



Physicochemical, Bioactive, Antioxidant, and Sensory Characteristics of Red Rice-Based Instant Porridge Enriched with Tempeh and Pumpkin

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Abstract

Instant red rice porridge has potential as a functional food; however, its low protein content and undesirable sensory attributes remain major limitations. This study investigated the effects of substituting tempeh, a source of protein and isoflavones, and pumpkin, a source of β -carotene, on the physicochemical properties, bioactive compounds, antioxidant activity, and sensory characteristics of instant red rice porridge. Formulations containing various ratios of red rice flour, tempeh, and pumpkin were processed using a drum dryer at 120°C. Physical properties (yield, bulk density, water activity, water solubility index, consistency, expansion ratio, viscosity, and color), chemical composition (proximate analysis, total phenolic content, and β -carotene), antioxidant activity, and sensory attributes were analyzed. Substitution with tempeh and pumpkin significantly increased the protein content, total phenolic content, β -carotene concentration, and antioxidant activity, although some physical parameters decreased. The high-substitution formulation (20:40:40) produced the highest bioactive content, whereas the medium-substitution formulation (40:30:30) was preferred by panelists due to its balanced nutritional quality, bioactive compounds, and sensory acceptance. Overall, incorporating tempeh and pumpkin enhances the nutritional and functional qualities of red rice-based instant porridge, demonstrating its potential as a locally sourced, health-promoting food innovation.

Introduction

Instant porridge is a popular food product due to its convenience (Duan et al., 2024). Red rice instant porridge is among the most popular types owing to its appealing flavor and distinctive color. However,

commercially available red rice instant porridge primarily provides carbohydrates. Therefore, substituting part of the red rice with nutrient-rich ingredients could improve its protein, vitamin, and antioxidant content. Tempeh is a widely consumed protein source in Indonesia (Sitanggang et al., 2021). Pumpkin is an abundant fruit

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rich in vitamins, particularly β -carotene and antioxidants (Werasakulchai et al., 2025).

Tempeh, a fermented soybean product, offers numerous health benefits (Romulo & Surya, 2021). Soybeans are widely fermented and consumed across Southeast Asia, including Indonesia (Rizzo & Baroni, 2018). Fermentation with *Rhizopus oligosporus* produces tempeh with higher functional value than conventionally processed soybeans (Starzyńska-Janiszewska et al., 2016). Haque et al. (2023) reported that tempeh has a protein content of 17 g. Tempeh is not only a source of protein but also a functional food source of antioxidants (Surya et al., 2024). In Indonesia, tempeh is a popular protein source among millennials (Fibri & Frøst, 2020). Tamam et al. (2019) reported that tempeh peptides exhibit antihypertensive, antitumor, and antioxidant potential. Tempeh flour was found to more effectively increase serum estrogen levels in aged female rats compared with tofu flour (Kridawati et al., 2019) and exhibits higher digestibility than conventionally processed soybeans (Wu et al., 2025).

Pumpkin (*Cucurbita moschata*) is an agricultural commodity abundantly available in Indonesia. Pumpkin contains bioactive compounds and nutrients with potential health benefits (Alqahtani, 2025) and is a notable source of carotenoids, particularly lutein and β -carotene (Fuenmayor et al., 2021). The β -carotene content of pumpkin fruit (approximately 950 $\mu\text{g}/100\text{ g}$) makes it a valuable source of provitamin A (Zhang et al., 2024a). Ahmed et al. (2023) also reported that pumpkin-derived vitamin A may help prevent childhood blindness. Fresh pumpkin exhibits an antioxidant activity of approximately 32% (Kristianto et al., 2021). Indrianingsih et al. (2024) noted that pumpkin substitution can increase carotenoid content and antioxidant activity in cookies. Substituting wheat with pumpkin enhances the nutritional value and antioxidant activity of noodles (Farzana et al., 2023). Similarly, Alefew et al. (2024) found that incorporating pumpkin in extruded snacks enhanced consumer preference. Moreover, instant brown rice and pumpkin porridge were shown to exhibit antidiabetic effects in rats (Slamet et al., 2022).

Therefore, substituting tempeh and pumpkin offers a promising strategy to enhance the nutritional quality of red rice instant porridge. To achieve optimal product quality, the substitution levels of these ingredients must be carefully optimized. This study aimed to evaluate the physicochemical properties, β -carotene content, antioxidant activity, and preference of red rice

instant porridge substituted with tempeh and pumpkin. The main findings of this study are intended for the information of the food industry, indicating that the substitution of tempeh and pumpkin in red rice instant porridge has the potential to be a functional food.

Materials and methods

1. Materials and chemicals

Red rice flour, tempeh, and pumpkin were used as the primary raw materials in this study. Red rice flour (Rose Brand, Yogyakarta, Indonesia) was purchased from a local distributor. The tempeh was traditionally fermented for two days, while fresh pumpkins with uniform orange color and without physical defects were obtained from Beringharjo Market, Yogyakarta, Indonesia.

Analytical reagents included HCl 0.02 N, anhydrous Na_2SO_4 , ethanol 95%, H_3BO_3 3%, petroleum benzene, DPPH (2,2-diphenyl-1-picrylhydrazyl), Na-thiosulfate, and a mixed digestion catalyst. All chemicals were of pro analysis (PA) grade and purchased from Sigma-Aldrich (Merck KGaA, Germany).

2. Sample preparation

The sample preparation procedure used in this study is outlined in Fig. 1 and described as follows. Tempeh and pumpkin were cut into small pieces and processed into slurries using a household grinder. Pumpkin was blended with water in a 3:1 ratio until a homogeneous pulp was obtained. Five formulations of red rice flour, tempeh, and pumpkin were prepared: 100:0:0, 80:10:10, 60:20:20, 40:30:30, and 20:40:40 (w/w/w). Each mixture was diluted with water at a 1:2 ratio prior to drying to ensure uniform heat transfer.

All mixtures were processed using a drum dryer (GRV 77, Holland Dryers B.V., Netherlands) operated at 120°C and 5 rpm. The resulting flakes were milled and sieved through an 80-mesh screen. The instant porridge powders were packed in polyethylene pouches and stored at room temperature until further analysis.

3. Color determination

Color attributes (L^* , a^* , b^*) were measured using a chromameter (CR-20, Konica Minolta, Japan). The CIELAB system was applied to quantify lightness and chromatic coordinates.

4. Surface morphology analysis

The microstructure of the instant porridge powders was examined using scanning electron microscopy (SU3500, Hitachi High-Tech Corporation, Japan) operating at 4.0 kV with 10,000 $\times$ magnification.

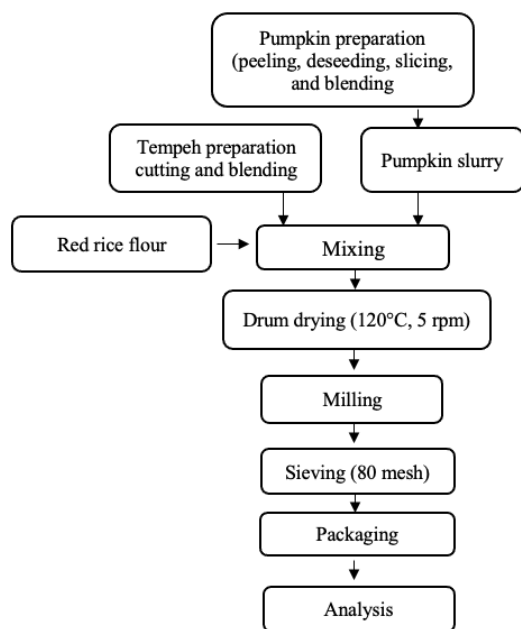


Fig. 1 Process flow diagram for the production of instant red rice porridge

5. Yield determination

Yield (%) was calculated as the ratio between the dried instant porridge weight and the initial wet mixture weight, multiplied by 100%, following the method of Andriyani et al. (2024).

6. Bulk density determination

Bulk density was measured according to Mujinda et al (2023). Approximately 50 g of powder was transferred into a 100 mL graduated cylinder and gently tapped until a constant volume was achieved. Bulk density (g/cm^3) was obtained by dividing the sample weight by its packed volume.

7. Determination of water activity

Water activity (a_w) was measured using an AquaLab 4TE water activity meter (AquaLab 4TE, Decagon Devices, Inc., USA).

8. Proximate analysis

The proximate composition of the instant porridge was determined following the official (Horwitz & Latimer, 2005) methods, including moisture (Method 925.09; Oven drying), ash (Method 923.03; Dry ashing), protein (Method 960.52; Kjeldahl method), fat (Method 920.85; Soxhlet extraction), and carbohydrate by difference (Method 993.21).

9. Total phenolic content analysis

The total phenolic content was determined using the method of Habiba et al. (2021) with minor modifications.

Absorbance was measured using a UV–Vis spectrophotometer (UV-1240, Shimadzu Corporation, Japan), and results were expressed as mg gallic acid equivalents (GAE)/g of sample.

10. Analysis of β -carotene content

The β -carotene content was quantified according to the method of Giau et al. (2024), which involves solvent extraction followed by spectrophotometric measurement. A total of 25 g of sample was extracted with 2-propanol at 60°C using a water bath. The resulting filtrate (5 mL) was partitioned with petroleum ether and diluted to a final volume of 50 mL. Absorbance was measured at 450 nm using a UV–Vis spectrophotometer, and β -carotene concentration was calculated from standard calibration curves.

11. Determination of antioxidant activity

Antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay as described by Galaz et al. (2017), with minor modifications. A 0.1 mM DPPH solution was mixed with the ethanol extract, and the absorbance was measured at 517 nm after incubation for 0 and 30 min in the dark. Radical scavenging activity (RSA) was calculated based on the percentage reduction in DPPH absorbance relative to the control. RSA is expressed as a percentage (%).

12. Sensory test

Twenty-five students from the Department of Agricultural Product Technology, Faculty of Agroindustry, Universitas Mercu Buana Yogyakarta, Indonesia, participated in the sensory evaluation. Panelists were regular consumers of red rice instant porridge and had no known allergies to red rice, tempeh, or pumpkin. The sensory evaluation assessed preferences for color, aroma, taste, viscosity, and overall acceptability. The instant porridge samples were prepared by dissolving 3 g of powder in 30 mL of boiling water (80°C) and stirring until the mixture was fully homogeneous. The samples were served warm (50–60°C) in small cups and evaluated immediately. A five-point hedonic scale adapted from Chen et al. (2021) was used, where 1 = strongly dislike, 2 = dislike, 3 = neutral, 4 = like, and 5 = strongly like. Drinking water was provided between samples to cleanse the palate. Ethical approval for the sensory evaluation was obtained from the Ethics Committee of Universitas Alma-Ata, Yogyakarta, Indonesia (Approval No. KE/AA/X/10111815/EC/2024).

13. Statistical analysis

All analyses were conducted using three independent production batches, and each batch was analyzed in

triplicate. The data were processed using SPSS software (Version 22, IBM Corp., USA). Analysis of variance (ANOVA) was applied to determine significant differences among treatments, followed by Duncan's multiple range test as the post-hoc comparison. A significance level of $p < 0.05$ was used for all statistical tests.

Results and discussion

1. The color of red rice instant porridge

The color of instant red rice porridge, with various variations of tempeh and pumpkin substitutions, is presented in Table 1. Photos of instant porridge are presented in Fig. 1.

Table 1 The color of instant red rice porridge in various variations of tempeh and pumpkin substitutions

Red rice flour substitution ratio of tempeh and pumpkin	L*	a*	b*
100:0:0	59.03±1.09 ^a	9.69±1.14 ^c	11.72±0.98 ^c
80:10:10	51.18±2.17 ^b	13.94±1.07 ^b	14.56±1.65 ^b
60:20:20	48.92±2.42 ^c	17.53±1.25 ^a	15.70±1.73 ^a
40:30:30	47.07±1.96 ^d	18.71±1.06 ^a	15.86±0.35 ^a
20:40:40	43.93±1.38 ^e	18.46±1.87 ^a	15.75±1.62 ^a

Remark: The results are presented as the mean ± standard deviation. Distinct superscript letters within a column denote values that differ significantly at the $p < 0.05$ level.

1.1 Lightness (L*)

The lightness (L*) values of the instant porridge ranged from 43.93 to 59.03, decreasing progressively with higher levels of tempeh and pumpkin substitution (Table 1). This reduction in brightness reflects the combined influence of browning reactions and pigment interactions during thermal processing. The presence of reducing sugars in pumpkin and amino groups from tempeh proteins facilitates non-enzymatic browning, which intensifies at high temperatures during drum drying (Herminiati et al., 2020; Žilić et al., 2021). Pumpkin also undergoes pigment degradation and Maillard-induced color changes under heat, contributing to darker final products (Fan et al., 2023). Additionally, caramelization at elevated temperatures can further decrease lightness (Usman et al., 2020). Pumpkin has been reported to increase brightness in certain starch matrices such as arrowroot porridge (Slamet et al., 2019). However, in the present study, the combined effects of higher pigment concentration, protein interactions, and thermal browning during drying resulted in lower L* values. Slight reductions in L* may signal a darker, more

roasted appearance, which some consumers associate with stronger flavor or higher nutritional value due to Maillard-derived antioxidants. However, excessive darkening may negatively affect acceptance in markets where lighter porridge is preferred. Balancing color development is therefore important for optimizing consumer appeal. Since changes in lightness often coincide with shifts in chromatic attributes, the influence of pumpkin pigments and browning reactions is also reflected in the redness values.

1.2 Redness (a*)

Redness (a*) increased with higher levels of tempeh and pumpkin substitution. This trend is linked to two primary mechanisms: (1) enhanced browning reactions during drum drying, which intensify reddish-brown hues (Galaz et al., 2017; Liu et al., 2020), and (2) the presence of β -carotene in pumpkin, an orange-red pigment that strongly influences chromaticity (Hagos et al., 2022). Studies have also shown that the addition of pumpkin increases redness in baked or extruded products (Indrianingsih et al., 2024). As substitution levels increased, the combined effects of pigment deposition and Maillard-driven color development produced higher a* values. Higher a* values often indicate the presence of carotenoids, which may enhance consumer perception of naturalness and nutritional richness. The β -carotene is a provitamin A compound; thus, visible redness may function as a cue for enhanced nutritional quality. However, very intense redness might be interpreted as over-processed or burnt by some consumers, depending on cultural food expectations. These pigment-related effects extend further to the yellowness (b*) parameter, which is strongly influenced by the carotenoid content of pumpkin.

1.3 Yellowness (b*)

The yellowness (b*) of instant porridge also increased with greater amounts of tempeh and pumpkin (Table 1). This is primarily attributed to the high carotenoid content of pumpkin, which imparts yellow to orange coloration (Slamet et al., 2026). Pumpkin also contains substantial glucose (Xu et al., 2024), and these reducing sugars can intensify brownish-yellow tones through Maillard reactions during drying (Onyeoziri et al., 2021). Heat-induced reactions such as Maillard browning and caramelization further modify the color matrix and enhance yellowness (Troiani et al., 2022). Therefore, both natural pigments and heat-driven reactions contribute to the increased b* values observed in higher-substitution formulations. Enhanced yellowness

is often associated with freshness and nutrient density in cereal-based foods, as consumers commonly associate yellow–orange hues with carotenoid-rich ingredients. This can enhance perceived health benefits, particularly for products marketed as functional foods. From a nutritional standpoint, the increased β -carotene content is visually reflected in the elevated b^* values, supporting the product's positioning as a food that enhances vitamin A. The changes in color attributes are consistent with structural modifications observed under SEM, where heat-induced reactions and compositional differences shape the microstructure of the porridge matrix.

Fig. 2 shows that instant porridge without tempeh and pumpkin substitution (A) is paler in color than instant porridge with tempeh and pumpkin substitution made from red rice. More substitution resulted in a browner

color. This is due to the Maillard reaction (Onyeoziri et al., 2021). During the drying process of instant porridge substituted with tempeh and pumpkin, the caramelization process occurs (Jariyah et al., 2024). Caramelization occurs during the drying process, producing the preferred brown color (Zhou et al., 2024).

2. Surface morphology of red rice instant porridge

The surface microstructure of the instant porridge is presented in Fig. 3. Scanning electron microscopy (SEM) observations revealed clear structural distinctions between the control sample (100:0:0) and the formulations containing tempeh and pumpkin. According to Indrianingsih et al. (2024), incorporating pumpkin at levels of up to 30% in cookie formulations results in a more compact and closed structure.

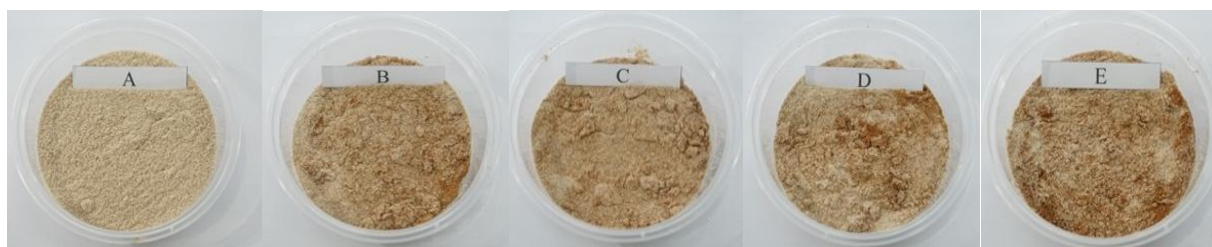


Fig. 2 Photo of red rice instant porridge A= 100:0:0, B=80:10:10, C= 60:20:20, D= 40:30:30, and E= 20:40:40

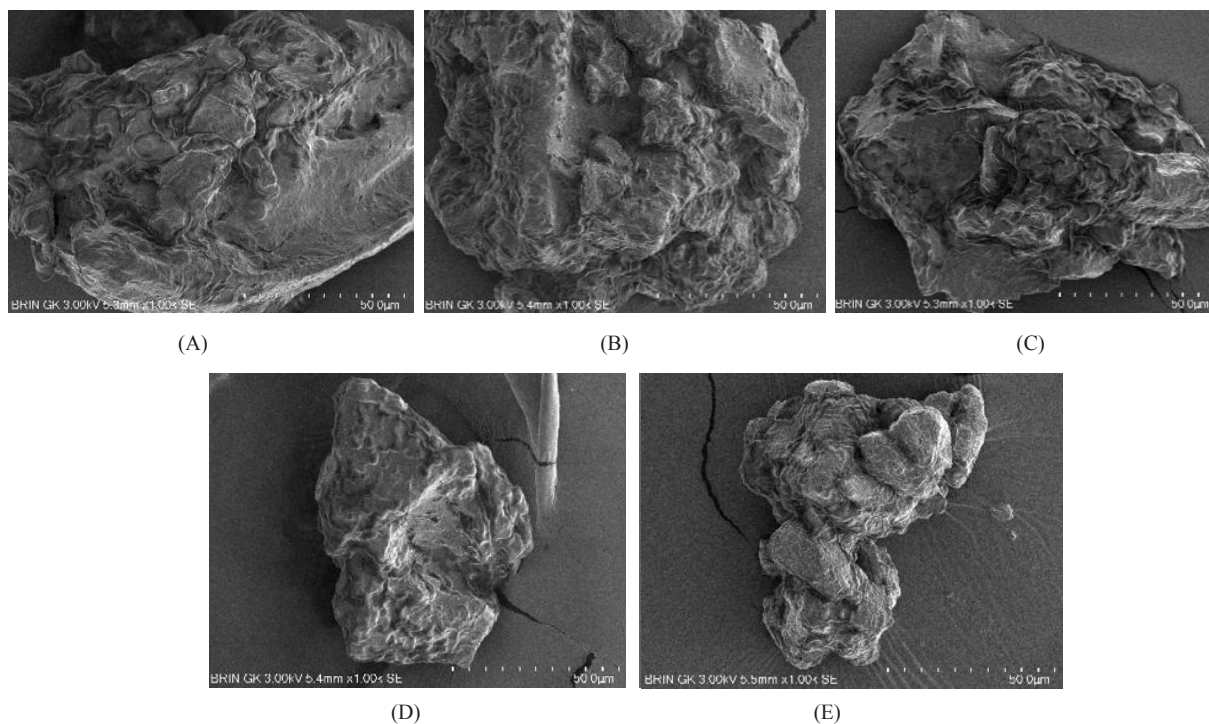


Fig. 3 Surface morphology of red rice instant porridge A= 100:0:0, B=80:10:10, C= 60:20:20, D= 40:30:30, and E= 20:40:40

The same trend was observed in this study, where the red rice instant porridge without substitution exhibited a more porous, open morphology than the substituted samples. These structural differences are likely associated with the presence of dietary fibers and other constituents originating from modified cassava flour and pumpkin flour. The surface tends to appear smoother when a higher proportion of starch is present (Liu et al., 2022). Furthermore, the gelatinization process can modify starch granules, producing more open and layered structures (Li et al., 2025a). Satmalawati and Paramita (2025) state that heated starch produces changes in the surface shape of starch granules.

3. Yield, bulk density, and water activity of red rice instant porridge

The yield, bulk density, and water activity of red rice instant porridge are presented in Table 2.

Table 2 Yield, bulk density, and water activity

Red rice flour substitution ratio of tempeh and pumpkin	Yield (%)	Bulk density (g/cm3)	Water activity
100:0:0	56.08±3.02 ^a	0.78±0.03 ^a	0.51±0.00 ^a
80:10:10	51.97±4.19 ^b	0.64±0.01 ^b	0.49±0.01 ^a
60:20:20	45.74±2.19 ^c	0.52±0.00 ^c	0.34±0.00 ^b
40:30:30	30.29±2.04 ^d	0.34±0.01 ^d	0.35±0.01 ^b
20:40:40	23.87±1.08 ^e	0.31±0.03 ^d	0.29±0.02 ^c

Remark: The results are presented as the mean ± standard deviation. Distinct superscript letters within a column denote values that differ significantly at the p<0.05 level.

3.1 Yield

The yield of instant porridge decreased progressively with higher levels of tempeh and pumpkin substitution. This reduction is primarily attributed to the lower carbohydrate, particularly starch, content in formulations containing greater proportions of pumpkin and tempeh. Since starch contributes substantially to solid recovery during drying, a decrease in starch concentration leads to reduced mass retention after moisture removal. In contrast, pumpkin and tempeh possess considerably higher moisture levels than red rice flour, resulting in greater water loss during the drum-drying process. Fresh pumpkin contains approximately 91.48% moisture (Ngaha Damndja et al., 2024), whereas tempeh contains around 55.3% moisture (Surya et al., 2024). In contrast, red rice flour has only 9.4% moisture (Alefew et al., 2024).

The higher initial moisture and lower starch content in tempeh and pumpkin mixtures, therefore, reduce drying efficiency and result in a lower final yield. As starch plays a key role in forming dry solids during gelatinization and dehydration, its replacement with

protein and fiber-rich materials results in decreased solid recovery (Zhang et al., 2024b).

3.2 Bulk density

The bulk density of the instant porridge ranged from 0.31 to 0.78 g/mL (Table 2). Bulk density decreased progressively with increasing levels of tempeh and pumpkin substitution. This reduction is primarily associated with compositional shifts in the formulations, as higher proportions of tempeh and pumpkin introduce greater amounts of protein and fiber, while reducing the starch content. Because starch undergoes gelatinization and expansion during drum drying, formulations with lower starch exhibit reduced structural compactness and consequently lower packed density.

Additionally, tempeh and pumpkin contain hygroscopic components that readily absorb water, resulting in more porous and less densely packed particles after drying. Such structural changes contribute to the observed decrease in bulk density. The values obtained in this study remain comparable to bulk densities reported for other legume and cereal porridges, such as cowpea porridge (0.64–3.85 g/mL) (Mujinda et al., 2023). Similarly, Tsegay et al. (2024) reported that bulk density values for wheat, cowpea, and yam flours typically range from 0.84 to 0.93 g/mL. These reference values indicate that the bulk density of the instant porridge produced in this study remains within the acceptable range for composite flour-based instant products.

3.3 Water activity

The water activity of the instant porridge ranged from 0.29 to 0.51 (Table 2). This water activity is low because the drying process using a drum dryer is more effective in reducing water content and water activity in instant porridge. The drying process triggers chemical reactions, specifically the Maillard reaction, protein denaturation, and a reduction in water content (Sun et al., 2018). Indriani et al (2020) found that red rice flour enriched with meal and betel leaf has a water activity between 0.84 and 0.87. Low water activity will positively affect the shelf life of wet noodles (Xing et al., 2021). Cowpea flour (*Vigna unguiculata*) has a water activity of 0.52 (Kahraman et al., 2023). The water activity is almost the same as that of instant porridge without pumpkin and tempeh, at 0.51.

4. Water absorption index, water solubility index, consistency, swelling power, and viscosity

Water absorption index, water solubility index, consistency, swelling power, and viscosity are presented in Table 3.

Table 3 Water absorption index and water solubility index

Red rice flour substitution ratio of tempeh and pumpkin	Water absorption index (g/g)	Water solubility index (%)	Consistency (N/m ²)	Swelling power (g/g)	Viscosity (cP)
100:0:0	7.76±0.67 ^a	8.42±0.24 ^a	498.80±6.08 ^a	9.81±1.98 ^a	4,872±15.07 ^a
80:10:10	6.17±1.01 ^b	8.19±0.95 ^a	496.72±4.93 ^a	8.94±1.02 ^b	3,349±9.17 ^b
60:20:20	5.74±0.75 ^c	7.03±0.04 ^b	353.48±3.87 ^c	8.02±0.09 ^c	3,201±12.39 ^b
40:30:30	5.19±0.09 ^d	6.57±0.87 ^c	349.93±4.52 ^c	7.86±0.89 ^b	2,908±10.15 ^c
20:40:40	4.79±1.21 ^c	5.81±0.72 ^d	374.76±3.59 ^b	6.73±1.75 ^c	2,891±13.06 ^c

Remark: Data are reported as mean ± standard deviation. Values with different superscript letters in the same column indicate significant differences ($p < 0.05$).

4.1 Water absorption index (WAI)

The WAI (Table 3) decreased significantly from 7.76 g/g in the control formulation (100:0:0) to 4.79 g/g in the highest substitution level (20:40:40). This decline reflects reduced hydration capacity as starch is progressively replaced with tempeh and pumpkin. Tempeh contributes protein and fiber, while pumpkin adds both soluble and insoluble fiber, all of which compete with starch granules for water. As a result, less water penetrates the granule structure, limiting swelling and reducing WAI.

Similar reductions in WAI in composite formulations have been attributed to the formation of protein-starch and fiber-starch interactions that limit granule expansion (Liu et al., 2022; Wang et al., 2024). Tsegay et al. (2024) also observed that fiber-rich ingredients produce more compact matrices with lower water-binding capacity. The downward trend in WAI indicates that higher tempeh–pumpkin substitution produces a structure that absorbs less water, which may lead to faster wetting but thinner porridge consistency during rehydration.

4.2 Water solubility index (WSI)

The WSI decreased from 8.42% in the control to 5.81% in the 20:40:40 formulation, indicating a reduction in the leaching of soluble components, such as amylose and low-molecular-weight dextrins. Unlike WAI, which reflects water binding within starch granules, WSI indicates the extent of starch degradation and solubilization.

The observed reduction suggests that proteins from tempeh and fibers from pumpkin reinforce the starch matrix, restricting amylose release during rehydration. Pumpkin fiber can reduce solubility by inducing hydrogen bonding and network entanglement (Indrianingsih et al., 2024), while tempeh proteins can bind amylose, forming less soluble complexes. These mechanisms are consistent with findings by Li et al. (2025a), who reported that protein and starch interactions decrease WSI in composite flour products. This phenomenon aligns with observations

that dietary fibers stabilize starch matrices and inhibit solubilization (Zhuang et al., 2024). Protein and starch complexation is also known to reduce amylose diffusion during heating (Chen et al., 2025). Lower WSI corresponds to less molecular dispersion and improved structural integrity, resulting in a smoother, cohesive porridge with fewer gritty or sticky characteristics.

4.3 Consistency

The consistency of instant porridge decreased significantly with increasing levels of tempeh and pumpkin substitution, ranging from 498.80 N/m² in the control formulation (100:0:0) to 374.76 N/m² in the highest substitution level (20:40:40) (Table 3). This reduction indicates a weakening of the gel structure, primarily due to the decreased availability of starch, the key component responsible for viscosity and network formation during hydration. When starch granules are heated in the presence of water, they swell and gelatinize, forming a three-dimensional matrix that contributes to the product's firmness. However, as pumpkin and tempeh replace part of the starch, fewer granules are available to undergo gelatinization, resulting in a softer and less cohesive texture.

Additionally, the protein and fiber contributed by tempeh and pumpkin interfere with starch gelatinization by competing for water, thereby limiting granule expansion. Protein and starch interactions are known to form surface complexes that hinder swelling and weaken gel formation (Scott & Awika, 2023). The presence of protein and fiber from tempeh and pumpkin further interferes with gel development by competing with starch for water and restricting granule swelling. Similar reductions in consistency have been documented in composite cereal systems where non-starch components dilute or hinder starch gelatinization (Subedi et al., 2022). Although the drum drying temperature in this study was 120°C, sufficient to induce starch gelatinization, the reduced starch fraction in substituted formulations limited the formation of a strong gel network. This aligns with observations by

Iwansyah et al. (2022), who reported that gelatinization of cassava starch occurs effectively around 100°C, supporting the explanation that temperature was adequate but starch availability was the limiting factor. From a technological perspective, lower consistency may improve dispersibility and ease of mixing, desirable characteristics for instant porridge preparation. However, excessively low consistency may affect consumer perception of thickness and richness, highlighting the importance of optimizing the starch-protein fiber ratio to achieve balanced textural properties.

4.4 Swelling power

The swelling power of the instant porridge decreased notably with increasing levels of tempeh and pumpkin substitution, ranging from 9.81 g/g in the control to 6.73 g/g at the highest substitution level (Table 3). This reduction reflects the diminished capacity of starch granules to absorb water and expand during heating when part of the starch is replaced by protein and dietary fiber. Both tempeh and pumpkin introduce non-starch components that compete with starch for available water, limiting granule hydration and restricting amylopectin unfolding. Dietary fibers are widely reported to hinder swelling by creating physical barriers that reduce water penetration into starch granules (Zhang et al., 2025).

These findings are consistent with earlier studies on rice-based systems. Li et al. (2025a) observed that swelling power decreases when the proportion of rice starch is reduced. Zainab et al. (2024) reported a similar decline in swelling capacity in indica rice noodles as rice levels varied. Tsegay et al. (2024) also documented lower swelling power in wheat flour (6.25 g/g) and cowpea flour (6.04 g/g), highlighting that flours with lower starch purity generally exhibit limited granule expansion.

Mechanistically, proteins from tempeh can interact with starch granules, forming surface complexes that restrict swelling. In contrast, pumpkin fiber contributes to structural rigidity, further suppressing gelatinization. Such starch, protein, and fiber interactions have been shown to reduce swelling power in composite flours due to decreased water accessibility and inhibited granule mobility (Santamaria et al., 2023). From a technological perspective, lower swelling power results in porridge with a smoother, less pasty texture, which is often preferred in instant products. However, excessive reduction may compromise thickness and overall mouthfeel, indicating the need for balanced formulation.

4.5 Viscosity

The viscosity of the instant porridge decreased substantially with increasing levels of pumpkin and tempeh substitution, ranging from 4,872 cP in the control formulation to 2,891 cP in the 20:40:40 formulation (Table 3). This decline is primarily attributed to the reduced proportion of starch in formulations with higher substitution levels. Starch is the principal contributor to paste viscosity because its granule swelling and amylose leaching form a continuous gel network during heating. When starch is partially replaced by protein and fiber from tempeh and pumpkin, this network becomes weaker, resulting in lower viscosity. Protein and starch interactions have been shown to inhibit granule swelling and limit amylose release, thereby decreasing viscosity (Li et al., 2025b).

The drying method also plays a critical role in determining viscosity properties. Bekele and Emire (2023) reported that viscosity is influenced by particle size and thermal treatment during the drying process.

The amount of starch and drying temperature will affect the gelatinization and viscosity of rice flour (Li et al., 2025a). Moreover, fiber-rich ingredients can restrict granule expansion and reduce paste viscosity by creating structural barriers around starch granules (Zhuang et al., 2024).

Overall, the reduction in viscosity with increasing substitution indicates that tempeh and pumpkin alter the gelatinization capacity and rheological behavior of red rice instant porridge. While lower viscosity may enhance dispersibility and ease of mixing, attributes desirable for instant preparation formulations, they must maintain sufficient thickness to ensure an acceptable mouthfeel.

5. Chemical composition

The composition of red rice instant porridge with various substitution variations is presented in Table 4.

The moisture content of instant porridge (Table 4) did not differ significantly between treatments. This is because each sample was dried using a drum drier at 120°C and under the same process conditions. The instant porridge produced in this study had a lower moisture content than the instant porridge mixture of corn, sweet potato, and moringa leaf powder, ranging from 5.60% to 8.50%. Galaz et al. (2017) reported that the drum drier is an effective and efficient drying machine for drying instant products. Drum driers are also effective for drying instant beverages (Rittisak et al., 2022). The moisture content will affect the moisture isotherm and shelf life of instant porridge (Slamet et al., 2020).

Table 4 Chemical composition of red rice instant porridge (%)

Red rice flour substitution ratio of tempeh and pumpkin	Moisture	Ash	Protein	Fat	Carbohydrate
100:0:0	4.62±0.01 ^a	2.30±0.18 ^c	3.07±0.24 ^d	0.80±0.03 ^c	89.21±2.71 ^a
80:10:10	4.55±0.13 ^a	4.53±0.06 ^b	6.68±0.96 ^c	3.02±0.85 ^d	81.22±1.08 ^b
60:20:20	4.58±0.21 ^a	4.69±0.02 ^b	8.09±1.22 ^b	4.84±1.03 ^c	77.80±0.95 ^c
40:30:30	4.60±0.03 ^a	4.82±0.19 ^a	9.82±0.95 ^a	5.06±0.86 ^b	75.70±1.14 ^d
20:40:40	4.59±0.17 ^a	4.85±0.20 ^a	9.95±1.13 ^a	5.42±1.07 ^a	75.19±1.52 ^d

Remark: Data are reported as mean ± standard deviation. Values with different superscript letters in the same column indicate significant differences ($p < 0.05$).

The ash content of the instant porridge increased with the substitution of more tempeh and pumpkin. Ash content comes from minerals in tempeh and pumpkin. Starzyńska-Janiszewska et al. (2016) reported that tempeh is also a source of Ca, Fe, and Mg minerals, in addition to protein. Tempeh is a source of isoflavones and minerals needed by the body (Romulo & Surya, 2021).

The protein content of the instant porridge increased significantly with the substitution of more tempeh and pumpkin. This is because the more tempeh is substituted, the higher the protein content of the instant porridge becomes. The protein content of the instant porridge ranged from 3.07 to 9.95%. Wahyuni et al. (2024) reported that the protein content of tempeh was 9.50%. Tempeh is a source of vegetable protein and is easy to process (Rahmawati et al., 2021). Dafne et al. (2025) reported that tempeh is a fermented food containing bioactive compounds that are beneficial for health.

The fat content of the instant porridge increased significantly with the increasing substitution of tempeh and pumpkin. The fat content of the instant porridge ranged from 0.80 to 5.42%. Ledbetter et al. (2024) reported that instant cereal porridge increased protein and fat levels. Instant porridge enriched with mung beans also increased fat content (Mahgoub et al., 2020).

The carbohydrate content of the instant porridge decreased (Table 4). The carbohydrate content of instant porridge without pumpkin and tempeh substitution was 89.21%. The decrease in carbohydrate content in the tempeh and pumpkin substitution treatment was primarily due to the use of mostly red rice as the carbohydrate source. Kumari et al. (2022) reported that the extruded snack's carbohydrate content decreased with the substitution of mung bean flour. The instant porridge mixture of mocaf, pumpkin, and cowpea flour had a reduced carbohydrate content with increasing amounts of pumpkin and cowpea flour (Slamet et al., 2025).

6. Total phenolic content, β -carotene, and antioxidant activity

Total phenolic content, β -carotene, and antioxidant

activity of red rice instant porridge from different variations of tempeh and pumpkin are presented in Table 5.

Table 5 Total phenolic content, β -carotene, and antioxidant activity

Red rice flour substitution ratio of tempeh and pumpkin	Total phenolic content mg GAE/g	β -carotene $\mu\text{g/g}$	Antioxidant activity (%)
100:0:0	6.98±0.63 ^d	3.97±0.24 ^d	2.43±0.18 ^c
80:10:10	14.87±1.01 ^c	120.74±5.09 ^c	28.71±3.96 ^d
60:20:20	16.09±0.94 ^b	165.08±7.72 ^b	32.08±3.03 ^c
40:30:30	17.56±1.08 ^a	193.87±4.64 ^a	33.42±2.94 ^b
20:40:40	18.94±1.13 ^a	201.95±5.09 ^a	34.75±1.63 ^a

Remark: The results are presented as the mean ± standard deviation. Distinct superscript letters within a column denote values that differ significantly at the $p < 0.05$ level.

The total phenolic content of instant porridge increased significantly with higher levels of tempeh and pumpkin substitution (Table 5). Although pumpkin contributes a measurable amount of phenolic compounds, as reported at 71 ng/mg by Krstić et al. (2023), and is recognized as a phenolic-rich commodity (Caballero-Gutiérrez et al., 2025), the substantial rise in phenolics in this study can also be attributed to tempeh. Tempeh contains considerably higher phenolic concentrations, reaching 9.12 mg/g (Starzyńska-Janiszewska et al., 2016), and is known to supply active phenolic constituents in addition to its protein content (Pamekas et al., 2025). Prior research similarly demonstrated that incorporating pumpkin into instant porridge formulations enhances phenolic content (Slamet et al., 2025). Together, these findings suggest that both ingredients contribute to the overall increase in phenolics, with tempeh likely providing the dominant input.

The β -carotene content of the instant porridge also rose markedly with increasing substitution levels. In this study, β -carotene ranged from 3.97 to 201.95 $\mu\text{g/g}$, with the lowest value observed in the control formulation lacking pumpkin and tempeh. Pumpkin is a particularly rich source of β -carotene, containing 376–451 $\mu\text{g/g}$ in fresh form (Hagos et al., 2022), and its incorporation confers a substantial carotenoid advantage to the final

product. This is consistent with previous reports showing elevated β -carotene levels in pumpkin-based instant porridges (Slamet et al., 2025), cookies enriched with pumpkin flour (Indrianingsih et al., 2024), and other food matrices supplemented with pumpkin (Shajan et al., 2024). The pronounced increase in β -carotene, therefore, reflects the strong carotenoid contribution of pumpkin within the composite formulation.

Antioxidant activity exhibited a parallel increase, with the highest substitution level (30:40:40) achieving 34.75% radical scavenging activity (Table 5). Much of this enhancement can be attributed to pumpkin, which possesses inherent antioxidant potential, with reported values ranging from 61.45 to 80.72% in pumpkin flour (Chikpah et al., 2022). Antioxidant compounds are distributed throughout the tissues of pumpkins, including the skin, pulp, and seeds (Susmi et al., 2023), and contribute substantially to the measured activity. Increased antioxidant activity following the substitution of pumpkin has also been documented in noodle systems (Farzana et al., 2023) and other pumpkin-enriched foods (Shi et al., 2013). In addition to pumpkin carotenoids, phenolic compounds supplied by both pumpkin and tempeh further contribute to free-radical scavenging mechanisms.

Collectively, the increasing levels of phenolics, isoflavone-rich tempeh components, and β -carotene provide a biochemical basis for the enhanced antioxidant activity observed. These compounds are known for their capacity to neutralize reactive oxygen species, thereby contributing to potential health-promoting effects such as mitigating oxidative stress and reducing cellular damage. Thus, the combined use of tempeh and pumpkin not only elevates the bioactive profile of instant porridge but also supports its value as a nutritionally functional food.

7. Panelist's preference level

The level of panelists' preference for red rice instant porridge based on the parameters of color, aroma, flavor, viscosity, and overall is presented in Table 6.

The sensory evaluation results (Table 6) indicated a clear improvement in consumer acceptance with increasing levels of tempeh and pumpkin substitution, which was consistent with the observed physicochemical properties. The enhanced color scores corresponded to the decrease in lightness (L^*) and the increase in a^* and b^* values in the color analysis, reflecting the intensified orange–brown hues resulting from carotenoid pigments in pumpkin (Zhang et al., 2024a) and Maillard-derived browning associated with interactions between reducing sugars from pumpkin and red rice flour and amino acids from tempeh (Liu et al., 2020). Similar color-related preference improvements have been noted in egg roll formulations where Maillard browning contributed to desirable visual attributes (Chan et al., 2020). The caramelization of natural sugars during heating may have further enhanced these appealing color tones.

Aroma scores also increased as the proportion of tempeh and pumpkin rose, with the 40:30:30 formulation receiving the highest acceptance (4.15). This improvement is consistent with the physicochemical contributions of both ingredients, where pumpkin provides naturally sweet and aromatic volatiles that enhance the overall sensory appeal (Arifin et al., 2019; Melese & Keyata, 2022; Ngaha Damndja et al., 2024). In parallel, fermentation-derived volatiles from tempeh likely enhanced the aromatic complexity, resulting in a richer and more layered aroma profile. The combined influence of these volatile compounds aligns with the observed sensory scores, suggesting a synergistic enhancement of aroma as substitution levels increase.

Flavor acceptance followed a similar pattern. The combined presence of pumpkin and tempeh likely produced a balanced taste profile, thanks to the natural sweetness of the pumpkin and the umami-rich compounds generated during tempeh fermentation. This finding is consistent with previous studies reporting improved flavor quality in products incorporating pumpkin (Melese & Keyata, 2022; Nanthachai et al., 2020) and the inherently preferred taste characteristics of tempeh-based

Table 6 Panelists' preference level

Red rice flour substitution ratio of tempeh and pumpkin	Color	Aroma	Flavor	Viscosity	Overall
100:0:0	2.55±0.17 ^c	3.11±0.60 ^c	2.04±0.91 ^c	3.70±0.54 ^b	2.97±0.52 ^d
80:10:10	2.72±0.95 ^d	3.54±0.09 ^b	3.36±0.83 ^c	3.65±0.19 ^b	3.55±0.71 ^b
60:20:20	3.08±0.02 ^c	3.69±0.74 ^b	3.69±0.07 ^b	3.38±0.52 ^c	3.62±0.67 ^a
40:30:30	4.42±0.41 ^b	4.15±0.92 ^a	3.94±0.11 ^a	4.01±0.70 ^a	3.70±0.95 ^a
20:40:40	4.78±0.08 ^a	2.97±0.85 ^d	3.07±0.67 ^d	2.17±0.14 ^d	3.24±0.91 ^c

Remark: Data are expressed as mean ± standard deviation. Different superscript letters within the same column indicate significant differences ($p < 0.05$).

foods (Romulo & Surya, 2021). Rohmatningsih et al. (2025) reported that adding more pumpkin can improve the taste of the cookies produced.

In contrast, viscosity scores decreased with higher substitution levels, which aligns with instrumental measurements showing reduced viscosity and swelling power as the proportion of pumpkin and tempeh increased. The reduction in starch content, resulting from partial replacement with pumpkin and tempeh, limited gelatinization and gel formation, as the functional contribution of starch to texture is substantial (Charles et al., 2016; Iwansyah et al., 2022). Consequently, formulations with greater substitution produced a thinner porridge consistency, which may be perceived as less desirable by some panelists.

Despite the lower viscosity scores, the overall preference increased markedly with substitution, with the 40:30:30 formulation achieving the highest overall acceptance (3.70). The improved overall liking is consistent with reports that pumpkin-enhanced products, such as cookies, biscuits, and instant porridge, tend to receive favorable evaluations due to their enhanced flavor, color, and nutritional value (Slamet et al., 2019; Melese & Keyata, 2022; Indrianingsih et al., 2024). The incorporation of pumpkin has also been shown to improve the texture and sensory quality of bakery products, such as bread (Shevchenko et al., 2023).

Collectively, the sensory outcomes, supported by the physicochemical and bioactive profiles, demonstrate that the integration of tempeh and pumpkin meaningfully enhances both the nutritional quality (protein, β -carotene, phenolics) and sensory appeal of red rice instant porridge. These results highlight the practical relevance of this formulation and reinforce its potential as a locally sourced functional food innovation.

Conclusion

Substituting tempeh and pumpkin in instant red rice porridge increased the protein content from 3.07 to 9.95%, total phenolic content from 6.98 to 18.94 mg GAE/g, β -carotene from 3.97 to 201.95 μ g/g, and antioxidant activity from 2.43 to 34.75%. The 20:40:40 formulation yielded the highest bioactive content, while the 40:30:30 formulation was preferred by panelists due to its balanced nutritional and sensory quality. These results demonstrate that the combination of tempeh and pumpkin can enhance the nutritional and functional quality of instant red rice porridge, indicating potential

for development as a locally based healthy food innovation.

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Conflicts of interest

The authors declare no conflicts of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

In preparing this manuscript, ChatGPT (OpenAI) was used to enhance clarity and readability, and Grammarly was used to verify grammar and spelling. The scientific framework, experimental design, data analysis, and conclusions were independently developed by the authors. The authors critically reviewed and edited the generated content and accept full responsibility for the accuracy and integrity of the final manuscript.

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