold storage at 10 °C are presented in Table 12. Before cold storage (Day 0), there was no significant difference in the pH between Tteokgalbi groups; however, in all groups the pH became significantly more acidic throughout the cold storage period. Compared to CON, the pH of the BP-treated Tteokgalbi after cold storage for 7 and 14 days was significantly higher ($p < 0.05$). Meanwhile, the addition of garlic to the pork patties decreased the

pH of the patties [28]; therefore, the effect of BP treatment on meat differed from that from garlic addition. All BP treatments exhibited lower TBA values than CON at each time point (0–14 days). TBA was significantly increased throughout the cold-storage period in all the Tteokgalbi groups. BP treatment suppressed TBA induction in a dose-dependent manner after 7 and 14 days of cold storage (CON > B1 > B2 > B3). Similarly, ginger treatment of the pork's rectum significantly reduced TBA during the cold-storage periods [34]. Moreover, ginger treatment reduces TBA induction by increasing the storage time of the meat product [35]. BP possesses strong antioxidant activity, owing to the high levels of flavonoids and polyphenols that may inhibit lipid peroxidation [36].

Table 11. Changes of DPPH and ABTS radical scavenging activity of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder during storage at 5 °C for 14 days.

	Storage Days	Treatments [1]				
		CON	REF	B1	B2	B3
DPPH radical scavenging activity (%)	0	18.87 ± 0.18 [2c3A4]	27.64 ± 0.84 [aA]	23.02 ± 1.14 [bA]	23.42 ± 0.31 [bA]	27.32 ± 0.59 [aA]
	7	13.88 ± 1.01 [cB]	26.57 ± 0.93 [aA]	25.50 ± 0.89 [bA]	24.96 ± 0.56 [bA]	28.60 ± 0.97 [aA]
	14	8.63 ± 0.06 [cC]	16.22 ± 1.13 [aB]	11.36 ± 0.99 [bB]	14.22 ± 0.97 [bB]	16.09 ± 0.93 [aB]
ABTS radical scavenging activity (%)	0	55.41 ± 0.60 [cA]	70.19 ± 0.53 [aA]	61.62 ± 1.67 [bA]	63.99 ± 0.84 [bA]	70.06 ± 1.11 [aA]
	7	31.14 ± 0.9 [cB]	47.48 ± 1.18 [aB]	43.12 ± 6.70 [bB]	46.08 ± 1.09 [aB]	46.50 ± 0.84 [aB]
	14	10.36 ± 0.98 [cC]	25.98 ± 0.67 [aC]	20.33 ± 0.78 [bC]	21.13 ± 0.87 [bC]	25.12 ± 0.65 [aC]

[1] Treatments are shown in Table 1. [2] Values are expressed as mean ± standard deviation (n = 3). [3] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [4] Means ± standard deviation with different superscripted capital letters within the same column differ significantly by Duncan's multiple range test ($p < 0.05$).

Table 12. Changes in pH, 2-thiobarbituric acid (TBA), volatile basic nitrogen (VBN), and total microbial count (TMC) of Tteokgalbi prepared with different levels of *Boesenbergia pandurata* (Roxb.) powder during storage at 5 °C for 14 days.

	Storage Days	Treatments [1]				
		CON	REF	B1	B2	B3
pH	0	6.07 ± 0.02 [2a3A4]	5.97 ± 0.03 [bA]	6.05 ± 0.01 [aA]	6.06 ± 0.02 [aA]	6.08 ± 0.02 [aA]
	7	5.15 ± 0.03 [dB]	5.16 ± 0.01 [dB]	5.22 ± 0.02 [cB]	5.48 ± 0.02 [bB]	5.56 ± 0.02 [aB]
	14	5.01 ± 0.02 [cC]	5.04 ± 0.01 [bC]	5.05 ± 0.01 [bC]	5.11 ± 0.02 [aC]	5.12 ± 0.02 [aC]
TBA [5] (mg malonadehyde/kg)	0	0.30 ± 0.00 [aC]	0.20 ± 0.00 [bC]	0.21 ± 0.03 [bC]	0.20 ± 0.00 [bC]	0.23 ± 0.00 [bC]
	7	0.49 ± 0.01 [aB]	0.41 ± 0.00 [dB]	0.46 ± 0.01 [bB]	0.44 ± 0.00 [cB]	0.41 ± 0.00 [dB]
	14	0.55 ± 0.00 [aA]	0.50 ± 0.00 [bA]	0.54 ± 0.02 [aA]	0.50 ± 0.01 [bA]	0.45 ± 0.01 [cA]
VBN [6] (mg/100 g)	0	6.75 ± 0.56 [NS7C]	6.58 ± 0.09 [C]	6.78 ± 0.99 [C]	6.82 ± 0.56 [C]	6.58 ± 0.27 [C]
	7	10.42 ± 0.14 [aB]	8.19 ± 1.02 [dB]	10.41 ± 0.84 [aB]	9.79 ± 0.21 [bB]	8.94 ± 0.48 [cB]
	14	20.59 ± 1.14 [aA]	16.11 ± 0.64 [bA]	19.97 ± 0.69 [aA]	18.53 ± 0.65 [abA]	16.20 ± 0.42 [bA]
TMC [8] (log CFU/g)	0	6.03 ± 0.01 [NSC]	6.02 ± 0.02 [C]	6.03 ± 0.03 [C]	6.00 ± 0.01 [C]	5.99 ± 0.01 [C]
	7	6.49 ± 0.03 [aB]	6.21 ± 0.01 [cB]	6.29 ± 0.03 [bC]	6.21 ± 0.02 [cB]	6.20 ± 0.03 [cB]
	14	7.67 ± 0.02 [aA]	7.53 ± 0.03 [bA]	7.51 ± 0.02 [bA]	7.53 ± 0.01 [bA]	7.00 ± 0.00 [cA]

[1] Treatments are shown in Table 1. [2] Values are expressed as means ± standard deviation (n = 3). [3] Means ± standard deviation with different superscripted small letters within the same row differ significantly by Duncan's multiple range test ($p < 0.05$). [4] Means ± standard deviation with different superscripted capital letters within the same column differ significantly by Duncan's multiple range test ($p < 0.05$). [5] TBA, 2-thiobarbituric acid; [6] VBN, volatile basic nitrogen; [7] NS: not significant; [8] TMC, total microbial counts.

At the initial storage time, there was no significant difference in the VBN content across all the Tteokgalbi treatments; however, the VBN content significantly increased with increasing duration of the cold-storage period in all groups. Compared to CON, the VBN content was significantly lower ($p < 0.05$) in > 1.0% (B2 > B3) and 1.5% (B3) of the BP-treated Tteokgalbi after cold storage for 7 and 14 days, respectively. In addition, garlic treatment of the pork rectum [34] and ginger treatment in a western-style smoked sausage [35] suppressed VBN induction by increasing the storage time, and the TMC was altered in a similar

pattern as VBN. Before cold storage, there was no significant difference in the TMC between all Tteokgalbi groups; however, the TMC increased significantly with longer periods of cold storage in all Tteokgalbi groups in a time-dependent manner. Compared to CON, the TMC was significantly lower ($p < 0.05$) in > 1.0% (B2 and B3) and 1.5% (B3) of the BP-treated Tteokgalbi after cold storage for 7 and 14 days, respectively. *Boesenbergia pandurata* (Roxb.) is widely used as a natural antibacterial resource to suppress *Staphylococcus aureus*, and *Bacillus cereus* grows more efficiently than ginger [8]. Lower microbial growth in meat products is closely related to increasing WHC and pH maintenance [37]. In our study, BP increased WHC and prevented the reduction in pH and TMC, as was also reported in a report on garlic powder addition in rabbit burger [38] and as a mixture of organic compounds [39]. The results of this study clearly demonstrate that BP treatment decreases the VBN content and microbial growth during cold storage in Tteokgalbi, probably due to the abundance of polyphenols and flavonoids in BP.

4. Conclusions

This study was designed to investigate the applicability of BP as a natural ingredient in Tteokgalbi. The addition of BP to Tteokgalbi did not affect the overall quality of the Tteokgalbi. The addition of BP increased antioxidative activity with the elevation of WHC, and suppressed fatty acid oxidation and microbial growth in Tteokgalbi. Therefore, BP is applicable as a natural preservative in Tteokgalbi for use in the meat industry.

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