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Research Article

Quality characteristics and antioxidant activity of roasted *yakgwa* according to the addition ratio of mealworm

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Abstract The proximate composition, quality characteristics, antioxidant activity, and sensory evaluation scores of *yakgwa* added with mealworm powder (MP) were examined. MP contained 5.83 wt% moisture, 55.70 wt% crude protein, 35.96 wt% crude fat, 3.70 wt% crude ash, and 2.43 wt% carbohydrate and feature total polyphenol and flavonoid contents of 406.52 mg GAE/100 g and 21.18 mg NE/100 g, respectively. The DPPH and $ABTS^{\bullet+}$ radical scavenging activities and the reducing power of MP were determined as 90.25%, 44.06%, and 1.74, respectively. Except for moisture and carbohydrate content, the proximate composition of mealworm *yakgwa* (MY) increased with the amount of MP increased. The pH of the dough increased with the addition of MP, whereas the expansion degree tended to decrease. Sugar content was highest at MP contents of 0 wt% and 12 wt% (FM4 group), and hardness was lowest in the FM4 group. With the increasing MP content, the L, b values and antioxidant activity increased, whereas *a* value decreased. The sensory evaluation scores for the overall preference, appearance, color, and taste were lowest in the FM4 group. These results suggested that MP contents of 6-9 wt% were optimal for mealworm-based *yakgwa*.

Keywords mealworm, *yakgwa*, antioxidant activity, quality characteristic, proximate composition

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1. Introduction

Given the growing interest in future foods, edible insects have been actively researched by the Food and Agriculture Organization. Moreover, the consumption of edible insects may help solve the problems posed by the increased food demand due to global population growth (Jung, 2013). Insects are currently consumed as protein, essential amino acid, and trace nutrient sources in countries across South America, Asia, Africa, and Australia (Yoo et al., 2013). In 2010, the Korea government started to enact legislation related to the support and development of the insect industry, as insects were accepted as food components through Paragraph 1 of Article 7 of the Food Sanitation Act (Yoon and Shin, 2023). The ten accepted edible insects (stand of 2021) are the larvae of mealworm beetles, silkworms, grasshoppers, *Batryticatus bombyx*, pupae of male bees, *Gryllus bimaculatus*, and larvae of *Zophobas atratus*, *Trypoxylus dichotomus*, *Locusta migratoria*, and *Protaetia brevitarsis* (Jang et al., 2022). The term “mealworm” refers to the larvae of mealworm beetles (*Tenebrio molitor*) of the order Coleoptera (Shin et al., 2020). Mealworms, often called “*Gosoae”* in Korea because of their sweet and nutty flavor (Kim et al., 2016), are rich in essential amino acids (e.g., histidine, leucine, lysine, threonine, phenylalanine, valine), unsaturated fatty acids (oleic acid and linoleic acid), calcium, iron, and vitamin A (Baek et al., 2017; Rumpold and Schluter, 2013). Dried mealworms have protein and fat contents of 50 and 33.8 wt%, respectively (Rumpold and Schluter, 2013). Additionally, the mealworm shell is rich in chitin (Hamed et al., 2016). Despite their high nutritional value and potential applicability in foods, mealworms have a negative image that hinders the development of mealworm- based foods (Shin, 2019). For mealworms to be applied as a dietary protein source, a variety of products should be developed to reduce consumer aversion and repulsion (Jeong, 2016). To date, mealworms have been incorporated into cookies (Min et al., 2016), fishcakes (Seo et al., 2020), rice cakes (Nam and Sim, 2021), muffins (Yoon and Shin, 2023), and pan breads (Lee et al., 2023), although some limitations compared to other foods exist.

Yakgwa is a food made by frying dough containing flour, oil, starch syrup, and refined rice wine followed by dipping in a traditional Korean rice syrup and is the equivalent of Western scones, pies, and pastries (Kwon et al., 2023). *Yakgwa* has been offered at national events and during ancestral rites since the era of the Unified Shilla Dynasty and was used as a high-cultural-value food at ceremonial and special events by the royal and noble families in the era of the Joseon Dynasty (Kim et al., 2017). The recent increase in the popularity of *yakgwa* has resulted in the coining of a new term, *yaketing*, referring to a combination of *yakgwa* and ticketing (Moon, 2024). The *halmaenial* (combination of *halmeoni* (grandma) and *millennial* (generation)) culture widely spread in the MZ generation (people born between the early 1980s and 2000s) is based on reinterpreting the old, e.g., foods (such as *yakgwa*) or clothes that had been popular with the *halmeoni* generation. The recent rise of the *halmaenial* culture, which has created new interesting perceptions, is positively viewed by numerous generations (Kim, 2023).

Herein, we produced mealworm powder (MP)-supplemented *yakgwa* (MY) to increase the consumer acceptance of edible insects and thus increase mealworm consumption. The proximate compositions, quality characteristics, and antioxidant activities of MY with different MP contents were determined to verify the applicability of mealworms as a supplement for the production of functional health foods.

2. Materials and methods

2.1. Materials

Mealworms (100%, Jeonnam Jangseong) were purchased from Chamgosoae (Jeonnam, Korea). Medium wheat flour (Gompyo, Korea), starch syrup (Chungjungone, Seoul, Korea), brown rice oil (Kasisuri, Busan, Korea), refined rice wine (Lotte Chilsung Beverage, Gunsan, Korea), salt (Cheil Jedang, Seoul, Korea), soybean oil (Sajo, Seoul, Korea), pepper (Shinsegae, Pocheon, Korea), and traditional rice syrup (Chungjungone) were purchased from a mart in Pocheon and an online mall.

Gallic acid, DPPH (α,α-diphenyl-β-picrylhydrazyl) and ABTS [2,2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid)] were purchased from Sigma Chemical Co. (St. Louis, MO, USA). All other chemicals and solvents were of commercial analytical grade.

2.2. MY preparation

Table 1 lists the MY components and their mixing ratios. The mixing ratio used for *yakgwa* dough preparation was determined in preliminary experiments according to previously reported methods (Kwon et al., 2023). MP contents of 0-12 wt% (with respect to flour) were used. All other materials (starch syrup, refined rice wine, rice bran oil, salt, pepper) were used in identical contents. The mealworms were pulverized for 30 s using a grinder (FM-909T, Hanil Elec., Bupyeong, Korea). Medium wheat flour, MP, salt, and pepper were mixed and sieved, and the mixture was supplemented with rice bran oil. The resulting dough was mixed using a motion that resembles cutting (50 times), supplemented with refined rice wine and starch syrup, mixed using the same motion (50 times), left in a refrigerator for 30 min, rolled out to a uniform thickness of 1 cm, cut to dimensions of 3 cm width×3 cm length, and shaped by making four holes. The shaped dough was rapidly dipped in cooking oil, immediately placed on the pan of a preheated electric oven (DHC10-II, Softmill, Gwangju, Korea), and baked at 120℃ for 15 min and then at 170℃ for 10 min. The resulting *yakgwa* (Fig. 1) was cooled at room temperature for 1 h without applying any syrup coating for subsequent analysis. For sensory evaluation, the raters were given *yakgwa* that had been dipped in syrup for 1.5 h and dried for 30 min. The syrup was prepared by boiling a 1:1:0.2 (w/w/w) mixture of traditional rice syrup, starch syrup, and water for 15 min.

2.3. Proximate composition analysis of MP and MY

The proximate compositions of MP and MY were determined using the AOAC method (2000). Moisture content was

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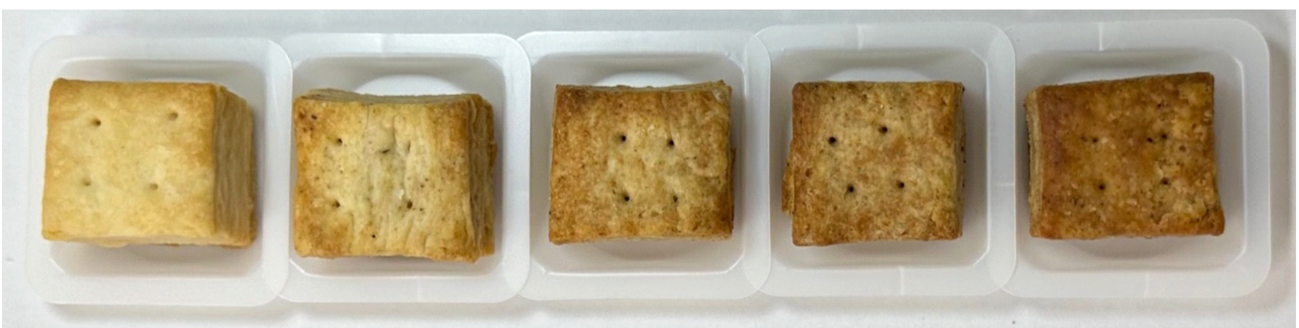
Table 1. The formula of *yakgwa* added with mealworm powder

Ingredient (g)	Mealworm *yakgwa*				
	FM0[1)]	FM1	FM2	FM3	FM4
Mealworm powder	0	6	12	18	24
Flour	200	194	188	182	176
Starch syrup	45	45	45	45	45
Refined rice wine	45	45	45	45	45
Rice bran oil	40	40	40	40	40
Salt	2	2	2	2	2
Pepper	0.2	0.2	0.2	0.2	0.2
Total	332.2	332.2	332.2	332.2	332.2

[1)]FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.



FM0 FM1 FM2 FM3 FM4

Fig. 1. **Appearance of *yakgwa* added with mealworm powder.** FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.

determined using an infrared moisture analyzer (MB45, Ohaus Corporation, Switzerland). Crude ash content was determined using the dry ashing method (KD210-B-1054 electric furnace, OPSIS, Furulund, Sweden). Crude protein content was determined using the micro-Kjeldahl method (KD210-B-1054 automatic distillation system, OPSIS). Crude fat content was determined using the Soxhlet method (SX-360-A2 extractor, OPSIS). Carbohydrate content was calculated as 100% minus the sum of moisture, crude ash, crude protein, and crude fat contents (Choi et al., 2016).

2.4. Measurement of volume and density of MY dough

The volume of the MY dough was measured by placing a 5 g sample in a graduated cylinder with 30 mL of distilled water and used to calculate the MY density (= weight/ volume).

2.5. Measurement of pH and sugar contents of MP and MY dough

For pH and sugar content measurements, a 3 g sample (MP or MY dough) was mixed with 27 mL of distilled water, and the mixture was homogenized and filtered. The pH and sugar content of filtrate were measured by a pH meter (STARA2115, Thermo Fisher Scientific Inc., Waltham, MA, USA) and Brix meter (Atago PR-101α, Atago Co., Tokyo, Japan), respectively.

2.6. Determination of MY expansion degree and cooking loss

The MY expansion degree was determined from pre-/postcooking widths, lengths, and heights, and cooking loss was calculated from pre-/postcooking weights.

Expansion degree (%)
= 100% × Postcooking volume (Width × Length × Height) / Precooking volume (Width × Length × Height)

Cooking loss (%)
= 100% × [(Precooking weight - Postcooking weight) / Precooking weight]

2.7. Measurement of MY hardness

MY hardness was measured using a texture analyzer (TAXT Plus, Stable Micro System Ltd., Godalming, UK) with a 2 mm cylinder as the probe (pretest speed=3.0 mm/s, test speed=1.0 mm/s, posttest speed=5.0 mm/s, test distance =5.0 mm/s, trigger force=5.0 g).

2.8. Measurement of MP and MY color

For MP color measurement, an experimental cell was completely filled with MP. MY color was measured using a Hunter system (JX 777, Juki, Tokyo, Japan) and expressed as the surface L (lightness), a (redness), and b (yellowness) values. The standard plate featured L=98.20, a=-0.02, b=-0.27.

2.9. Determination of total polyphenol and flavonoid contents of MP and MY

MP or MY (30 g) was mixed with 70% ethanol (70 mL), and the mixture was agitated in a shaking incubator (C-SK-2, Changshin Science Co., Seoul, Korea) at 20℃ and 150 rpm for 12 h.

For total polyphenol content measurement, the agitated mixture (0.1 mL) was supplemented with 2 N phenol (0.2 mL) and distilled water (2 mL), shaken, and left to react for 3 min at room temperature. The resulting solution was mixed with 10 wt% Na_2CO_3 (2 mL) and left in the dark for 1 h, and the absorbance measured at 765 nm (EMC-18PC-UV, EMCLAB GmbH, Duisburg, Germany) was converted into total polyphenol content, which was expressed as mg gallic acid equivalents (mg GAE)/100 g. For total flavonoid content measurement, the agitated mixture (0.1 mL) was supplemented with 1 N NaOH (0.3 mL) and diethylene glycol (2 mL) and left to react (37℃, 1 h). Subsequently, the absorbance measured at 420 nm was converted into total flavonoid content, which was expressed as mg naringin equivalent (mg NE)/100 g.

2.10. Analysis of antioxidant activities of MP and MY

MP and MY samples were prepared as described in Section 2.9. For the measurements of 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) scavenging activity, the sample (0.5 mL) was supplemented with a 0.15 mM DPPH solution (2 mL) and left in the dark for 30 min, after which the absorbance was measured at 517 nm and converted into DPPH scavenging activity as

DPPH scavenging activity (%)
= 100% × [1 - (Sample absorbance / Blank absorbance)]

For the measurements of 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) cation radical ($ABTS^{•+}$) scavenging activity, 7 mM ABTS and 2.45 mM potassium persulfate solutions were mixed in a 14:1 (v/v) ratio, and the mixture was left to react for 20 h. The resulting solution (1.6 mL) and sample of interest (0.1 mL) were mixed and left to react for 5 min, after which the absorbance was measured at 734 nm and converted into $ABTS^{•+}$ scavenging activity as

$ABTS^{•+}$ scavenging activity (%)
= 100% × [1 - (Sample absorbance / 0.70)]

For reducing power measurements, the sample (0.5 mL) was supplemented with 0.2 M sodium phosphate buffer (0.5 mL) and 1 wt% potassium ferricyanide (0.5 mL), and the mixture was left to stand at 50℃ for 20 min. Next, 10 wt% trichloroacetic acid (0.5 mL) was added, and the mixture was centrifuged. The supernatant (1 mL) was supplemented with distilled water (1 mL) and 0.1 wt% $FeCl_3$ (0.2 mL), and the absorbance was measured at 700 nm.

2.11. Sensory evaluation of MY

Sixty panelists (17 male and 43 female undergraduates in their 20s) were recruited from Daejin University (Daejin University Institutional Review Board (IRB) No. 1040656-202309-HR-01-05) and fully familiarized with the sensory evaluation method. The samples were cut to an identical size (width 1.5 cm×length 1.5 cm×height 3 cm), placed on a white plate, and evaluated by panelists provided with lukewarm water for mouth rinsing. Evaluation was performed on a seven-point scale (one: strongly dislike, seven: strongly

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like) in terms of overall preference, appearance, color, flavor, texture, and taste.

2.12. Statistical analysis

All measurements were performed in triplicate, and the results were expressed as the corresponding means±standard deviations. The SPSS Statistics software (ver. 27, IBM Co., Armonk, NY, USA) was used. The significance of the differences across samples was tested using the analysis of variance. In the case of significance, Duncan's multiple range test was performed ($p<0.05$).

3. Results and discussion

3.1. Proximate compositions of MP and MY

Table 2 presents the proximate compositions of MP and MY, revealing that MP contained 2.69 wt% moisture, 55.70 wt% crude protein, 35.96 wt% crude fat, 3.70 wt% crude ash, and 2.43 wt% carbohydrate. This composition almost agreed with those previously reported for freeze-dried mealworms by Lee et al. (2016) (0.11 wt% moisture, 51.38 wt% crude protein, 30.25 wt% crude fat, 3.47 wt% crude ash) and Jin et al. (2021) (0.80 wt% moisture, 54.07 wt% crude protein, 36.78 wt% crude fat, 3.29 wt% crude ash) with the exceptions of moisture and carbohydrate contents. Beom et al. (2007) reported that the moisture content of hot air-dried *Acorus calamus* leaves considerably exceeded that of the corresponding freeze-dried leaves. Thus, the lower moisture content of MP observed herein was ascribed to the use of hot air-drying in the present study and freeze-drying in previous studies. The proximate composition of *Gryllus bimaculatus* was previously determined as 6.20 wt% moisture, 65.02 wt% crude protein, 18.25 wt% crude fat, and 5.22 wt% crude ash (Baik et al., 2022), i.e., the crude protein content exceeded that observed herein for MP. The high crude protein content of mealworms (≥50 wt%) makes them a promising food supplement for increasing protein intake (Lee et al., 2023).

The moisture content was 6.14 wt% in the FM0 group, significantly decreasing to 4.44 wt% in the FM4 group ($p<0.05$). The crude protein/fat contents in the FM0 and FM4 groups were 8.37/20.87 wt% and 11.70/28.45 wt%, respectively, significantly increasing with the increasing MP content ($p<0.05$). The crude ash content did not significantly vary across the FM0-FM3 groups (1.29-1.33 wt%) but significantly increased to 1.45 wt% in the FM4 group ($p<0.05$). The carbohydrate content ranged from 53.96 to 63.30 wt% and decreased with the increasing MP content ($p<0.05$). In previous studies on MP-supplemented pan bread (Lee et al., 2023) and muffins (Yoon and Shin, 2023) and rice cookies supplemented with *Tenebrio molitor* larvae, *Protaetia cataphracta* larvae, and *Gryllus bimaculatus* powder (Jang et al., 2022), the moisture and carbohydrate contents decreased with the increasing additive content, while the crude protein, fat, and ash contents concomitantly increased, in agreement with the results of the present study. These findings verify the effects of the differences in proximate composition between flour and edible insects on the foods they are applied to (Lee et al., 2023). Hence, the addition of 3-12 wt% MP during the production of *yakgwa* was anticipated to increase its protein and fat contents but decrease the carbohydrate content and thus enhance nutritional functions.

Table 2. **The proximate composition of mealworm powder and *yakgwa* added with mealworm powder**

	Moisture (%)	Crude protein (%)	Crude fat (%)	Crude ash (%)	Carbohydrate (%)
Mealworm powder	2.69±0.06[2)]	55.70±1.08	35.96±2.49	3.70±0.29	2.43±1.91
FM0[1)]	6.14±0.30[a3)]	8.37±0.15[e]	20.87±0.28[d]	1.33±0.02[b]	63.30±0.56[a]
FM1	4.87±0.11[b]	8.97±0.15[d]	26.46±0.18[c]	1.29±0.04[b]	58.43±0.40[b]
FM2	4.60±0.01[bc]	9.63±0.23[c]	26.59±0.25[c]	1.30±0.09[b]	57.90±0.46[b]
FM3	4.55±0.24[bc]	10.57±0.06[b]	27.35±0.04[b]	1.33±0.02[b]	56.20±0.26[c]
FM4	4.44±0.13[c]	11.70±0.12[a]	28.45±0.22[a]	1.45±0.03[a]	53.96±0.29[d]

[1)]FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.
[2)]All values are mean±SD (n=3).
[3)]Different superscripts (a-e) in the same column indicate significant differences (p⟨0.05).

3.2. Density of MY dough

Table 3 presents the measured density of MY dough. Koh and Noh (1997) showed that cookie density can serve as a quality indicator, with low density indicating low cookie quality and facilitating crumbling. The density of MY dough in the present study was 0.17 g/mL across all samples without any significant variation, which agreed with the results of a previous study on rice cookies supplemented with *Tenebrio molitor* larvae, *Protaetia cataphracta* larvae, and *Gryllus bimaculatus* powder (Jang et al., 2022). Park and Joo (2021) also showed that sea buckthorn leaf powder content had no effect on sample density, which was attributed to the fact that this content was low and indicated that it did not significantly impact cookie quality. The lack of density change observed herein was therefore ascribed to the relatively low MP content.

3.3. pH and sugar contents of MP and MY dough

The results of pH and sugar content analyses are listed in Table 3. The pH and sugar content of MP were 6.93 and 1.70 °Brix, respectively. The pH reported by Nam and Sim (2021) for MP was 6.82 and agreed with that obtained herein.

pH values of 5.72, 5.97, 6.17, 6.32, and 6.42 were obtained for the FM0, FM1, FM2, FM3, and FM4 groups, respectively, significantly increasing with the increasing MP content ($p<0.001$). In a previous study on rice cakes supplemented with MP (Nam and Sim, 2021), pH increased with the increasing MP content, in line with the results presented herein. Park and Joo (2021) reported that the pH of sea buckthorn leaf powder was lower than that of flour and thus rationalized the decrease in dough pH with the increasing MP content. Thus, the increase in the dough pH with the increasing MP content observed herein was ascribed to the lower pH of flour (5.99) compared with that of MP (6.93).

The sugar content of FM0-FM4 groups ranged from 1.70 to 1.80 °Brix and was insignificantly higher in the FM0 and FM4 groups ($p<0.05$). Park and Joo (2021) reported that the sugar content of sea buckthorn leaf powder-supplemented samples exceeded that of flour and showed that the dough pH increased with the increasing sea buckthorn leaf powder content. On the contrary, the sugar content of our MP (1.70 °Brix) was low to not significantly affect the sugar content of MY.

3.4. Expansion degree and cooking loss of MY

Table 4 lists the expansion degrees and cooking losses of MY. Expansion degrees of 20.93%, 14.81%, 15.24%, 15.49%, and 12.83% were observed in the FM0, FM1, FM2, FM3, and FM4 groups, respectively, significantly decreasing with the increasing MP content ($p<0.001$). Oh and Sim (2017) reported that samples with moisture contents below that of the medium wheat flour featured low expansion degrees because of the low amounts of moisture available for gluten formation. The moisture content of MP in the present study (5.83 wt%) was lower than that of the medium wheat flour (11.72 wt%); hence, the insufficient amount of moisture for gluten formation led to low expansion degrees. Cho et al. (2017) reported that mealworm proteins created a network structure through fusion during high-temperature extrusion, whereby compactness increased and the expansion degree deceased. Hence, the increase in protein content with the increasing content of MP in MY resulted in increased compactness and thereby decreased the expansion degree.

Cooking loss is largely due to the loss of moisture during

Table 3. Density, pH and sugar content of mealworm powder and *yakgwa* dough added with mealworm powder

	Mealworm powder	Mealworm *yakgwa* dough				
		FM0[1)]	FM1	FM2	FM3	FM4
Density (g/mL)	–	0.17±0.00[2)NS3)]	0.17±0.00	0.17±0.00	0.17±0.00	0.17±0.00
pH	6.93±0.01	5.72±0.02[e4)]	5.97±0.01[d]	6.17±0.01[c]	6.32±0.01[b]	6.42±0.01[a]
Sugar content (°Brix)	1.70±0.00	1.80±0.00[a]	1.70±0.00[b]	1.70±0.00[b]	1.70±0.00[b]	1.80±0.00[a]

[1)]FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.
[2)]All values are mean±SD (n=3).
[3)]NS, not significant.
[4)]Different superscripts (a–e) in the same row indicate significant differences (p<0.05).

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Table 4. Physiochemical characteristics of mealworm powder and *yakgwa* added with mealworm powder

		Mealworm powder	Mealworm *yakgwa*				
			FM0[1)]	FM1	FM2	FM3	FM4
Expansion ratio (%)		-	20.93±0.75[2)a3)]	14.81±1.12[b]	15.24±0.34[b]	15.49±0.77[b]	12.83±0.73[c]
Baking loss rate (%)		-	9.70±0.17[NS4)]	7.99±1.04	8.10±3.14	8.41±0.67	7.77±1.77
Hardness (kg)		-	1.18±0.21[a]	1.09±0.15[a]	1.08±0.18[a]	1.03±0.27[a]	0.85±0.13[b]
Color value	Hunter L	43.93±0.39	74.17±1.25[a]	62.60±0.97[b]	61.06±1.25[b]	60.95±1.21[c]	56.11±0.94[d]
	Hunter a	5.83±0.29	0.47±0.14[d]	5.72±0.60[c]	5.97±0.75[c]	6.61±0.43[b]	7.75±0.61[a]
	Hunter b	12.95±0.42	22.28±0.80[c]	25.67±1.04[a]	23.10±1.26[b]	22.75±0.36[bc]	22.00±0.34[c]

[1)]FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.
[2)]All values are mean±SD (n=5).
[3)]Different superscripts ([a-d]) in the same row indicate significant differences (p<0.05).
[4)]NS, not significant.

the heating of dough in the baking process (Chung et al., 2014). For cookies, which are generally produced similarly to *yakgwa*, the MP added to the dough is known to generate bound water through physicochemical reactions and thus reduce cooking loss (Oh et al., 2022). The cooking loss in the FM0-FM4 groups equaled 7.77-9.70% and was not significantly affected by the MP content. Thus, the MP content had a negligible effect on the cooking loss of MY.

3.5. Hardness of MY

The hardness of *yakgwa* depends on the raw materials used, production methods, and sample characteristics (Kwon et al., 2023). Herein, hardness of 1.18, 1.09, 1.08, 1.03, and 0.85 kg were observed for groups FM0, FM1, FM2, FM3, and FM4, respectively, decreasing with the increasing MP content ($p<0.05$; Table 4). In a study on MP-supplemented pasta (Kim et al., 2014), a decrease in hardness with the increasing MP content was observed and ascribed to the concomitant reduction in gluten formation. Chabot (1979) and Shin (2015) reported that cookie hardness depended on the content of moisture, specific weight, and pore development and decreased with the decreasing expansion degree and water loss as a result of the development of abundant pores or reduced gluten formation. Hence, the negative correlation between MY hardness and MP content observed herein was attributed to the prevention of gluten formation in *yakgwa*, which, in turn, reduced the expansion degree and cooking loss.

3.6. Color of MP and MY

Table 4 presents the color values of MP and MY based on the Hunter system. The L, a, and b values of MP equaled 43.93, 5.83, and 12.95, respectively, and agreed with those reported by Nam and Sim (2021) (44.84, 2.33, and 10.14, respectively). In multiple previous studies, MP was reported to be dark brown, with MP addition therefore causing food darkening and reddening (Kim et al., 2014; Nam and Sim, 2021; Lee et al., 2023; Yoon and Shin, 2023). Thus, we expected MP addition to reduce lightness and increase redness.

The L value equaled 74.17 in the FM0 group, corresponding to the highest lightness, and 56.11-62.60 in the FM1-FM4 groups, indicating darkening with the increasing MP content ($p<0.001$). The a value of MY was the lowest (0.47) in the FM0 group, increasing with the increasing MP content ($p<0.001$). The b value of MY decreased with the increasing MP content, with the exception of the FM0 group ($p<0.001$). In a study on MP-supplemented cookies (Min et al., 2016), the L and b values decreased, whereas the a value increased with the increasing MP content, which agreed with the trend observed herein. Shin (2019) reported that food color was greatly influenced by the color of the main and added materials. The MP proteins were shown to facilitate the Maillard reaction and, hence, the browning of MP-containing rice cakes. Thus, the color change of MY due to MP addition was ascribed to the influence of the Maillard reaction of proteins and sample color.

3.7. Total polyphenol and flavonoid contents of MP and MY

Table 5 presents the total polyphenol and flavonoid contents of MP and MY. The total polyphenol and flavonoid contents of MP were 406.52 mg GAE/100 g and 21.18 mg NE/100 g, respectively, deviating from the values (335.75 mg GAE/100 g and 8.44 mg GAE/100 g, respectively) previously reported by Jin et al. (2021). This deviation was ascribed to the variations in the mealworm breeding conditions/duration and employed drying method (Jin et al., 2021).

The total polyphenol content of MY ranged from 77.00 to 167.54 mg GAE/100 g, significantly increasing with the increasing MP content (e.g., by 118% upon going from FM0 to FM4). The total flavonoid content of MY increased by as low as 38% and as high as 114% in proportion to the added amount of the sample compared to the control group ($p<0.001$). Similar results, namely an increase in the total flavonoid and polyphenol contents with the increasing additive content, were obtained for muffins supplemented with MP (Yoon and Shin, 2023), *yakgwa* supplemented with tartary buckwheat flour (Kim et al., 2023), and *yakgwa* supplemented with kumquat (Kwon et al., 2023). In addition, as high total polyphenol and flavonoid contents were reported to result in excellent antioxidant activities, the addition of MP was anticipated to enhance antioxidant activity (Jin et al., 2021; Yoon and Shin, 2023).

3.8. Antioxidant activities of MP and MY

Table 5 lists the antioxidant activities of MP and MY. The DPPH and $ABTS^{•+}$ scavenging activities and reducing power of MP were 90.25%, 44.06%, and 1.74 OD, respectively, deviating from the values reported by Jin et al. (2021) (82.60%, 66.39%, and 1.02 OD, respectively). As in the case of the total polyphenol and flavonoid contents, this deviation was ascribed to the variations in the mealworm breeding conditions and drying method.

For MY, the DPPH scavenging activity was the lowest at 28.22% (FM0), significantly increasing with the increasing MP content ($p<0.001$). The $ABTS^{•+}$ scavenging activity was also lowest in the FM0 group, increasing 2.31-4.24-fold upon MP addition. The reducing power increased with the increasing MP content, equaling 0.18, 0.39, 0.43, 0.54, and 0.62 OD in the FM0, FM1, FM2, FM3, and FM4 groups, respectively. In studies on rice cakes supplemented with MP (Nam and Sim, 2021) and *yakgwa* supplemented with mulberry (Shin et al., 2014), the DPPH and $ABTS^{•+}$ scavenging activities and reducing power significantly increased with the increasing additive content. In their study on rice cookies supplemented with *Tenebrio molitor* larvae, *Protaetia cataphracta* larvae, and *Gryllus bimaculatus* powder, Jang et al. (2022) reported that antioxidant activity (and hence, bioactivity) increased with the increasing insect content. Cho et al. (2017) reported that the presence of selenium in mealworms could be responsible for their beneficial effect on antioxidant activity, and Lee et al. (2014) reported that the hydrolysis of mealworm proteins at high temperatures released certain substances with antioxidant activities. Hence, the increase in the antioxidant activity of MY with the increasing MP content

Table 5. Antioxidant activities of mealworm powder and *yakgwa* added with mealworm powder

	Mealworm powder[2)]	Mealworm *yakgwa*[3)]				
		FM0[4)]	FM1	FM2	FM3	FM4
Total phenol content (mg GAE[1)]/100 g)	406.52±8.30	77.00±2.14[5)e6)]	97.29±4.24[d]	128.60±2.21[c]	153.91±3.53[b]	167.54±3.83[a]
Total flavonoid content (mg NE/100 g)	21.18±3.11	20.00±0.90[e]	27.52±1.93[d]	34.90±1.61[c]	39.35±1.31[b]	42.81±0.97[a]
DPPH radical scavenging activity (%)	90.25±1.98	28.22±0.98[d]	55.90±2.05[c]	73.82±1.73[b]	87.11±1.33[a]	88.59±1.07[a]
$ABTS^{•+}$ radical scavenging activity (%)	44.06±1.49	16.98±1.16[e]	39.25±0.58[d]	52.22±0.43[c]	66.91±2.74[b]	72.06±2.65[a]
Reducing power (Abs_{700})	1.74±0.18	0.18±0.00[e]	0.39±0.01[d]	0.43±0.01[c]	0.54±0.01[b]	0.62±0.01[a]

1)GAE, gallic acid equivalent; NE, naringin equivalent.
2)The measured concentration for radical scavenging activity(DPPH, $ABTS^{•+}$) and reducing power were 50 and 100 mg/mL, respectively.
3)The measured concentration for DPPH radical scavenging activity, $ABTS^{•+}$ radical scavenging activity and reducing power were 150 mg/mL.
4)FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.
5)All values are mean±SD (n=3).
6)Different superscripts (a-e) in the same row indicate significant differences ($p<0.05$).

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was ascribed to the effects of the selenium, polyphenols, and flavonoids contained in MP as well as the products of mealworm protein hydrolysis during *yakgwa* production. The addition of MP was therefore concluded to effectively increase the antioxidant activity of *yakgwa*.

3.9. Sensory evaluation of MY

Table 6 presents the sensory evaluation results for MY, revealing that the overall preference score showed no significant differences across the samples in groups FM0-FM3 (5.30-5.53) and was lowest for the FM4 group (4.50). The appearance and color scores were 6.10 and 5.73 in the FM0 group and 6.10 and 5.89 in the FM1 group, respectively, significantly decreasing with the increasing MP content ($p < 0.001$). The flavor and texture scores did not vary significantly across the samples. The taste score was 5.48, 5.47, 5.35, and 5.33 in the FM0, FM1, FM2, and FM3 groups, respectively, showing no significant differences across the samples, and was lowest in the FM4 group (4.43, $p<0.001$). In a study on rice cakes (Nam and Sim, 2021), the addition of >6 wt% MP with respect to rice flour decreased the preference scores. In a study on pan bread (Lee et al., 2023), the addition of >5 wt% MP with respect to the bread mix powder also decreased the preference scores. In a study on rice cookies supplemented with *Tenebrio molitor* larvae, *Protaetia cataphracta* larvae, and *Gryllus bimaculatus* powder (Jang et al., 2022), most preference scores were higher in the control group than in the groups with added insect powder. In a study on fishcakes supplemented with MP (Seo et al., 2020), the scores of all five items tested in the sensory evaluation were higher in the control group. Although edible insects have attracted growing interest with the steadily decreasing negative consumer perceptions (Jeong, 2017), low preference scores were reported for foods containing edible insects in previously conducted sensory evaluations. Herein, the FM4 group featured the lowest preference scores of the six tested items (4.10-5.07); however, these scores were still above the moderate level of 4.0. The overall preference, flavor, texture, and taste scores of the FM3 group (MP content=9 wt%,) were not significantly different from those of the control group. Thus, *yakgwa* was determined to be well suited for supplementation with MP to enhance the consumer preference for mealworms.

The results of proximate composition, quality characteristics, antioxidant activity, and consumer preference analyses collectively suggested that 6-9 wt% MP with respect to flour is the most suitable level for increasing the protein content and antioxidant activity of *yakgwa* without markedly decreasing consumer preference. Additional studies aiming to increase the MY preference scores should be carried out to develop a healthy, tasty, and stylish traditional Korean dessert with a high consumer preference.

4. Conclusions

Yakgwa with MP contents of 0-12 wt% with respect to

Table 6. The sensory evaluation of *yakgwa* added with mealworm powder

	Mealworm *yakgwa*				
	FM0[1)]	FM1	FM2	FM3	FM4
Overall preference	5.53±1.29[2)a3)]	5.37±1.37[a]	5.17±1.24[a]	5.30±1.14[a]	4.50±1.46[b]
Appearance	6.10±1.07[a]	5.73±1.15[a]	5.10±0.96[b]	4.70±1.45[b]	4.10±1.41[c]
Color	6.10±1.28[a]	5.89±1.08[a]	5.02±1.16[b]	4.83±1.42[b]	4.17±1.47[c]
Flavor	5.29±1.28[NS4)]	5.27±1.30	5.22±1.08	5.23±1.13	4.85±1.29
Texture	5.40±1.20[NS]	5.38±1.45	5.38±1.12	5.35±1.13	5.07±1.41
Taste	5.48±1.24[a]	5.47±1.28[a]	5.35±1.29[a]	5.33±1.24[a]	4.43±1.61[b]

[1)]FM0, flour added with 0% mealworm powder; FM1, flour added with 3% mealworm powder; FM2, flour added with 6% mealworm powder; FM3, flour added with 9% mealworm powder; FM4, flour added with 12% mealworm powder.
[2)]All values are mean±SD (n=60).
[3)]Different superscripts (a-c) in the same row indicate significant differences ($p<0.05$).
[4)]NS, not significant.

flour was prepared and characterized in terms of proximate composition, quality characteristics, antioxidant activity, and sensory evaluation scores. The proximate composition of MP was determined as 5.83 wt% moisture, 55.70 wt% crude protein, 35.96 wt% crude fat, 3.70 wt% crude ash, and 2.43 wt% carbohydrates. With the increasing MP content, the moisture and carbohydrate contents of MY decreased, whereas those of crude ash, protein, and fat increased. The MY dough density did not significantly vary across the samples (0.17 g/mL), while pH significantly increased with the increasing MP content. The sugar content of the MY dough was highest (1.80 °Brix) for the FM0 and FM4 groups. The expansion degree of MY significantly decreased with the increasing MP content, whereas the cooking loss did not significantly vary across the samples. The lowest hardness was observed for the FM4 group. The L, a, and b values of MP were 43.93, 5.83, and 12.95, respectively. With the increasing MP content, the L and b values decreased, and the *a* value increased. The total polyphenol and flavonoid contents of MP were 406.52 mg GAE/100 g and 21.18 mg NE/100 g, respectively, and those of MY increased with the increasing MP content. The DPPH and $ABTS^{\bullet+}$ scavenging activities and reducing power of MP were 90.25%, 44.06%, and 1.74 OD, respectively, and those of MY increased with the increasing MP content. Sensory evaluation revealed that the flavor and texture scores did not significantly vary across the samples, whereas the overall preference, appearance, color, and taste scores were lowest for the FM4 group. Thus, taking into account the proximate composition, quality characteristics, antioxidant activities, and sensory evaluation results, we determined the optimal MP content as 6-9 wt%.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Joo SY. Methodology: Kim JE, Joo SY. Formal analysis: Joo SY. Validation: Kim JE. Writing - original draft: Kim JE. Writing - review & editing: Joo SY.

Ethics approval

This research was approved by IRB from the institute (1040656-202309-HR-01-05).

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References

AOAC. Official Method of Analysis. 17th ed. Association of Official Analytical Chemists, Gaithersburg MD, USA, p 1-26 (2000)

Baek M, Hwang JS, Kim MA, Kim SH, Goo TW, Yun EY. Comparative analysis of nutritional components of edible insects registered as novel foods. J Life Sci, 27, 334-338 (2017)

Baik W, Jeong Y, Park SS, Shin EC, Lee Y. Textural and sensory characteristics of soy meat with the addition of *Gryllus bimaculatus* powder produced using a 3D food printer. J Korean Soc Food Sci Nutr, 51, 1364-1369 (2022)

Beom HJ, Kang DJ, Lee BD, Shon S, Im JS, Eun JB. Physicochemical characteristics of powder from hot air and freeze dried leaves and roots of *Acorous calamus* L. J Korean Soc Food Sci Nutr, 36, 1451-1457 (2007)

Chabot JF. Preparation of food science sample for SEM. Scan Electron Microsc, 3, 279-286 (1979)

Cho SY, Jeong DH, Ryu GH. Effect of extrusion process variable on physicochemical properties of extruded rice snack with mealworm. Korean J Food Sci Technol, 49, 444-452 (2017)

Choi KS, Kim YH, Shin KO. Effect of mulberry extract on the lipid profile and liver function in mice fed a high fat diet. Korean J Food Nutr, 29, 411-419 (2016)

Chung HS, Lim JA, Lee JH. Quality and antioxidant properties of pound cakes supplemented with flaxseed powder. J Korean Soc Food Sci Nutr, 43, 1959-1963 (2014)

Hamed I, Ozogul F, Regenstein JM. Industrial applications of crustacean by-products (chitin, chitosan, and chitooligosaccharides): A review. Trends Food Sci Technol, 48, 40-50 (2016)

Jang HB, Baek JY, Choi YS, Jang HW. Quality characteristics and antioxidant activities of rice cookies prepared with *Tenebrio molitor*, *Protaetia brevitarsis*, and *Gryllus*

 https://doi.org/10.11002/fsp.2024.31.2.245

bimaculatus powder. Korean J Food Sci Technol, 54, 171-178 (2022)
Jeong YJ, Processing and quality characteristics of chalddukpie prepared using mealworm powder. MS Thesis, Kyonggi University, Suwon, Korea p 18-30 (2017)
Jin KN, Jeong EJ, Kim YS. Antioxidant components and antioxidant activities of mealworm (*Tenebrio molitor* Larvae). J Food Hyg Saf, 36, 86-92 (2021)
Jung CE, Prospects of insect food commercialization: A mini review. Korean J Soil Zool, 17, 5-8 (2013)
Kim CY, Lim SH, Jang HW, Jung JY, Kim JH. Quality characteristics of *yakgwa* by the addition of bitter buckwheat flour. Culi Sci Hos Res, 29, 27-35 (2023)
Kim HJ. *Halmaenial* dessert that appeals to the MZ generation. Korea Inst Local Finance, 69, 102-105 (2023)
Kim SH, Kim KB, Noh JS, Yun EY, Choi SK. Quality characteristics of pasta with addition of mealworm (*Tenebrio molitor*). J Food Ser Ind, 10, 55-64 (2014)
Kim SH, Shon JY, Park JS, Kim JW, Kang JH, Yun EY, Hwang JS, Kim HM. Change in dietary intake and nutritional status using mealworms as hospital meal in postoperativepatie, J Korean Diet Assoc, 22, 292-309 (2016)
Kim SI, Lee JS, Son DK. Quality characteristics of baked *yakgwa* containing different amounts of *Perilla frutescens* powder. J Korean Soc Food Sci Nutr, 46, 1106-1113 (2017)
Koh WB, Noh WS. Effect of sugar particle size and level on cookie spread. J East Asian Soc Diet Life, 7, 159-165 (1997)
Kwon JE, An SH, Lim HC. Quality characteristics of *yakgwa* added with freeze-dried kumquat powder. Culi Sci Hos Res, 29, 36-48 (2023)
Lee JH, Lee J, Whang J, Nam JS, Han HK, Kim SM, Im JY, Choi Y, Kim HR, Kim SN. Changes in food composition of *Tenebrio molitor* by life stage. Korean J Food Cook Sci, 32, 656-663 (2016)
Lee KH, Kim MJ, Kim AJ. Physiochemical composition and antioxidative activities of *Rhynchosia nulubilis* according to roasting temperature. J Korean Soc Food Sci Nutr, 43, 675-681 (2014)
Lee YJ, Ju YE, Cho EC, Park SJ, Kim DH, Hwang HJ, Yoon YA, Shin KO. Quality characteristics and nutritional functions of bread added with *Tenebrio molitor* Linnaeus (mealworm) powder. J East Asian Soc Diet Life, 33, 251-263 (2023)
Min KT, Kang MS, Kim MJ, Lee SH, Han JS, Kim AJ. Manufacture and quality evaluation of cookies prepared with mealworm (*Tenebrio molitor*) powder. Korean J Food Nutr. 29, 12-18 (2016)
Moon SJ. *Yakgwa* craze in the *Halmaenieol* trend. Available from: https://m.kmib.co.kr/view.asp?arcid=0018239128. Accessed Feb. 14, 2024.
Nam HH, Sim KH. Quality characteristics of garaedduk enriched with mealworm (*Tenebrio molitor*) powder. Korean J Food Nutr, 34, 272-288 (2021)
Oh HL, Kim MH, Han YS. Antioxidant activities and quality characteristics of perilla seed meal and plant-based rice added cookies prepared with the addition of perilla seed meal powder. J Korean Soc Food Sci Nutr, 51, 950-959 (2022)
Park MG, Joo SY. Quality characteristics and antioxidant activity of rye cookies supplemented with sea buckthorn leaf powder. J Korean Soc Food Sci Nutr, 50, 464-475 (2021)
Rumpold BA, Schluter OK. Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res, 57, 802-823 (2013)
Seo JH, Hong CY, Shin DE, Kang TS, Lee J, Jeong HS. Quality characteristics of fish cakes containing different amounts of mealworm powder (*Tenebrio molitor*). Korean J Food Sci Technol, 52, 403-408 (2020)
Shin DG, Lee SJ, Choi HR, Chung YH, Jang HS, Yoo JS, Cho KH, Kwon GT. Study of intestinal microbiota in *Tenebrio molitor* L. (mealworm larvae) hydrolysate. J Korean Soc Food Sci Nutr, 49, 304-310 (2020)
Shin GM. Quality characteristics of *Lycii fructus* powder added sponge cake. Culi Sci & Hos Res, 21, 63-75 (2015)
Shin SK, Kim HJ, Kim MR. Quality characteristics of *yackwa* added with mulberry concentrate. J East Asian Soc Dietary Life, 24, 136-142 (2014)
Shin SM. Quality characteristics of sulgidduk prepared with different levels of defatted mealworm powder. J Korea Acad Industry Coop Soc, 20, 523-530 (2019)
Yoo J, Hwang JS, Goo TW, Yun EY. Comparative analysis of nutritional and harmful components in Korean and Chinese mealworms (*Tenebrio molitor*). J Korean Soc Food Sci Nutr, 42, 249-254 (2013)
Yoon JA, Shin KO. Nutritional functionality and quality characteristics of muffins supplemented with *Tenebrio molitor* Linne (mealworm) powder. J Korean Soc Food Sci Nutr, 52, 938-946 (2023)