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EFFECT OF PROCESSING TECHNIQUES (FERMENTATION, GERMINATION, ROASTING AND SOAKING) ON THE PROXIMATE COMPOSITION, MINERAL, VITAMIN, ANTIOXIDANT AND SENSORY PROPERTIES OF SORGHUM–QUINOA PORRIDGE

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Abstract

Gluten-free grains such as sorghum and quinoa are drawing renewed attention from breakfast-food manufacturers, largely because refined-cereal porridges tend to fall short on both micronutrient density and satiety. But raw grain rarely performs as well as processed grain, and how it is processed matters a great deal. This study set out to find which of four common treatments – fermentation, germination, roasting and soaking – does the most for a sorghum-quinoa porridge, judged against raw sorghum-quinoa porridge and an ordinary wheat porridge as benchmarks. Six batches (T0–T5) were prepared and analysed in triplicate for proximate composition, minerals, amino acids, vitamins, colour and pH, water absorption and bulk density, anti-nutritional load, antioxidant capacity, and sensory acceptance; differences among treatments were tested by one-way ANOVA. Fermentation pulled moisture down to 3.21% and produced the densest mineral profile of any treatment – calcium at 40.3 mg/100 g, magnesium at 199.5, iron at 4.32 and potassium at 501.7 mg/100 g – along with the strongest radical-scavenging activity (69.5% DPPH inhibition). Germination told a different story: protein climbed to 12.64%, phenolic content reached 44.56 mg GAE/g, and thiamine, pyridoxine and vitamin E all peaked here too. Both processed treatments also cut tannin and saponin levels well below what raw sorghum-quinoa carried. Colour shifted predictably with heat and fermentation – L, a* and b* all moved in step with processing intensity. Where the results got interesting was sensory scoring: panellists rated germinated and roasted porridge highest on taste and smell, yet overall preference still went to the plain wheat control, at 8.9 out of 9. Fermentation and germination come out as the two processes worth pursuing further for a nutrient-dense, gluten-free porridge, though closing the gap between what the science says and what people actually prefer remains the harder problem.*

INTRODUCTION

Breakfast has a disproportionate influence on how a day's diet turns out. People who eat it regularly tend to carry a lower body mass index, show better cardiovascular markers and perform better on cognitive tasks (Croisier et al., 2021), which is one reason food scientists keep returning to the breakfast-cereal category even though it looks, on the surface, like a solved problem. Cereals split roughly into two camps: "ready-to-eat" products eaten straight from the box, and "hot" cereals such as porridge that need cooking (Lewis et al., 2021).

Porridge in particular has stayed popular across almost every age group, from weaning infants to the elderly, mostly because it is cheap, easy to digest and forgiving to prepare (Goyat et al., 2019). There is also a growing clinical case for it regular porridge consumption has been linked to improved lipid profiles and reduced inflammatory markers in people with metabolic syndrome components (Mišan et al., 2017), and in animal studies a multigrain version even showed hepatoprotective effects (Olagunju, 2022).

Two grains keep coming up in the functional-breakfast literature: quinoa, a pseudocereal, and sorghum, a true cereal. Both are gluten-free, both are nutritionally dense relative to wheat, and that combination has made them attractive for coeliac and gluten-intolerant consumers in particular (Graziano et al., 2022). Sorghum (Sorghum bicolor L. Moench) has deep roots in north-eastern Africa and today feeds somewhere between 500 and 750 million people across the semi-arid tropics of Africa, Asia and South America. It digests slowly, carries a useful spread of micronutrients and bioactive compounds, and has been studied as a dietary tool for obesity and diabetes management (Sharanagat et al., 2023). Its bran is where most of the phenolic content concentrates — up to six times higher than in the whole grain — which is largely why sorghum keeps being proposed as a functional ingredient for chronic-disease risk reduction (Birhanu, 2021).

Quinoa (Chenopodium quinoa Willd.) brings something different to the table. Native to the Andes, it is naturally gluten-free and its protein content, 13–17% depending on variety, includes lysine and methionine in proportions that most plant foods lack (Väkeväinen et al., 2020). It is also rich in omega-3 and omega-6 fatty acids, vitamin E, iron, zinc, manganese and copper, and in parts of China it is already eaten as a whole-grain porridge (Zhang et al., 2019). When sorghum and quinoa flours are blended, the resulting product tends to outperform either grain alone on protein quality and antioxidant capacity — the two seem to complement each other's nutrient and phytochemical gaps (Martinez et al., 2020).

None of this potential is fixed, though — how the grain is processed changes almost everything downstream. Fermentation lowers phytate and, in doing so, frees up iron, zinc and calcium for absorption, while also releasing phenolics that were previously bound and therefore biologically inactive (Lazarte et al., 2021). Roasting works differently: it reshapes the grain's morphology and thermal behaviour, and in quinoa, roasting at 190°C for half an hour has been shown to produce the highest antioxidant activity of any tested condition (Kheto et al., 2022). Germination switches on hydrolytic enzymes, which both raises amino-acid bioavailability and strips out anti-nutrients like phytate, tannin and trypsin inhibitors (Sharanagat et al., 2022). Soaking is the gentlest of the four — it softens the grain, activates amylolytic enzymes and reduces phytic acid, improving digestibility without the energy input the other methods require (Rajabi Dehnavi et al., 2020). Put together, these four routes offer genuinely different ways of reshaping the same starting material (Sharma et al., 2022), but almost nothing in the literature compares them head-to-head on the same sorghum-quinoa base.

That comparison is what this study attempts. Six porridge treatments — raw, fermented, germinated, roasted and soaked sorghum-quinoa, plus a wheat-porridge control — were prepared and evaluated across nutritional, physicochemical, functional and sensory dimensions, with three specific aims in mind: to compare how each processing method performs against the others; to work out, from the nutritional and textural data together, which method is most worth adopting; and to check whether consumer sensory response actually tracks the nutritional improvements, or diverges from them.

Aims and Objectives

The specific objectives this study worked toward were:

- Comparing fermentation, germination, roasting and soaking as processing routes for sorghum-quinoa porridge
- Using sensory, nutritional and physicochemical data together to identify the most effective processing method
- Assessing how well consumer preference lines up with the nutritional gains measured in the laboratory

2. Material and Methods

This work was carried out across the Food Processing and Preservation Lab, the Food Technology Lab and the Food Analytical Lab in the Department of Food Science and Technology at Government College Women University, Faisalabad (GCWUF), and was built around a straightforward comparison: six porridge treatments, prepared under standardised conditions, then run through an identical battery of analyses.

2.1. Procurement of raw materials

Sorghum and quinoa grains were sourced from the local Faisalabad market and screened by hand to exclude anything with visible insect damage, foreign material or other defects before processing began.

2.2. Sample preparation and porridge treatments

After cleaning to remove dust and debris, the grains were divided into batches and processed four different ways — roasting (following Sharanagat et al., 2019), fermentation (Ewuoso et al., 2020), germination (Arouna et al., 2020) and soaking — with salt, brown sugar and milk added during porridge preparation for all treatments. The full treatment structure is set out in Table 1.

Table 1: Treatment structure for the formulation of sorghum-quinoa porridge

Treatment	Description
T0 (–ve control)	Wheat porridge
T1 (+ve control)	Raw sorghum and quinoa porridge
T2	Fermented sorghum and quinoa porridge
T3	Germinated sorghum and quinoa porridge
T4	Roasted sorghum and quinoa porridge
T5	Soaked sorghum and quinoa porridge

2.3. Compositional (proximate) analysis

Moisture, fat, protein, ash, fibre and carbohydrate were all determined in triplicate using AOAC (2019) methods: oven-drying to constant weight for moisture, Kjeldahl for protein (N × 6.25), Soxhlet extraction with hexane for fat, acid-alkali digestion for crude fibre, and dry ashing at 550±5°C for 3–5 hours for ash. Carbohydrate was obtained by difference, and total caloric value calculated from the Atwater factors as applied by Kim and Kang (2023).

2.4. Mineral and amino-acid analysis

Calcium, magnesium, iron, potassium and zinc were quantified by flame atomic absorption spectrometry after wet digestion in $H_2SO_4/H_2O_2/HNO_3$, following Zhang et al. (2022). Amino-acid composition — lysine, methionine, valine, leucine and iso-leucine — was determined by HPLC after acid hydrolysis and PITC derivatisation, following the method described by Umokaso et al. (2022).

2.5. pH, colour and vitamin analysis

pH was read from a 1:9 sample-to-water slurry with a calibrated meter (Mayachiew et al., 2015), and colour was measured on a laboratory colorimeter and reported as L*, a* and b* (Goñi and Salvadori, 2017). Water-soluble vitamins (B1, B2, B3, B6) and vitamin E were quantified by fluorescence HPLC after enzymatic digestion with Takadiastase, as described by Kim and Kang (2023).

2.6. Functional properties

Water absorption index followed Mandge et al. (2014); bulk density was measured by tapping a filled measuring cylinder to constant volume and dividing mass by that volume, following Mayachiew et al. (2015).

2.7. Anti-nutritional factors and antioxidant assays

Tannins were assayed by the butanol/HCl method (Palacios et al., 2021), saponins spectrophotometrically (Melini and Melini,

2021), total phenolic content by Folin-Ciocalteu and expressed as mg GAE/g (Kayitesi et al., 2012), and antioxidant activity by DPPH radical scavenging (Mohapatra et al., 2019).

2.8. Sensory evaluation

A semi-trained panel scored taste, odour, smoothness, thickness and overall acceptability on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely), following the approach set out by Onyeoziri et al. (2021).

2.9. Statistical analysis

Every analysis was run in triplicate. Data went through one-way ANOVA in Statistix 8.1, with treatment means compared as described by Montgomery (2017); a result was treated as significant below $p \leq 0.05$.

3. Results and Discussion

Sorghum and quinoa are already recognised as good sources of vitamins, lysine, carotenoids and minerals such as phosphorus and potassium on their own; the question here was what processing does to that baseline. The porridge samples were run through proximate, mineral, functional, anti-nutritional and sensory testing to build a fuller picture across all six treatments.

3.1. Proximate composition and total caloric value of sorghum-quinoa porridge

Table 2 sets out the full proximate breakdown. Moisture and fat responded most strongly to treatment ($p \leq 0.01$), with protein, ash, fibre and carbohydrate also shifting significantly ($p \leq 0.05$). Raw porridge, T1, held onto the most water (9.63±0.48%), while fermentation drove moisture down to 3.21±0.41% — a predictable outcome, since fermentation both consumes free water metabolically and the product tends to lose more during subsequent handling (Ariyantoro et al., 2020). Fat followed a similar downward trend under processing, from 4.32% in T1 to 3.00% in germinated porridge (T3), broadly matching what has been reported for other germinated-grain porridges (Khadka, 2023). Protein told the opposite story: it rose from 11.21% in the wheat control to 12.64% in T3, which fits the general pattern of germination unlocking protein that was previously bound by inhibitors and made less accessible (Dhital, 2021). Ash ranged from 2.50% (T1) down to 1.59% (T4, roasted), and carbohydrate stayed in a tight band between 66.4% and 67.7% across treatments, peaking in soaked porridge (T5). Fibre dropped sharply with processing — from 10.2% in the wheat control to just 3.25% in roasted porridge — consistent with the fibre losses reported during fermentation of finger-millet flour, where microbial activity appears to break fibre down directly (Mutshinyani et al., 2020). Total energy tracked closely with fat and protein content, running from 445.5 kcal/100 g in T1 down to 439.4 kcal/100 g in T2.

Table 2: Mean values for proximate composition and total caloric value of sorghum-quinoa porridge

Treatment	Moisture %	Fat %	Protein %	Ash %	Fibre %	Carbohydrate %	Energy kcal/100g
T0	11.61±1.04a	2.46±0.05bc	11.21±1.04ab	1.9±0.42bc	10.2±0.05a	66.42±0.05ac	402.10±0.14a
T1	9.63±0.17ab	4.32±0.04b	12.34±0.17ab	2.5±0.43ab	4.98±0.04b	67.37±0.04c	445.48±0.10ab
T2	3.21±0.14ab	3.13±0.43cd	12.80±0.14ab	1.7±0.15c	3.91±0.43c	67.70±0.43bc	439.38±0.08c
T3	3.52±0.38ab	3.00±0.35a	12.64±0.38a	2.1±0.02c	3.82±0.35d	67.09±0.35c	441.08±0.06d
T4	3.44±0.11b	3.40±0.14d	12.27±0.11b	1.78±0.02a	3.25±0.14d	67.24±0.14d	440.22±0.10e
T5	4.32±0.46ab	3.57±0.12b	12.42±1.05ab	1.62±0.3bc	3.34±0.12d	67.61±0.12d	441.24±0.02ed

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.2. Mineral content of sorghum-quinoa porridge

Calcium showed the strongest treatment effect ($p \leq 0.01$), with magnesium, iron, potassium and zinc all differing significantly too ($p \leq 0.05$) (Table 3). Fermented porridge came out on top across nearly every mineral measured — calcium at 40.3 mg/100 g, magnesium at 199.5, iron at 4.32 and potassium at 501.7 mg/100 g — while zinc was actually highest in T1 (2.62 mg/100 g). This isn't a coincidental clustering: fermentation is well known to break down phytate, and phytate is precisely what locks up divalent minerals like iron, zinc and calcium and keeps them from being absorbed (Lazarte et al., 2021). The iron figures here also sit within the range reported for fermented sorghum porridges elsewhere, which ran from 3.2 to 9.9 mg/100 g (Proietti et al., 2013).

Table 3: Mean values for mineral content (mg/100 g) of sorghum-quinoa porridge

Treatment	Calcium	Magnesium	Iron	Potassium	Zinc
T0	34.2±0.36cde	136.2±0.36a	3.12±0.06cde	430.1±0.52c	2.5±0.06a
T1	36.56±0.34b	179.2±0.34cd	4.00±0.05b	450.3±0.54d	2.3±0.05ab
T2	40.3±0.3de	199.5±0.3c	4.32±0.03de	501.2±0.5b	2.62±0.03a
T3	39.95±0.28a	190.2±0.28e	4.15±0.01a	471.3±0.47e	2.5±0.01b
T4	36.45±0.24e	171.7±0.24b	3.76±0.02e	432.85±0.45a	2.26±0.02ab
T5	36.1±0.2cd	171.2±0.2de	3.51±0.04cd	432.8±0.42b	2.24±0.4ab

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.3. Amino-acid profile of sorghum-quinoa porridge

None of the five essential amino acids measured differed significantly across treatments ($p \geq 0.05$) (Table 4), though there's a visible numerical trend worth noting. Lysine peaked in germinated porridge (0.281 mg/g) and was lowest in soaked porridge (0.24 mg/g); leucine showed a comparable pattern, topping out in roasted porridge at 0.892 mg/g. Methionine and valine, interestingly, were both highest in the wheat control rather than any of the sorghum-quinoa treatments. The lysine and leucine trends line up reasonably well with what's been reported about germination activating proteolytic enzymes and thereby making amino acids more available (Thakur et al., 2021), even if the differences here didn't reach statistical significance.

Table 4: Mean values for essential amino-acid content (mg/g) of sorghum-quinoa porridge

Treatment	Lysine	Methionine	Valine	Leucine	Iso-leucine
T0	0.142±0.36	0.262±0.06	0.422±0.52	–	–

Treatment	Lysine	Methionine	Valine	Leucine	Iso-leucine
T1	0.242±0.34	0.176±0.05	0.342±0.54	0.643±0.52	0.382±0.36
T2	0.262±0.3	0.186±0.03	0.384±0.5	0.772±0.54	0.370±0.34
T3	0.281±0.2	0.195±0.01	0.390±0.47	0.854±0.5	0.342±0.3
T4	0.234±0.24	0.162±0.02	0.324±0.45	0.892±0.47	0.360±0.28
T5	0.240±0.2	0.164±0.04	0.334±0.42	0.734±0.45	0.290±0.24

—: not reported for T0. Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.4. pH and colour of sorghum-quinoa porridge

pH swung considerably across treatments ($p \leq 0.01$) (Table 5) — from 6.64 in raw porridge down to 4.23 in fermented porridge, a drop that reflects the organic acids fermentation microbes generate as they work, and one that closely mirrors the pH curve reported for mahewu, a South African fermented porridge, which fell from 6.75 to 3.30 over 36 hours of fermentation (Fadahunsi and Soremekun, 2017). Colour moved with treatment too: T0 was the lightest (L* = 77.2) and T2 the darkest (67.2); redness (a*) peaked in T2 at 4.1; and yellowness (b*) was highest in roasted porridge at 19.3, almost certainly the result of Maillard browning under dry heat — a pattern that has also been documented in roasted quinoa-chia blends (Barman et al., 2019).

Table 5: Mean values for pH and colour (L*, a*, b*) of sorghum-quinoa porridge

Treatment	pH	L*	a*	b*
T0	6.41±0.05a	77.2±0.05a	1.4±0.05a	0.75±0.14a
T1	6.64±0.04ba	71.5±0.04b	2.1±0.04b	12.1±0.01b
T2	4.23±0.43c	67.2±0.43ac	4.1±0.08ab	16.2±0.8ca
T3	5.6±0.35d	69.3±0.35d	3.9±0.6c	14.4±0.6d
T4	6.1±0.14e	69.2±0.14da	2.3±0.1d	19.3±0.14e
T5	6.3±0.12de	72.4±0.12e	2.1±0.02e	13.4±0.02ab

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.5. Vitamin content of sorghum-quinoa porridge

Thiamine and riboflavin held fairly steady across treatments ($p \geq 0.05$), but niacin and vitamin E both shifted significantly ($p \leq 0.01$) (Table 6). Thiamine was numerically highest in germinated porridge (0.426 mg/100 g) and lowest after roasting (0.31 mg/100 g), which tracks with how sensitive B-vitamins generally are to heat exposure. Riboflavin, by contrast, was actually highest in roasted porridge and lowest in the wheat control. Niacin ran the opposite direction to most other nutrients here — it was highest in T0 (5.1 mg/100 g) and lowest in T3 (2.563 mg/100 g). Pyridoxine and vitamin E both peaked in germinated porridge (0.552 and 1.66 mg/100 g respectively), which sits alongside earlier findings that wet fermentation raises B-vitamin content more than dry processing does in maize porridge (Ansari et al., 2020).

Table 6: Mean values for vitamin content (mg/100 g) of sorghum-quinoa porridge

Treatment	Thiamine B1	Riboflavin B2	Niacin B3	Pyridoxine B6	Vitamin E
T0	0.418±0.36a	0.122±0.06c	5.1±0.52cde	0.321±0.5cde	0.6±0.36a
T1	0.356±0.34ab	0.225±0.05d	2.1±0.54b	0.461±0.54b	1.3±0.34cd
T2	0.401±0.28a	0.261±0.03b	2.542±0.5de	0.532±0.5de	1.6±0.3c
T3	0.426±0.28b	0.273±0.01e	2.563±0.5a	0.552±0.47a	1.66±0.28e
T4	0.31±0.24ab	0.202±0.02a	1.981±0.45e	0.416±0.45e	1.24±0.24b
T5	0.33±0.2ab	0.215±0.04b	2.091±0.42cd	0.416±0.42cd	1.32±0.2de

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.6. Functional properties of sorghum-quinoa porridge

Neither water absorption index nor bulk density differed significantly across treatments ($p \geq 0.05$) (Table 7). WAI ranged narrowly, from 1.9% in roasted porridge to 2.6% in fermented porridge, sitting comfortably within the range reported for extruded millet-soybean porridge blends (Urembo et al., 2023). Bulk density spanned 0.64 g/cm³ (T1) to 1.02 g/cm³ (T5, soaked), broadly matching values reported for dried finger-millet porridge powder (Kabeer et al., 2023). The lack of significant variation here is arguably a reassuring result — it suggests none of the four processing routes compromises the porridge's handling or packaging behaviour relative to the others.

Table 7: Mean values for functional properties of sorghum-quinoa porridge

Treatment	Water absorption index %	Bulk density g/cm3
T0	1.9±0.42	0.75±0.14
T1	2.5±0.43	0.64±0.01
T2	2.6±0.15	0.66±0.08
T3	2.2±0.02	0.65±0.06
T4	1.9±0.02	0.67±0.06
T5	2.1±0.3	1.02±0.12

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.7. Anti-nutritional factors, total phenolic content and antioxidant activity

Tannins differed significantly by treatment ($p \leq 0.05$) — highest in raw porridge (0.44 mg/g) and lowest in the wheat control (0.03 mg/g), with the four processed treatments sitting somewhere in between, all reduced relative to raw grain. That reduction fits well with what's already known about fermentation, germination, roasting and soaking all lowering tannin content in sorghum (Rahman and Osman, 2011). Saponins moved the same way, only more sharply ($p \leq 0.01$): 6.01 mg/g in T1 against 0.04 mg/g in T0, with every processing method cutting saponin levels well

below the raw-grain figure, mirroring reductions reported for fermented sorghum-cowpea blends (Ojokoh et al., 2020).

The antioxidant results are where fermentation and germination really separated themselves from the pack. Total phenolic content peaked in germinated porridge at 44.56 mg GAE/g, well above the wheat control's 30.2 mg GAE/g, and within the range reported elsewhere for processed finger-millet porridge (Kumari et al., 2020). DPPH scavenging activity, meanwhile, was highest in fermented porridge (69.5%) against just 34.5% in the wheat control — both differences highly significant ($p \leq 0.01$), and both consistent with reports that fermentation releases phenolic compounds otherwise bound within the cereal matrix, making them available to react (Subastri et al., 2015).

Table 8: Mean values for anti-nutritional factors, total phenolic content and antioxidant activity of sorghum-quinoa porridge

Treatment	Tannins mg/g	Saponins mg/g	TPC mgGAE/g	DPPH % inhibition
T0	0.03±1.04a	0.04±0.4a	30.2±1.4a	34.5±0.05ad
T1	0.44±0.17ab	6.01±0.04da	38.9±0.52b	41.2±0.04acd
T2	0.26±0.15ac	1.6±0.43de	40.1±0.36ab	69.5±0.43abd
T3	0.31±0.14cd	1.3±0.35ad	44.56±0.48c	61.6±0.35acd
T4	0.29±1.04d	1.12±0.14de	35.8±0.6d	44.6±0.14ad
T5	0.28±1.05dc	1.02±0.12dc	36.9±0.5e	43.1±0.12adc

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

3.8. Sensory evaluation of sorghum-quinoa porridge

Taste and odour both varied significantly with treatment ($p \leq 0.05$); smoothness did not, while thickness and overall acceptability both did (Table 9). Taste peaked with germinated porridge (8.2) and dipped lowest for raw porridge (6.8), and odour followed almost the same ranking, with germinated (8.2) and roasted (8.1) porridge scoring closely together at the top. Smoothness was rated best for roasted porridge (7.3) and worst for the wheat control (6.1), while soaked porridge (T5) came out thickest at 7.2. What stands out most, though, is that none of this translated into overall preference: the wheat control still won on overall acceptability (8.9), followed by roasted porridge (8.1), while germinated porridge — despite topping the nutritional and antioxidant tables — finished last on overall liking, at 6.9. This kind of disconnect between measured quality and consumer preference isn't unique to this study; it's been observed before in millet-based instant porridges, where processing improved the objective quality metrics but familiarity still won out in the final acceptability score (Onyeoziri et al., 2021). It points to a practical takeaway: getting the nutrition right may not be enough on its own, and closing that gap will likely need either gradual reformulation or some effort at consumer education alongside the product itself.

Table 9: Mean values for sensory evaluation (9-point hedonic scale) of sorghum-quinoa porridge

Treatment	Taste	Odour	Smoothness	Thickness	Overall acceptability
T0	7.8±0.36ac	7.8±0.36ab	6.1±0.52	6.9±0.52ab	8.9±0.52a
T1	6.8±0.34a	6.8±0.34ad	6.3±0.54	6.6±0.54dc	7.6±0.54dc

Treatment	Taste	Odour	Smoothness	Thickness	Overall acceptability
T2	7.2±0.03d	7.2±0.03b	6.9±0.5	6.8±0.03ab	7.8±0.03a
T3	8.2±0.06d	8.2±0.06ba	7.1±0.47	6.9±0.06d	6.9±0.06d
T4	8.1±0.28a	8.1±0.28a	7.3±6.8	6.1±0.28d	8.1±0.28d
T5	7.2±0.24d	7.2±0.24d	7.2±0.24	7.2±0.24dc	7.2±0.24dc

Means followed by different superscript letters within a column differ significantly ($p \leq 0.05$). Values are mean ± SD of triplicate determinations. T0 = wheat porridge (control); T1 = raw sorghum-quinoa porridge; T2 = fermented sorghum-quinoa porridge; T3 = germinated sorghum-quinoa porridge; T4 = roasted sorghum-quinoa porridge; T5 = soaked sorghum-quinoa porridge.

Conclusion

Taken together, the results make a fairly clear case that how sorghum-quinoa porridge is processed matters just as much as what it's made from. Fermentation came out ahead on minerals and antioxidant capacity — it delivered the highest calcium, magnesium, iron and potassium of any treatment, alongside the strongest DPPH activity, while also bringing tannin and saponin levels down from where they sat in raw grain. Germination took the lead on protein, phenolics, thiamine, pyridoxine, vitamin E and lysine, and edged out every other treatment on taste and odour scores — yet it finished last on overall acceptability, trailing even the plain wheat control. Roasting's main contribution was on texture and colour, largely through Maillard browning, while soaking made smaller, more modest improvements to carbohydrate content and bulk density. What this leaves is a genuinely useful but incomplete result: fermented and germinated sorghum-quinoa porridge are strong candidates for a gluten-free, nutrient-dense breakfast product, and worth building into a balanced diet, but their path to the table likely runs through further work on consumer acceptance — larger and more varied sensory panels, shelf-life and packaging studies, and probably some strategy for narrowing the gap between what tests well in the lab and what people actually choose to eat.

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