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ORIGINAL ARTICLE

Development of instant rice-groundnut porridge flour mix: effect of processing method on functional and nutritional properties

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Abstract

Instant cereal–legume porridges are widely consumed in developing regions, yet limited research exists on optimizing their pasting, nutritional, and antioxidant properties. This study aimed to develop and characterize rice–groundnut–date palm flour mixes as instant porridge formulations. Rice was untreated, malted, pre-gelatinized, and fermented; groundnut was defatted; and date palm flour was prepared using standard protocols. A 4 × 2 × 3 factorial design produced 24 blends plus a control. Pasting characteristics, antioxidant activity and amino acid profile were assessed using visco-amylography, spectrophotometry, and ion exchange chromatography. Results showed that the pasting properties varied significantly ($p < 0.05$), with CU1 exhibiting the highest viscosities, suggesting strong thickening potential, while PU1 recorded the lowest. Processing methods differentially influenced viscosity trends, with untreated/fermented samples decreasing and malted/pre-gelatinized samples increasing with groundnut addition. Amino acid analysis revealed that groundnut markedly improved lysine, methionine, and overall balance, with FU3 and MD3 recording the highest essential and non-essential amino acids, respectively. Antioxidant activity differed significantly ($p < 0.05$); MD1 showed the strongest FRAP (0.95 mmol Fe (II)/100 g) and DPPH scavenging (42.29 mmol Trolox/100 g), alongside high phenolic content (72.55 mg/100 g). Fermentation, malting, and increased groundnut inclusion enhanced the nutritional and antioxidant qualities. The optimized blends demonstrate strong potential as nutrient-dense, instant porridge with improved protein quality and bioactive enrichment.

Keywords Rice · Groundnut · Date palm · Porridge · Pasting · Nutritional

Introduction

Instant cereal-based porridges have attracted growing attention in recent years because of their convenience, quick preparation, and potential to serve as nutritionally balanced meals. Among cereals, rice remains one of the most widely consumed staples worldwide due to its digestibility, energy density, and versatility in food applications (Chen et al. 2022). However, rice alone is deficient in essential amino acids, particularly lysine (Zhu et al. 2025). This limits its nutritional adequacy when consumed as a primary dietary source. To address this shortcoming, rice can be complemented with legumes such as groundnut, which is rich in protein, essential fatty acids, and micronutrients. The inclusion of groundnut not only improves protein quality but also enhances the overall nutritional value of rice-based products, making them suitable for children, adults, and nutritionally vulnerable populations (Yunusa et al. 2022).

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The pasting and nutritional qualities of instant porridge flours are strongly influenced by processing methods such as extrusion, roasting, and drying. Among these, extrusion cooking has been widely applied due to its ability to gelatinize starch, denature proteins, and inactivate anti-nutritional factors, thereby improving digestibility, shelf stability, and consumer acceptability (Chen et al. 2022; Ali et al. 2024).

Although earlier studies have examined rice–cowpea blends (Yogeshwari et al. 2023), broken rice reconstitution (Chen et al. 2022), and sorghum–groundnut porridges (Yunusa et al. 2022), little is known about how different processing methods affect rice–groundnut porridge formulations. Developing an optimized instant rice–groundnut porridge mix could therefore provide a low-cost, nutrient-dense, and shelf-stable option that combines the complementary strengths of cereals and legumes.

In Nigeria, rice–groundnut porridge, commonly known as *kunun shinkafa*, is a popular traditional beverage prepared from rice grits and groundnut, it is often flavored with spices. Traditionally, groundnuts are roasted and wet-milled before mixed with broken rice and boiled into a thick paste. Small quantities of sugar and spices are usually added to improve taste (Zhang et al. 2024). The beverage is widely consumed at home and during social gatherings. It is valued both as a refreshing drink and as a complementary food for infants. Compared with carbonated beverages and other cereal-based drinks, *kunun shinkafa* offers superior nutritional benefits due to its balanced content of macro- and micronutrients (Ndukwe et al. 2023).

Despite its popularity, the traditional preparation of *kunun shinkafa* is labor-intensive, time-consuming, and lacks standardization in both ingredient composition and processing. Recent research has sought to overcome these challenges by either modifying the production process or enriching the nutritional profile through the incorporation of other cereals and legumes. For example, Halilu et al. (2023) developed an instant *kunun shinkafa* powder from rice, groundnut, sesame, and germinated soybean, reporting that groundnut fortification significantly improved protein content. Similarly, Madrigales et al. (2024) used extrusion cooking on malted sorghum and roasted groundnut blends, demonstrating that germination and extrusion enhanced both digestibility and nutrient quality.

Building on these efforts, this study aims to develop an instant *kunun shinkafa* mix flour using defatted groundnut flour, pre-gelatinized, fermented, and malted rice grit, with date palm fruit flour as a natural alternative to refined sugar. This formulation is expected to improve nutrient density by lowering fat content while eliminating added sugars, thereby reducing health risks associated with excessive fat and sugar intake.

Some previous studies have explored cereal-legume blends for instant porridge and modified versions of *kunun shinkafa*. Most of these studies have focused primarily on protein enrichment or single processing techniques such as extrusion or germination without comparison. Limited attention has been given to explore the best processing formulations and methods within a rice–groundnut system, particularly in formulations designed to simultaneously reduce fat content and eliminate refined sugar. Furthermore, the use of defatted groundnut flour and natural sweeteners such as date palm fruit flour in instant *kunun shinkafa* has not been comprehensively investigated.

This study addresses these gaps by developing a nutritionally optimized instant rice–groundnut porridge mix formulated with defatted groundnut flour and differently processed rice grits (pre-gelatinized, fermented, and malted), while incorporating date palm fruit flour as a natural alternative to refined sugar. This study provides new insights into improving the functional, pasting, and nutritional properties of a traditional beverage by integrating processing innovation with health-oriented reformulation. This would advance its potential as a standardized, shelf-stable, and nutrient-dense product suitable for diverse consumer groups. The study offers instant mix with simplify and reproducible preparation that offers consumers a standardized, time saver, convenient, and nutritious beverage that retains the cultural essence of *kunun shinkafa*.

Materials and methods

Materials

FARO (Federal Agricultural Research Oryzae) 67 Rice paddy was purchased from the National Cereal Research Institute, Badeggi, Niger State, Nigeria. Groundnut (Samnut 24) was purchased from the National Agricultural Seed Council, Kano, Nigeria and date palm was purchased from Kure Ultra-Modern Market, Minna, Nigeria.

Methods

Pre-preparation of samples

Rice paddy and groundnut were manually cleaned to remove stones, damaged and discolored grains and other contaminants. This was achieved through winnowing, sieving and hand picking. Subsequently, the grains were packed in plastic buckets and covered for further processing and analysis.

Preparation of rice grits

Rice paddy was cleaned manually to remove damaged grains/extraneous materials and then divided into three portions. One portion was pre-gelatinized, the second was fermented, while the third was malted. Pre-gelatinization was done using the method outlined by Bagirei et al. (2020) with slight modifications. A 3 kg of rice paddy was introduced into a basin containing 10 L of boiling water. The rice paddy was gently stirred into the basin and boiled for 10 min, after which heating was terminated and the paddy was left in the boiled water for 12 h. The water was drained and the rice paddy was dried at 55 °C in a hot air oven until it attained a moisture content of 12%. The rice paddy was then dehusked, winnowed, dry-milled into grits. The dry-milled grits were subsequently packaged in Ziploc bags.

Malting was done using the method described by Ocheme et al. (2018). A 3 kg of cleaned rice paddy was washed with potable tap water and then soaked in 7.5 L of tap water for 24 h. Soaked water was changed every 6 h. At the end of soaking, the water was drained off and the rice paddy was evenly spread on a jute bag and covered with the same material in a dark, secluded area and allowed to germinate for 72 h. Water was sprinkled on the germinating grains at 24-h intervals to prevent drying out. At the end of the germination period, the grains were dried at 55 °C in a hot air oven until it attained a moisture content of 12%. The rootlets were removed by rubbing the grains between the palms. It was then dehusked, winnowed, milled into grits and packaged in Ziploc bags.

Fermentation was done according to the method outlined by Akande et al. (2018) with slight modifications. A 3 kg of rice paddy was washed using tap water and steeped in 7.5 L of water in a covered plastic container for 24 h at ambient temperature. After 24 h of fermentation, the rice paddy was rewashed with clean water, drained and dried at 55 °C in a hot air oven until it attained a moisture content of 12%. It was then dehusked, winnowed, milled into grits and packaged in Ziploc bags.

Preparation of defatted ground nut flour

Defatted groundnut flour was prepared as described by Ocheme et al. (2018) with slight modifications. The nuts were sorted to remove extraneous materials and pretreated for 5 min with a mixture of 5.25% sodium hypochlorite and de-ionized water (1:10 v/v) to control microbial growth. The nuts were then rinsed with de-ionized water (1:3 w/v) and oven dried at 50 °C for 24 h. The nuts were roasted at 140 °C for 6 min, decoated manually and milled in a Ninja blender BL610 (SharkNinja LLC, Needham, U.S.A). The milled ground nut flour was then mixed with food-grade n-hexane at a ratio of 1:10(w/v). The mixture was heated at 60 °C with continuous shaking for 30 min in a water bath, cooled to ambient temperature and centrifuged at 11,000 × g for 25 min at 15 °C. The resulting pellet was air-dried at ambient temperature for 48 h to rid it of solvent odor. It was finally milled and packaged in Ziploc bags.

Preparation of date palm

The date palm fruit was sorted, cleaned, washed, and deseeded before oven dried at 50 °C until it attained a moisture content of ≤12%. It was then dry-milled in a Ninja blender BL610 (SharkNinja LLC, Needham, U.S.A)., sealed in a Ziploc bag and kept at ambient temperatures until it was required for use.

Experimental design (blend formulation)

The experimental design adopted was $4 \times 2 \times 3$ factorial design consisting of four rice samples (untreated, malted, pregelatinized and fermented); two groundnut samples (defatted and undefatted); and three blending ratios for rice, groundnut and date flours (Table 1). Traditional rice-groundnut porridge served as the control. Experimental Design: 4 rice treatments × 2 ground nut treatments × 3 blend ratios $= 24 + 1$ (control) $= 25$ samples.

Determination of the pasting properties The pasting properties were measured using a Brabender visco-amylograph as described by Ocheme et al. (2018). The rice-groundnut porridge slurry was heated progressively at a rate of 2.5 °C/min from 30 to 95 °C. It was then kept at that temperature for 15 min before cooling to 50 °C at the same rate. The amylogram's graduated sheet automatically recorded the pasting performance. The amylograph measurements were used to calculate various parameters, including peak, trough, breakdown, final, setback, peak time, and pasting temperature.

Determination of antioxidant properties

Using the approach of Beta et al. (2005), the ferric reducing antioxidant power (FRAP), radical scavenging activity, flavonoids, phenolics, and tocopherols of the rice-groundnut porridge slurry mix samples were assessed.

Amino acid profile of the mix

Ion Exchange Chromatography (IEC), as reported by Onwuka (2005), was used to determine the samples' amino acid profile. The Technicon sequential multi-sampling amino

Table 1 Treatment combinations as per experimental design for the flour mixes (sample formulations)

Sample code	Description	Ratio blend (rice: groundnut: date palm flour)
CT	Control (traditional *kunu shinkafa*)	1:2
CD1	Untreated rice and defatted groundnuts	70:20:10
CD2	Untreated rice and defatted groundnuts	60:30:10
CD3	Untreated rice and defatted groundnuts	50:40:10
CU1	Untreated rice and undefatted groundnut	70:20:10
CU2	Untreated rice and undefatted groundnut	60:30:10
CU3	Untreated rice and undefatted groundnut	50:40:10
MD1	Malted rice and defatted groundnut	70:20:10
MD2	Malted rice and defatted groundnut	60:30:10
MD3	Malted rice and defatted groundnut	50:40:10
MU1	Malted rice and undefatted groundnut	70:20:10
MU2	Malted rice and undefatted groundnut	60:30:10
MU3	Malted rice and undefatted groundnut	50:40:10
PD1	Pre-gelatinized rice and defatted groundnut	70:20:10
PD2	Pre-gelatinized rice and defatted groundnut	60:30:10
PD3	Pre-gelatinized rice and defatted groundnut	50:40:10
PU1	Pre-gelatinized rice and undefatted groundnut	70:20:10
PU2	Pre-gelatinized rice and undefatted groundnut	60:30:10
PU3	Pre-gelatinized rice and undefatted groundnut	50:40:10
FD1	Fermented rice and defatted groundnut	70:20:10
FD2	Fermented rice and defatted groundnut	60:30:10
FD3	Fermented rice and defatted groundnut	50:40:10
FU1	Fermented rice and undefatted groundnut	70:20:10
FU2	Fermented rice and undefatted groundnut	60:30:10
FU3	Fermented rice and undefatted groundnut	50:40:10

acid analyzer was used to inject the sample after it had been hydrolyzed and evaporated in a rotatory evaporator.

Statistical analyses

All experiments were performed in triplicate. The data collected were subjected to variance analysis using the SPSS version 20.0 statistical package.

Results and discussion

Pasting properties of rice-groundnut-date palm flour mix

Pasting characteristics describe the physicochemical changes that occur when starch-based foods are heated in the presence of water. These changes influence the food's texture, viscosity, utilization, and digestion (Ocheme et al. 2018). Variations in pasting parameters often arise from the relative quantities and interactions of proteins, fats, and starches within the food system. The pasting properties of rice-groundnut-date palm flour mix are presented in Table 2. Generally, the samples exhibited significantly different ($p<0.05$) pasting behaviors, especially for peak, trough, breakdown, final and setback viscosities, and pasting temperature. This is an indication that starch functionality was markedly affected by the processing method and blend ratio. Córdoba-Cerón et al. (2023) also reported the influence of processing method and blend ratio on the pasting properties of corn: rice: cassava flour mixes. .

Increasing groundnut substitution (20–40%) generally reduced peak, trough, final, and setback viscosities (defatted and undefatted series). For undefatted samples, peak viscosity decreased from 726.00 RVU (CU1, 70:20:10) to 207.67 RVU (CU3, 50:40:10), while in the defatted samples it decreased from 448.33 RVU (CD1) to 164.00 RVU (CD3). This reduction may be attributed to starch dilution and interference from groundnut proteins and lipids. Paternina-Contreras et al. (2025) mentioned that the reduction in viscosities could be due to the interactions between starch and protein which restrict the swelling and gelatinization of the starch granules during cooking through increased cross-linking activities. Similar observations were also reported in cereal–legume blends where protein–starch and lipid–starch interactions altered pasting profiles (Ocheme et al. 2018; Chen et al. 2022).

Pre-gelatinized samples (PD and PU series) recorded the lowest overall viscosity values. Peak viscosity ranged from 59.33 to 105.67 RVU (PD series) and 61.00–171.67 RVU (PU series). Pre-gelatinization partially disrupts starch granules during pre-treatment, thereby limiting further swelling and viscosity development upon reheating. Córdoba-Cerón et al. (2023) also observed a gelatinization induced decrease in peak viscosity after extrusion of corn: rice: cassava flour mixtures.

It is interesting to note that within the pre-gelatinized series, increasing groundnut proportion slightly increased viscosity (e.g., PU1: 61.00 RVU to PU3: 171.67 RVU). This suggests structural reorganization and modified starch–protein interactions after pre-treatment. Similar processing-induced structural changes affecting cooking and pasting behavior have been reported in comparative studies on germinated and treated rice systems (Ma et al. 2023).

Fermented samples (FD and FU series) exhibited markedly lower pasting viscosities compared to untreated counterparts (CD and CU groups). Peak viscosity ranged from 151.67 RVU (FD1) to 95.00 RVU (FD3) in the defatted group and from 277.67 RVU (FU1) to 148.33 RVU (FU3) in the undefatted group. The progressive decrease with higher groundnut inclusion could be attributed to combined effects of starch hydrolysis during fermentation and starch dilution.

Table 2 Pasting properties of rice-groundnut-date palm flour mix

Sample	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Peak time (min)	Pasting temp (°c)
CT	$185.00^{f}\pm1.00$	$147.67^{f}\pm1.20$	$37.33^{def}\pm1.33$	$641.00^{f}\pm7.00$	$493.33^{f}\pm5.93$	$6.98^{ab}\pm0.02$	$90.17^{n}\pm0.03$
CD1	$448.33^{c}\pm1.67$	$361.00^{c}\pm3.06$	$87.33^{a}\pm1.45$	$1208.33^{b}\pm2.03$	$847.33^{a}\pm2.19$	$7.00^{a}\pm0.00$	$91.20^{kl}\pm0.12$
CD2	$276.67^{d}\pm1.20$	$211.33^{d}\pm1.20$	$65.33^{b}\pm0.67$	$865.67^{d}\pm6.12$	$654.33^{c}\pm5.04$	$7.00^{a}\pm0.00$	$92.23^{cde}\pm0.07$
CD3	$164.00^{h}\pm1.73$	$124.00^{h}\pm1.00$	$40.00^{cde}\pm1.00$	$554.67^{g}\pm3.28$	$430.67^{g}\pm3.67$	$7.00^{a}\pm0.00$	$92.26^{cd}\pm0.01$
CU1	$726.00^{a}\pm1.00$	$687.67^{a}\pm1.33$	$38.33^{de}\pm0.33$	$1498.33^{a}\pm3.33$	$810.67^{b}\pm4.67$	$7.00^{a}\pm0.00$	$91.75^{fghi}\pm0.53$
CU2	$506.33^{b}\pm1.86$	$469.67^{b}\pm1.76$	$36.67^{efg}\pm0.33$	$1060.33^{c}\pm1.45$	$590.67^{d}\pm2.03$	$7.00^{a}\pm0.00$	$92.90^{a}\pm0.03$
CU3	$207.67^{e}\pm1.33$	$166.00^{e}\pm2.08$	$41.67^{cd}\pm1.45$	$561.00^{g}\pm5.03$	$395.00^{h}\pm3.61$	$7.00^{a}\pm0.00$	$92.67^{ab}\pm0.03$
FD1	$151.67^{jk}\pm1.67$	$118.00^{ik}\pm1.00$	$33.67^{fgh}\pm0.67$	$446.33^{i}\pm4.37$	$328.33^{ij}\pm3.38$	$7.00^{a}\pm0.00$	$90.40^{mn}\pm0.00$
FD2	$115.33^{l}\pm1.20$	$91.00^{l}\pm0.00$	$24.33^{i}\pm1.20$	$305.67^{l}\pm9.94$	$214.67^{l}\pm9.94$	$6.91^{b}\pm0.06$	$91.43^{ijkl}\pm0.03$
FD3	$95.00^{n}\pm1.00$	$81.33^{n}\pm0.88$	$13.67^{kl}\pm0.33$	$253.67^{m}\pm4.37$	$172.33^{m}\pm3.84$	$6.95^{ab}\pm0.02$	$92.93^{a}\pm0.09$
FU1	$277.67^{d}\pm1.33$	$208.00^{d}\pm1.15$	$69.67^{b}\pm1.76$	$767.00^{e}\pm17.35$	$559.00^{e}\pm17.16$	$7.00^{a}\pm0.00$	$91.12^{kl}\pm0.19$
FU2	$156.33^{ij}\pm1.76$	$124.00^{ij}\pm1.15$	$32.33^{gh}\pm0.67$	$387.33^{j}\pm6.36$	$263.33^{k}\pm5.21$	$7.00^{a}\pm0.00$	$91.50^{hijk}\pm0.03$
FU3	$148.33^{k}\pm0.88$	$127.33^{k}\pm0.67$	$22.00^{ij}\pm0.00$	$333.33^{kl}\pm2.33$	$205.33^{l}\pm2.33$	$6.93^{ab}\pm0.00$	$91.71^{ghij}\pm0.00$
PU1	$61.00^{q}\pm1.15$	$51.00^{q}\pm0.58$	$11.00^{l}\pm0.00$	$114.00^{p}\pm0.58$	$62.00^{q}\pm0.00$	$7.00^{a}\pm0.00$	$92.45^{bc}\pm0.08$
PU2	$108.00^{m}\pm1.00$	$90.33^{m}\pm0.67$	$17.67^{jk}\pm0.33$	$223.00^{n}\pm1.15$	$132.67^{n}\pm0.67$	$7.00^{a}\pm0.00$	$92.11^{cdef}\pm0.01$
PU3	$171.67^{g}\pm0.88$	$138.00^{g}\pm0.00$	$33.67^{fgh}\pm0.88$	$360.33^{jk}\pm0.33$	$222.33^{l}\pm0.33$	$7.00^{a}\pm0.00$	$91.32^{kl}\pm0.01$
PD1	$61.67^{q}\pm0.88$	$50.67^{q}\pm0.88$	$11.00^{l}\pm0.00$	$116.00^{p}\pm0.58$	$65.33^{pq}\pm1.33$	$7.00^{a}\pm0.00$	$91.10^{l}\pm0.00$
PD2	$59.33^{q}\pm0.33$	$47.33^{q}\pm0.33$	$12.00^{l}\pm0.58$	$112.33^{p}\pm3.18$	$65.00^{pq}\pm2.89$	$6.98^{ab}\pm0.02$	$91.11^{kl}\pm0.01$
PD3	$105.67^{m}\pm0.33$	$85.33^{m}\pm0.67$	$20.67^{ij}\pm0.67$	$243.67^{mn}\pm5.49$	$162.33^{m}\pm2.33$	$7.00^{a}\pm0.00$	$90.71^{m}\pm0.00$
MU1	$87.33^{o}\pm1.20$	$76.00^{o}\pm3.00$	$14.33^{kl}\pm0.33$	$175.67^{o}\pm2.85$	$91.00^{op}\pm0.58$	$7.00^{a}\pm0.00$	$90.20^{n}\pm0.00$
MU2	$162.33^{hi}\pm1.45$	$130.67^{hi}\pm1.20$	$31.67^{h}\pm0.33$	$387.67^{j}\pm2.96$	$257.00^{k}\pm2.00$	$7.00^{a}\pm0.00$	$90.48^{mn}\pm0.02$
MU3	$213.67^{e}\pm0.67$	$170.33^{e}\pm1.20$	$44.33^{c}\pm0.67$	$514.00^{h}\pm1.15$	$346.00^{i}\pm0.58$	$7.00^{a}\pm0.00$	$90.42^{mn}\pm0.01$
MD1	$74.67^{p}\pm0.88$	$63.33^{p}\pm0.67$	$11.33^{l}\pm0.33$	$157.00^{o}\pm3.06$	$93.67^{o}\pm2.40$	$6.93^{a}\pm0.04$	$92.07^{defg}\pm0.03$
MD2	$110.67^{lm}\pm0.33$	$93.00^{lm}\pm0.58$	$17.67^{jk}\pm0.33$	$270.00^{m}\pm3.79$	$177.00^{m}\pm4.04$	$7.00^{a}\pm0.00$	$91.87^{efgh}\pm0.03$
MD3	$149.00^{k}\pm1.00$	$117.67^{k}\pm1.20$	$31.33^{h}\pm0.33$	$419.33^{i}\pm2.40$	$302.67^{j}\pm0.67$	$7.00^{a}\pm0.00$	$91.35^{jkl}\pm0.03$

Values are means ± SD of triplicate determinations. Means in the same column with different superscripts are significantly different ($p<0.05$)

It could be further explained that fermentation promoted enzymatic degradation of starch molecules. This resulted in the wakening of granule integrity and reduced swelling power. Hence, fermented blends recorded lower final and setback viscosities, which indicate reduced gel-forming ability and lower retrogradation tendency. These findings are consistent with reports that fermentation significantly modifies starch structure and functional properties in cereal-based systems (Ma et al. 2023; Chen et al. 2022).

Malted samples (MD and MU series) showed intermediate viscosity values relative to untreated and fermented samples. In the defatted malted group, peak viscosity increased from 74.67 RVU (MD1) to 149.00 RVU (MD3) with increasing groundnut inclusion. A similar increasing trend was observed in the undefatted malted counterparts (MU1–MU3). Malting activates endogenous enzymes that hydrolyze starch into smaller dextrins and sugars. Although enzymatic hydrolysis typically reduces viscosity (Mashau et al. 2025), the moderate increase observed at higher substitution levels suggest complex interactions between partially hydrolyzed starch fragments and groundnut proteins. Comparable effects of germination (analogous to malting) on cereal functionality have been documented by Ma et al. (2023).

Good thermal and shear stability of the formulations were evident with the relatively low breakdown viscosities (11.00–87.33 RVU) obtained. The highest breakdown was observed in CD1 (87.33 RVU), while pre-gelatinized samples (PD1 and PU1) exhibited the lowest (11.00 RVU). Lower breakdown values indicate resistance to structural disintegration during heating and stirring (Córdoba-Cerón et al. 2023). Good thermal and shear stability is desirable for instant porridge formulations, such as *kunun saki*, that needs to maintain its consistency during preparation and consumption. These results align with findings that processing and protein enrichment can enhance paste stability (Chen et al. 2022; Munoz-Tebar et al. 2024).

Final viscosity is an indication of paste stability after cooling. It was highest in CU1 (1498.33 RVU) and CD1 (1208.33 RVU). This is a reflection of strong thickening and gel-forming capacity in untreated blends with lower groundnut substitution. Conversely, fermented and pre-gelatinized samples showed substantially lower final viscosities, which indicate softer textures.

Setback viscosity, which reflects retrogradation tendency, followed similar patterns. Higher setback values recorded for untreated samples (e.g., CD1: 847.33 RVU) indicated their greater tendencies to retrograde. However, the low setback viscosity values exhibited by fermented and pre-gelatinized samples could indicate their lower susceptibility to staling and enhanced storage stability. Similar trends were reported by Ma et al. (2023) and Munoz-Tebar et al. (2024) on influence of enzymatic and thermal modification on starch retrogradation behavior.

The relatively consistent peak time across all the samples (approximately 7 min) reflects comparable cooking durations despite compositional differences. Pasting temperatures, which ranged from 90.17 °C (CT) to 92.93 °C (FD3), reflect variations in the energy required for starch gelatinization.

In this study, samples such as CU1 and CD1 demonstrated superior pasting properties, with higher peak, final, and setback viscosities, indicating strong thickening and gelling potential. In contrast, PU1 and PD2 exhibited weaker pasting profiles. These may limit their suitability as potential formulations for instant *kunun zaki* which requires high viscosity and gel strength.

The results from this study demonstrate that processing method was the primary determinant of pasting behavior. This was followed by groundnut substitution level and fat status (defatted vs. undefatted). Untreated blends exhibited the highest viscosities and strongest gel structure, while fermentation and pre-gelatinization significantly reduced viscosity and retrogradation tendency. Malting produced intermediate profiles with balanced functionality. The interaction between the processed rice grits, groundnut flour and date palm flour generated a diverse range of viscosity profiles, allowing for the tailoring of porridge texture and consistency. These results corroborate previous studies of Ma et al. (2023) and Munoz-Tebar et al. (2024) which concluded that combination of processing strategies and ingredient optimization can be effectively used to develop nutrient-dense instant porridges with desirable functional characteristics.

Amino acid profile of rice-groundnut-date palm flour mix

The essential and non-essential amino acid profiles of the instant rice–groundnut porridge mix are presented in Tables 3 and 4. The significant ($p < 0.05$) differences observed among the samples indicate that the various processing treatments (fermentation, malting, defatting, pre-gelatinization) and blend ratios significantly influenced both total essential amino acids (TEAA) and total non-essential amino acids (TNEAA).With respect to essential amino acids, fermented–defatted samples exhibited superior TEAA values compared to other treatments. Notably, sample FD3 recorded the highest TEAA value (22.81 mg/g protein). This demonstrates the combined positive effects of fermentation and defatting. This is in line with the findings of Okolie et al. (2023). Similarly, Arya et al. (2025) explained that microbial activity during fermentation hydrolyzes complex storage proteins into simpler, more bioavailable peptides and amino acids, and may also synthesize certain essential amino acids, thus increasing overall TEAA content. The enhanced TEAA in FD3 therefore reflects the synergistic effect of protein concentration (via defatting) and biochemical modification (via fermentation).

In contrast, sample CU1 has the lowest TEAA (4.85 mg/g protein). The sample was the least processed blend with the lowest level of undeffated ground nut flour. The low value of TEAA observed in CU1 may be attributed to the absence of pre-processing steps and relatively high fat content from of undeffated groundnut flour, which dilutes protein concentration. In addition, the absence of preprocessing steps likely permitted the persistence of antinutritional factors capable of binding amino acids and reduce their bioavailability (Fortification, 2025).

Based on groundnut treatment, samples with defatted groundnut shows significantly higher TEAA compared with the undafatted samples. It is thought that the removal of lipid through the defatting process led to concentration of protein and the proportional increase of amino acids. This observation aligns with the findings of Dirr et al. (2025), who reported that fat removal from legumes significantly increases the relative protein proportion and improves the final amino acid profile. Furthermore, the high fat content of undefatted samples may interfere with protein digestibility and reduce amino acid accessibility.

On the impact of mixing ratio, increasing the substitution level of rice flour with groundnut flour generally resulted in higher TEAA values. This is expected because groundnut (a legume) is richer in protein and particularly high in lysine, an essential amino acid typically limiting in cereals such as rice. Sa et al. (2024) also reported similar observation. In this study concluded FD3 emerged as the most nutritional superior sample in terms of TEAA content. This could be a direct result of combined effect of fermentation and defatting preprocessing steps.

For non-essential amino acids, significant differences ($p < 0.05$) were also observed among samples (Table 4). TNEAA values ranged from 9.33 to 26.48 g/100 g protein. The highest TNEAA was recorded in sample MD3 (26.48 g/100 g protein), which was markedly higher than the control sample CT (20.17 g/100 g protein). This substantial increase indicates the effectiveness of malting combined with defatting and higher blend ratios in enhancing non-essential amino acid content. Penaranda (2025) mentioned that enhancing the TNEAA content, particularly through processing, remains a key objective in improving the nutritional value of cereal-legume blends. The superior

Table 3 Essential amino acids profile of rice-groundnut-date palm flour mix (g/100 g protein)

Sample	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Valine	TEAA
CT	$0.74^{def}\pm0.03$	$1.45^{c-f}\pm0.03$	$2.45^{e}\pm0.01$	$2.48^{a}\pm0.00$	$2.54^{d}\pm0.01$	$2.68^{e}\pm0.01$	$2.57^{c}\pm0.02^{c}$	$2.53^{cd}\pm0.02$	$2.76^{b}\pm0.03$	20.2
CD1	$0.77^{cde}\pm0.02$	$0.79^{g-j}\pm0.02$	$1.77^{i}\pm0.00$	$1.67^{d}\pm0.00$	$2.12^{e}\pm0.03$	$1.82^{i}\pm0.00$	$1.58^{j}\pm0.01$	$1.86^{h}\pm0.01$	$1.56^{j}\pm0.01$	13.94
CD2	$0.66^{e-h}\pm0.03$	$0.90^{ghi}\pm0.02$	$2.46^{de}\pm0.01$	$1.85^{c}\pm0.03$	$2.74^{c}\pm0.01$	$2.05^{g}\pm0.01$	$1.77^{h}\pm0.01$	$1.42^{j}\pm0.01$	$1.85^{h}\pm0.01$	15.07
CD3	$0.88^{abc}\pm0.02$	$1.46^{c-f}\pm0.04$	$2.84^{c}\pm0.00$	$1.97^{b}\pm0.00$	$2.88^{b}\pm0.00$	$2.93^{c}\pm0.01$	$1.96^{g}\pm0.00$	$1.99^{g}\pm0.00$	$2.13^{f}\pm0.00$	19.04
CU1	$0.55^{h-k}\pm0.04$	0.34 ± 0.02^{j}	$0.35^{p}\pm0.01$	$0.50^{m}\pm0.00$	$0.43^{o}\pm0.01$	$0.48^{r}\pm0.01$	$0.68^{p}\pm0.01$	$0.73^{p}\pm0.01$	$0.79^{m}\pm0.01$	4.85
CU2	$0.40^{l}\pm0.02$	$0.63^{hij}\pm0.01$	$0.85^{mn}\pm0.02$	$0.88^{ij}\pm0.01$	$0.91^{l}\pm0.02$	$0.93^{p}\pm0.01$	$0.65^{p}\pm0.01$	$0.68^{q}\pm0.01$	$0.69^{n}\pm0.00$	6.16
CU3	$0.55^{h-k}\pm0.02$	$0.77^{g-j}\pm0.02$	$1.30^{k}\pm0.01$	$1.42^{f}\pm0.01$	$1.54^{h}\pm0.02$	$1.64^{j}\pm0.01$	$0.86^{o}\pm0.01$	$0.82^{o}\pm0.01$	$0.75^{m}\pm0.00$	9.65
FD1	$0.65^{f-i}\pm0.01$	$1.45^{c-f}\pm0.03$	$1.48^{j}\pm0.01$	$1.53^{e}\pm0.00$	$1.65^{g}\pm0.01$	$1.58^{k}\pm0.01$	$2.45^{d}\pm0.00$	$2.55^{c}\pm0.01$	$2.62^{c}\pm0.01$	15.96
FD2	$0.71^{ef}\pm0.00$	$1.79^{bc}\pm0.01$	$2.30^{g}\pm0.01$	$1.83^{c}\pm0.00$	$2.54^{d}\pm0.00$	$1.64^{j}\pm0.01$	$3.46^{b}\pm0.01$	$2.63^{b}\pm0.00$	$2.75^{b}\pm0.00$	19.65
FD3	$0.88^{abc}\pm0.00$	$1.56^{b-e}\pm0.42$	$3.15^{b}\pm0.00$	$1.97^{b}\pm0.01$	$3.37^{a}\pm0.00$	$1.82^{i}\pm0.00$	$3.54^{a}\pm0.01$	$3.25^{a}\pm0.00$	$3.27^{a}\pm0.01$	22.81
FU1	$0.54^{ef}\pm0.01$	$0.77^{g-j}\pm0.02$	$0.30^{p}\pm0.01$	$0.42^{n}\pm0.01$	$0.53^{n}\pm0.01$	$1.12^{o}\pm0.00$	$0.46^{q}\pm0.01$	$0.62^{r}\pm0.01$	$0.75^{m}\pm0.00$	5.51
FU2	$0.66^{e-h}\pm0.01$	$0.97^{fgh}\pm0.02$	$1.11^{l}\pm0.00$	$1.45^{f}\pm0.00$	$1.15^{k}\pm0.01$	$1.64^{j}\pm0.01$	$1.25^{k}\pm0.00$	$1.20^{l}\pm0.00$	$1.35^{k}\pm0.00$	10.78
FU3	$0.55^{h-k}\pm0.00$	$1.25^{d-g}\pm0.02$	$0.54^{o}\pm0.04$	$0.63^{l}\pm0.02$	$1.39^{i}\pm0.01$	$1.45^{l}\pm0.00$	$1.66^{i}\pm0.00$	$1.88^{h}\pm0.00$	$1.62^{j}\pm0.01$	10.97
PU1	$0.41^{l}\pm0.03$	$0.35^{j}\pm0.03$	$0.84^{mn}\pm0.01$	$0.88^{ij}\pm0.01$	$0.90^{l}\pm0.01$	$0.93^{p}\pm0.01$	$0.98^{n}\pm0.01$	$0.68^{q}\pm0.01$	$0.69^{n}\pm0.00$	6.66
PU2	$0.55^{h-k}\pm0.02$	$1.44^{c-f}\pm0.02$	$1.84^{i}\pm0.01$	$1.27^{h}\pm0.00$	$1.28^{j}\pm0.00$	$1.93^{h}\pm0.01$	$0.96^{n}\pm0.00$	$0.88^{n}\pm0.00$	$1.35^{k}\pm0.02$	11.5
PU3	$0.63^{f-i}\pm0.02$	$1.55^{b-e}\pm0.03$	$2.35^{fg}\pm0.01$	$1.40^{fg}\pm0.00$	$1.43^{i}\pm0.01$	$2.48^{f}\pm0.00$	$0.65^{p}\pm0.01$	$0.93^{m}\pm0.01$	$1.79^{i}\pm0.01$	13.21
PD1	$0.44^{kl}\pm0.03$	$1.23^{efg}\pm0.03$	$2.00^{h}\pm0.00$	$0.48^{m}\pm0.00$	$1.45^{i}\pm0.01$	$1.35^{n}\pm0.00$	$2.56^{c}\pm0.01$	$1.80^{i}\pm0.00$	$1.78^{i}\pm0.01$	13.09
PD2	$0.57^{g-j}\pm0.02$	$1.48^{cde}\pm0.02$	$2.43^{ef}\pm0.01$	$1.65^{d}\pm0.00$	$1.65^{g}\pm0.01$	$1.38^{mn}\pm0.01$	$2.35^{e}\pm0.01$	$2.37^{e}\pm0.01$	$2.39^{e}\pm0.01$	16.27
PD3	$0.95^{a}\pm0.01$	$1.65^{b-e}\pm0.03$	$2.43^{ef}\pm0.01$	$1.86^{c}\pm0.01$	$2.52^{d}\pm0.01$	$1.55^{k}\pm0.01$	$1.65^{i}\pm0.00$	$2.50^{d}\pm0.00$	$2.54^{d}\pm0.01$	17.65
MU1	$0.54^{ijk}\pm0.04$	$0.46^{ij}\pm0.01$	$0.79^{n}\pm0.01$	$0.75^{k}\pm0.01$	$0.88^{l}\pm0.01$	$0.88^{q}\pm0.00$	$2.35^{e}\pm0.01$	$0.97^{m}\pm0.01$	$0.87^{l}\pm0.01$	8.49
MU2	$0.68^{efg}\pm0.01$	$0.87^{ghi}\pm0.01$	$0.88^{m}\pm0.01$	$0.85^{j}\pm0.01$	$0.86^{l}\pm0.01$	$0.92^{pq}\pm0.01$	$1.25^{k}\pm0.01$	$1.19^{l}\pm0.02$	$1.33^{k}\pm0.01$	8.83
MU3	$0.47^{jkl}\pm0.02$	$0.92^{ghi}\pm0.03$	$1.33^{k}\pm0.01$	$1.36^{g}\pm0.01$	$1.38^{i}\pm0.00$	$1.42^{m}\pm0.01$	$2.05^{f}\pm0.00$	$1.28^{k}\pm0.01$	$1.91^{g}\pm0.00$	12.12
MD1	$0.56^{h-k}\pm0.02$	$1.75^{bcd}\pm0.02$	$2.54^{d}\pm0.04$	$1.63^{d}\pm0.02$	$1.64^{g}\pm0.04$	$2.75^{d}\pm0.00$	$1.54^{j}\pm0.01$	$1.85^{h}\pm0.00$	$1.97^{g}\pm0.01$	16.23
MD2	$0.90^{ab}\pm0.03$	$2.01^{b}\pm0.02$	$3.15^{b}\pm0.00$	$1.87^{c}\pm0.01$	$1.87^{f}\pm0.00$	$3.42^{b}\pm0.00$	$1.16^{n}\pm0.00$	$2.08^{f}\pm0.01$	$2.11^{f}\pm0.00$	18.57
MD3	$0.83^{bcd}\pm0.03$	$4.69^{a}\pm0.01$	$4.71^{a}\pm0.01$	$0.91^{i}\pm0.01$	$0.78^{m}\pm0.01$	$3.82^{a}\pm0.01$	$1.05^{m}\pm0.01$	$1.27^{k}\pm0.01$	$1.34^{k}\pm0.01$	19.04

Values are means ± SD of triplicate determinations. Means in the same column with different superscripts are significantly different ($p<0.05$)

Table 4 Non-essential amino acids profile of rice-groundnut-date palm flour mix (g/100 g protein)

Sample	Arginine	Alanine	Asparagine	Cysteine	Glutamiine	Glycine	Proline	Serline	Tyr	TNEAA
CT	$3.90^{a}\pm0.02$	$3.65^{a}\pm0.02$	$3.66^{a}\pm0.01$	$2.75^{b}\pm0.00$	$2.78^{b}\pm0.01$	$0.83^{k}\pm0.01$	$0.86^{j}\pm0.01$	$0.88^{p}\pm0.01$	$0.86^{k}\pm0.04$	20.17
CD1	$0.80^{p}\pm0.00$	$0.88^{m}\pm0.01$	$0.97^{k}\pm0.01$	$0.97^{l}\pm0.01$	$0.96^{m}\pm0.00$	$0.95^{j}\pm0.00$	$1.22^{gh}\pm0.00$	$1.28^{l}\pm0.01$	$2.35^{hij}\pm0.00$	10.38
CD2	$1.64^{ij}\pm0.01$	$1.56^{g}\pm0.02$	$0.98^{k}\pm0.00$	$1.56^{i}\pm0.01$	$1.55^{i}\pm0.00$	$1.26^{h}\pm0.01$	$1.85^{b}\pm0.04$	$2.01^{d}\pm0.01$	$2.95^{d-g}\pm0.01$	15.36
CD3	$3.22^{b}\pm0.01$	$1.88^{d}\pm0.01$	$1.30^{i}\pm0.00$	$2.24^{d}\pm0.01$	$2.26^{c}\pm0.01$	$1.35^{g}\pm0.01$	$1.49^{e}\pm0.01$	$3.66^{a}\pm0.01$	$3.36^{c-f}\pm0.00$	20.76
CU1	$0.84^{op}\pm0.01$	$0.87^{m}\pm0.01$	$0.99^{k}\pm0.00$	$0.84^{m}\pm0.02$	$0.85^{n}\pm0.00$	$0.65^{l}\pm0.03$	$0.74k\pm0.01$	$1.00^{o}\pm0.00$	$2.55^{ghi}\pm0.00$	9.33
CU2	$0.73^{q}\pm0.01$	$0.79^{n}\pm0.01$	$0.78^{m}\pm0.00$	$0.83^{mn}\pm0.01$	$0.89^{n}\pm0.01$	$1.04^{i}\pm0.01$	$1.25^{g}\pm0.01$	$1.29^{l}\pm0.01$	$1.83^{j}\pm0.51$	9.43
CU3	$2.41^{e}\pm0.01$	$1.77^{e}\pm0.01$	$1.08^{j}\pm0.01$	$1.84^{g}\pm0.04$	$1.98^{d}\pm0.00$	$0.90^{j}\pm0.01$	$0.96^{i}\pm0.01$	$3.05^{c}\pm0.01$	$2.71^{gh}\pm0.01$	16.7
FD1	$1.35^{m}\pm0.00$	$1.97^{c}\pm0.01$	$0.95^{kl}\pm0.00$	$1.66^{h}\pm0.00$	$1.82^{f}\pm0.00$	$1.94^{b}\pm0.01$	$1.35f\pm0.01$	$1.55^{i}\pm0.00$	$3.42^{cde}\pm0.0$	16.01
FD2	$2.45^{de}\pm0.00$	$0.88^{m}\pm0.01$	$2.71^{b}\pm0.02$	$2.68^{c}\pm0.01$	$1.97^{d}\pm0.00$	$0.95^{j}\pm0.00$	$1.22^{gh}\pm0.00$	$1.28^{l}\pm0.01$	$2.55^{ghi}\pm0.00$	16.69
FD3	$1.80^{h}\pm0.00$	$1.88^{d}\pm0.00$	$1.97^{e}\pm0.01$	$2.27^{d}\pm0.01$	$1.87^{e}\pm0.01$	$1.55^{f}\pm0.00$	$1.17^{h}\pm0.01$	$1.28^{l}\pm0.01$	$2.95^{d-g}\pm0.00$	16.74
FU1	$0.80^{p}\pm0.00$	$0.88^{m}\pm0.01$	$0.91^{l}\pm0.00$	$0.77^{n}\pm0.01$	$0.87^{n}\pm0.01$	$1.92^{b}\pm0.00$	$1.35^{f}\pm0.00$	$1.29^{l}\pm0.01$	$3.35^{c-f}\pm0.00$	12.14
FU2	$1.22^{n}\pm0.01$	$1.35^{i}\pm0.00$	$1.27^{i}\pm0.01$	$1.45^{j}\pm0.00$	$1.42^{j}\pm0.00$	$0.84^{k}\pm0.01$	$1.55^{e}\pm0.00$	$1.15^{n}\pm0.00$	$3.66^{bc}\pm0.01$	13.91
FU3	$1.66^{i}\pm0.01$	$1.68^{f}\pm0.01$	$1.83^{f}\pm0.01$	$1.87^{g}\pm0.01$	$1.68^{g}\pm0.01$	$0.95^{j}\pm0.00$	$0.95^{i}\pm0.01$	$1.15^{n}\pm0.00$	$2.87^{e-h}\pm0.01$	14.64
PU1	$0.73^{q}\pm0.01$	$0.79^{n}\pm0.01$	$0.80^{m}\pm0.02$	$0.83^{mn}\pm0.01$	$0.89^{n}\pm0.01$	$1.04^{i}\pm0.01$	$1.25^{g}\pm0.01$	$1.00o\pm0.00$	$2.00^{ij}\pm0.00$	9.33
PU2	$1.60^{jk}\pm0.00$	$0.88^{lm}\pm0.00$	$0.66^{n}\pm0.01$	$1.68^{h}\pm0.00$	$0.78^{o}\pm0.01$	$0.83^{k}\pm0.01$	$0.86^{j}\pm0.01$	$1.30^{l}\pm0.00$	$2.88^{e-h}\pm0.00$	11.47
PU3	$1.84^{h}\pm0.01$	$1.46^{h}\pm0.00$	$1.88^{f}\pm0.00$	$1.84^{g}\pm0.02$	$0.86^{n}\pm0.01$	$0.90^{j}\pm0.01$	$0.96i\pm0.01$	$1.21^{m}\pm0.01$	$3.36^{c-f}\pm0.00$	14.31
PD1	$1.57^{k}\pm0.02$	$1.28^{j}\pm0.01$	$1.30^{i}\pm0.00$	$1.24^{k}\pm0.01$	$1.26^{k}\pm0.01$	$1.35^{g}\pm0.01$	$1.49^{e}\pm0.01$	$1.16^{n}\pm0.01$	$4.11^{ab}\pm0.01$	14.76
PD2	$2.46^{d}\pm0.01$	$0.93^{kl}\pm0.01$	$0.95^{kl}\pm0.00$	$2.05^{f}\pm0.01$	$1.17^{l}\pm0.01$	$1.22^{h}\pm0.01$	$1.34f\pm0.01$	$1.35^{k}\pm0.00$	$3.65^{bc}\pm0.00$	15.12
PD3	$2.58^{c}\pm0.01$	$0.96^{k}\pm0.00$	$1.11^{j}\pm0.02$	$2.75^{b}\pm0.00$	$1.85^{ef}\pm0.00$	$1.92^{b}\pm0.00$	$1.35f\pm0.01$	$1.88^{e}\pm0.00$	$3.89^{bc}\pm0.00$	18.29
MU1	$0.86^{o}\pm0.01$	$0.85^{m}\pm0.01$	$0.77^{m}\pm0.01$	$1.52^{ij}\pm0.01$	$1.59^{h}\pm0.00$	$1.63^{e}\pm0.01$	$1.63^{d}\pm0.01$	$1.42^{j}\pm0.01$	$3.38^{c-f}\pm0.01$	13.65
MU2	$1.36^{m}\pm0.01$	$1.38^{i}\pm0.01$	$1.46^{h}\pm0.01$	$1.53^{i}\pm0.01$	$1.63^{h}\pm0.01$	$1.69^{d}\pm0.00$	$1.74^{c}\pm0.01$	$1.79^{f}\pm0.01$	$3.80^{bc}\pm0.01$	16.38
MU3	$1.92^{g}\pm0.01$	$1.56^{g}\pm0.00$	$2.18^{d}\pm0.01$	$2.04^{f}\pm0.01$	$1.42^{j}\pm0.02$	$1.55^{f}\pm0.00$	$1.35^{f}\pm0.01$	$1.65^{h}\pm0.00$	$2.81^{fgh}\pm0.00$	16.48
MD1	$1.95^{g}\pm0.00$	$1.65^{f}\pm0.00$	$2.27^{c}\pm0.02$	$2.15^{e}\pm0.01$	$1.85^{f}\pm0.01$	$1.76^{c}\pm0.01$	$1.55^{e}\pm0.00$	$1.71^{g}\pm0.01$	$3.52^{cd}\pm0.01$	18.41
MD2	$2.32^{f}\pm0.01$	$2.35^{b}\pm0.01$	$2.71^{b}\pm0.01$	$2.68c\pm0.00$	$1.97^{d}\pm0.00$	$1.94^{b}\pm0.01$	$1.72^{c}\pm0.01$	$3.05^{c}\pm0.00$	$4.66^{a}\pm0.00$	23.4
MD3	$1.45^{l}\pm0.01$	$1.54\ g\pm0.01$	$1.58^{g}\pm0.00$	$3.48^{a}\pm0.00$	$3.57^{a}\pm0.00$	$3.81^{a}\pm0.00$	$3.65^{a}\pm0.00$	$3.25^{b}\pm0.00$	$4.15^{ab}\pm0.00$	26.48

Values are means ± SD of triplicate determinations. Means in the same column with different superscripts are significantly different ($p<0.05$)

performance demonstrated by sample MD3 confirms the recent nutritional research that malting by activates endogenous proteases that break down storage proteins into smaller peptides and free amino acids, thereby increasing amino acid concentration and bioavailability (Hager, 2022; Penaranda, 2025). This same sample (MD3) also recorded the highest values for cysteine (3.48 g/100 g), glutamine (3.57 g/100 g), glycine (3.81 g/100 g) and proline (3.65 g/100 g). These evidenced MD3 as the most nutritionally optimized mixes in terms of TNEAA.

Conversely, the lowest TNEAA values were observed in CU1 and PU1 samples (9.33 g/100 g), representing less than half of the control value. The poor performance of CU1 may be attributed to the absence of effective processing and lower inclusion of groundnut flour. In the case of PU1, pre-gelatinization appears less effective in promoting protein hydrolysis compared to fermentation or malting. Additionally, the use of undefatted groundnut likely contributed to reduced protein concentration due to higher lipid content, resulting in lower overall TNEAA.

Table 5 Ferric reducing and radical scavenging antioxidant properties of rice-groundnut-date palm flour mix (mg/100 g)

Sample	Ferric reducing antioxidant properties (FRAP) mmol Fe (II) equivalents/100 g sample	DPPH radical scavenging activity mmolTrolox equivalents/100 g sample
CT	$0.18^{jkl} \pm 0.02$	$35.63^{a-d} \pm 0.01$
CD1	$0.19^{jkl} \pm 0.01$	$35.86^{a-d} \pm 0.01$
CD2	$0.22^{ijk} \pm 0.01$	$36.77^{abc} \pm 0.02$
CD3	$0.26^{hi} \pm 0.01$	$36.84^{ab} \pm 0.02$
CU1	$0.26^{hi} \pm 0.01$	$37.35^{ab} \pm 0.01$
CU2	$0.28^{ghi} \pm 0.01$	$31.15^{b-f} \pm 0.00$
CU3	$0.25^{ij} \pm 0.02$	$33.95^{b-f} \pm 0.00$
FD1	$0.26^{hi} \pm 0.01$	$34.84^{a-d} \pm 0.00$
FD2	$0.23^{ij} \pm 0.02$	$29.55^{b-f} \pm 0.00$
FD3	$0.34^{fg} \pm 0.01$	$27.95^{def} \pm 0.00$
FU1	$0.36^{f} \pm 0.03$	$26.23^{ef} \pm 0.02$
FU2	$0.32^{fgh} \pm 0.02$	$29.55^{b-f} \pm 0.00$
FU3	$0.15^{l} \pm 0.00$	$29.65^{b-f} \pm 0.00$
PU3	$0.15^{kl} \pm 0.00$	$30.00^{b-f} \pm 0.00$
PU2	$0.16^{kl} \pm 0.02$	$26.25^{ef} \pm 0.00$
PU1	$0.56^{bcd} \pm 0.01$	$25.98^{f} \pm 0.00$
PD3	$0.55^{cd} \pm 0.01$	$27.85^{def} \pm 0.00$
PD2	$0.54^{d} \pm 0.01$	$34.55^{a-d} \pm 5.00$
PD1	$0.47^{e} \pm 0.02$	$34.25^{a-e} \pm 5.00$
MU3	$0.46^{e} \pm 0.01$	$30.20^{b-f} \pm 0.00$
MU2	$0.45^{e} \pm 0.02$	$26.00^{f} \pm 0.00$
MU1	$0.63^{b} \pm 0.01$	$28.65^{c-f} \pm 0.00$
MD3	$0.62^{bc} \pm 0.01$	$29.23^{b-f} \pm 0.00$
MD2	$0.63^{b} \pm 0.00$	$28.32^{def} \pm 0.00$
MD1	$0.95^{a} \pm 0.02$	$42.29^{a} \pm 0.03$

Values are means ± SD of triplicate determinations. Means in the same column with different superscripts are significantly different ($p < 0.05$)

The control sample (CT) showed relatively high levels of arginine (3.90 g/100 g), alanine (3.65 g/100 g), and asparagine (3.66 g/100 g). This reflects the inherent amino acid composition of the raw materials. However, the preprocessing steps (fermentation and malting) proved more effective in enhancing both essential and non-essential amino acid profiles. Overall, the study demonstrates that combining fermentation or malting with defatting and optimized blend ratios significantly improves the amino acid quality of rice–groundnut composite flour formulations.

Ferric reducing and radical scavenging antioxidant properties of rice-groundnut-date palm flour mix

The antioxidant properties (ferric reducing antioxidant power (FRAP) and DPPH radical scavenging activities) of the rice-groundnut-date palm flour mixes are presented in Table 5. Significant differences ($p < 0.05$) were observed among the samples, an indication that both processing methods and formulation ratios influenced antioxidant capacity. The FRAP values ranged from 0.15 mmol Fe (II) equivalents/100 g in samples FU3 and PU3 to a high value of 0.95 mmol Fe (II) equivalents/100 g in sample MD1. The highest value recorded in MD1 indicates that the malted sample possessed the most potent ferric reducing ability among all blends. This is in line with the findings of Sejpal et al. (2024) on the rich antioxidant profile of date palm (*Phoenix dactylifera* L.). Notably, the malted samples (MU1, MD1–MD3) exhibited markedly higher FRAP values (0.62–0.95 mmol Fe (II)/100 g) compared to fermented and control samples. This suggests that malting process enhanced the bioavailability or activity of reducing compounds (Murungweni et al. 2024) possibly through enzymatic hydrolysis and release of bound phenolics. In addition, the inclusion of date palm, known for its rich antioxidant constituents, may have contributed to the observed reducing power (Sejpal et al., 2024). Pre-gelatinized–defatted samples (PD1–PD3) and pregelatinized sample with the lowest inclusion of undeffated groundnut (PU1) also showed relatively high FRAP values (0.47–0.55 and 0.56 mmol Fe (II)/100 g, respectively). The high values obtained suggest the shielding effect of lipids on antioxidants compounds were reduced. Conversely, lower FRAP values in FU3, PU2, and PU3 (0.15–0.16 mmol Fe (II)/100 g) indicate that fermentation or pre-gelatinization alone, without defatting or optimal blend ratio, may not sufficiently enhance ferric reducing potential. For radical scavenging activity, the DPPH values ranged from 25.98 mmol Trolox equivalents/100 g (PU1) to 42.29 mmol Trolox equivalents/100 g (MD1). Similar to the FRAP resultsMD1 samples again showed superior performance with the highest DPPH radical scavenging activity.

Table 6 Bioactive compounds of rice-groundnut-date palm flour mix (mg/100 g)

Sample	Flavonoids	Phenolics	Tocopherols
CT	$2.15^{j}\pm0.00$	$39.39^{b}\pm0.07$	$0.63^{abc}\pm0.01$
CD1	$2.00^{k}\pm0.00$	$34.92^{c}\pm0.01$	$0.65^{abc}\pm0.00$
CD2	$1.95^{l}\pm0.00$	$34.88^{c}\pm0.02$	$0.82^{ab}\pm0.00$
CD3	$2.00^{k}\pm0.00$	$25.04^{l}\pm0.02$	$0.55^{abc}\pm0.00$
CU1	$1.66^{o}\pm0.01$	$26.04^{k}\pm0.02$	$0.60^{abc}\pm0.01$
CU2	$1.89^{m}\pm0.01$	$29.64^{gh}\pm0.03$	$0.77^{ab}\pm0.02$
CU3	$2.00^{k}\pm0.00$	$23.10^{n}\pm0.00$	$0.87^{ab}\pm0.01$
FD1	$1.56^{p}\pm0.01$	$24.23^{m}\pm0.03$	$0.95^{a}\pm0.00$
FD2	$1.77^{n}\pm0.00$	$24.97^{l}\pm0.02$	$0.51^{abc}\pm0.01$
FD3	$2.00^{k}\pm0.00$	$28.69^{i}\pm0.02$	$0.57^{abc}\pm0.02$
FU1	$2.00^{k}\pm0.00$	$30.41^{f}\pm0.02$	$0.62^{abc}\pm0.02$
FU2	$2.00^{k}\pm0.00$	$33.91^{d}\pm0.02$	$0.63^{abc}\pm0.01$
FU3	$6.12^{e}\pm0.00$	$28.68^{i}\pm0.01$	$0.68^{abc}\pm0.03$
PU3	$2.15^{j}\pm0.00$	$29.50^{gh}\pm0.43$	$0.85^{ab}\pm0.00$
PU2	$2.15^{j}\pm0.00$	$29.39^{h}\pm0.06$	$0.63^{abc}\pm0.01$
PU1	$6.25^{c}\pm0.01$	$32.26^{e}\pm0.06$	$0.95^{a}\pm0.01$
PD3	$6.22^{c}\pm0.01$	$32.19^{e}\pm0.00$	$0.56^{abc}\pm0.01$
PD2	$5.36^{g}\pm0.01$	$32.22^{e}\pm0.00$	$0.83^{ab}\pm0.01$
PD1	$2.68^{i}\pm0.01$	$25.14^{l}\pm0.03$	$0.78^{ab}\pm0.01$
MU3	$3.33^{h}\pm0.01$	$25.33^{l}\pm0.01$	$0.81^{ab}\pm0.01$
MU2	$6.76^{a}\pm0.01$	$27.12^{j}\pm0.00$	$0.89^{ab}\pm0.01$
MU1	$6.33^{b}\pm0.00$	$28.65^{i}\pm0.00$	$0.72^{abc}\pm0.01$
MD3	$6.00^{f}\pm0.00$	$30.00^{fg}\pm0.00$	$0.72^{abc}\pm0.02$
MD2	$6.00^{f}\pm0.00$	$29.72^{gh}\pm0.00$	$0.43^{bc}\pm0.40$
MD1	$6.15^{d}\pm0.00$	$72.55^{a}\pm0.00$	$0.27^{c}\pm0.01$

Values are means ± SD of triplicate determinations. Means in the same column with different superscripts are significantly different ($p<0.05$)

The MD1 formulation emerged as the most promising among all, demonstrating the highest values for both FRAP and DPPH assays. This indicates a synergistic effect between the malting process and optimized blend ratio, which possibly increased phenolic release and improved hydrogen-donating capacity. However, the relationship between FRAP and DPPH was not strictly linear across all samples. For instance, PU1 showed relatively high FRAP (0.56 mmol Fe (II)/100 g) but recorded one of the lowest DPPH values (25.98 mmol Trolox equivalents/100 g). It may be that different antioxidant compounds or mechanisms are involved in electron transfer (FRAP) versus radical scavenging (DPPH) assays.

In this study, MD1 emerged as the most promising formulation in terms of antioxidant potential, it exhibited the highest values in both FRAP and DPPH assays. This indicates a strong synergistic interaction between malting, defatting, and ingredient proportion in enhancing antioxidant activity. The findings support previous reports that optimized composite flour formulations can significantly improve antioxidant properties through appropriate processing strategies (Murungweni et al. 2024; Sejpal et al., 2024).

Bioactive compounds of rice-groundnut-date palm flour mix

The bioactive composition of the rice–groundnut–date palm flour mixes (Table 6) varied significantly ($p<0.05$) across blends. This is an indication that both processing method and blend ratio could influence the concentration of health promoting phytochemicals when the processes and blend ratio are carefully selected and optimized. A recent study has also demonstrated that the formulation of composite flours can be optimized to enhance specific bioactive compounds, leading to improved antioxidant and anti-inflammatory properties (Udeh et al. 2024).

The flavonoid content of the samples ranged from 1.56 mg/100 g to 6.76 mg/100 g. The lowest value was recorded in FD1 (1.56 mg/100 g), while the highest was observed in MU2 (6.76 mg/100 g). This was closely followed by MU1 (6.33 mg/100 g), PU1 (6.25 mg/100 g), PD3 (6.22 mg/100 g), MD1 (6.15 mg/100 g), FU3 (6.12 mg/100 g), and MD2/MD3 (6.00 mg/100 g). Malted samples consistently exhibited elevated flavonoid levels compared to the control (CT: 2.15 mg/100 g). This implies that malting enhanced flavonoid extractability. It may be that malting worked by aiding the enzymatic degradation of cell wall matrices and subsequent release of bound phenolic compounds. Udeh et al. (2024) also observed that optimization of optimization of cereal-legume composite formulations can significantly enhance flavonoid concentration and antioxidant potential. The high flavonoid content in PU1 and PD3 further indicates that pre-gelatinization combined with appropriate blend ratios may also improve flavonoid retention or release. Adebo (2025) reported that legumes are naturally rich in flavonoids and can substantially contribute to the phytochemical profile of composite flours. Therefore, increasing groundnut proportion in the blends likely contributed to the elevated flavonoid levels observed in several treated samples.

Phenolic content varied widely, from 23.10 mg/100 g (CU3) to 72.55 mg/100 g (MD1). Sample MD1 showed a remarkably high phenolic content (72.55 mg/100 g). This reinforces the strong influence of malting combined with defatting and optimal blend ratio to enhance availability of bioactive compounds, including phenols. It is known that malting activates endogenous enzymes such as β-glucosidase and esterase. These enzymes hydrolyze bound phenolic compounds leading to increase in their extractability and measurable concentration. Udeh et al. (2024) also reported composite flour optimization can significantly enhance phenolic content and antioxidant capacity.

Tocopherol content ranged from 0.27 to 0.95 mg/100 g. The highest tocopherol values in FD1 and PU1 may be attributed to better retention of lipid-soluble components in these formulations. Since tocopherols are fat-soluble antioxidants, processing methods that preserve lipid fractions or prevent oxidative degradation may enhance their retention. Although variations in tocopherol were less pronounced compared to flavonoids and phenolics, PU1 and FD1 clearly emerged as the most effective formulations for tocopherol enrichment.

The results from this study showed that strategic formulation and processing can significantly influence the bioactive profile of rice–groundnut–date palm composite flour. Malted samples, particularly MD1, were most effective in phenolic enhancement and correspondingly exhibited superior antioxidant capacity. MU, and some PU and PD samples showed pronounced flavonoid enrichment, while PU1 and FD1 stood out for tocopherol retention. These findings highlight the potential of combining appropriate bioprocessing techniques with optimized blend ratios to develop functional composite flours, such as instant *kunun saki*, with enhanced nutritional and health-promoting properties (Udeh et al. 2024; Adebo 2025).

Conclusion

This study comprehensively evaluated the pasting, physicochemical, antioxidant, amino acid, and bioactive properties of instant rice–groundnut porridge mixes formulated with untreated, malted, pre-gelatinized, and fermented rice, in combination with defatted groundnut flour and date palm flour. The factorial design revealed that both processing methods and blend ratios significantly ($p < 0.05$) influenced studied properties of the blends.

Pasting properties varied significantly ($p < 0.05$) among samples, with rice processing methods playing a decisive role in the functional performance exhibited. Untreated control blend (CU1) displayed the highest peak, trough, final, and setback viscosities, indicating strong thickening and gel-forming ability, while pre-gelatinized samples exhibited lower viscosities and enhanced dispersibility.

Nutritional analysis showed that groundnut inclusion markedly improved the essential amino acid profile, particularly lysine, methionine, and tryptophan, with several formulations meeting or surpassing FAO/WHO requirements. Fermentation and malting processes further enriched the amino acid balance, offering superior protein quality.

Antioxidant evaluation revealed substantial variation among blends. Malted and fermented blends (notably MD1) exhibited highest ferric reducing power, radical scavenging activity, and phenolic enrichment. This indicates a superior antioxidant potential. This enhanced activity demonstrates a strong relationship between phenolic enrichment and antioxidant performance. Malted samples generally showed elevated flavonoid levels, with MU2 recording the highest flavonoid content (6.76 mg/100 g), while PU1 and FD1 were most effective for tocopherol retention (0.95 mg/100 g). These results confirm that appropriate processing strategies can selectively enhance specific bioactive compounds.

The integration of groundnut and date palm flour with processed rice significantly improved the nutritional, and bioactive profiles of the instant porridge mixes compared to traditional formulations. Fermentation and malting consistently impart better quality, enhancing protein availability, antioxidant potential, and properties as shown with their pasting behaviors. These findings underscore the potential of rice–groundnut–date palm flour blends as affordable, nutrient-dense, and convenient instant porridge formulations suitable for dietary diversification and combating protein–energy malnutrition.

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Author contributions Each author declares substantial contributions through the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content.

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Data availability All data and material that are not included in the manuscript and are part of the research work are available on request.

Declarations

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

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