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Physicochemical and Sensory Characteristics of Instant Porridge Made from Modified Cassava, Red Bean, and Pumpkin Flours

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Abstract

The development of instant porridge based on locally available raw materials is important for promoting food diversification and enhancing the utilization of sustainable agricultural resources. However, comprehensive information on the physicochemical, functional, and sensory characteristics of instant porridge formulated from modified cassava flour (MOCAF), red bean flour, and pumpkin flour in different proportions remains limited. This study evaluated the effects of different proportions of MOCAF, red bean flour, and pumpkin flour on the physicochemical, functional, and sensory characteristics of instant porridge. Five formulations (70:20:10, 65:20:15, 60:20:20, 55:20:25, and 50:20:30, MOCAF:red bean flour:pumpkin flour, w/w) were prepared and evaluated for their physical properties, chemical composition, functional properties, antioxidant activity, and sensory characteristics. Increasing the proportion of pumpkin flour from 10 to 30% while reducing MOCAF from 70 to 50% significantly decreased yield, lightness, water solubility index, water absorption index, swelling power, and carbohydrate content, whereas protein content, water activity, and bulk density increased significantly. Carbohydrate content decreased from 75.20 to 73.15%, while protein content increased from 11.81 to 13.72%. Among the formulations evaluated, the 55:20:25 formulation achieved the highest overall sensory preference score. These findings demonstrate that optimizing the proportions of MOCAF, red bean flour, and pumpkin flour enhances the nutritional quality and consumer acceptability of instant porridge, highlighting its potential as a locally sourced product to support sustainable food diversification.

Keywords: antioxidant activity; drum drying; food diversification; functional properties; total phenolic content

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INTRODUCTION

Food diversification based on locally available raw materials has become an important strategy for strengthening sustainable food systems and reducing dependence on a single staple food source. Among local carbohydrate resources, cassava has considerable potential due to its wide availability, high starch content, and adaptability to diverse agroecological conditions (Rozi et al., 2023; Statistics Indonesia, 2025). Processing cassava into modified cassava flour (MOCAF) further enhances its functionality, making it suitable for the development of various processed foods, including instant products.

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Cassava is one of the local agricultural commodities with potential to be developed as an alternative food source, owing to its high starch content, relatively high productivity, and broad adaptability across various agroecological conditions. Processing cassava into MOCAF has been reported to improve the functional characteristics of flour, including its rheological properties and applicability in various processed food products. These characteristics make MOCAF suitable for application in instant food products and flour-based composite products (Wang et al., 2022; Martínez et al., 2024). However, MOCAF-based food products are still predominantly carbohydrate-rich, so their use as alternative foods requires enrichment with other ingredients to improve the nutritional value and functional properties of the final product (Richirose and Soedirga, 2023; Matita et al., 2024).

Red beans (*Phaseolus vulgaris* L.) are a source of vegetable protein and dietary fiber with potential as an additive in starch-based food products. In addition to their relatively high protein content, red beans also contain other bioactive compounds that contribute to their nutritional quality. The addition of bean flour to instant porridge formulations has been reported to increase protein content, alter product physical properties, and improve texture and viscosity (Keyata et al., 2023; Teferi et al., 2024). The combination of starch and vegetable protein also contributes to the matrix structure of instant products, which, in turn, affects water absorption, rehydration characteristics, and the product's physical stability during storage (Katunzi-Kilewela et al., 2022).

Beyond protein enhancement, the formulation of food products derived from local ingredients should also consider the presence of bioactive compounds that confer functional benefits. Pumpkin (*Cucurbita moschata*) is a locally available ingredient known for its high content of bioactive compounds, particularly β-carotene, which functions as a provitamin A and a natural antioxidant. Previous studies have demonstrated that incorporating yellow squash into flour-based products enhances β-carotene levels, antioxidant activity, and total phenolic content, while simultaneously improving the final product's visual appeal through its characteristic natural color (Indrianingsih et al., 2024; Abedin et al., 2025). These bioactive constituents play an important role in the development of functional foods that extend beyond meeting basic energy requirements by offering potential health-promoting effects (Tekin and Dincer, 2023; Yan et al., 2024). Therefore, incorporating pumpkin flour into MOCAF-based instant porridge is expected to improve its nutritional quality, physicochemical characteristics, and consumer acceptability while promoting the utilization of locally available agricultural resources for sustainable food diversification.

The combination of MOCAF, red bean flour, and pumpkin flour was selected to provide complementary nutritional and functional attributes. MOCAF serves as the primary carbohydrate source (Khasanah et al., 2023), whereas red bean flour is an important source of plant protein (Vieler et al., 2026), and pumpkin flour contributes minerals, β-carotene, and natural antioxidants (Nurbaiti et al., 2023). The complementary characteristics of these ingredients were expected to improve the nutritional quality, physicochemical properties, functional characteristics, and sensory acceptability of MOCAF-based instant porridge while promoting the utilization of locally available agricultural resources.

Instant porridge is a practical food product that is easy to prepare and can be consumed by various age groups, thus having the potential to diversify the food supply using local ingredients (Putra et al., 2021). Instant porridge products are widely used as breakfast foods, snacks, and complementary foods for certain groups, making physical characteristics, nutritional value, and consumer acceptance important aspects in their development. The development of instant porridge based on local ingredients using appropriate drying technology, such as drum dryers, has been reported to yield products with good rehydration properties, adequate physical stability, and consumer acceptance (Guo et al., 2024; Slamet et al., 2025). Drum dryer technology is also relatively simple and applicable to the processing of agricultural-based food products (Courtois, 2024).

However, ingredient formulation and drying conditions can affect the physical characteristics, bioactive compound content, and palatability of the instant porridge product. Changes in ingredient proportions can affect the structure of the product matrix, rehydration properties, and the stability of bioactive components during processing (Rasdi et al., 2024). Therefore, the design of instant porridge formulations based on local ingredients requires comprehensive research so that the resulting products have adequate physical quality, functional value, and consumer acceptance.

Several studies have investigated the development of instant porridge based on local ingredients and composite flours, including formulations containing MOCAF or other locally available raw materials (Slamet et al., 2019; Katunzi-Kilewela et al., 2022). However, limited information is available regarding the combined use of MOCAF, red bean flour, and pumpkin flour. In particular, studies on how their complementary nutritional composition influences the physicochemical, functional, and sensory characteristics of instant porridge are lacking. Therefore, this study provides new scientific evidence regarding the effects of combining these locally available ingredients on the nutritional quality, physicochemical, functional, and sensory characteristics of instant porridge. Based on this research gap, the present study aimed to evaluate the effects of different proportions of MOCAF, red bean flour, and pumpkin flour on the physicochemical, functional, and sensory characteristics of instant porridge. An integrated multi-parameter approach was employed to comprehensively assess product quality and provide scientific evidence supporting the use of locally available raw materials for sustainable food diversification.

MATERIALS AND METHOD

Materials and equipment

This study used MOCAF (Mocafin brand), red bean flour (Hasil Bumiku brand), and pumpkin flour (Hasil Bumiku brand) as the main ingredients in the instant porridge formulation. All of these ingredients were obtained from small and medium-sized enterprises (SMEs) in Sleman Regency, Yogyakarta, Indonesia. The chemicals used for analysis were of pro-analysis grade and were obtained from Sigma-Aldrich (St. Louis, MO, USA).

The equipment used in the instant porridge production process included a laboratory mixer, a drum dryer, a tray, a grinder, and an 80-mesh sieve. The tools used for analysis included an analytical balance (OHAUS Pioneer), a colorimeter (Konica Minolta), a water activity/aw meter (AquaLab), a centrifuge (Hettich), a UV-VIS Spectrophotometer (Shimadzu), and a scanning electron microscope (SEM) (JEOL). Supporting glassware such as beakers, measuring flasks, and measuring cups (Iwaki Pyrex).

Methods

Instant porridge formulation

This study formulated instant porridge using a mixture of MOCAF, red bean flour, and pumpkin flour in 5 formulations. The proportions of the ingredients were set at 70:20:10, 65:20:15, 60:20:20, 55:20:25, and 50:20:30 (MOCAF: red bean flour:pumpkin flour), respectively.

The process of making instant porridge

Instant porridge slurry was prepared by mixing dry ingredients with water to obtain a total solids content of approximately 20 to 25% (w/w). The homogenized slurry was then dried using a drum dryer at a drum surface temperature of 120 °C with a rotation speed of approximately 1.0 rpm. The dry product formed on the drum dryer surface was scraped into thin sheets and then cooled at room temperature. The dry sheets were then ground and sieved to obtain instant porridge powder with a uniform particle size. The instant porridge was then vacuum-packed for further analysis.

Proximate analysis

Proximate analysis of all instant porridge samples was performed using the standard method of the Association of Official Analytical Chemists (AOAC, 2005). The proximate analysis included: determination of moisture content (No. 926.5), total fat (No. 935.38), total protein (No. 950.36), and ash content (No. 930.22). The carbohydrate content of instant porridge was calculated by difference as 100% minus the sum of moisture, protein, fat, and ash contents.

Color of instant porridge

The color of instant porridge was analyzed using a colorimeter. Instant porridge powder samples were placed in a measuring container and leveled to obtain a homogeneous surface. Color measurements were taken at several measurement points on each sample to obtain representative values. The color parameters observed include lightness (L*), redness–greenness (a*), and yellowness–blueness (b*). Color values were expressed as the average of the measurement results.

Functional properties

Water absorption index (WAI)

The WAI was measured following the method described by Anderson et al. (1970). Approximately 1 g of instant porridge powder was mixed with distilled water and gently stirred until a uniform suspension was obtained. The mixture was left to hydrate at room temperature for 30 minutes before being centrifuged at 3,000×g for 15 minutes. The supernatant was then discarded, and the hydrated residue was weighed. WAI was expressed as the ratio of the hydrated residue weight to the initial dry sample weight (g g^{-1}).

Water solubility index (WSI)

The WSI of instant porridge samples was determined according to the method of Anderson et al. (1970) to measure the fraction of solids soluble in water. A 0.5 g sample of instant porridge powder was dissolved in 10 ml of distilled water. The solution was homogenized and heated in a water bath at 85 to 90 °C for 30 minutes, with stirring throughout. The solution was then cooled and centrifuged at 3,000 rpm for 15 minutes. The resulting supernatant was then dried at 105 °C to a constant weight. The WSI value was expressed as the percentage of dry soluble solids produced relative to the initial dry weight of the instant porridge sample.

Swelling power

Swelling power was determined according to the method of Leach et al. (1959) with slight modifications. Swelling power was determined by heating a suspension of instant porridge (0.5 g, dry basis) in 10 ml of distilled water at 90 ºC for 30 minutes with intermittent gentle mixing. Upon completion of heating, the sample was cooled to room temperature and centrifuged at 3,000 rpm for 15 minutes. The supernatant was decanted, and the remaining hydrated gel was weighed. Swelling power was expressed as the ratio of gel weight to the initial dry sample weight (g g^{-1}).

Physical properties

Yield

Yield was calculated to describe the efficiency of instant porridge production by comparing the mass of the dried final product with the total mass of ingredients prior to drying. The weight of the instant porridge after drying was recorded as the final product mass, while the combined weight of raw ingredients was measured before drying. Yield was calculated as a percentage (%) based on Equation 1.

Water activity

The water activity of instant porridge was measured using a water activity meter (AquaLab 4TE, Meter Group Inc., Pullman, WA, USA) according to the manufacturer's instructions. A sample of instant porridge powder was placed into the sample cup until it adequately filled the measurement chamber without excessive compaction. The measurement was continued until equilibrium was reached, as indicated by a stable water activity value, and the final water activity value was recorded.

Bulk density

The bulk density of instant porridge powder was evaluated using the free-flowing approach. The powder was carefully transferred into a graduated cylinder until a predetermined volume was attained without applying tapping or compression. The mass of the powder occupying the specified volume was measured, and the bulk density was determined as mass per unit volume, expressed in g ml^{-1}.

Microstructure analysis

The microstructure of instant porridge was observed using scanning electron microscopy (SEM). Instant porridge powder samples were dried to a stable condition, then placed on a sample holder (stub) using conductive adhesive and coated with a thin conductive layer before observation. Observations were made at several magnification levels to evaluate the surface morphology, particle size, and shape, and matrix structure of the instant porridge resulting from the drying process. The microimages obtained were used to describe the microstructural characteristics and their relationships with the physical properties of instant porridge.

Analysis of bioactive compounds

β-carotene analysis

The β-carotene content of instant porridge was quantified using high-performance liquid chromatography (HPLC). Analysis was performed using an HPLC system equipped with a UV/Vis detector and a C18 reversed-phase column. Separation was achieved with a methanol-based mobile phase containing butylated hydroxytoluene (BHT) as an antioxidant at a flow rate of 1.0 ml $minute^{-1}$ and a column temperature of 24 °C. Detection was carried out at 450 nm, and quantification was performed using an external calibration curve prepared from β-carotene standard solutions. Results were expressed as µg β-carotene per g dry basis (µg g^{-1} db) (Luterotti et al., 2013). β-carotene content was calculated according to Equation 2.

Total phenolic content

The total phenolic content of instant porridge was determined using the Folin–Ciocalteu method. The extract was reacted with the Folin–Ciocalteu reagent, and sodium carbonate was then added to promote color development. Following

$$\text{Yield (\%)} = (\text{Wf} / \text{Wi}) \times 100 \quad (1)$$

Where, Wf = weight of instant porridge (g), Wi = slurry weight (g).

$$\beta\text{-carotene content} = (C \times V \times F) / W \quad (2)$$

Where, C = β-carotene concentration in the extract based on the standard curve (μg ml^{-1}), V = total extract (ml), F = dilution factor, W = dry sample weight (g).

$$\text{Antioxidant activity} = (A_0 - A_s) / A_0 \times 100 \quad (3)$$

Where, A_0 = the absorbance of the DPPH control solution, A_s = the absorbance of the DPPH solution after the addition of the sample extract.

incubation, the intensity of the blue-colored complex produced through the oxidation-reduction reaction of phenolic compounds was measured spectrophotometrically at 765 nm. Results were expressed as mg GAE g^{-1} based on a gallic acid calibration curve (Pérez et al., 2023).

Antioxidant activity

Antioxidant activity of the instant porridge was assessed by the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. Methanolic extracts were prepared from powdered samples and filtered prior to measurement. An aliquot of the extract was incubated with a DPPH solution of known concentration in the dark at room temperature to assess radical scavenging. The reduction in absorbance was measured at 517 nm using a spectrophotometer, with a DPPH solution without sample addition as the control (Sharma et al., 2016). Antioxidant capacity was calculated and expressed as the percentage of DPPH radical inhibition. Antioxidant activity was calculated using Equation 3.

Preference test

Sensory evaluation of rehydrated instant porridge was conducted using a 5-point hedonic preference test (Stone et al., 2020). The evaluation involved 30 untrained undergraduate panelists (12 males and 18 females, aged 18 to 21 years) from the Department of Agricultural Product Technology, Universitas Mercu Buana Yogyakarta, Indonesia. Panelists with no self-reported allergies to MOCAF, red bean flour, or pumpkin flour were selected. Samples were prepared by dispersing 250 g of powder in 250 ml of hot water (100 °C) and served in 10 g portions per formulation, coded with random 3-digit numbers and presented in randomized order. Color, aroma, taste, viscosity, and overall acceptability were evaluated using a 5-point hedonic scale (1 = strongly dislike; 5 = strongly like), with mineral water provided between samples to minimize carry-over effects. The protocol was approved by the Research Ethics Commission of Universitas Alma-Ata, Yogyakarta, Indonesia (approval No. 125/EC/X/2025).

Statistical analysis

The experiment was conducted using a completely randomized design (CRD) with one factor consisting of five instant porridge formulations. Data were presented as mean±standard deviation (SD). Prior to one-way analysis of variance (ANOVA), the assumptions of normality and homogeneity of variance were assessed using the Shapiro–Wilk and Levene's tests, respectively. Subsequently, the data were analyzed using one-way ANOVA, followed by Duncan's multiple range test (DMRT) for mean separation at $p < 0.05$. Pearson's correlation analysis was also performed to evaluate the relationships among physicochemical, functional, chemical, and sensory characteristics. All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA).

RESULTS AND DISCUSSION

Proximate composition of the raw materials

The proximate composition of the raw materials used for instant porridge production is presented in Table 1. Characterizing the nutritional composition of MOCAF, red bean flour, and pumpkin flour is essential because differences in their chemical composition are expected to influence the nutritional value and quality attributes of the final product. Therefore, the proximate composition of these raw materials provides a basis for interpreting the physicochemical, functional, and sensory properties of the developed instant porridge.

Significant differences ($p < 0.05$) were observed among MOCAF, red bean flour, and pumpkin flour for all proximate components. Moisture content ranged from 8.85 to 10.18%, indicating that all raw materials were sufficiently stable for dry food processing. MOCAF contained the highest carbohydrate content (86.87%) and the lowest protein (1.27%), fat (0.89%), and ash (0.79%) contents, confirming its primary role as the carbohydrate source in the formulation (Richirose and Soedirga, 2023). Red bean flour exhibited the highest protein content (23.59%), reflecting its potential as a plant-based protein source for improving the nutritional quality of instant porridge (Teferi et al., 2024). Pumpkin flour showed the highest ash (5.84%) and fat (2.83%) contents, indicating its relatively greater mineral and lipid contents than the other raw materials (Indrianingsih et al., 2024).

The complementary nutritional composition of these 3 raw materials provides a scientific basis for developing nutritionally improved instant porridge. MOCAF primarily supplies starch as the major carbohydrate source (Richirose and Soedirga, 2023), whereas red bean flour contributes to protein enrichment (Keyata et al., 2023). Pumpkin flour enhances the nutritional quality of the formulation by providing minerals and provitamin A carotenoids, particularly β-carotene (Abedin et al., 2025). Varying proportions of these ingredients are expected to influence the proximate composition as well as the physicochemical, functional, and sensory characteristics of the developed instant porridge, as discussed in the following sections.

Proximate composition of instant porridge

The proximate composition of instant porridge formulated with different proportions of MOCAF, red bean flour, and pumpkin flour is presented in Table 2. Significant differences ($p < 0.05$) were observed among the formulations for all proximate components, indicating that variations in ingredient proportions influenced the nutritional composition of the developed instant porridge.

Moisture content

Increasing the proportion of pumpkin flour from 10 to 30%, followed by a decrease in the proportion of MOCAF, had no significant effect ($p > 0.05$) on the moisture content, which ranged from 5.61 to 5.73% (Table 2). The absence of a significant difference in the moisture content of instant porridge indicates that heat transfer and the rate of water evaporation during drum drying at 120 °C were more dominant than the hygroscopic effects of the ingredients. Lower moisture content inhibits microbial growth, enzyme activity, and decay, thereby extending shelf life (Rifna et al., 2022). Direct contact between the dough and the drum dryer surface causes free water to evaporate quickly, so that differences in starch and fiber composition are not reflected in the final moisture content of the product (Adgidzi and Ani, 2021). The moisture content of the instant porridge produced was consistent with that of instant porridge supplemented with moringa leaf flour (Zakaria et al., 2024), MOCAF, and winged bean (Slamet et al., 2025).

Fat

Table 2 shows that variations in ingredient proportions had a significant effect ($p < 0.05$) on fat content, which increased from 3.29% in the 70:20:10 formulation to values ranging from 3.58 to 3.65% in formulations containing higher pumpkin flour proportions. MOCAF is dominated by starch with very low fat content, while pumpkin flour contains natural lipids associated with carotenoid fractions and cell membranes. MOCAF is mainly composed of carbohydrates, with a very low fat content ranging from 0.43

Table 1. Proximate composition of the raw materials

Raw material	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrate (%)
MOCAF	10.18 ± 0.29^{a}	0.89 ± 0.00^{c}	1.27 ± 0.01^{c}	0.79 ± 0.00^{c}	86.87 ± 3.82^{a}
Red bean flour	9.17 ± 0.20^{b}	1.47 ± 0.01^{b}	23.59 ± 0.18^{a}	3.46 ± 0.02^{b}	62.31 ± 2.75^{c}
Pumpkin flour	8.85 ± 0.61^{c}	2.83 ± 0.04^{a}	8.52 ± 0.21^{b}	5.84 ± 0.15^{a}	73.96 ± 3.53^{b}

Note: Values are expressed as mean±standard deviation (SD). Mean values sharing the same superscript letter within a column are not significantly different at $p < 0.05$

Table 2. Proximate composition of instant porridge

MOCAF:red bean flour:pumpkin flour	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrates (%)
70:20:10	5.73 ± 0.97^{a}	3.29 ± 0.04^{c}	11.81 ± 1.01^{c}	3.97 ± 0.09^{a}	75.20 ± 1.43^{a}
65:20:15	5.68 ± 0.81^{a}	3.47 ± 0.92^{bc}	12.05 ± 0.95^{bc}	3.80 ± 0.86^{ab}	75.00 ± 1.09^{a}
60:20:20	5.70 ± 0.05^{a}	3.40 ± 0.05^{bc}	12.76 ± 1.13^{b}	3.59 ± 0.63^{c}	74.55 ± 1.73^{ab}
55:20:25	5.64 ± 0.93^{a}	3.65 ± 0.11^{a}	13.58 ± 0.97^{a}	3.76 ± 0.71^{bc}	73.37 ± 1.18^{b}
50:20:30	5.61 ± 0.06^{a}	3.58 ± 0.62^{ab}	13.72 ± 0.17^{a}	3.94 ± 0.80^{a}	73.15 ± 1.32^{c}

Note: Values are expressed as mean±standard deviation (SD). Mean values sharing the same superscript letter within a column are not significantly different at $p < 0.05$

to 0.75% (Khasanah et al., 2022). Red bean flour, used at a fixed proportion of 20%, acted as a relatively stable basic fat contributor, so it was not a major factor in fat content variation between treatments. Therefore, the increase in fat content was mainly influenced by an increase in pumpkin flour and a decrease in the MOCAF fraction. The fat derived from red bean flour had no effect because the proportion added to the samples was the same (20%). This is consistent with the results of research on instant porridge substituted with red bean flour (Purbowati et al., 2021).

Protein

Variations in the proportions of MOCAF and pumpkin flour significantly affected the protein content ($p < 0.05$). An increase in pumpkin flour proportion, accompanied by a reduction in MOCAF, raised the protein content from 11.81% in the 70:20:10 formulation to 13.72% in the 50:20:30 formulation (Table 2). This trend is primarily attributed to the low protein content of MOCAF, which is dominated by starch, such that its reduction decreased the overall non-protein carbohydrate fraction. In contrast, pumpkin flour contributed additional vegetable protein, while the constant proportion of red bean flour served as the main and stable protein source in the formulation. Consequently, the observed increase in protein content reflected a compositional shift of the matrix from starch-dominated to non-starch components, rather than being associated with differences in the drying process (Mahgoub et al., 2020). The protein content obtained in formulations containing 20% and 25% pumpkin flour (13.58 to 13.72%) was comparable to that reported for brown rice instant porridge fortified with kale (*Brassica oleracea* var. acephala) (Thanaratikul and Supaking, 2025).

Ash

Variations in ingredient proportions had a significant effect ($p < 0.05$) on the ash content, which ranged from 3.59 to 3.97%. An increase in pumpkin flour and a decrease in MOCAF increased the mineral contribution because MOCAF contains less ash than pumpkin flour and red bean flour. The non-linear fluctuation in ash content indicates that the specific mineral composition of each ingredient and the effect of concentration during thermal drying were more decisive than the proportional increase of a single ingredient (Anberbir et al., 2024). The ash content of the instant porridge obtained in this study was higher than that reported for Nutrimix porridge flour (2.1%) (Gupta et al., 2025). This difference is due to the different materials and proportions used.

Carbohydrate

Variations in ingredient proportions had a significant effect ($p < 0.05$) on the carbohydrate content. A decrease in the proportion of MOCAF from 70 to 50%, accompanied by an increase in pumpkin flour, reduced the carbohydrate content from 75.20 to 73.15%. The carbohydrate content was almost the same as that of instant porridge with the addition of 10 or 15% pumpkin flour. MOCAF is primarily a starch-based product. The characteristics of MOCAF, which is a source of carbohydrates, make it an alternative to gluten-free flour in various food products (Hamidi and Banowati, 2019). Therefore, a decrease in starch content directly reduces the carbohydrate fraction in the product (Hastati et al., 2024; Zaidiyah et al., 2024). The carbohydrate content of instant porridge enriched with inulin was reported to be 76.03% (Herminiati et al., 2020).

Color characteristics of instant porridge

The color characteristics (L*, a*, and b*) of instant porridge formulated with different proportions of MOCAF, red bean flour, and pumpkin flour are presented in Table 3.

Lightness (L)*

Variations in the proportions of MOCAF, red bean flour, and pumpkin flour had a significant effect on L* ($p < 0.05$). The L* value decreased from 61.96 in the 70:20:10 formulation to 54.94 in the 50:20:30 formulation, indicating that

Table 3. Colors of instant porridge

MOCAF:red bean flour:pumpkin flour	L*	a*	b*
70:20:10	61.96±2.81^{a}	15.56±1.07^{c}	13.01±1.81^{c}
65:20:15	59.07±3.35^{ab}	15.01±1.86^{c}	13.92±2.05^{c}
60:20:20	58.11±3.01^{b}	17.63±2.04^{bc}	15.58±1.63^{bc}
55:20:25	55.62±2.78^{c}	19.49±1.51^{b}	17.63±2.86^{b}
50:20:30	54.94±2.15^{c}	21.73±1.48^{a}	18.05±2.40^{a}

Note: All values are presented as mean±standard deviation (SD). Means assigned the same letter in a given column indicate the absence of significant differences ($p < 0.05$)

an increase in the proportion of pumpkin flour and a decrease in MOCAF caused the product color to become darker (Table 3). The decrease in L* value is related to the increase in the natural pigment content of pumpkin flour, especially carotenoids, which reduce the light reflectance of the product surface. In addition to the pigment effect, the decrease in L* is also influenced by non-enzymatic browning reactions, particularly the Maillard reaction, which is more intense in formulations with higher reducing sugar and amino acid contents (Žilić et al., 2021). Because MOCAF has a low protein content, reducing its proportion increases the ratio of reducing sugars to amino acids and potentially enhances the Maillard reaction (Purwani et al., 2024). Both pumpkin flour and red bean flour provide precursors for the Maillard reaction. This is a non-enzymatic browning reaction involving the interaction of carbonyl compounds, such as reducing sugars, with amino-containing compounds, such as amino acids (Fan et al., 2023). These reactions significantly affect the color, taste, and nutritional value of food products (Qi et al., 2025).

Redness (a)*

Variations in the proportions of MOCAF: red bean flour:pumpkin flour had a significant effect on a* ($p < 0.05$). The a* value increased from 15.56 in the 70:20:10 formulation to 21.73 in the 50:20:30 formulation, indicating that increasing the pumpkin flour proportion and decreasing the MOCAF proportion made the product more reddish. The increase in a* value, which represents the red color component, was mainly influenced by the accumulation of orange-red pigments, especially carotenoids, in pumpkin flour (Gaby and Singh, 2024). Conversely, MOCAF has a relatively neutral color; therefore, reducing its proportion diminished the color dilution effect and further enhanced the redness intensity of the instant porridge. Carotenoids are compounds responsible for yellow, orange, and red colors (Mustika and Kartika, 2020).

Yellowness (b)*

Changes in the proportion of MOCAF: red bean flour:pumpkin flour had a significant effect on b* ($p < 0.05$). The b* value increased from 13.01 in the 70:20:10 formulation to 18.05 in the 50:20:30 formulation, indicating that an increase in the proportion of pumpkin flour and a decrease in the proportion of MOCAF increased the yellow color intensity of the product. The increase in b* value was mainly influenced by the high β-carotene content in pumpkin flour, which is the main carotenoid pigment that contributes to the yellow-orange color in food ingredients (Nurrahman et al., 2024). The presence of β-carotene increases light reflection in the yellow spectrum, thereby increasing the b* value in the instant porridge system. Conversely, MOCAF has a relatively white color and few pigments, so reducing its proportion reduced the color dilution effect. During the drying process, the interaction between reducing sugars and amino compounds in pumpkin and red bean flours occurred via the Maillard reaction. The Maillard reaction produces yellow-to-brown colors in food products (Ohe and Yoshimura, 2020).

Appearance of instant porridge

The appearance of instant porridge products resulting from variations in the proportions of MOCAF, red bean flour, and pumpkin flour is shown in Figure 1. The figure shows visual differences between treatments, reflecting changes in color and product characteristics as the proportion of pumpkin flour increases.

Figure 1 shows changes in the appearance of instant porridge across various formulations of MOCAF, red bean flour, and pumpkin flour. Formulations 70:20:10 and 65:20:15 showed relatively pale to cream colors, while an increase in the proportion of pumpkin flour in 60:20:20, 55:20:25, and 50:20:30 produced increasingly intense yellow to yellow-orange colors. These color changes were associated with the increased carotenoid pigment content in pumpkin flour, particularly β-carotene, which contributed to the product’s yellow-orange color. Conversely, MOCAF has a white base color, so reducing its proportion reduced the color dilution effect and enhanced the final color intensity of the instant porridge. Pumpkin flour is rich in carotenoids, which are pigments that give it a yellow to orange color. An increase in the proportion of pumpkin flour increased carotenoid concentration, resulting in a more intense and brighter product color (Santoso et al., 2024).

In addition to the influence of ingredient composition, the drum-drying process at a surface temperature of 120 °C affected the product’s appearance. Intensive heating can intensify color by increasing pigment concentration and promoting non-enzymatic browning reactions, especially in formulations with higher sugar and amino acid contents. Figure 1 shows that increasing the proportion of pumpkin flour and decreasing MOCAF consistently changed the

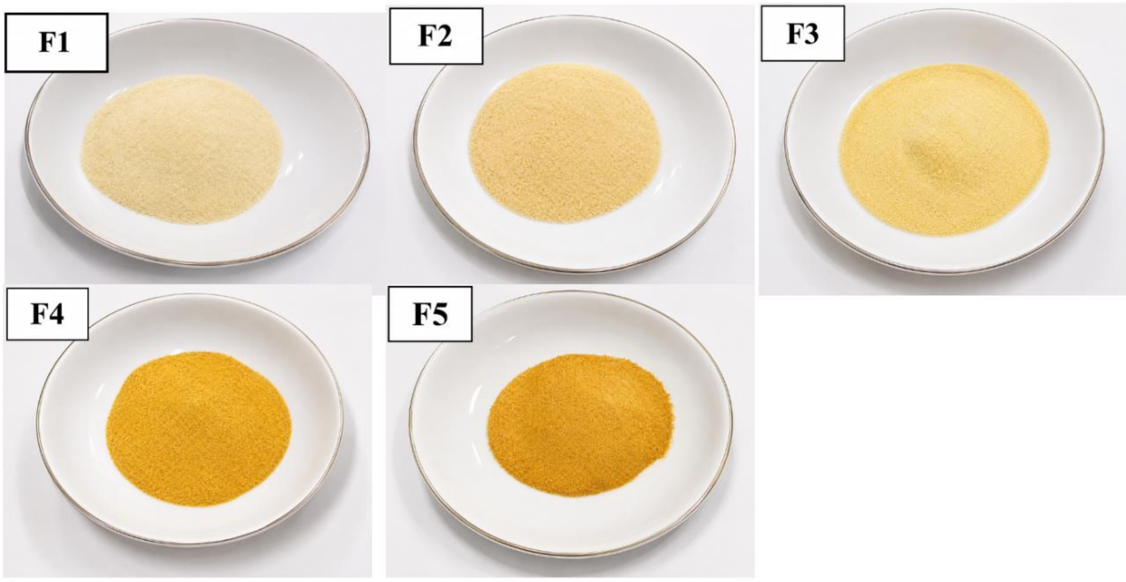

Figure 1. Appearance of instant porridge
Note: F1 = 70:20:10, F2 = 65:20:15, F3 = 60:20:20, F4 = 55:20:25, F5 = 50:20:30

visual appearance of instant porridge, which was consistent with color measurements on the L*, a*, and b* parameters. The Maillard reaction that occurs during pumpkin flour processing can also affect the product's color. However, the addition of acids such as L-ascorbic acid and citric acid can help maintain color by suppressing the intensity of the Maillard reaction and inhibiting carotenoid oxidation (Fan et al., 2023).

Physical properties of instant porridge

The physical properties of instant porridge powder at various proportions of MOCAF, red bean flour, and pumpkin flour are presented in Table 4.

Yield

Table 4 shows that variations in the proportions of MOCAF:red bean flour:pumpkin flour had a significant effect on the yield ($p < 0.05$). The yield values ranged from 69.01 to 76.62%, with the highest value in the 65:20:15 formulation (76.62%) and the lowest in the 50:20:30 formulation (69.01%). The yield decreased as the proportion of pumpkin flour increased and MOCAF decreased. The dominance of MOCAF increased product release during drying due to its starch content, which provides better flow and release properties from the drum surface. Therefore, formulations with a higher proportion of MOCAF produce greater yields. Meanwhile, an increase in pumpkin flour reduced the yield due to the dough stickiness. Batter with higher fiber and sugar content tends to stick more readily to the drum dryer surface (Bekele and Emire, 2023). This resulted in increased material loss during drying and reduced yield of the final product. These findings reflect the general characteristics of each ingredient in instant porridge products (Susilowati et al., 2020).

Water activity

The water activity of instant porridge increased from 0.42 in the formulation with 70% MOCAF, 20% red bean flour, and 10% pumpkin flour to 0.68 in the formulation with 50% MOCAF, 20% red bean flour, and 30% pumpkin flour. This increase indicates that increasing the proportion of pumpkin flour and decreasing the proportion of MOCAF raised the free water availability in the product (Taoukis and

Table 4. Physical properties of instant porridge

MOCAF:red bean flour:pumpkin flour	Yield (%)	Water activity	Bulk density (g ml^{-1})
70:20:10	75.09±3.27^{ab}	0.42±0.00^{c}	0.53±0.01^{e}
65:20:15	76.62±2.50^{a}	0.51±0.01^{c}	0.61±0.05^{d}
60:20:20	73.81±3.71^{b}	0.58±0.04^{b}	0.78±0.00^{c}
55:20:25	70.37±2.56^{c}	0.61±0.08^{b}	0.94±0.04^{b}
50:20:30	69.01±2.79^{c}	0.68±0.00^{a}	1.08±0.07^{a}

Note: All values are presented as mean±standard deviation (SD). Means assigned the same letter in a given column indicate the absence of significant differences ($p < 0.05$)

Richardson, 2020). The increase in water activity was associated with the dietary fiber and sugar content of pumpkin flour, which can bind and retain water within the product matrix. During drum drying at 120 °C, some of the water bound to the fiber fraction was not fully evaporated, thereby increasing the water activity in formulations with a higher proportion of pumpkin flour. Conversely, MOCAF dominated by starch tends to produce a dry structure with lower free water. Although water activity increased, all formulations remained below 0.70, indicating that instant porridge was still stable against microbial growth. Water activity is a key parameter for food stability and safety because it reflects the availability of free water for microbial growth, regardless of the product's total water content (Tapia et al., 2020).

Bulk density

Variations in ingredient proportions had a significant effect on the bulk density ($p < 0.05$). The bulk density increased from 0.53 g ml^{-1} in the 70:20:10 formulation to 1.08 g ml^{-1} in the 50:20:30 formulation. This increase indicates that the instant porridge became denser as the proportion of pumpkin flour increased and the proportion of MOCAF decreased. The increase in bulk density with increasing pumpkin flour proportion is supported by various studies. Pumpkin flour shows a positive correlation with bulk density, including in extrudate products. Increasing the pumpkin flour ratio significantly increases the mass density of the product (Eftekhariyazdi et al., 2025). The increase in bulk density was due to a more compact and heavier particle structure resulting from the high fiber and non-starch carbohydrate content in pumpkin flour. During the drying process, fibrous materials tend to form dense particle aggregates, reducing the formation of air voids and thereby increasing the product's mass density. Conversely, starch-rich MOCAF tends to form a more porous and lighter structure after drying. Products with low bulk density and high porosity, such as freeze-dried materials, exhibit better rehydration capacity because their larger voids facilitate water absorption (Yussof et al., 2025).

Functional properties of instant porridge

The functional properties of instant porridge are presented in Table 5. Significant differences ($p < 0.05$) were observed among the formulations for all measured parameters, indicating that variations in the proportions of MOCAF, red bean flour, and pumpkin flour significantly affected the hydration properties of the developed instant porridge. The changes in WAI, WSI, and swelling power are discussed in relation to the compositional characteristics of the raw materials and their interactions within the product matrix.

Water absorption index (WAI)

Table 5 shows that the combination of MOCAF, red bean flour, and pumpkin flour had a significant effect on the WAI value. Differences in ingredient proportions caused significant changes in WAI values. Formulating 70% MOCAF, 20% red bean flour, and 10% pumpkin flour yielded a WAI of 9.86 g g^{-1}, whereas adjusting the proportions to 50% MOCAF, 20% red bean flour, and 30% pumpkin flour reduced the WAI to 5.76 g g^{-1}. Millet- and legume-based instant porridge formulations showed WAI values of 3.07 to 3.34 g g^{-1} (Kumari et al., 2022). This value is lower than those of formulations based on MOCAF, red bean flour, and pumpkin flour, indicating that ingredient type and component interactions play an important role in determining WAI.

Water solubility index (WSI)

Variations in ingredient composition significantly affected the WSI ($p < 0.05$). The WSI decreased from 11.07% in the 70:20:10 formulation to 7.51% in the 50:20:30 formulation. This reduction in WSI indicates a decrease in the proportion of degraded starch and water-soluble components, which was associated with the reduced proportion of MOCAF. Conversely, the increased incorporation of pumpkin flour, which is rich in dietary fiber, contributed to the lower

Table 5. Functional properties of instant porridge

MOCAF:red bean flour:pumpkin flour	WAI (g g^{-1})	WSI (%)	Swelling power (g g^{-1})
70:20:10	9.86±1.08^{a}	11.07±1.02^{a}	10.98±1.05^{a}
65:20:15	8.65±0.95^{b}	10.82±0.96^{ab}	9.17±0.87^{b}
60:20:20	7.09±0.69^{c}	10.03±0.77^{b}	8.54±0.54^{bc}
55:20:25	6.92±0.85^{c}	9.74±0.45^{bc}	7.08±0.65^{c}
50:20:30	5.76±0.04^{d}	7.51±0.86^{c}	6.11±0.76^{d}

Note: All values are presented as mean±standard deviation (SD). Means assigned the same letter in a given column indicate the absence of significant differences ($p < 0.05$)

solubility of solid components in water. Fiber tends to absorb water but is not soluble, thereby reducing WSI (Otondi et al., 2020).

Swelling power

Variations in ingredient proportions significantly affected swelling power ($p < 0.05$). Swelling power values decreased from 10.98 g g^{-1} in the 70:20:10 formulation to 6.11 g g^{-1} in the 50:20:30 formulation. This decrease was associated with a reduction in the content of starch that expands during rehydration. Formulations with higher proportions of pumpkin flour, which is rich in dietary fiber, form a denser matrix that limits starch granule expansion during rehydration (Ge et al., 2021). The integrity of the starch granule structure plays an important role in its swelling behavior. Starch granules with a more intact outer layer or lower porosity exhibit higher swelling power than those with a damaged or porous outer layer (Zhang et al., 2025).

Bioactive compounds of instant porridge

The bioactive compounds of instant porridge are presented in Table 6. Significant differences ($p < 0.05$) were observed among the formulations for all measured parameters. This indicates that variations in the proportions of MOCAF, red bean flour, and pumpkin flour markedly influenced the antioxidant-related characteristics of the developed instant porridge.

Total phenolic content

As presented in Table 6, changes in ingredient proportions resulted in significant differences ($p < 0.05$) in the total phenolic content. The total phenolic content values increased from 14.62 mg GAE g^{-1} in the 70:20:10 formulation to 23.91 mg GAE g^{-1} in the 50:20:30 formulation, indicating a progressive enhancement with increasing pumpkin flour substitution. This trend suggests that pumpkin flour acted as the primary contributor of phenolic compounds in the formulation system, while red bean flour likely supported the phenolic profile by providing complementary phenolic constituents. The accumulation of phenolic compounds associated with higher pumpkin flour levels was accompanied by an improvement in the antioxidant-related functionality of the instant porridge. Comparable observations have been reported in pumpkin flour-enriched bread, where the incorporation of 20% pumpkin flour significantly increased both total phenolic content and antioxidant activity (Alija et al., 2025). Phenolic compounds are well documented for their biological activities, including antioxidant activity, anti-inflammatory, and anticancer properties (Santos-Buelga et al., 2019).

β-carotene

Variations in ingredient proportions had a significant effect ($p < 0.05$) on the β-carotene content of instant porridge. The β-carotene content increased from 136.83 μg g^{-1} in the 70:20:10 formulation to 189.17 μg g^{-1} in the 50:20:30 formulation (Table 6). This increase reflects the accumulation of carotenoids, especially β-carotene, from pumpkin flour, whose proportion increased. The drum-drying process at 120 °C still retained measurable amounts of β-carotene, so the increase in content was mainly determined by ingredient composition rather than by process degradation. This method helps maintain the product's nutritional quality (Dutta et al., 2006). Enriching food products with β-carotene-rich ingredients, such as pumpkin and orange-fleshed sweet potatoes, significantly increases β-carotene levels. In baked goods, increasing the proportion of orange-fleshed sweet potato puree generally increases β-carotene levels (Kolawole et al., 2020).

Antioxidant activity

Variations in ingredient composition had a significant effect on the antioxidant activity ($p < 0.05$). Antioxidant activity increased from 15.92% in the 70:20:10 formulation to 28.61% in the 50:20:30 formulation. The increase in antioxidant activity corresponded to increases in total phenolics and β-carotene, which act as

Table 6. Bioactive compounds of instant porridge

MOCAF:red bean flour:pumpkin flour	Total phenolic content (mg GAE g^{-1})	β-carotene (μg g^{-1})	Antioxidant activity (%)
70:20:10	14.62±1.08^{e}	136.83±3.91^{e}	15.92±1.01^{e}
65:20:15	17.84±2.75^{d}	148.15±4.86^{d}	19.56±1.42^{d}
60:20:20	19.56±1.54^{c}	159.64±3.04^{c}	23.75±2.05^{c}
55:20:25	21.07±1.80^{b}	176.80±4.64^{b}	26.08±1.43^{b}
50:20:30	23.91±2.75^{a}	189.17±5.80^{a}	28.61±2.91^{a}

Note: All values are presented as mean±standard deviation (SD). Means assigned the same letter in a given column indicate the absence of significant differences ($p < 0.05$)

proton donors and free-radical scavengers. Thus, the increased incorporation of pumpkin flour and the stable proportion of red bean flour synergistically enhanced the product's antioxidant capacity. Processing conditions also play a role, as autoclave time has been shown to affect the antioxidant activity of cassava-based instant porridge, with optimal time yielding the highest activity (Iwansyah et al., 2023). Variations in ingredient ratios caused significant differences in antioxidant content. For example, research on instant porridge formulations with different ratios of Japanese taro flour and purple sweet potato flour showed noticeable differences in antioxidant activity, with the best formulation producing the highest antioxidant activity (Mappiratu et al., 2022).

Microstructure of instant porridge

The microstructure of instant porridge at various proportions of MOCAF, red bean flour, and pumpkin flour is shown in Figure 2. Differences in microstructural characteristics between treatments can be attributed to variations in ingredient proportions in the formulation.

Figure 2 shows that variations in the proportions of MOCAF, red bean flour, and pumpkin flour significantly affected the microstructural characteristics of instant porridge. At a formulation ratio of 70:20:10, the particles exhibited a more compact and dense structure with relatively smooth surfaces and limited porosity. This dense starch matrix likely restricted water penetration during the initial stage of rehydration. The increase in the proportion of pumpkin flour in 65:20:15 and 60:20:20 led to a more irregular microstructure, characterized by inter-starch gaps and a rougher particle surface, allowing water to more easily wet and penetrate the particles during rehydration. The addition of various types of flour can modify the microstructure (Ge et al., 2021). For example, the addition of chayote leaf powder to cassava-based pasta has been reported to reduce particle size and increase the product's swelling power, water solubility, and oil absorption capacity (Lawal et al., 2021).

At a formulation ratio of 55:20:25, the microstructure showed higher porosity and surface roughness while maintaining particle integrity. These structural features facilitated wetting and liquid penetration, thereby enhancing the product's instant properties and sensory acceptance. Conversely, at 50:20:30, with the highest proportion of pumpkin flour, particles tended to form larger, irregular aggregates, which could inhibit uniform water diffusion despite increased porosity. Overall, increasing the proportion of pumpkin flour altered the microstructure of instant porridge, from a dense to a more porous and rougher structure. Indrianingsih et al. (2024) reported that cookies with pumpkin flour added had a more open granular structure. Similarly, the addition of mung bean flour to soba noodles was reported to yield a more compact and uniform network structure with smaller pores, thereby improving the mechanical properties of the gel matrix (Zhou et al., 2024).

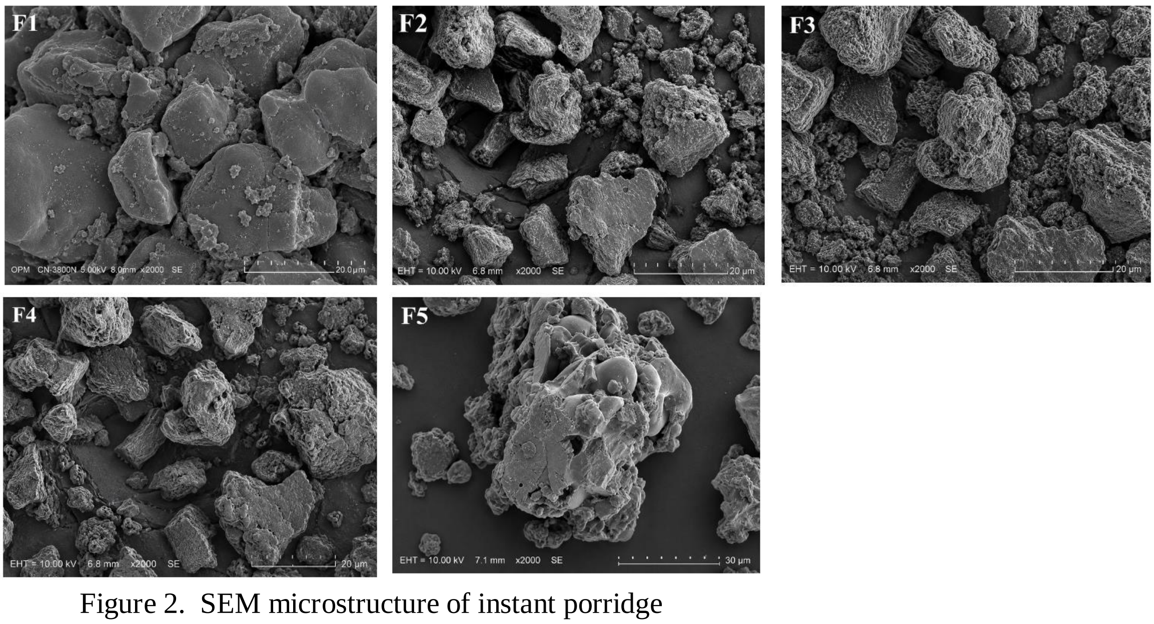

Figure 2. SEM microstructure of instant porridge
Note: F1 = 70:20:10, F2 = 65:20:15, F3 = 60:20:20, F4 = 55:20:25, F5 = 50:20:30

Sensory characteristics of instant porridge

The panelists' preference levels for instant porridge products with varying proportions of MOCAF, red bean flour, and pumpkin flour are presented in Table 7. There were significant differences among treatments ($p < 0.05$) in sensory attributes, indicating that one formulation had the best overall acceptance.

Color

The color preference for instant porridge products increased as the proportion of pumpkin flour increased. The 55:20:25 formulation showed the highest value of 3.90, while the 70:20:10 formulation showed the lowest value of 2.96 (Table 7). The more intense yellow-orange color of instant porridge with a higher proportion of pumpkin flour increased its visual appeal to panelists. This increase is supported by the finding that higher pumpkin flour content enhances the intensity of the yellow-orange color, thereby increasing the product's visual appeal to consumers (Nurminah et al., 2022). Visual appeal is an important factor in consumer preferences; brighter colors are generally preferred (Korzeniowska et al., 2024).

Aroma

Table 7 shows that ingredient variation significantly affected the aroma of instant porridge products. The highest aroma preference score was 3.82 for the 55:20:25 formulation, while the lowest score of 3.07 was observed for the 70:20:10 formulation. The increase in aroma was related to the contribution of volatile compounds from pumpkin and red bean flours during the cooking of instant porridge. The instant porridge formulation containing 35% rice, 25% pumpkin, and 25% tuna showed the best sensory properties, including aroma, as assessed by semi-trained panelists (Sudargo et al., 2023). Another study on instant porridge made from pumpkin flour, skim milk, soy flour, and sucralose for the elderly was developed, with the best formulation showing good sensory properties, including aroma, and was positively accepted by the panelists (Mardiah et al., 2022).

Flavor

Taste preference for instant porridge products increased with the addition of pumpkin flour. The 50:20:30 formulation showed the highest score of 3.96, while the 70:20:10 formulation showed the lowest score of 2.91. A higher proportion of pumpkin flour yielded a sweeter and more distinctive taste, thereby increasing taste acceptance. Research on instant porridge made from brown rice, pumpkin, and mung beans found that the formulation containing 20% pumpkin powder was most preferred in sensory evaluation (Mottan et al., 2024). Pumpkin also positively contributes to the taste and overall acceptance of baby porridge products (Sari et al., 2017).

Viscosity

Treatment variations significantly affected the viscosity preferences for instant porridge products. The 65:20:15 formulation showed the highest value of 3.90. The 50:20:30 formulation showed the lowest viscosity preference of 2.51. The decrease in viscosity preference at high pumpkin flour proportions was due to a reduction in the starch's ability to absorb and expand, leading to a thinner texture in the instant porridge. Porridge with medium viscosity of 2,500 to 3,000 cP is preferred because it is easier to consume (Nansereko et al., 2023). In the development of instant coix seed porridge, extrusion treatment reduced viscosity and improved stability and consumer acceptance, indicating that lower viscosity was preferred by panelists (Duan et al., 2024).

Overall favorability

The balance between sensory attributes influenced overall preference for instant porridge products. The 55:20:25 formulation showed the highest preference rating of 3.77. Meanwhile, the 70:20:10 (3.30) and 50:20:30 (3.08) formulations showed lower overall preference ratings. These

Table 7. Sensory characteristics of instant porridge

MOCAF:red bean flour:pumpkin flour	Color	Aroma	Flavor	Viscosity	Overall favorability
70:20:10	$2.96{\pm}0.91^{c}$	$3.07{\pm}0.04^{c}$	$2.91{\pm}0.01^{c}$	$3.84{\pm}0.87^{a}$	$3.30{\pm}0.84^{c}$
65:20:15	$3.08{\pm}0.74^{c}$	$3.43{\pm}0.51^{b}$	$3.45{\pm}0.76^{b}$	$3.90{\pm}0.09^{a}$	$3.51{\pm}0.67^{bc}$
60:20:20	$3.65{\pm}0.66^{b}$	$3.57{\pm}0.78^{b}$	$3.56{\pm}0.31^{b}$	$3.75{\pm}0.65^{a}$	$3.61{\pm}0.96^{b}$
55:20:25	$3.90{\pm}0.01^{a}$	$3.82{\pm}0.94^{a}$	$3.71{\pm}0.45^{b}$	$3.80{\pm}0.44^{a}$	$3.77{\pm}0.54^{a}$
50:20:30	$3.14{\pm}0.45^{bc}$	$3.17{\pm}0.83^{bc}$	$3.96{\pm}0.05^{a}$	$2.51{\pm}0.67^{b}$	$3.08{\pm}0.88^{c}$

Note: All values are presented as mean±standard deviation (SD). Means assigned the same letter in a given column indicate the absence of significant differences ($p < 0.05$)

results indicate that the balance of color, aroma, taste, and consistency determines panelists' acceptance. Providing a variety of flavors, such as pumpkin, corn, and barley, can satisfy diverse taste preferences and increase overall product acceptance (Lee et al., 2020). Various studies show that formulations containing brown rice, pumpkin, and tuna were well accepted by elderly consumers because they have desirable sensory characteristics (Sudargo et al., 2023). Nurminah et al. (2022) also reported that adding pumpkin flour to cassava and anchovy flour increased panelist acceptance.

Pearson correlation among physicochemical, functional, and sensory characteristics

To provide a more comprehensive interpretation of the relationships among the measured quality attributes, Pearson's correlation analysis was performed, with the results presented in Figure 3. This analysis complemented the one-way ANOVA by providing an integrated interpretation of the relationships among the physicochemical, functional, chemical, and sensory characteristics of instant porridge formulated with different proportions of MOCAF, red bean flour, and pumpkin flour. Overall, the results demonstrated that formulation modifications simultaneously influenced multiple quality attributes, indicating that the quality characteristics of instant porridge were closely interconnected rather than acting independently.

Several notable relationships were observed among the physicochemical and functional properties. Protein content was strongly negatively correlated with carbohydrate content ($r = -0.99$), reflecting the gradual replacement of starch-rich MOCAF with pumpkin flour, thereby altering the nutritional composition of the formulations. WAI exhibited a very strong positive correlation with swelling power ($r = 0.99$), indicating that formulations with greater water absorption capacity also possessed a greater ability for starch granule expansion during rehydration. Conversely, bulk density was negatively correlated with WAI ($r = -0.96$) and swelling power ($r = -0.97$), suggesting that denser powder structures restricted water penetration, thereby reducing hydration and swelling capacities. These relationships indicate that variations in ingredient composition modified the

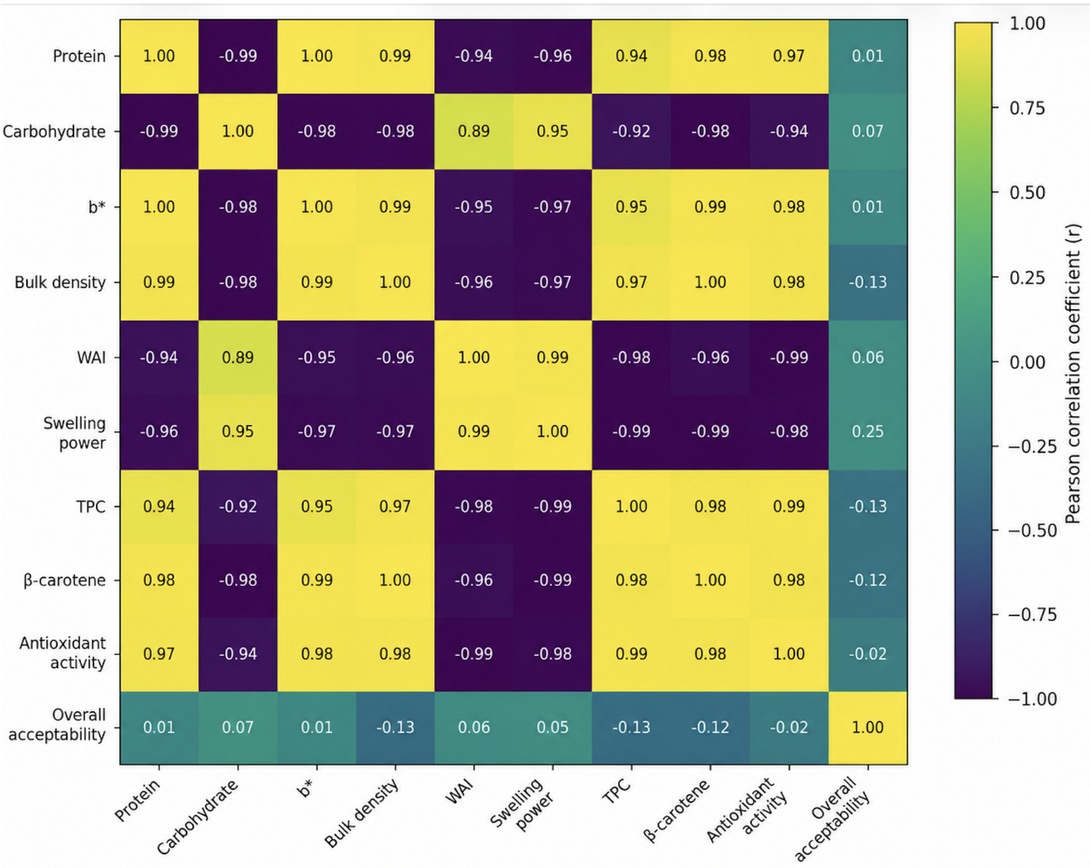

Figure 3. Pearson's correlation among the physicochemical, functional, and sensory characteristics of instant porridge

structural organization of the powder matrix, which subsequently influenced its hydration behavior and reconstitution properties. This is consistent with previous reports describing the effects of starch–fiber interactions on water absorption and swelling characteristics (Ge et al., 2021).

The correlation analysis also revealed close associations among total phenolic content, β-carotene, and antioxidant activity. Total phenolic content was strongly positively correlated with antioxidant activity (r = 0.99), confirming that phenolic compounds substantially contributed to the antioxidant capacity of the developed instant porridge through their hydrogen-donating and free-radical-scavenging activities. Likewise, β-carotene exhibited a very strong positive correlation with yellowness (b*) (r = 0.99), demonstrating that increasing the proportion of pumpkin flour directly enhanced the characteristic yellow-orange color of the product due to its carotenoid pigments (Abedin et al., 2025). Collectively, these findings indicate that pumpkin flour played a major role in improving the antioxidant capacity and color characteristics of the instant porridge by simultaneously increasing β-carotene content, total phenolic content, antioxidant activity, and yellowness (Alija et al., 2025).

In contrast, sensory acceptance exhibited comparatively weaker relationships with the measured physicochemical, functional, and chemical characteristics. Although increasing the proportion of pumpkin flour consistently improved total phenolic content, β-carotene content, and antioxidant activity, these improvements were not accompanied by proportional increases in overall acceptability. Instead, the formulation containing 55% MOCAF, 20% red bean flour, and 25% pumpkin flour achieved the highest overall sensory score despite not exhibiting the highest values of total phenolic content, β-carotene, or antioxidant activity. This finding indicates that consumer acceptance depends on a balanced combination of color, aroma, flavor, texture, and nutritional quality rather than on a single attribute alone, consistent with the principles of sensory perception in food evaluation (Yadav et al., 2024). Therefore, improving the nutritional and functional quality of instant porridge should be accompanied by the maintenance of desirable sensory characteristics to achieve optimal consumer acceptance.

Overall, Pearson’s correlation analysis provided complementary evidence that the physicochemical, functional, chemical, and sensory characteristics of instant porridge were closely interconnected. The analysis demonstrated that optimizing the proportions of MOCAF, red bean flour, and pumpkin flour simultaneously modified compositional, structural, functional, chemical, and sensory attributes. Therefore, formulation development should consider these interdependent quality characteristics to achieve an appropriate balance among nutritional quality, technological functionality, and consumer acceptability.

Study limitations

This study has several limitations that should be acknowledged. First, total dietary fiber was not determined; therefore, its contribution to the functional properties of instant porridge could only be inferred from the formulation composition and previous literature. Second, the shelf-life and storage stability of the developed instant porridge were not evaluated; therefore, changes in physicochemical, functional, bioactive, and sensory characteristics during storage remain unknown. Future studies are recommended to include total dietary fiber determination and shelf-life evaluation to provide a more comprehensive assessment of the nutritional quality, functionality, and storage stability of instant porridge.

CONCLUSIONS

Variations in the proportions of MOCAF, red bean flour, and pumpkin flour significantly affected the physicochemical, functional, and sensory characteristics of instant porridge. MOCAF served as the primary carbohydrate source, red bean flour contributed to protein enrichment, whereas pumpkin flour improved total phenolic content, β-carotene, antioxidant activity, and several quality attributes of the product. Among the formulations evaluated, the 55:20:25 formulation exhibited the best overall balance of nutritional quality, physicochemical and functional properties, and sensory acceptability. These findings provide scientific evidence that the complementary use of locally available ingredients can improve the quality and consumer acceptability of instant porridge while supporting sustainable food diversification. Future studies should evaluate the storage stability and shelf life of the developed instant porridge to support its practical application and commercialization.

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DECLARATION OF GENERATIVE AI USE

Generative AI-assisted tools were used solely to improve the English language, grammar, readability, and formatting of the manuscript, and to enhance the quality of figures, without altering, generating, or manipulating any scientific data or results. All aspects of the research, including the study design, data collection, data analysis, interpretation of results, discussion, conclusions, and final manuscript preparation and revision, were performed, critically evaluated, and approved by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript.

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