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Original article

Evaluation of the physicochemical and sensory properties of branched-chain amino acid-fortified perilla mousse after retort sterilisation as a dysphagia diet

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Summary Dysphagia and difficulty swallowing, lead to a heightened risk of respiratory disorders and malnutrition. This study aimed to assess the physicochemical and sensory properties of a branched-chain amino acids-fortified perilla mousse (PM) and its retorted version (RPM) to determine their suitability for dysphagia patients. PM and RPM were evaluated for texture, colour, free amino acids content, sensory acceptance, and the International Dysphagia Diet Standardisation Initiative (IDDSI) levels were determined. The results showed that PM and RPM met IDDSI Levels 3–4. RPM exhibited a redder, darker colour and a firmer texture compared with PM. Moreover, RPM showed no syneresis and maintained high viscoelasticity from 20 °C to 80 °C. Additionally, retort sterilisation increased essential amino acid levels in RPM, and it received high sensory acceptance. This mousse offers a promising option for dysphagia patients, providing enhanced nutritional value with ease of swallowing. Future research should explore the long-term impacts on dysphagia management.

Keywords Branched-chain amino acid, dysphagia diet, easily chewable and swallowable, IDDSI, retort sterilisation.

Introduction

The number of patients suffering from dysphagia is increasing owing to an aging population. The disorder causes malnutrition and sarcopenia, as well as other health problems. Twenty percent of Koreans aged 65 or more are reported to have experienced dysphagia (Lee *et al*., 2022), and the prevalence of dysphagia steadily increased over the 10 years from 2006 to 2016 (Kwon *et al*., 2023). Dysphagia is the inability to swallow food properly (Sura *et al*., 2012). Aspiration occurs frequently in patients with dysphagia, and the risk of developing respiratory disorders, including airway damage and aspiration pneumonia, is high (Rommel & Hamdy, 2016). In addition, the elderly in undernourished conditions have a high risk of transitioning to sarcopenia (Shin *et al*., 2016; Landi *et al*., 2019). Sarcopenia in the elderly leads to a decrease in swallowing-related muscle function, which is accompanied by “dysphagia due to sarcopenia” (Azzolino *et al*., 2019). Sarcopenia-induced dysphagia increases malnutrition and leads to an irreversible cycle of frailty.

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A dysphagia diet or texture-modified food can solve the problems caused by dysphagia. A dysphagia diet refers to food explicitly designed for patients with dysphagia by adjusting the rheological properties of food to increase cohesiveness and lower adhesiveness (Ryu, 2014). Dysphagia meals are mainly classified following the International Dysphagia Diet Standardisation Initiative (IDDSI) framework, which consists of Levels 0–7 (International Dysphagia Diet Standardization Initiative (IDDSI), 2019). Levels 0–4 are related to drinks, whereas Levels 3–7 include solid foods, with Level 3 representing liquid type and Level 4 representing puree-like texture (Cichero *et al*., 2017). By ingesting texture-modified foods that contain thickening agents, aspiration can be reduced (Methacanon *et al*., 2021). In particular, in patients with dysphagia, taking nutrition-enhanced texture-modified foods can be helpful in preventing malnutrition and sarcopenia (Germain, 2022). Therefore, precise research is needed on dysphagia foods that take nutritional aspects into account.

To prevent malnutrition and sarcopenia in patients with dysphagia, high-quality protein must be crucially consumed (Ang *et al*., 2022). Although meat can provide protein, it can be challenging for

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the elderly with difficulty chewing and swallowing. Therefore, adding protein to texture-modified foods may be more effective for this population (Mirazimi *et al.*, 2022). One method to supplement nutrition is by adding branched-chain amino acids (BCAAs) (Lee & Shin, 2023). BCAAs refer to three essential amino acids, leucine, valine, and isoleucine, which play a significant role in protein synthesis (Hinkle *et al.*, 2022). They constitute approximately 17% of the essential amino acids found in muscle proteins (Gorissen & Phillips, 2019), and leucine was reported to help prevent sarcopenia (Leenders & van Loon, 2011). Furthermore, taking BCAAs can lower the amount of free tryptophan that goes to the brain, which can decrease the feeling of fatigue after exercise (Watson *et al.*, 2004; Choi *et al.*, 2013).

Recently, a study conducted on retort chicken curry mousse with added BCAAs reported that the retort sterilisation process could increase the content of BCAAs (Lee & Shin, 2023). However, ready-to-eat meals with enriched plant-based amino acids have yet to be developed. Perilla is a traditional Korean ingredient rich in omega-3 fatty acids and high-quality plant-based protein (Lee *et al.*, 2002). According to Lee *et al.* (2002), perilla seeds have an oil content of 44% as well as a protein content of 16% per 100 g, making them one of the plant-based foods with high protein content. Additionally, perilla has been identified as a Korean substitute for olive oil in the MIND (Mediterranean-DASH) diet, known for its cognitive benefits (Park *et al.*, 2020). The abundance of plant-based protein and nutritional effects from omega-3 fatty acids make perilla seeds a suitable food option for the elderly. Therefore, the purpose of this study is to develop a BCAA-fortified perilla mousse (PM) as a ready-to-eat meal option for patients with dysphagia as a follow-up to the study by Lee & Shin (2023).

Materials and methods

Materials

The ingredients used in this study are listed in Table 1. Perilla seed-added mushroom sauce as the main ingredient of our samples was purchased from the online store Total Meal Solution (Shinwon TMS Inc., Seoul, Korea). Perilla seed and mushroom each constituted 8.52% and 16.83%, respectively, of the sauce (Appendix S1). Unflavoured BCAA powder was acquired from Nutricost (Nutricost Co., Ltd. Vineyard, UT, USA), with no added ingredients. Additionally, the unflavoured viscosity enhancer consisted of xanthan gum, dextrin, and guar gum (Softia-G, Nutri Co., Ltd., Yokaichi, Japan).

Table 1 Composition of perilla mousse

Materials	Composition (%)	Manufacturer
Perilla seed mushroom sauce	96.50	Shinwon TMS, Seoul, Korea
BCAA	1.500	Nutricost, Vinyard, USA
(L-Leucine)	0.750	
(L-Isoleucine)	0.375	
(L-Valine)	0.375	
Viscosity enhancer	2	Nutri, Yokaichi, Japan

BCCA, branched-chain amino acids.

Perilla mousse cooking procedure

The perilla seed-added mushroom sauce was heated in a pot to a centre temperature of 60 °C. Then, the sauce was blended using a blender (Masterpiece Collection; Electrolux, Guangzhou, China) until there were no lumps. Viscosity enhancer and BCAAs powder were scattered widely and blended homogeneously. The determination of BCAA content was conducted through a preliminary sensory evaluation with an expert panel group. Figure 1 provides a detailed description of the PM preparation steps.

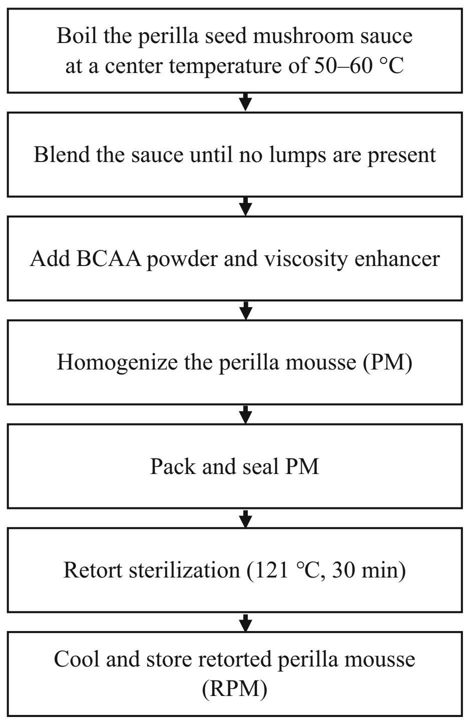


Figure 1 Flow diagram for preparation of retorted perilla mousse (RPM).

Retort sterilisation and sample preparation

Retort sterilisation was conducted using a 45 L autoclave (LTS Co. Ltd., Ansan, Korea). Ninety grams of PM was filled in the retort pouch with dimensions of 16 cm × 19 cm and sealed at 200 °C for 30 s by removing air. The retort temperature was set at 121 °C for 30 min under 200 ± 50 kPa during the entire process. After the thermal processing, two types of mousse were prepared: retorted PM (RPM) and non-retorted PM.

International dysphagia diet standardisation initiative

IDDSI fork drip test

The fork drip test based on IDDSI was utilised in this study to determine the appropriate viscosity enhancer concentration for PM; 1%, 2%, and 3% concentrations of viscosity enhancer were added according to the IDDSI framework (International Dysphagia Diet Standardization Initiative (IDDSI, 2019). This method was conducted according to Malouh *et al.* (2020) with slight modification. The fork drip test was employed to analyse the food texture that could be consistently applied to puree or paste type which did not need mastication. Level 3 food has a viscosity similar to that of fruit syrup, allowing it to be consumed from a cup and slowly flowing between fork prongs. In contrast, pureed or thick-textured food (Level 4) should not drip down between the fork prongs when lifted and should form a moderately raised shape on the fork. A detailed visual description of the fork drip test is shown in Fig. 2.

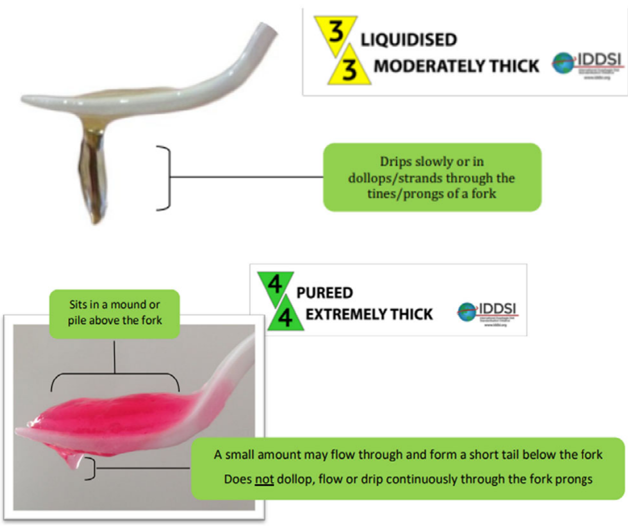


Figure 2 International Dysphagia Diet Standardisation Initiative (IDDSI) framework fork drip test (Levels 3 and 4), version 2.0. *Source*: IDDSI, 2019.

IDDSI spoon tilt test

The IDDSI spoon tilt test was used to analyse the effect of retort sterilisation based on the IDDSI framework classification. The spoon tilt test was conducted at 55 °C with PM and at 55 °C and 36 °C with RPM. In Level 4, the viscosity of the food is smooth, without any lumps or stickiness, and can be easily eaten with a spoon. It does not require chewing and holds its shape on the spoon. However, it falls off the spoon easily, and must not be firm or sticky if the spoon is tilted or lightly flicked. In Level 5, the food should also hold its shape on a spoon but should fall off easily if the spoon is tilted or flicked lightly. Like in Level 4, the food must not be firm or sticky. The spoon tilt test was performed as in Malouh *et al.* (2020) with minor modification and is described in detail in Fig. 3.

Physicochemical properties of PM

Colour

The colour of the PM and RPM was measured using a chromameter (CR-400; Konica Minolta, Tokyo, Japan), following the methods outlined in previous research (Lee & Shin, 2023). The experiment was performed by placing 6 g of each sample in a 35 mm diameter Petri dish. Before the analysis, calibration of the instrument was performed using a white standard ceramic tile with Reference No. 1353123, having a Y value of 92.7, x value of 0.3133, and y value of 0.3193. The L^* value is a measure of the lightness of a sample, ranging 0–100 (black–white), a^* indicates redness ($+a^*$: redness, $-a^*$: greenness), and b^* indicates yellowness ($+b^*$: yellowness, $-b^*$: blueness). The value of delta E was calculated using the equation from the study of Tomasevic *et al.* (2019).

Frequency sweep test

The viscoelasticity of PM and RPM was assessed by a frequency sweep test using a hybrid rheometer (Discovery HR-2; TA Instruments, New Castle, DE, USA). The experimental conditions were based on the study of Ahmed & Ramaswamy (2006). A 40 mm diameter parallel plate sensor with a 1 mm gap was prepared with 0.1% strain at a frequency range of 0.1–10 Hz. The samples were prepared at 25 °C and the results were calculated using the software TRIOS 5.1.1 (TA Instruments, New Castle, DE, USA).

Temperature sweep test

To further clarify the IDDSI spoon tilt test, a temperature sweep test was additionally conducted using the same hybrid rheometer as in the frequency sweep test. The experimental conditions were based on the study of Shi *et al.* (2022). The temperature sweep test was conducted at a temperature range of 20 °C–80 °C with a heating rate of 5 °C min^{-1}, strain of 0.1%, and angular frequency of 1 Hz. The calculations were

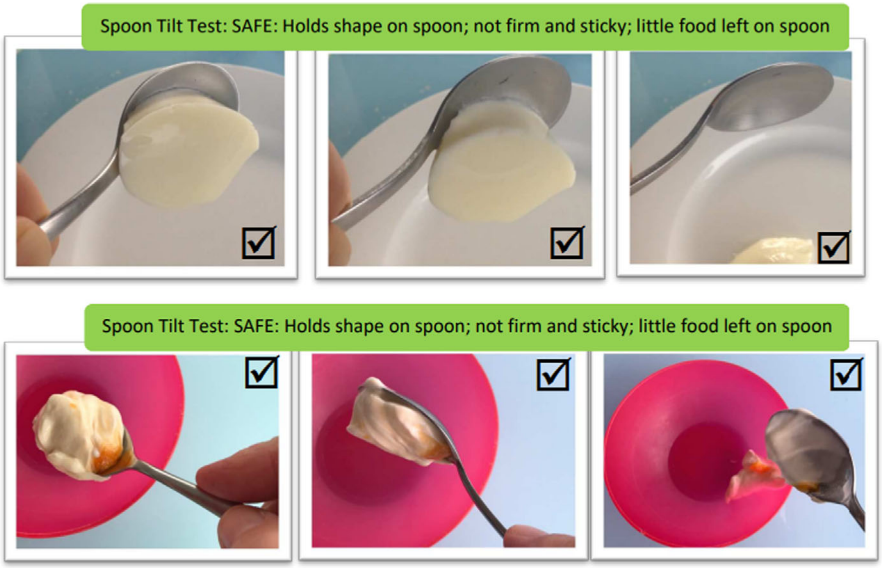


Figure 3 International Dysphagia Diet Standardisation Initiative (IDDSI) framework spoon tilt test (Levels 4 and 5), version 2.0. *Source*: IDDSI, 2019.

performed using the software TRIOS 5.1.1 (TA Instruments, New Castle, DE, USA). This procedure yielded a mechanical spectrum, wherein the storage modulus (G') and loss modulus (G'') were documented as functions of frequency (Hz) in triplicate.

Texture profile analysis

The effect of retort processing on the texture of PM and RPM was analysed as described by Lee & Shin (2023). The texture profile was analysed to determine the values of hardness, cohesiveness, adhesiveness, springiness, gumminess, and chewiness. Each sample (30 g) was placed in an individual cup, which was then penetrated to a depth of 25 mm with a 25 mm diameter aluminium cylinder probe at a speed of 1 mm s^{-1} using a 250 N load cell. The probe retraced its path at the identical speed to the initial point, with a percentage of deformation in the test of 50 and a trigger force of 0.15 N. The experiment was conducted using a texture analyser (TMS-Pilot; Food Technology Corporation, Sinfold, UK).

Syneresis

Syneresis was measured using a filter paper blotting method described by Ferrero *et al.* (1994) and Pant *et al.* (2021) with modifications. Each mousse sample (1 g) was placed at the centre of a Whatman Grade 4 filter paper such that it covered a circle 1 cm in diameter. The filter paper was left for 30 min to seep the liquid from the PM and RPM. Then, the spreading area was photographed and calculated with ImageJ software 1.54 (National Institutes of Health, Bethesda, MD, USA).

Analysis of free amino acids

The free amino acid content of the sample was analysed before and after retort treatment using an automatic analyser in compliance with the Food Code in Korea (MFDS, 2022). A standard solution of Amino Acids Mixture Standard Solution Type AN-II, Type B was diluted with 0.02 N HCl to a suitable concentration. An ion exchange resin #2622PF, with a column diameter of 4.6 mm and a length of 60 mm, was utilised in the experiment. The mobile phase contained various components: a ninhydrin solution, buffer solution for the ninhydrin-derived compound, 5% ethanol and buffer for the biological fluid PF-1 KANTO (PF-1), PF-2, PF-3, PF-4, and PF-RG. Pump 1 maintained a flow rate of 0.35 mL min^{-1}, whereas pump 2 operated at 0.3 mL min^{-1}. The UV detector settings were 570 nm and 440 nm, and the temperature of the central column ranged from 38 °C to 70 °C, whereas the reaction column was set at 135 °C. A 20 μL sample was injected. During the preparation of the sample, water extraction was applied to the paste samples. A precisely measured 1 g of the uniform sample was attached, and 10 times the amount of water was added. The mixture underwent heating, solidification, and filtration in a boiling water bath to eliminate the water layer. The resulting residue was rinsed three times with a minimal amount of water and the dissolved residue was obtained by concentrating and drying the water layer under reduced pressure in 0.02 N HCl, to obtain a test solution. The insoluble matter was subsequently separated by filtration through a membrane filter.

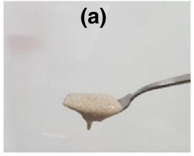
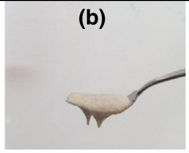
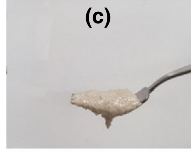
Concentration of Thickener	1%	2%	3%
Fork Test	(a) 	(b) 	(c) 

Figure 4 International Dysphagia Diet Standardisation Initiative (IDDSI) fork drip test of the perilla mousse with different concentrations of the viscosity thickener; (a–c) represent perilla mousse samples with 1%, 2%, and 3% of thickener, respectively.

Preliminary consumer acceptance test

A preliminary consumer acceptance test was conducted to investigate the effect of retort sterilisation on the sensory characteristics of PM. Participants who were healthy elderly without cognitive disabilities were recruited from the Yongsan Senior Welfare Centre in Seoul through voluntary participation. Seventeen assessors were determined as the minimum number of participants needed for statistical significance at 95%, with a power of 80%, using the G-power software and an effect size of 1.54 as described in Zargaraan *et al.* (2015). Moreover, a sample size of 18 was followed from the usability test for designating senior-friendly food, according to the assessment guidelines from Food Polis, the Ministry of Agriculture, Food and Rural Affairs, Korea (Food Polis, Senior-Friendly Foods, 2024). The actual sensory panels included 18 panellists, consisting of three males and 15 females, aged between 61 and 91 years. Each panellist was given 10 g of PM and RPM at 35 °C in a cup with a 3-digit random number code marked, in random order. They tasted and rated the samples on a 9-point hedonic scale ranging from 1 (extreme dislike) to 9 points (extreme like). The evaluation was based on the colour, odour, bitterness, smoothness, cohesiveness, adhesiveness, and overall acceptability of each sample. The elderly participants were briefed in detail about the terms (adhesiveness and cohesiveness) and provided written consent prior to the experiment. Adhesiveness referred to the degree to which the mousse sticks to the mouth, whereas cohesiveness referred to how much the mousse clumped in the mouth. When the mousse stuck to the mouth or clumped in the mouth, subjects gave high scores, with a maximum of 9 points. This study received approval from the Institutional Review Board of Hanyang University (IRB number HYUIRB-202211-002-1).

Statistical analysis

The results were obtained from triplicate tests and are presented as the mean ± standard deviation. The statistical analysis was conducted using SPSS software 27.0 (SPSS Inc., Chicago, IL, USA). The data were analysed by performing the Student's *t*-test. Statistical significance was set at a level of 95% and indicated using asterisks (*).

Results and discussion

International dysphagia diet standardisation initiative (IDDSI)

Determination of the thickener concentration using the IDDSI fork drip test

The IDDSI test is a widely utilised method for assessing the rheological properties of dysphagia diets. To determine the concentration of thickening agents, 1%, 2%, and 3% of viscosity enhancer were added to untreated PM, and fork tests were conducted (Fig. 4). Upon observation of the appearance of the mousse between the prongs of the fork, the 1% PM (Fig. 4a) was judged to be at approximately Level 3 (Fig. 3). From the images, it can be noted that the surface of the 3% PM (Fig. 4b) was rougher than that of the 1% and 2% PM and exhibited cohesive lumps. The dysphagia diet should be adjusted in terms of thickener quantity based on individual viscosity preferences, with low adhesiveness and high cohesiveness being desirable traits. Moreover, the texture should be free from lumps. Therefore, the addition of 2% thickening agent to the PM (Fig. 4c) was deemed to be appropriate for achieving the desired dysphagia diets.

Classification of PM based on the IDDSI spoon tilt test under different temperatures

According to the IDDSI framework, foods categorised between Levels 3 and 4 can be diagnosed for their consistency through both the fork and spoon tests. Additionally, the characteristics of food networks vary with temperature. Therefore, spoon tests based on temperature were conducted and the results are shown in Fig. 5. When PM, perceived by the participants as warm, was subjected to the spoon test at 55 °C (Fig. 5a), it exhibited low adhesiveness and high cohesiveness, as evidenced by the clean release of the spoon without any residual food. However, in the case of RPM at the same temperature (55 °C), residual food adhered to the spoon (Fig. 5b). Conversely, when the

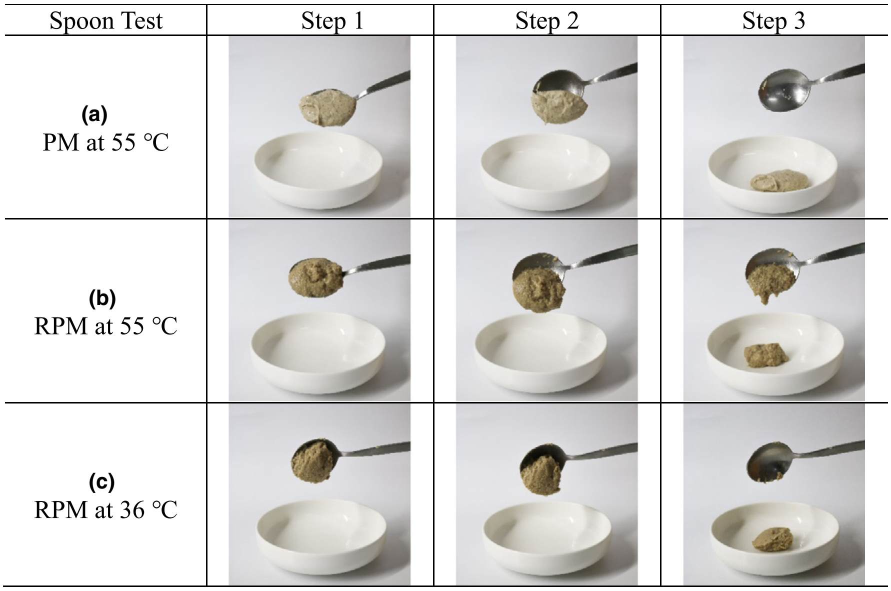


Figure 5 International Dysphagia Diet Standardisation Initiative (IDDSI) spoon tilt test of the perilla mousse at 55 °C and 36 °C before and after retort sterilisation; (a) represents perilla mousse (PM), and (b, c) represent retorted perilla mousse (RPM) at 55 °C and 36 °C, respectively.

spoon test was conducted at a lukewarm temperature approximating body temperature, the results of RPM resembled those of the control mousse, displaying a clean release without any residual mousse (Fig. 5c). Park *et al*. (2014) reported that when employing a xanthan gum-based viscosity enhancer, a higher quantity was required at temperatures of ~65 °C, in comparison to that at room temperature (25 °C), to achieve comparable rheological properties.

Effect of retort sterilisation on PM

Changes in PM colour

The difference in the colour of PM before and after retorting is presented in Table 2. The L^* and b^* values significantly decreased, whereas the a^* value increased across all parameters. In other words, the colour shifted towards a darker, more reddish, and closer to a blue hue. Total colour difference (delta E) was 8.05 and this colour change aligns with the findings reported by Lee & Shin (2023) and Yeoh *et al*. (2014). In both studies, a decrease in L^*, an increase in a^*, and a decrease in b^* value yielded consistent results. It is hypothesized that the retort process, influenced by the added BCAAs and heat and pressure, played a role in this colour transformation. Lee & Shin (2023) speculated that during this process, free amino acids within the protein in the mousse underwent Maillard reactions. As a result, this alteration affected the texture and taste of the food.

Table 2 Colour of the perilla mousse before and after retort sterilisation

Colour parameter	PM	RPM
L^*	72.32 ± 2.18	64.37 ± 0.55**
a^*	2.01 ± 0.09	2.90 ± 0.02*
b^*	19.88 ± 0.29	19.31 ± 0.32**
ΔE	8.05 ± 1.48	

Data are expressed as mean ± standard deviation of colour from three replicates. L^*-a^*-b^* is the three-dimensional CIELAB colour system. L^* = lightness axis; a^* = green-red axis, + = redder; b^* = blue-yellow axis, + = yellower. * $P < 0.05$; ** $P < 0.01$. P-values were obtained using the Student's t-test.

Changes in PM texture profiles

To further elucidate the anticipated texture of PM based on the results of the IDDSI spoon tilt test, texture profiles of PM were analysed before and after retorting, and the results are presented in Table 3. A notable difference was observed in cohesiveness and hardness, whereas the remaining parameters, namely, adhesiveness, springiness, gumminess, and chewiness, exhibited no significant differences. The hardness of RPM was higher than that of PM, and this may be attributed to the reinforcement of gel networks by polysaccharides in the viscosity enhancer and proteins after the heating-pressure process owing to starch gelatinization and protein denaturation (Belitz *et al*., 2008). Low adhesiveness and high cohesiveness in

Table 3 Texture profile of the perilla mousse (PM) and retorted perilla mousse (RPM)

Texture profile	PM	RPM
Hardness (N)	1.67 ± 0.04	2.80 ± 0.23*
Adhesiveness (N.mm)	4.52 ± 0.16	3.31 ± 0.75^{NS}
Cohesiveness (Ratio)	0.79 ± 0.04	0.51 ± 0.11 *
Springiness (mm)	7.80 ± 0.13	8.24 ± 0.27^{NS}
Gumminess (N)	1.35 ± 0.08	1.49 ± 0.19^{NS}
Chewiness (mJ)	10.56 ± 0.73	12.29 ± 1.39^{NS}

Data are expressed as mean ± standard deviation from three replicates. *$P < 0.05$; NS, not significant. *P*-values were obtained using the Students' *t*-test.

dysphagia diets have been deemed desirable. In the present study, the texture profile of PM revealed that after retort processing, the adhesiveness decreased, albeit without a significant difference, and cohesiveness marginally decreased. However, the values were inherently low regardless of retort processing, and as observed in the IDDSI fork and spoon tilt tests, both samples met the IDDSI classification. Therefore, the retort process did not induce marked changes in the texture profiles of PM although changes have been shown in other researches. Ali *et al.* (2005) and Yang *et al.* (2022) showed appreciable changes in the texture profiles of sardine and duck meat respectively. However, a study from Ramaswamy *et al.* (1995) indicated that there was no significant difference in the texture profiles after retorting gelatinized starch solution, which was consistent with our findings. For samples with high moisture content, such as mousse or liquid formulations, it can be cautiously inferred that there is not a particularly noticeable change in the texture profile due to the retort processing.

Viscoelasticity of PM under different conditions

Viscoelasticity is an important property of a dysphagia diet. Figure 6 presents two graphs illustrating the frequency sweep test results of PM and RPM. Figure 6a depicts G', which indicates elasticity, and Fig. 6b shows G'', which presents viscosity. Retorted PM showed high G' and G'' values, which can be explained by the fact that the retorted sample had both high viscosity and elasticity. This corresponds to the results of the IDDSI spoon tilt test (Fig. 5) and texture profiles (Table 3). Heating treatment may promote a strong network as more hydrophobic groups could be revealed (Wi *et al.*, 2020); similar results were reported by Lee & Shin (2023).

The results of the temperature sweep test are presented in Fig. 7. Figure 7a,b depicts the G' and G'' of PM and RPM, respectively, as the temperature is increased from 20 °C to 80 °C. Figure 7c,d illustrates the G' and G'' of PM and RPM as the temperature

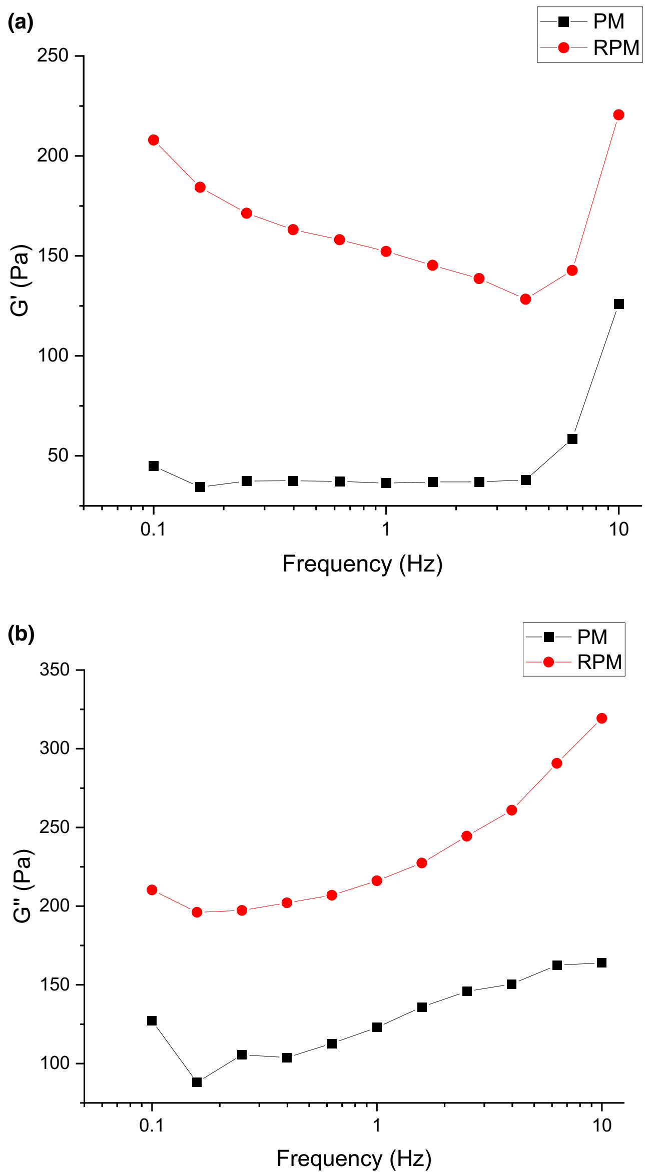


Figure 6 Frequency sweep test of the perilla mousse before and after retort sterilisation. ■, perilla mousse (PM); ●, retorted perilla mousse (RPM). (a) represents storage modulus (G') and (b) represents loss modulus (G'').

decreased from 80 °C to 20 °C. Noteworthily, as the temperature increased, the viscoelasticity exhibited a decreasing trend in all mousse samples until approximately 50 °C–55 °C, at which point the viscosity and elasticity of RPM showed an increase. It is speculated that RPM, which underwent a heating process resulting in starch gelatinization, experienced a transformation in polysaccharide binding at ~50 °C–55 °C (Martinez *et al.*, 2018). Fang *et al.* (2020) suggested that within this temperature range, the helical structure

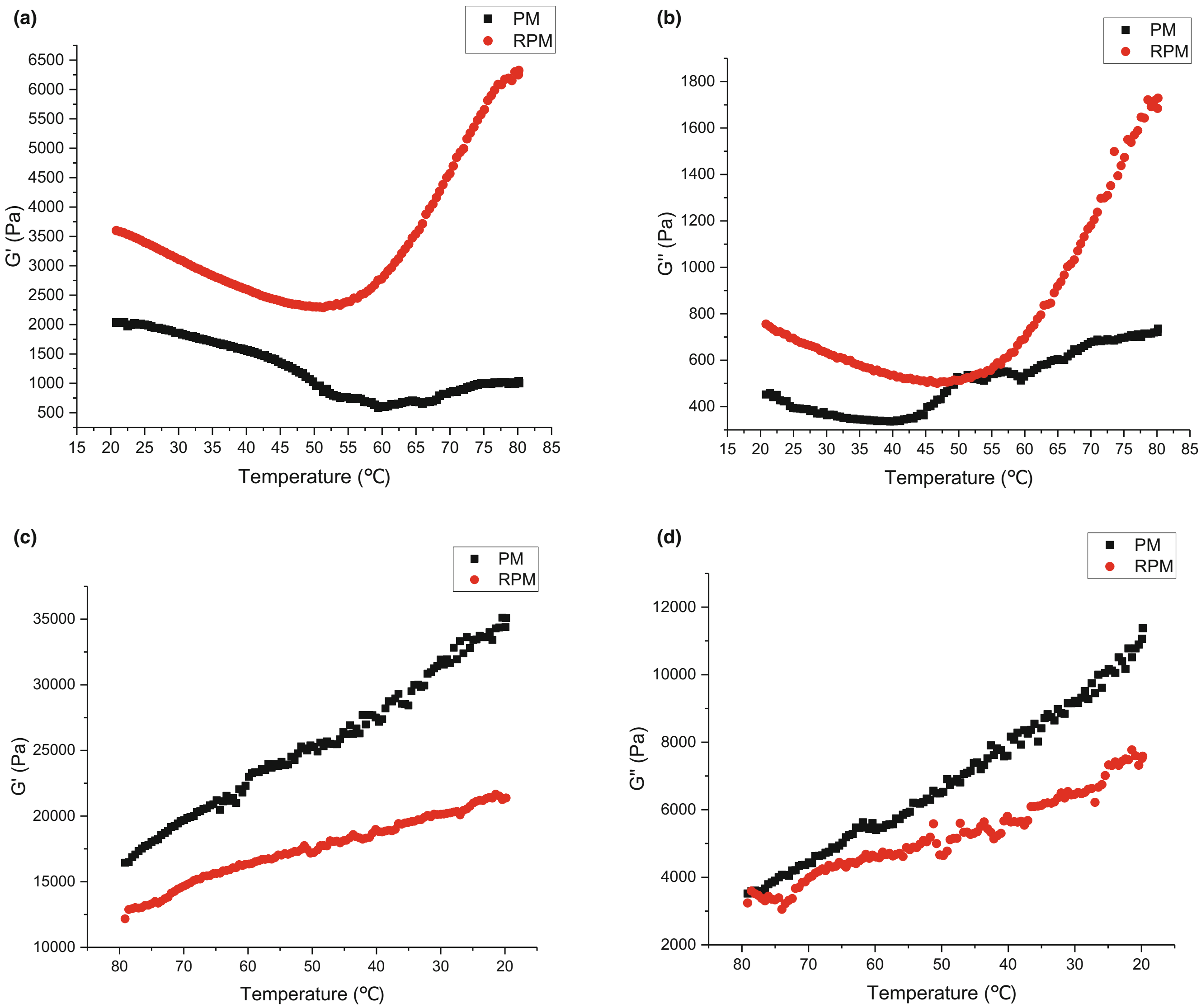


Figure 7 Temperature sweep test of the perilla mousse before and after retort sterilisation. ■, perilla mousse (PM); ●, retorted perilla mousse (RPM). (a) and (b) show the storage modulus (G′) and loss modulus (G″), respectively, as the temperature is increased from 20 °C to 80 °C. (c) and (d) depict the G′ and G″, respectively, as the temperature is decreased from 80 °C to 20 °C.

was presumed to melt, indicating a potential disruption of intermolecular bonds of amylopectin. Moreover, the decline in *G*′ values of the paste-type samples within the 50 °C–60 °C range aligns with the findings of Matalanis *et al.* (2009). The increasing trend in viscosity and elasticity beyond 60 °C is postulated to be attributed to the dehydration of the matrix at elevated temperatures leading to resistance to phase change (Masotti *et al.*, 2018; Ahsan *et al.*, 2024). Ahsan *et al.* (2024) developed cheese analogs that showed an increase in viscosity and elasticity when heated at 70 °C–100 °C. Both RPM and the cheese analogs shared commonalities in their manufacturing processes, as they contained polysaccharides, underwent a heating process, and were subject to reheating during the temperature sweep test. When the mousse was subsequently cooled to ~20 °C, both viscosity, and elasticity exhibited an increasing trend, consistent with typical outcomes observed in traditional mousse-type food products (Joshi *et al.*, 2011).

Changes in PM syneresis after retort sterilisation

A more commonly employed experimental method for observing syneresis is centrifugation after storage. However, although a gel formed efficiently, PM exhibited sedimentation of its solid components after

Table 4 Syneresis of perilla mousse (PM) and retorted perilla mousse (RPM) in 30 min

	Spreading area after 0 min (cm^2)	Spreading area after 30 min (cm^2)
PM	4.48 ± 0.52	7.54 ± 2.23 *
RPM	6.37 ± 0.45	5.56 ± 1.47^{NS}

Data are expressed as mean ± standard deviation from three replicates. *, $P < 0.05$; NS, not significant. *P*-values were obtained using the Student's *t*-test.

centrifugation, resulting in no observable phase separation but distinct layering. Conversely, the retorted PM showed no discernible separation. A study from Lee *et al.* (2021) mentioned that 3D printing ink with xanthan gum had a better ability to retain water and formed hydrogel phase. Xanthan gum in the viscosity thickener may affect both PM and RPM more stable. To investigate this further, an additional experiment was conducted to measure the water spread area on filter paper (Table 4). A wide spreading area was observed for PM; however, the water spreading area of RPM did not differ significantly. The addition of a gelling agent led to the interconnection of particles, thereby reducing the spreading area owing to enhanced cohesion. Furthermore, viscosity enhancers likely reinforced the gel network during the retort treatment. Velazquez *et al.* (2021) demonstrated that the protein network in gels obtained from blue crab meat was stabilised through the application of high-pressure processing and thermal treatment. The long and complex chains of the hydrocolloid could assist in retaining water and minimising its infiltration into the matrix (Dhakal *et al.*, 2023).

Changes in free amino acids content of PM after retort sterilisation

Table 5 presents the effect of retort sterilisation on the free amino acid content in PM and RPM. Excluding the undetected free amino acids, all analysed parameters exhibited a significant increase after retort processing. The identified amino acids include essential amino acids containing BCAAs, aspartic acid, serine, glutamic acid, glycine, alanine, cystathionine, and tyrosine. Hydroxyproline, proline, and cysteine were presumed to be undetected, possibly owing to their distant origin from the raw materials used in PM production. The aspartic acid and glutamic acid were speculated to be derived from mushrooms, constituting ~16.83% of the perilla seed mushroom sauce. These two amino acids play a crucial role in imparting umami flavour to mushrooms (Hur, 1989). Kim *et al.* (2009) observed that when comparing the amino acid content of mushrooms, glutamic acid is detected at significantly higher levels

Table 5 Effect of retort sterilisation on the content of free amino acids in the perilla mousse (PM) and retorted perilla mousse (RPM)

Free amino acids	PM (mg/100 g)	RPM (mg/100 g)
L-Aspartic acid	6.50 ± 0.62	12.03 ± 1.24*
L-Hydroxyproline	-	-
L-Threonine	1.60 ± 0.10	4.50 ± 0.35***
L-Serine	2.03 ± 0.12	6.00 ± 0.44***
L-Glutamic acid	8.53 ± 0.83	20.97 ± 1.45***
L(−)-Proline	-	-
Glycine	1.13 ± 0.58	3.40 ± 0.26***
L-Alanine	5.07 ± 0.23	14.07 ± 0.92**
L-Valine	84.70 ± 3.65	228.33 ± 13.37**
L(−)-Cystine	-	-
L-Methionine	0.40 ± 0.00	1.00 ± 0.00***
L-Cystathionine	0.57 ± 0.06	2.03 ± 0.15***
L-Isoleucine	82.60 ± 3.66	224.07 ± 13.75**
L-Leucine	169.20 ± 7.29	459.47 ± 27.42**
L-Tyrosine	1.40 ± 0.10	4.07 ± 0.32**
L-Phenylalanine	2.83 ± 0.25	8.50 ± 0.53***
L-Lysine	2.67 ± 0.15	7.67 ± 0.59***
L-Histidine	1.10 ± 0.00	2.87 ± 0.25***
L-Arginine	9.27 ± 0.23	30.57 ± 2.29**

Data are expressed as mean ± standard deviation from three replicates. *, **, and *** represent $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively. *P*-values were obtained using the Student's *t*-test. The significance for the bold values are 0.002.

than the other amino acids. Furthermore, Lee *et al.* (1990) identified that perilla seed had a composition similar to that of other oil seed crops, but higher in lysine and methionine content, and glutamic acid and arginine were the major amino acids.

Among the observed free amino acids (Table 5), BCAA content is individually shown in Fig. 8. An equal amount of BCAA powder was added to both samples, irrespective of retort treatment; however, the RPM subjected to the retort process exhibited more than twice the BCAA content detected in PM. Particularly, the added valine, isoleucine, and leucine revealed final concentrations of 228.33 mg g^{-1}, 224.07 mg g^{-1}, and 459.47 mg g^{-1}, respectively. Similar results were observed by Khoonin *et al.* (2022) and Lee & Shin (2023). They suggest that during the retorting process, peptide bonds could undergo hydrolysis, leading to an augmentation in free amino acid levels. The World Health Organisation recommends daily intake levels of BCAA at 20 mg kg^{-1} for isoleucine, 39 mg kg^{-1} for leucine, and 26 mg kg^{-1} for valine, totalling 5100 mg for an adult weighing 60 kg as the sum of BCAAs (F. A. O. and World Health Organization, 2007). Supplementing a meal with 100 g of RPM would result in an intake of 911.87 mg of BCAAs and in total, over 1000 mg of essential amino acids, suggesting that this supplementation could be considered nutritionally adequate. This increased free amino acids

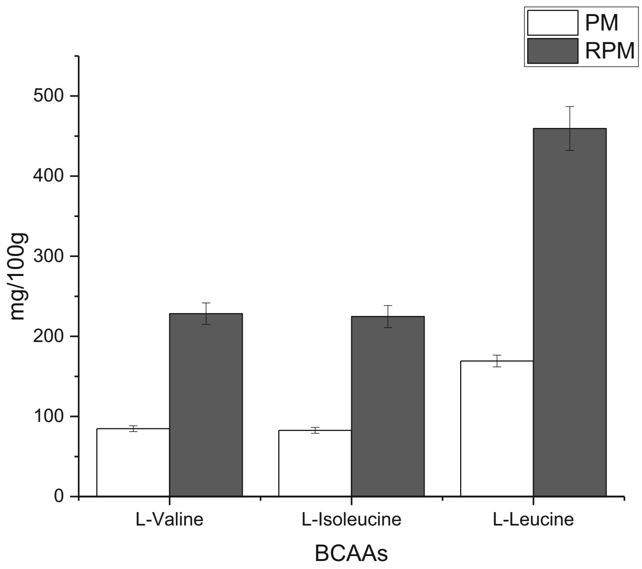


Figure 8 Effect of retort sterilisation on the content of branched-chain amino acids in the perilla mousse. □, perilla mousse (PM); ■, retorted perilla mousse (RPM). ** $P < 0.01$ obtained using the Student's *t*-test.

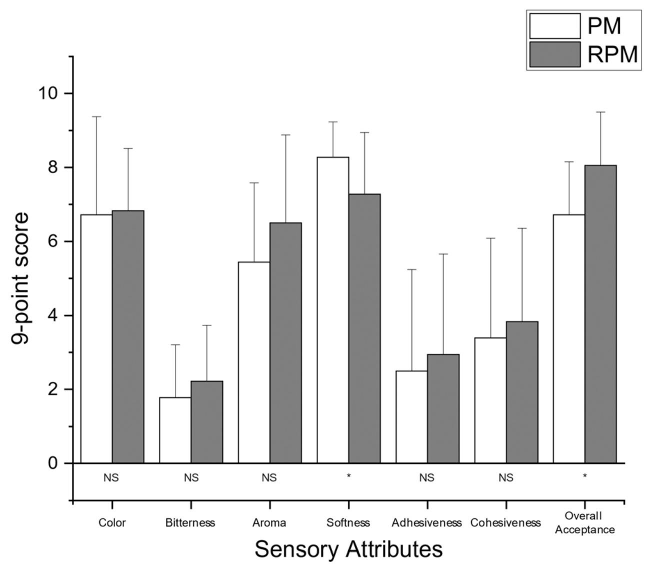


Figure 9 Sensory attributes of the perilla mousse with and without retort sterilisation measured on a 9-point hedonic scale (n = 18). □, perilla mousse (PM); ■, retorted perilla mousse (RPM). * $P < 0.05$ obtained using the Student's *t*-test; NS, not significant.

content may be expected to provide additional nutritional value and enhanced flavour intensity to RPM.

Preliminary consumer acceptance test of PM

Sensory attributes of PM and RPM are presented in Fig. 9. Retorted PM showed significantly lower scores in softness, and higher scores in overall acceptance than those of PM. Statistical differences were absent between the two samples for colour, bitterness, aroma, adhesiveness, and cohesiveness. Although a colour difference was observed between PM and RPM based on the results of the chromameter, participants did not notably perceive this difference. After retort processing, the elevated hardness in the texture profiles of samples (Table 3) indicated a corresponding reduction in sensory softness. Contrary to cohesiveness in the texture profiles, cohesiveness in the preliminary consumer acceptance test did not show a significant difference. Thus, the changes in cohesiveness of texture may be assumed to be slight. Several sensory attributes exhibited statistically disparate outcomes, potentially influenced by the advanced age of the assessors, considering the potential effect of age-related diminished sensory perceptions within the tongue and oral cavity (Liu *et al.*, 2022). In the usability test for designating senior-friendly food in Korea, the product should receive over 3.5 out of 5 scores (Food Polis, Senior-Friendly Foods, 2024). Based on this guideline, the overall acceptance scores of PM and RPM showed suitable for senior-friendly food. The acceptance score of RPM indicated higher than that of PM, suggesting that the retorted sample yielded favourable results. Despite age-related declines in sensory perceptions, the elderly may still recognise overall enhanced and enriched taste owing to factors such as Maillard reactions (Table 2) and increased free amino acids (Table 5) in RPM.

Conclusions

Our research aimed to develop ready-to-eat BCAA-fortified PM as a dysphagia diet. After retort processing, the mousse exhibited varying viscoelastic characteristics at different temperatures, along with a deepened colour; however, it fell within the appropriate consistency range for the IDDSI level. Moreover, RPM had a firm texture profile at room temperature, and no syneresis was exhibited, which is related to the stable matrix. Furthermore, the increased BCAA content of RPM compared with that of PM showed enhanced nutritional value and flavour richness. This observation was confirmed through a preliminary consumer acceptance test, wherein assessors expressed a high acceptance of RPM. Patients with dysphagia often face limited menu choices when selecting their meals. However, it is anticipated that they can have a broader range of texture-modified food choices through the development of this new product. Additionally, the supplementation of high-quality amino acids in RPM is expected to contribute to the prevention of sarcopenia in the elderly. Through this study, the retort process, which is traditionally employed for preservation purposes, was demonstrated to offer various advantages in food beyond enhanced shelf life. This study will serve as a foundation for developing BCAA-fortified foods that enhance nutritional value and provide customised meals for patients with dysphagia. However, a limitation of this study is the small sample size in the preliminary consumer acceptance test, indicating the need for further research with a larger sample size. Future research should include inquiries about clinical trials to assess the long-term health effects, and investigate the scale-up process for this product.

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Author contributions

Hye-Ji Jeon: Conceptualization; methodology; data curation; visualization; writing – original draft; writing – review and editing; investigation; formal analysis. **Su-Yeong Hwang:** Conceptualization; methodology; formal analysis; writing – review and editing; investigation; data curation. **Weon-Sun Shin:** Writing – review and editing; project administration; resources; funding acquisition; supervision; conceptualization; validation.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics and informed consent

This study was approved by the Institutional Review Board of Hanyang University (IRB number: HYUIRB-202211-002). Informed consent from all study participants was obtained for the experiments with human subjects.

Peer review

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Data availability statement

The corresponding author can provide the data supporting this study upon request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Comparison of calculated nutrients between perilla seeds, perilla mushroom sauce, and perilla mousse by CAN-Pro 5.0 software (Computer-aided nutritional analysis program, version 5.0).

Figure S1. Photographs of the perilla mousse after centrifugation. (A) and (B), perilla mousse (PM) and retorted perilla mousse (RPM), respectively.

