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Research Article

Quality characteristics of muffins added with fresh ginseng and different amounts of *Gryllus bimaculatus* powder

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Abstract Edible insects, such as the two-spotted cricket (*Gryllus bimaculatus*, GB), have high nutritional value but are not widely consumed because of their appearance and smell. Consequently, the development of foods containing these insects in less recognizable forms, e.g., flour-like powders, has drawn considerable attention. Herein, we investigated the quality characteristics of muffins prepared from wheat flower supplemented with fresh ginseng (5%) and GB (0, 10, 20, and 40%) powders. GB loading was negatively correlated with muffin volume, height, moisture content, and textural properties (hardness, springiness, cohesiveness, and chewiness) and positively correlated with crude protein content and antioxidant properties. Significant ($p<0.05$) color differences were observed between samples with different GB loadings. The contents of hexanal and nonanal, which are the major volatiles responsible for off-flavor, increased with increasing GB loading, and the number of volatiles maximized at 40% GB. Sensory preference decreased in the order of 0% GB>10% GB≈20% GB>40% GB. Based on these results, a GB loading of 20% offered the best trade-off between attractiveness and nutritional value. Thus, this study promotes the widespread use of GB in the food industry and the development of various edible-insect-based food products.

Keywords *Gryllus bimaculatus*, fresh ginseng, muffin, off-flavor, quality characteristics

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1. Introduction

Edible insects are a sustainable alternative source of protein because of their high nutritional value; high protein, fiber, mineral, and vitamin contents; and environmental benefits. In particular, insect protein, which constitutes 40%-70% of the insect mass, contains all essential amino acids and has a high digestibility of 76%-98% (Gravel and Doyen, 2020; Rumpold and Schlüter, 2013). The cultivation of edible insects is environmentally friendly, offering the benefits of high food conversion efficiency, modest land and water requirements during breeding, and low greenhouse gas and ammonia production (Nakagaki and Defoliart, 1991; Rumpold

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and Schlüter, 2013). *Gryllus bimaculatus* (two-spotted cricket, GB) is a high-protein low-fat insect in the order Orthoptera, family Gryllidae, with excellent essential amino acid composition and antioxidant properties (Kim et al., 2020b). This edible insect can be used as a supplement improving the nutritional value of food products (Çabuk, 2021). However, consumers are not aware of edible insects, and the direct consumption of such insects can cause food neophobia due to disgust or repulsion (Megido et al., 2016). These problems can be resolved by processing insects, converting them to less recognizable forms, such as flour-like powder, and adding them to familiar foods, such as bread, biscuits, and cookies (Mishyna et al., 2020).

Ginseng (*Panax ginseng* C.A. Meyer), a perennial herbaceous plant in the family Araliaceae, is a well-known medicinal crop containing pharmacologically active compounds in its roots (Kim et al., 2023). The main volatile aroma compounds of ginseng are terpenes, alcohols, aromatics, and esters (Cui et al., 2015), including acetone, acetic acid, 2-methyl-1-propanol, *p*-xylene, heptanal, limonene, β-pinene, myrcene, and tetramethylpyrazine (Cho et al., 2012; Ryu et al., 2002).

Bakery products made from wheat flour are a major food class consumed worldwide. Muffins are a popular high-calorie bakery product made from wheat flour, sugar, oil, eggs, and milk (Bala et al., 2019). Given that muffins are often consumed for breakfast or as snacks, they can be a good option for nutritional replenishment (Çabuk, 2021). Edible insects are rich in protein, essential amino acids, vitamins, and minerals (Zielińska et al., 2015) and are often used to supplement bakery products with protein or other nutrients (Gantner et al., 2022). Bakery products containing edible insects include termite- and cricket-supplemented crackers (Akullo et al., 2018), termite-supplemented cookies (Awobusuyi et al., 2020), protein-enriched muffins supplemented with grasshopper and mealworm powder (Çabuk, 2021), protein-enriched bread supplemented with mealworm powder (Roncolini et al., 2019), and high-energy biscuits supplemented with silkworm pupae and grasshoppers (Akande et al., 2020).

Food taste and odor are important factors determining consumer preferences and choices (Mishyna et al., 2020). Odor is detected by receptors in the nasal cavity; off-odor is caused by the presence of volatiles, e.g., aldehydes, alcohols, and ketones (Czerny et al., 2008), and is responsible for unpleasant food taste and aroma (Roland et al., 2017). Cricket powder has a strong odor, resembling those of crustaceans, cooked beans, plants, and soil (Roncolini et al., 2019), which can be perceived as off-odor and thus lowers consumer acceptance. Strategies for eliminating off-odor include off-odor avoidance, removal, blocking, masking, and blending. In particular, masking involves the addition of food products with different odors to change off-odor perception (McDonald, 2017). Although aromas are widely used to improve the taste and odor of processed foods (Haraguchi et al., 2013), studies on enhancing the odor of edible-insect-containing products, particularly those on off-odor masking for food processing, are scarce.

Ginseng is usually consumed in the form of powder or pieces (Cho, 2015). Several studies have examined the use of ginseng powder in processed foods, including sponge cakes (Yoon et al., 2007), cookies (Kang et al., 2009), and Korean rice cakes (Lee et al., 2011). However, the applicability of fresh ginseng powder in processed foods, especially for off-odor masking, has not yet been verified.

Herein, we used fresh ginseng powder to mask the off-odor of GB-powder-supplemented muffins and evaluated their quality characteristics to determine the optimal GB loading. This study contributes to the development of processed food products containing edible insects.

2. Materials and methods

2.1. Materials

Euthanized, washed, and hot-air-dried crickets purchased from MG Natural Co. Ltd. (Damyang, Korea) in November 2022 were ground in a blender (SHMF-3260S, Hanil Electric, Bucheon, Korea), and the resulting powder was dispersed in fermentation ethanol (Ethanol Supplies World Co. Ltd., Jeonju, Korea) at a 1:5 (w/v) ratio. The dispersion was agitated for 1 h at 40℃ and 150 rpm using a shaking incubator (JSSI-300C, JS Research Inc., Gongju, Korea) and left to settle for 15 min. Subsequently, the ethanolic phase containing dissolved fat was removed. This process was repeated five times, and the resulting GB precipitate was placed in a fume hood overnight to evaporate the remaining ethanol. The dried defatted GB precipitate was passed through a 60-mesh sieve to prepare a powder with a uniform particle size. The composition of the defatted GB powder was determined as 6.55±0.02% water, 78.54±0.00% crude protein, 1.38±0.13% crude fat, and 9.42±0.02% carbohydrate, and its pH was evaluated to be 6.74±0.01. Washed ginseng harvested from Punggi-eup, Yeongju-si, Gyeongsangbuk-do, Korea in November 2021 was freeze-dried at -50℃ [LP20(XX), Ilshinbio, Dongducheon, Korea], ground in the blender (SHMF-3260S, Hanil Electric) and passed through a 60-mesh sieve to prepare fresh ginseng powder.

Cake flour (Daehan Flour Co., Seoul, Korea), baking powder (Bread Garden, Seongnam, Korea), butter (Fonterra Limited, Auckland, New Zealand), sugar (TS Corporation Co. Ltd., Seoul, Korea), eggs (Ohmyung Animal Husbandry, Daegu, Korea), milk (Seoulmilk, Seoul, Korea), and salt (Hanju Salt, Ulsan, Korea) were purchased from a local supermarket.

2.2. Muffin preparation

The muffin preparation process and GB loading were optimized using preliminary experiments. Muffins were prepared at GB loadings of 0%, 10%, 20%, and 40% (relative to flour mass), and the respective samples were denoted as GB0, GB10, GB20, and GB40. The ratios of all used ingredients are listed in Table 1. Butter was placed in a stainless steel bowl and blended for 1 min at speed level 1 using a hand mixer (LW-2003 A, Llantek Electrical Appliances Co., Ltd., Guangdong, China). Next, sugar was added and mixed for 1.5 min at speed level 2. The mixture was supplemented with eggs in three batches and mixed for 5 min at speed level 3. Subsequently, the previously mixed defatted GB powder, fresh ginseng powder, cake flour, baking powder, and salt were added, and the mixture was homogenized for 30 s using a scraper. Finally, milk was added, and the slurry was mixed for 30 s using the scraper. The resulting batter was placed in a paper-lined muffin tray (upper diameter=77 mm, lower diameter=56 mm, height=54 mm; 80.0±0.5 g batter per cup) and baked for 30 min in an oven (KEBINFT, Gumbok Stoke Co., Seoul, Korea) with upper and lower temperatures of 180 and 160℃, respectively. The baked muffins were cooled for 1 h at 25℃ in a climatic chamber (JSRH-150CP, JS Research Inc.).

2.3. Water holding capacity (WHC) and specific gravity measurement

The WHC of flour was measured using the method

Table 1. Formula of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

Ingredients (g)	Samples			
	GB0[1)]	GB10	GB20	GB40
Wheat flour	300	270	240	180
Gryllus bimaculatus powder	0	30	60	120
Fresh ginseng powder	15	15	15	15
Butter	150	150	150	150
Sugar	150	150	150	150
Egg	150	150	150	150
Milk	180	180	180	180
Baking powder	12	12	12	12
Salt	3	3	3	3

[1)] GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

reported by Bchir et al. (2014). The GB-supplemented wheat flour sample was homogenized for 3 min at a speed of 3 strokes/s using a laboratory blender (BagMixer 400, Interscience, Paris, France). The resulting powder (1 g) was placed in a conical tube (50 mL) containing distilled water (20 mL), and the mixture was homogenized and hydrated for 1 h (25℃, 100 rpm) in a shaking incubator (JSSI-300C, JS Research Inc.) and then centrifuged (1580MGR, Gyrozen Co. Ltd., Daejeon, Korea) for 2 min at 4℃ and 1,000 ×*g*. The supernatant was discarded, the residue was turned over, fixed, and oven-dried for 10 min at 90℃ (JSOF-100, JS Research Inc.). The WHC was calculated from the weight of dried flower after hydration (w_h) and that of flour before hydration (w_f) as

$$\text{WHC (\%)} = 100 \times w_h/w_f. \quad (1)$$

The specific gravity of the batter was calculated from the weight of the batter (w_b) and weight of water (w_w), which were determined using a pycnometer according to standard method 10-15.01 (AACC, 2000).

$$\text{Specific gravity} = w_b/w_w. \quad (2)$$

2.4. Measurement of muffin height, specific volume, and baking loss

The height of muffins was measured after cutting them vertically in the midline as the distance from the base to the highest point. The specific volume of muffins was calculated from the muffin volume (V_m) and muffin weight (w_m). V_m was measured using the method reported by Choi and Chung (2006) based on the seed-displacement technique (Pyler, 1979). A glass beaker (500 mL) was completely filled with millet seeds, and approximately two-thirds of the seeds were removed and set aside. The muffin was placed in the beaker, which was then filled with the previously removed seeds, and the top was made flat using a rectangular scraper. The seeds that did not fit in the beaker were placed in a graduated cylinder to determine their volume.

$$\text{Specific volume (mL/g)} = V_m \text{ (mL)}/w_m \text{ (g)} \quad (3)$$

Baking loss was calculated as

$$\text{Baking loss (\%)} = \{(w_b - w_m)/w_b\} \times 100 \quad (4)$$

2.5. Muffin quality characteristic, color, and appearance evaluation

The water content of the muffins was measured using the normal-pressure oven-drying method described in the Korean Food Code, and the crude protein content was measured using the micro-Kjeldahl method. For pH measurement, the specimen (10 g) was blended with distilled water (30 mL) using a hand blender (SU07843, Philips Co. Ltd., Amsterdam, the Netherlands), the slurry was passed through Grade 4 Whatman filter paper (WHA1004090, Maidstone, UK), and the pH of the filtrate was measured using a pH meter (Orion 3-Star, Thermo Fisher Scientific, Waltham, MA, USA). Color was measured in terms of the L^* (lightness), a^* (redness), and b^* (yellowness) of the muffin crosssections using a colorimeter (CR-400, Minolta, Tokyo, Japan) calibrated with a white calibration plate (L^*=81.42, a^*=0.47, b^*=8.13). For imaging, crosssectioned muffins were placed in the center of a studio light box (PULUZ Photo Studio Light Box, Shenzhen Puluz Technology Co. Ltd., Guangdong, China), and photographs were taken using a camera (iPhone 12 Pro, Apple, California, USA) at an illuminance of 680 lux.

2.6. Antioxidant activity measurement

The total phenolic content (TPC) and 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity were determined using ethanolic (Duksan Chemical Co., Ansan, Korea) muffin extracts. The specimen was ground with a hand blender (SU07843, Philips Co., Ltd.), and a 5 g portion was mixed with 70% ethanol (45 mL). The slurry was ultrasonicated (DH.WUC.D22H, Daihan Scientific Co., Ltd., Wonju, Korea) at a frequency of 40 kHz and an output power of 200 W. The extract was centrifuged (1580MGR, Gyrozen Co. Ltd.) for 15 min at 1,000 ×*g*, and the supernatant was collected, filtered through a nylon syringe filter (SN25P020NS, HYUNDAI MICRO Co., Ltd., Seoul, Korea), and used as the muffin extract.

TPC was measured using the Folin-Ciocalteu method (Swain and Hillis, 1959). The muffin extract was diluted four-fold with 70% ethanol, and the diluted sample (1 mL) was mixed with 50% Folin-Ciocalteu's phenol reagent (1 mL; JUNSEI, Tokyo, Japan) and left to react in the dark for 15 min. Subsequently, 10% Na_2CO_3 (1 mL; DUKSAN) was added, and the mixture was left for 1 h in the dark. Subsequently, the absorbance of the mixture at 750 nm was measured using a UV-vis spectrophotometer (Evolution 201, Thermo Fisher Scientific Inc., Madison, WI, USA). Gallic acid (Sigma-Aldrich Co., St. Louis, MO, USA) was used as a standard to obtain a calibration curve, and TPC was expressed as mg gallic acid equivalent (mg GAE)/weight of sample (100 g).

The DPPH radical scavenging activity was measured using the Blois method (Blois, 1958). The muffin extract was diluted four-fold with 70% ethanol, the diluted sample (1 mL) with a concentration of 27.78 mg/mL was mixed with 0.1 mM DPPH solution (2 mL; Sigma-Aldrich Co.) and the mixture was left to react in the dark for 30 min. Subsequently, the absorbance of the mixture at 517 nm was measured using the abovementioned UV-vis spectrophotometer. The DPPH radical scavenging activity was calculated from the absorbance of the sample (A_s) and that of the control with no added extract (A_c):

$$\text{DPPH radical scavenging activity (\%)} = (1 - A_s/A_c) \times 100 \quad (5)$$

2.7. Textural property measurement

Muffin texture was assessed using a rheometer (Compac-II, Sunscientific Co., Tokyo, Japan) fitted with a 50 mm diameter cylinder probe to perform duplicate compression tests. Hardness, springiness, cohesiveness, and chewiness were determined for the 20 mm×20 mm×20 mm samples cut from the muffin inside. The measurement conditions were as follows: pretest speed=2 mm/s, test speed=1 mm/s, posttest speed=1 mm/s, load cell=2 kgf, distance=10 mm, and clearance=7 mm.

2.8. Volatile compound analysis via headspace solid phase microextraction (HS-SPME/GC-MS)

The volatile compounds in muffins were analyzed using HS-SPME/GC-MS according to the method of Lee et al. (2021). A muffin sample (5 g) was placed in a glass vial (20 mL) and held at 70℃ for 20 min. Subsequently, carboxen/divinylbenzene/polydimethylsiloxane (CAR/DVB/PDMS)-coated SPME fiber was added to the vial, kept there for 30 min to absorb volatiles, and then inserted into a gas chromatograph (Agilent 7890 B GC and 5977 B-MSD, Agilent Technologies Inc., Santa Clara, CA, USA) for 1 min in split mode (1:20). The volatiles were separated using a DB-wax column (length=60 m, internal diameter=0.25 mm, film thickness=0.25 μm; Agilent Technologies Inc.). Helium was used as a carrier gas at a flow rate of 1 mL/min. Raw GC-MS data were analyzed using the Agilent MassHunter software (Agilent Technologies Inc.) in combination with a spectrum library (W11N17main.L, John Wiley & Sons Inc., Hoboken, New Jersey, USA) to identify the detected volatiles.

2.9. Sensory property evaluation

Sensory properties were evaluated by 15 trained students from Kyungpook National University. Samples (20 mm×20 mm×20 mm) were prepared by cutting the muffin insides and evaluated in terms of appearance, earthy smell, fresh ginseng smell, taste, texture, and overall acceptance on seven-point scales. Earthy and fresh ginseng smells were evaluated in terms of intensity, with a stronger smell assigned to a higher score. Properties other than smell were evaluated in terms of preference, with higher preferences assigned higher scores. Sensory evaluation was conducted after receiving approval for exemption from the institutional review board of Kyungpook National University (approval no.: KNU-2023-0244).

2.10. Statistical analysis

The results were presented as the mean and standard deviation of 5 (color and texture), 15 (sensory properties), and 3 (other properties) replicates. The IBM SPSS Statistics software (26, IBM Co., Armonk, NY, USA) was used for the analysis of variance (ANOVA), Duncan's multiple range test, and the analysis of significant differences between samples ($p<0.05$).

3. Results and discussion

3.1. WHC and specific gravity

Table 2 lists the WHC and specific gravity of the samples, revealing that the WHC significantly ($p<0.05$) increased with increasing GB loading, in agreement with the results reported by Bresciani et al. (2022). This finding indicates that the WHC of GB powder exceeded that of wheat flour because of the high crude fiber and protein content of the former (Çabuk, 2021). The specific gravity of the muffin batter indicates the number of bubbles included therein, i.e., the ability to form and retain bubbles. A low specific gravity indicates a good

Table 2. Water holding capacity for powder, specific gravity of batter, and physicochemical properties of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

Samples	Water holding capacity (%)2)	Specific gravity3)	Height (mm)4)	Specific volume (mL/g)	Baking loss (%)
GB0 1)	61.33±0.58 5)^{d}	0.95±0.00^{c} 6)	58.66±1.13^{a}	1.91±0.05^{a}	8.59±0.26^{a}
GB10	66.67±2.52^{c}	0.97±0.00^{b}	56.10±0.50^{b}	1.88±0.02^{a}	8.04±0.15^{b}
GB20	84.00±1.00^{b}	0.98±0.00^{a}	55.69±0.39^{b}	1.85±0.01^{a}	8.43±0.08^{ab}
GB40	120.33±1.15^{a}	0.93±0.01^{d}	55.07±0.13^{b}	1.70±0.02^{b}	8.53±0.33^{a}

1) GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

2) Water holding capacity was measured by homogenized mixed powder of wheat flour and *Gryllus bimaculatus* powder.

3) Specific gravity was measured in the batter of the muffins.

4) Height, specific volume, and baking loss were measured for muffins.

5) Values are mean±SD (n=3).

6) Means with different superscript letters ($^{a-d}$) in each column are significantly different by Duncan's multiple range test ($p<0.05$).

ability to form and retain bubble, and thus a high final volume after baking (Bala et al., 2019; Jyotsna et al., 2007). The specific gravity of the batter affects quality characteristics, such as volume and texture, with high specific gravity being associated with few bubbles and resulting in a dense, less airy product with a low volume (Joung et al., 2017). The specific gravity of the batter with GB loadings of 0%, 10%, 20%, and 40% was 0.95, 0.97, 0.98, and 0.93, respectively, indicating that it largely increased with increasing GB loading. The decrease observed at 40% reflected the fact that specific gravity is affected by the types of ingredients, batter temperature, mixing, mixing speed, and chemical leavening agents (Baik et al., 2000). The positive correlation between GB loading and specific gravity (except for the case of 40% GB) was ascribed to the decrease in the content of wheat protein (gluten) with increasing GB loading and the resulting loss of the ability to form and retain bubbles (Kim and An, 2021). In the study of Bala et al. (2019), the batter made only from several types of protein exhibited a higher specific gravity than that containing a mixture of wheat flour and protein, demonstrating that the gluten content of wheat affects the specific gravity of the batter.

3.2. Muffin height, specific volume, and baking loss

Table 2 lists the heights, specific volumes, and baking losses of different samples. Muffin height decreased with increasing GB loading and was the largest (58.66 mm) for GB0. Notably, no significant differences between muffins with added GB were observed ($p<0.05$). As GB loading increased from 0% to 40%, the specific volume of the muffins decreased from 1.91 to 1.70 mL/g. According to Park and Lim (2007), the decrease in the gluten content with increasing GB loading can weaken the gluten network and impair the ability of the batter to trap air, which explains the low height, volume, and specific volume of GB-containing muffins. Kowalski et al. (2022a) replaced up to 30% of wheat flour with buffalo worm, cricket, and mealworm powder, revealing that the loading of this powder was negatively correlated with height and specific volume. Similarly, in a study on bread with wheat flour replaced by mealworm powder, insect powder loading was found to be negatively correlated with height and specific volume (Khuenpet et al., 2020). Baking loss was the highest for GB0 but otherwise increased with increasing GB loading. Low specific volume in muffins leads to reduced water evaporation during baking, ultimately resulting in lower baking loss (Çabuk, 2021). However, no significant correlations between baking loss and specific volume were observed herein.

3.3. Muffin quality characteristics and color

Table 3 shows the water and crude protein contents, pH, and colors of muffins with different GB loadings. Water content affects texture, with higher water contents resulting in moister, softer products (Ahn and Song, 1999). With increasing GB loading, moisture content decreased, while crude protein content significantly increased ($p<0.05$). This finding was ascribed to the fact that the protein content of GB (~70%) considerably exceeds that of cake flour (7%-9%). Khuenpet et al. (2020) reported a significant increase in the protein content of bread with the increasing loading of mealworm powder. Muffin pH decreased with increasing GB loading, which was ascribed to the lower pH of defatted GB (6.74) than that of GB-free muffins (6.98). Previous studies have shown that when an ingredient has a pH lower than that of the existing product, the pH of the product decreases with the increasing loading of this ingredient (Lee et al., 2015; Yoon et al., 2021). In addition to texture and volume, color is an important characteristic of bakery products that affects consumer acceptance (González et al., 2019). Herein, increased GB loading was associated with decreased L^*, increased a^*, and decreased b^*. The changes in all three values were significant ($p<0.05$). The photographs of the external appearance and internal crosssections (Fig. 1) showed progressive darkening and browning with increasing GB loading. Similar trends were observed in a study on bread with wheat flour replaced by mealworm powder (Khuenpet et al., 2020). The color changes observed in our samples were consistent with those reported for muffins with added grasshopper and mealworm powders prepared by Çabuk (2021), which may originate from the original colors of insect powder.

3.4. Antioxidant activity

The results of antioxidant activity evaluation are shown in Fig. 2. The GB-free muffins showed a certain antioxidant activity (TPC=128.62 mg GAE/100 g, DPPH radical scavenging activity=8.65%), which significantly increased upon the incorporation of GB ($p<0.05$). Chong et al. (2017) showed that the

Table 3. Quality characteristics and color value (CIE L^*, a^*, b^*) of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

Samples	Moisture contents (%)	Crude protein (%)	pH	Color value		
				L^*	a^*	b^*
GB0[1]	$33.35\pm0.06^{2)a}$	6.37 ± 0.14^{d}	6.98 ± 0.01^{a}	$74.05\pm0.75^{3)a}$	-4.43 ± 0.15^{d}	30.57 ± 0.58^{a}
GB10	$32.06\pm0.04^{b4)}$	8.54 ± 0.01^{c}	6.88 ± 0.02^{b}	56.22 ± 0.46^{b}	2.58 ± 0.24^{c}	22.48 ± 0.30^{b}
GB20	31.98 ± 0.02^{b}	10.88 ± 0.08^{b}	6.86 ± 0.01^{b}	49.25 ± 0.63^{c}	5.00 ± 0.32^{b}	20.92 ± 0.72^{c}
GB40	31.74 ± 0.11^{c}	14.88 ± 0.10^{a}	6.81 ± 0.01^{c}	39.71 ± 0.27^{d}	6.46 ± 0.29^{a}	18.64 ± 0.51^{d}

[1] GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

[2] Values are mean±SD (n=3).

[3] Values are mean±SD (n=5).

[4] Means with different superscript letters ($^{a-d}$) in each column are significantly different by Duncan's multiple range test ($p<0.05$).

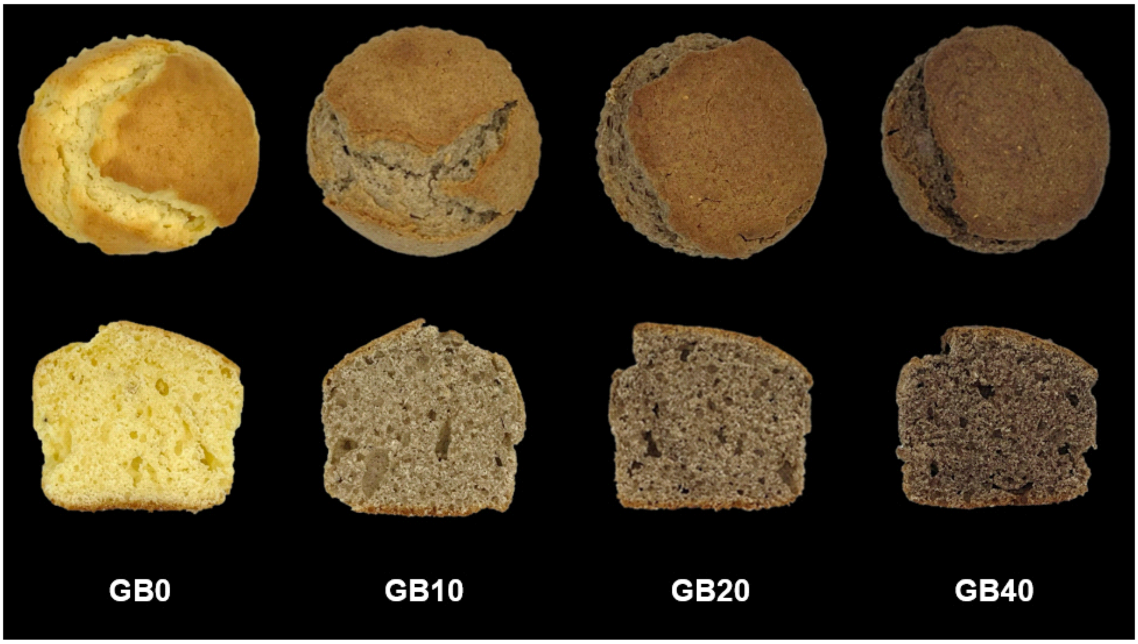

Fig. 1. Photographs of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder. In the codes listed for formula; GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

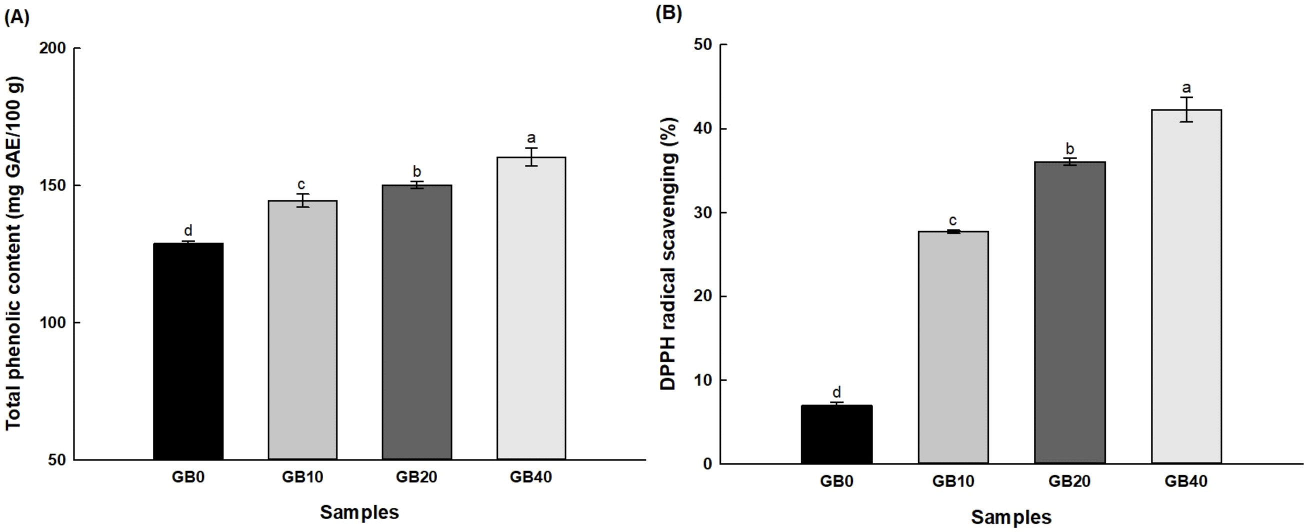

Fig. 2. Total phenolic content (A) and DPPH radical scavenging (B) of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder. In the codes listed for formula; GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour. GAE, gallic acid equivalent. Sample concentration of the DPPH radical scavenging is 27.78 mg/mL. Values are mean±SD (n=3). Means with different superscript letters ($^{a-d}$) on the bars are significantly different by Duncan's multiple range test ($p<0.05$).

TPC and DPPH radical scavenging activity of cookies significantly increased with the increasing loading of mealworm powder. Similarly, in the study of Zielińska et al. (2021), the TPC and DPPH radical scavenging activity of muffins increased with the increasing loading of cricket and mealworm powders. Edible insects are rich in physiologically active compounds with antioxidant and anti-inflammatory properties (Zielińska et al., 2017). The high TPC and DPPH radical scavenging activity of GB were studied by Kim et al. (2020a). Thus, in our case, antioxidant activity increased with increasing GB loading because of the high antioxidant activity of GB itself.

3.5. Texture

Table 4 shows the results of texture analysis (hardness, springiness, cohesiveness, and chewiness). Hardness decreased with increasing GB loading and was the lowest at 40% GB (2.37 N/cm^2). With increasing GB loading, total protein content increased, while gluten and starch contents decreased. The hardness of bakery products depends on their starch content (Feili et al., 2013), and gluten development is also an important factor (Bala et al., 2019). The decrease in gluten and starch contents with increasing GB loading is considered to have weakened the gluten network. Springiness is the ability of a sample to return to its original state after a deforming force is removed (Szczesniak, 2002). Herein, springiness decreased with increasing GB loading, which indicates that GB addition resulted in muffin densification. The decreased springiness could be related to the inhomogeneity of the muffin matrix; it was also observed when wheat flour was replaced with mealworm and grasshopper powders (Çabuk, 2021). Cohesiveness and chewiness significantly decreased with increasing GB loading ($p<0.05$). In particular, chewiness decreased from 255.29 to 100.09 N upon an increase in GB loading from 0 to 40%. Decreased cohesiveness could also be consistent with lower springiness, which reflects low cohesiveness inside muffins (Çabuk, 2021). Pauter et al. (2018) reported that muffin hardness, springiness, cohesiveness, and chewiness decreased with the increasing loading of cricket powder. In summary, the introduction of GB resulted in textural property deterioration, probably because of the concomitant decrease in wheat gluten content (Kowalski et al., 2022b).

3.6. Volatile compounds

Fig. 3 shows the chromatograms recorded during volatile compound analysis via HS-SPME/GC-MS. Table 5 shows the 24 volatile compounds with match scores of ≥90% alongside the peak areas of the compounds present at each retention time (RT). Off-odor is known to be caused by $C_{5\text{-}8}$ fatty alcohols, ketones, and aldehydes (Kumari et al., 2015). Aldehydes are produced by the oxidative lysis of fatty acids, and hexanal and nonanal are aldehydes that are found in edible insects and can

Table 4. Texture profile analysis of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

Samples	Hardness (N/cm^2)	Springiness (%)	Cohesiveness (%)	Chewiness (N)
GB0[1]	3.34±0.55[2]^{a}	83.66±1.83^{a}[3]	58.62±2.58^{a}	255.29±31.97^{a}
GB10	2.95±0.08^{a}	82.28±1.47^{a}	49.30±2.03^{b}	187.79±6.57^{b}
GB20	2.53±0.10^{b}	76.60±2.49^{b}	41.98±2.21^{c}	127.56±5.84^{c}
GB40	2.37±0.16^{b}	71.56±2.44^{c}	37.66±2.81^{d}	100.09±13.84^{d}

[1] GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.
[2] Values are mean±standard deviation (n=5).
[3] Means with different superscript letters ($^{a-d}$) in each column are significantly different by Duncan's multiple range test ($p<0.05$).

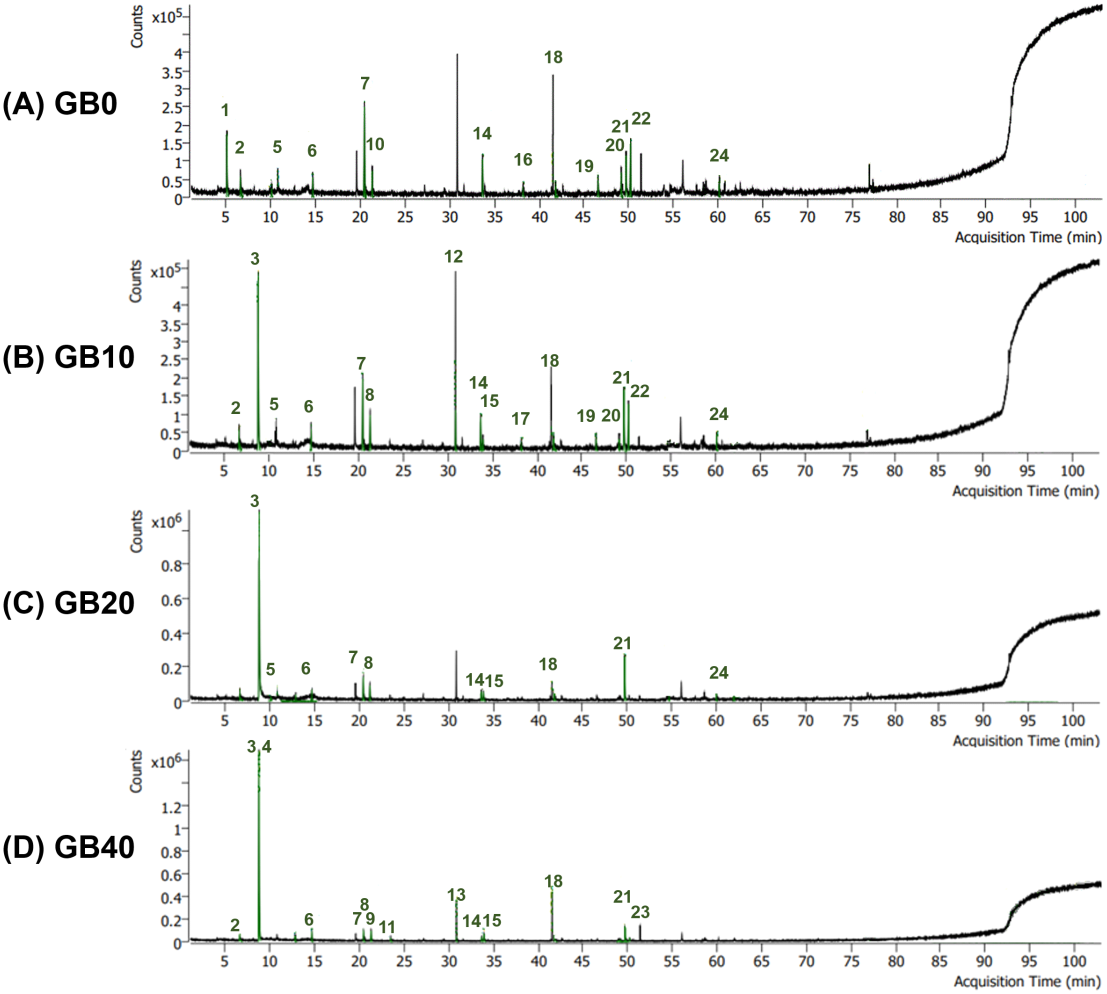

Fig. 3. GC-MS chromatograms of volatile flavor compounds of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder. In the codes listed for formula; (A) GB0, (B) GB10, (C) GB20, and (D) GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour. The numbers in the chromatogram correspond to the numbers in Table 5.

contribute to off-odor (González et al., 2019; Leonard et al., 2022). Hexanal has an unpleasant fishy/earthy odor and is associated with undesirable taste (Barido et al., 2022; Zhang et al., 2023). The contents of hexanal and nonanal increased with the increasing GB loading. Some compounds did not show a dose-dependent increase in the peak area with increasing GB loading, which was ascribed to the fact that the qualitative analysis was performed to identify compounds in an unknown sample by analyzing information such as the retention times and areas of the peaks of isolated compounds. Thus, we could not determine the absolute concentrations of unknown compounds. In addition, compounds absorbed in the headspace were analyzed by fiber coating, which could have been affected by high temperatures during heating, also influencing the distribution of the analyzed substances. This could explain the non-dose-dependent behavior of peak areas (Zhang, 2021).

2-furanmethanol, 2-undecanone, and (1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexanol were detected

Table 5. Vollatile compounds identified with retention time (RT) and peak area of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

No	RT (min)	Compounds	Peak area (×10^5)			
			GB0[1]	GB10	GB20	GB40
1	5.05	Carbon disulfide	6.42	-	-	-
2	6.57	Hexamethylcyclotrisiloxane	3.22	3.00	-	3.12
3	8.74	Dimethylamine-D1	-	20.62	54.99	76.60
4	8.75	Nitric acid, methyl ester	-	-	-	19.78
5	10.05	2-Pentanone	1.19	1.23	1.13	-
6	14.67	Hexanal	2.09	2.16	2.28	2.94
7	20.45	2-Heptanone	10.66	8.32	5.68	3.55
8	21.28	2-Bornene	-	4.18	3.80	3.88
9	21.29	2-Phenyl-1-p-tolyethanol	-	-	-	1.37
10	21.32	D-Limonene	3.15	-	-	-
11	23.49	2-Pentylfuran	-	-	-	1.36
12	30.84	3-Methoxy-4-hydroxy-17-methyl-18-[(Z)-.alpha.-methylbenzylidene]-3-(triphenylmethoxy)-5,14-ethanomorphinan-6-one	-	3.49	-	-
13	30.85	3-Acetoxy-16.beta.-hydroxy-24-nor-5.alpha.-cholan-23-oic acid - 23->16-.delta.-lactone	-	-	-	1.02
14	33.67	2-Nonanone	4.90	3.98	2.27	1.70
15	33.91	Nonanal	-	1.44	2.18	3.28
16	38.19	Furfural	1.41	-	-	-
17	38.20	3-Furaldehyde	-	1.02	-	-
18	41.82	N-Benzylidene-dimethylammonium chloride	1.75	2.11	2.57	3.53
19	46.59	2-Undecanone	1.99	1.41	-	-
20	49.17	(1R,2S,5R)-2-isopropyl-5-methyl-cyclohexanol	3.37	1.37	-	-
21	49.72	Silanediol, dimethyl-	5.98	8.55	13.01	7.37
22	50.20	2-Furanmethanol	6.86	5.86	-	-
23	50.21	3-Furanmethanol	-	-	-	1.23
24	60.14	Silanediol, dimethyl-	1.16	1.31	1.41	-

[1] GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

in GB0 and GB10. 2-furanmethanol is a major volatile compound in fresh ginseng, contributing to its antioxidant activity (Abd El-Aty et al., 2008; Fuster et al., 2000). 2-undecanone is mostly detected in *Houttuynia cordata* and other plants, contributes to flavor and odor profiles, and has been studied for its functional properties (Qi et al., 2022; Yan et al., 2020). (1*R*,2*S*,5*R*)-2-isopropyl-5-methylcyclohexanol is a plant-derived compound with various biological activities, including functional properties (Singh et al., 2012). Carbon disulfide, D-limonene, and furfural were found only in the control group (GB loading=

0%). Carbon disulfide is found in natural resources, such as plants, and has a sweet smell in the pure form. D-limonene is a volatile monoterpene responsible for the fresh odor of citrus plants and is found in ginseng (Adelina et al., 2021; Cho, 2015). Furfural is a major compound generated during heat treatment and has been associated with the sweet smell and the odor of freshly baked bread (Boscaino et al., 2017; Cho et al., 2021). Thus, the ginseng-supplemented control sample contained the aroma compounds characteristic of ginseng and sweet aroma compounds found in bread. Ginseng is used in processed food products and cooking because of its unique aroma properties (Cho, 2015). GB0 and GB10 contained volatiles from ginseng and plant sources, which is considered to have contributed to the fresh ginseng odor.

All GB-supplemented muffins contained dimethylamine-D1, 2-bornene, and nonanal, and the peak areas of these compounds increased proportionally to the GB loading, particularly in the case of dimethylamine-D1 (RT=8.74). Among the secondary amines, dimethylamine-D1 has a strong ammonia-like odor (BenchChem, 2023) and is thought to be responsible for the strong odor of GB. Methyl nitrate, 2-phenyl-1-*p*-tolylethanol, 2-pentylfuran, 3-acetoxy-16-*β*-hydroxy-24-nor-5-*α*-cholan-23-oic acid-23-16-*δ*-lactone, and 3-furanmethanol were only found in GB40. Among these, 2-pentylfuran is produced by the oxidation of linoleic acid and is responsible for earthy and bean-like smells (Boscaino et al., 2017). Compared to GB20, GB40 showed higher levels of aroma compounds, especially those with the earthy smell (e.g., hexanal and 2-pentylfuran). Thus, given the changes in off-odor upon GB supplementation, the optimal GB loading was identified as 20%.

3.7. Sensory properties

Consumer acceptance is a key parameter determining the feasibility of products for launching and is strongly influenced by product taste, odor, and appearance (Kowalski et al., 2022b). Table 6 shows the results of sensory evaluation for the samples with varying GB loading, revealing that this loading was negatively correlated with the external appearance score. Appearance is evaluated on the basis of external parameters, such as shape and color (Kim et al., 2020a). With increasing GB loading, lightness decreased and brownness increased (Table 3), i.e., the muffins became darker (Fig. 1). These color changes are considered to have contributed to the decreased appearance scores. The earthy smell was evaluated according to a previous study, in which GB was reported to have an earthy odor (Smarzyński et al., 2021), intensifying with increasing GB loading. Pauter et al. (2018) found that muffin

Table 6. Sensory scores of fresh ginseng-added muffins with different amounts of *Gryllus bimaculatus* powder

Samples	Appearance	Earthy smell	Fresh ginseng smell	Taste	Texture	Overall acceptance
GB0[1]	6.67±0.62[2]^{a}	1.27±0.46^{c}[3]	3.47±0.92^{a}	6.00±0.76^{a}	5.93±0.80^{a}	6.07±0.80^{a}
GB10	5.47±0.64^{b}	2.73±0.59^{b}	2.73±1.22^{b}	4.87±0.83^{b}	5.07±0.80^{b}	4.93±0.80^{b}
GB20	5.07±0.80^{b}	3.07±0.96^{b}	2.33±0.82^{b}	4.47±0.74^{b}	4.47±0.74^{c}	4.60±0.74^{b}
GB40	4.00±0.53^{c}	4.07±0.70^{a}	2.20±0.77^{b}	3.80±0.86^{c}	3.73±0.70^{d}	3.80±0.68^{c}

[1] GB0, GB10, GB20, and GB40 mean fresh ginseng-added muffins replacing *Gryllus bimaculatus* powder (GB) by 0%, 10%, 20%, and 40% compared to wheat flour.

[2] Values are mean±standard deviation (n=15).

[3] Means with different superscript letters ($^{a-d}$) in each column are significantly different by Duncan's multiple range test ($p<0.05$).

appearance and color became less appealing with increasing GB loading. The ginseng smell was the strongest in the control group. In the GB-containing muffins, the ginseng smell lost intensity with increasing GB loading, although the corresponding differences were not statistically significant. In the case of taste, the highest and lowest scores were obtained at GB loadings of 0% and 40%, respectively. Although this score was higher for GB10 than for GB20, the corresponding difference was not significant (p〈0.05). With increasing GB loading, the texture scores significantly decreased (p〈0.05), and so did the textural property indices obtained by mechanical measurement (Table 4). The overall preference decreased with increasing GB loading. Haber et al. (2019) reported a decrease in overall preference for bread with increasing grasshopper powder loading. The low sensory preference for muffins fortified with edible insects was reported to be related to their dark color, odor, dense structure, and low specific volume (Çabuk, 2021). GB40 showed the lowest scores in all preference categories and featured a significantly lower preference than GB20 (p〈0.05). The addition of GB to muffins increased their protein content and antioxidant activity but decreased their sensory performance, particularly at a loading of 40%. No significant difference in consumer preference was observed between GB10 and GB20. Thus, considering both nutritional enhancement and sensory preference, we concluded that a GB loading of 20% was optimal.

4. Conclusions

The quality characteristics of muffins with added fresh ginseng and varying amounts of GB were analyzed to determine the optimal GB loading. With increasing GB loading, moisture content and pH decreased, while protein content, antioxidant activity, darkness, and brownness increased. The decrease in gluten content and gluten network strength with increasing GB loading resulted in lower height and specific volume and poor textural characteristics. Moreover, high GB loadings resulted in the increased levels of hexanal and nonanal, which are responsible for off-odor. The highest amount of volatiles was observed for GB40. Regarding sensory evaluation, no significant differences were observed between GB10 and GB20, and the lowest preference was observed for GB40. Therefore, considering the effects of GB loading on protein content, antioxidant activity, aroma compounds, and sensory preferences, we concluded that the muffins with a GB loading of 20% has an acceptable off-odor and quality characteristics. The negative effects of GB on muffin volume and texture can be mitigated through the use of hydrocolloids or leavening agents, as will be reported in future studies. Thus, this work lays the foundation for the development of cricket containing bakery products and demonstrates the utility of fresh ginseng powder for reducing off-odor.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Kim JH, Moon KD. Methodology: Kim JH, Kim J, Kim JS. Formal analysis: Kim JH, Kim I, Nam I. Validation: Kim JH. Writing - original draft: Kim JH. Writing - review & editing: Kim JH, Kim J, Lim JH, Choe D.

Ethics approval

The sensory evaluation of this research was safely carried out with the approval of exemption (No. KNU-2023-0244) from the IRB of Kyungpook National University.

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