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Effect of malted iron-rich beans flour inclusion on nutritional and sensory properties of broken rice-based complementary food: a community-based experimental study

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Abstract

Background Iron and zinc deficiencies are a major public health concern among children aged 6–24 months in Northern Uganda, particularly in the Acholi sub-region. These deficiencies are largely linked to complementary foods prepared from inadequately processed local ingredients with high anti-nutritional factors, which impair micro-nutrient absorption. This study investigated the effect of malting on broken rice-iron-rich beans composite flour, focusing on sensory properties, nutrient composition, bioavailability, and anti-nutritional content.

Methods Nine formulations (four malted, four unmalted, and one control) were analyzed. Sensory evaluations were conducted with 124 mothers of children aged 6–24 months. Proximate composition, micronutrient content, and anti-nutritional factors were determined in the laboratory. Data were analyzed using two-way ANOVA at $p \leq 0.05$.

Results For children aged 6–11 months, the most preferred formulation was composite F (30% unmalted beans: 70% rice), while composite C (40% malted beans: 60% rice) was most acceptable for 12–24 months. Composite A (30% malted beans: 70% rice) and G (40% unmalted beans: 60% rice) recorded moisture contents of 2.3% and 3.0%, respectively, with G being significantly higher ($p \leq 0.05$). Composite E (30% unmalted beans: 70% rice) showed the highest water absorption capacity, while malting reduced oil absorption capacity and bulk density. Ash content was higher in malted samples ($A = 1.45\%$, $C = 2.28\%$) than unmalted ($E = 1.52\%$, $G = 1.76\%$). Carbohydrate levels were consistent but highest in the control (100% rice = 91.71%). Protein digestibility was higher in malted samples ($A = 33.16\%$, $C = 12.35\%$), while zinc bioavailability was highest in C (4.14%). Malting increased zinc, calcium, iron, magnesium, potassium, and fiber, and reduced phytate and trypsin inhibitors, though polyphenols and tannins slightly increased.

Conclusions Malting improved nutritional quality, functional properties, and acceptability of complementary foods. Composite A is suitable for 6–11 months, and composite C for 12–24 months. Promoting iron-rich bean composites through caregiver education and early childhood feeding programs could enhance nutrient intake, support growth, and prevent micronutrient deficiencies.

Keywords Iron-rich beans, Malting, Bioavailability, Composite flour, Complementary feeding, Sensory evaluation

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Background

Undernutrition remains a leading cause of child mortality worldwide, with an estimated 165 million children affected globally [1, 2]. The burden is especially severe in sub-Saharan Africa (SSA) and Asia, where deficiencies in essential micronutrients particularly iron and zinc pose significant public health challenges [3, 4]. In Uganda, nearly half (approximately 50%) of children aged 6 to 59 months suffer from iron-deficiency anemia, and zinc deficiency is similarly widespread [5, 6]. These micronutrient inadequacies are largely attributed to poor dietary quality, with heavy reliance on plant-based foods that are often rich in anti-nutritional factors and low in bio-available nutrients [7–9]. Children aged 6–24 months are especially vulnerable during the complementary feeding phase, a critical transition from exclusive breastfeeding to solid foods [10, 11]. Diets during this period are frequently characterized by low diversity and dominated by starchy staples, resulting in high rates of stunting, wasting, underweight, weakened immunity, and recurring illnesses [12–14]. This is compounded by the fact that commonly consumed complementary foods in Uganda often lack adequate amounts of iron, zinc, calcium, selenium, and essential vitamins [15].

Nonetheless, locally available plant-based foods such as common beans and rice offer promising nutritional benefits. Beans, variety developed by National Agriculture Research Organization (NARO), particularly the NARO Bean 3 variety, are rich in protein and contain substantial levels of iron (34–89) and zinc (21–54 mg/kg [16], making them valuable for addressing micronutrient deficiencies [17, 18]. Similarly, rice is an important food security crop in Uganda, ranking fourth in cereal production, with upland varieties accounting for over 70% of cultivation [19]. However, substandard milling practices, particularly in northern Uganda result in large volumes of broken rice, which are typically underutilized or discarded due to low market value, despite their potential nutritional and economic benefits.

Combining broken rice with iron-rich beans offers a practical approach to enhance complementary foods while reducing post-harvest losses. However, both cereals and legumes contain anti-nutritional compounds such as phytates, tannins, and trypsin inhibitors, which inhibit mineral absorption [20–22]. Processing methods like soaking, boiling, germination, extrusion, and particularly malting have been shown to reduce these anti-nutrients and consequently improve nutrient bioavailability [23–26]. Among these, malting is particularly advantageous because it activates endogenous enzymes such as phytases and amylases, resulting in greater phytate degradation and improved mineral and protein bioavailability, while remaining cost-effective and suitable for

low-resource settings [24]. Despite these advances, there is limited empirical evidence on the use of malted iron-rich bean flour specifically from the NARO Bean 3 variety in combination with broken rice for the development of nutrient-enhanced complementary foods. Moreover, the influence of malting on sensory characteristics such as taste, aroma, and texture which are crucial for acceptability among young children remains poorly understood [27]. Sensory rejection of otherwise nutritious foods can significantly affect dietary intake and overall nutrition outcomes [24, 28, 29]. Therefore, this study aimed to investigate the effects of incorporating malted NARO Bean 3 flour into broken rice composites on their nutritional composition, anti-nutrient levels, and sensory acceptability. The results are expected to contribute to the development of improved complementary foods and support global nutrition targets, including the World Health Organization (WHO) goal of reducing stunting among children under five by 40% by the year 2025.

Materials and methods

Study design

This study used a combination of a cross-sectional design and a Completely Randomized Design (CRD) to address different study objectives. The cross-sectional design was used for the community sensory evaluation, where mothers and caregivers in Nwoya and Amuru districts assessed the acceptability of nine malted and unmalted composite flour formulations. After identifying the most preferred formulations from the community evaluation, these samples were taken to the laboratory for further analysis using a CRD, where malting was the main treatment factor. All laboratory analyses were conducted under controlled conditions, and samples were analyzed in duplicates following standard food chemistry analytical procedures [30]. This was mainly due to limited laboratory resources and equipment availability. Although more replicates would have provided stronger statistical precision, duplicate analysis was considered acceptable for this study and this has been clearly acknowledged under the limitations section. Data were mainly quantitative, obtained during sensory evaluation. Sensory evaluation was conducted in the community, after which the most preferred formulations were subjected to laboratory analysis for sensory perception, proximate composition, mineral content (iron and zinc), in-vitro protein digestibility (IVPD), and functional properties.

Study area

The field study was conducted in Amuru (02°50'N, 33°05'E) and Nwoya (02°38'N, 32°00'E) districts in Northern Uganda (Fig. 1), part of the Acholi sub-region where rice and beans are widely grown but micronutrient

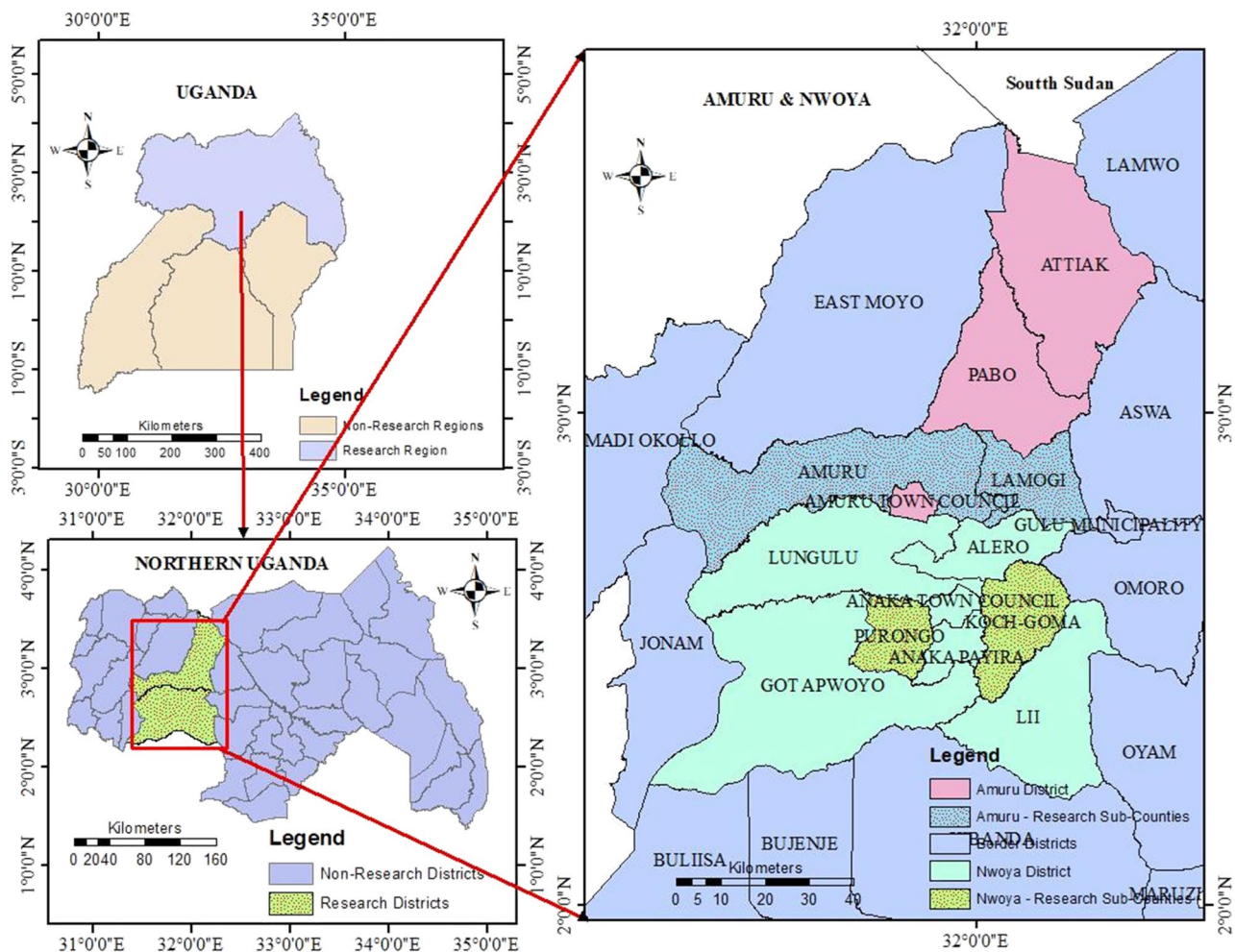


Fig. 1 Location of the study area in Northern Uganda showing Amuru and Nwoya districts within the Acholi sub-region where the field study was conducted

deficiencies remain prevalent [28, 31]. This region is also characterized by low dietary diversity among children and low prevalence of consumption of iron-rich foods [28, 32, 33].

Study population

The participants were mothers/caregivers of children aged 6-24 months, selected because they are primarily responsible for child feeding [34] and thus able to evaluate sensory attributes.

Sample size estimation

The sample size was determined using the Fischer formula [35], based on a 71% prevalence of iron deficiency among children in the region [24, 33].

$$n = \frac{z^2 pq}{d^2}$$

Where: n = the preferred sample size; z = the standard normal deviation at the mandatory confidence level 95% (standard value = 1.96); p = the rate of or prevalence of Iron deficiency among the Children aged 6-24 months in Acholi sub region is about 71% [31]; q = Proportion not expected to be suffering from Iron deficiency $1-p = (1-0.71) = 0.29$; d = the degree of accuracy set 0.05.

$$n = \frac{(1.96^2)(0.71)(0.29)}{(0.05^2)} = 316$$

Therefore, from the above formula;
Considering Non response rate of 10%.

The total preferred sample size = $n = \frac{\text{the obtained sample size}}{(1 - \text{Non response rate})}$

$$n = \frac{316}{(1 - 0.1)} = 351$$

Although the computed sample size was 351 for population-level estimates, this study focused on sensory evaluation, where smaller panels are methodologically appropriate. Therefore, 124 caregivers were included, consistent with similar product development studies [30] and within the recommended sensory panel range of 30-150 participants [36]. Of the nine formulations, the five most preferred (four composites and one control) were selected for laboratory analysis and analyzed in duplicates, yielding ten samples per parameter to ensure reliability.

Sampling procedure

Caregivers

A multistage sampling technique was used. Nwoya and Amuru districts were purposively selected, followed by random selection of sub-counties, parishes, and villages. With the help of Local Council One (LC1) leaders, eight caregivers per village with children aged 6-24 months were purposively enrolled. Hence, a total of 124 caregivers participated in the study.

Raw materials

Sixty kilograms (60 kg) of NARO Bean 3 from a farmer attached to the National Crops Resources Research Institute (NaCRRI) beans program and 60 kg of broken rice (Nylon variety) were procured from local farmers and millers in Purongo Sub-County (Nwoya) and Palema Sub-County (Amuru) during the second harvest season (November to December) of 2020. Materials were transported in 100 kg sacks, properly sealed, and temporarily stored at ambient room temperature at Gulu University in the Faculty of Agriculture and Environment prior to processing.

Preparation of composite flour

Malting by traditional methods was undertaken with caregivers in the community, while roasting, grinding, extrusion, and milling were carried out at Kawanda Agricultural Research Institute (KARI). Broken rice was cleaned, washed, and sun-dried to 11%-13% moisture content. NARO Bean 3 was then divided into malted and unmalted portions. For the malted samples, beans were soaked using a 1:3 bean-to-water ratio for 12 h, followed by 48 h of germination under ambient humidity conditions (approximately 70%). The germinated beans were then sun-dried for approximately 5 days at 28-30 °C before being roasted at 200 °C for 1 h. The unmalted portion was processed without germination and used as a control for comparison. Formulations were developed

to meet iron and zinc requirements using the Harvest-Plus Food Composition Table for Central and Eastern Uganda [37]. The blended grains were first milled and then subjected to extrusion processing under controlled conditions, including a barrel temperature of 120 °C, a screw speed of 60 revolutions per minute (rpm), and a residence time of approximately three (3) minutes. These conditions were used to ensure uniform cooking, improve product safety, and enhance product quality. The extruded material was then re-milled, sieved using a 0.5 mm (mm) mesh, cooled to room temperature, and packed in High-Density Polyethylene (HDPE) bags. The final products were stored at room temperature until further analysis [38, 39].

Composite flour formulation

Malted and un-malted beans were blended with broken rice in different proportions (Table 1) based on the Recommended Dietary Allowance (RDA) of iron and zinc for children aged 6-24 months (9.3 and 4.1 mg/day, respectively) [40]. Nutrient composition data from the Harvest-Plus Food Composition Table were used to determine blending ratios [37].

Sensory evaluation

A total of 124 caregivers participated in four sensory sessions. Porridge was prepared uniformly (400 g flour to 1600 ml boiling water). Samples were served in labeled white disposable cups to avoid bias. Sensory attributes (color, aroma, texture, thickness, taste, and overall acceptability) were rated on a 5-point hedonic scale, with 1 representing “dislike very much”, 2 (Dislike moderately, 3 (neither like nor dislike), 4 (like moderately), and 5 representing “like very much” to rank the different formulations [41]. This was done in different shifts to prevent bias in ranking of the samples of

Table 1 Formulations of broken rice-iron-rich bean composite flour

Sample ID	Age group (months)	Broken rice (%)	Malted beans (%)	Un-malted beans (%)
Control	6-24	100	0	0
CF11	6-11	70	30	0
CF12	6-11	30	70	0
CF13	12-24	60	40	0
CF14	12-24	40	60	0
CF21	6-11	70	0	30
CF22	6-11	30	0	70
CF23	12-24	60	0	40
CF24	12-24	40	0	60

the formulations. Clean drinking water was provided for palate cleansing. Mean scores were computed, and the four highest-scoring malted and unmalted formulations, plus the control, were selected for laboratory testing.

Proximate composition

Laboratory analyses were carried out at KARI and the Faculty of Agriculture and Environment of Gulu University. Moisture, crude protein, crude fat, crude fiber, ash, and carbohydrate contents were determined following standard AOAC methods. Moisture content was measured using oven drying (AOAC, 2000; Method No. 925.10), as described by [42] while crude protein was analyzed by the Kjeldahl method (ISO 5983-2, 2009), as described by [43]. Crude fat was determined using Soxhlet extraction (AOAC, 2005; Method No. 920.39), described by [42], and crude fiber was analyzed using the Weende method (ISO 6865:2000). Ash content was measured by dry ashing at 550 °C (AOAC, 2000, Method No. 923.03), and carbohydrate content was calculated by difference, as described by [44]. These are shown in the equations below:

$$\% \text{Moisture content} = \frac{((\text{Wt of petridish} + \text{fresh sample}) - (\text{wt of petridish} + \text{dry sample}))}{(\text{wt of fresh sample})} \times 100 \quad (1)$$

where: Wt = weight

$$\% \text{Crude protein} = \% \text{NXF} \quad (2)$$

$$\% \text{Crude fat (db)} = \frac{\text{Extracted fat}}{\text{dried sample weight}} \times 100 \quad (3)$$

$$\% \text{Crude fibre} = \frac{F_1 - F_2}{F_o} \times 100 \quad (4)$$

Where: F_1 = ash content; F_2 = weight after cooling in a desiccator.

$$\% \text{Crude ash} = \frac{(W_2 - W_1)}{\text{weight of sample}} \times 100 \quad (5)$$

where: w_1 = weight of empty crucible, and w_2 = weight of crucible with ash.

Total carbohydrate in 100 g of food.

$$= 100 - \text{weight in g of (Protein + Water + Ash + Fat + Fibre)} \quad (6)$$

where; g = grams.

In-vitro protein digestibility

Protein digestibility was assessed using the enzymatic procedure outlined by [45], where samples were digested with pepsin and the undigested fraction determined using the Kjeldahl method.

Digestibility was expressed as the percentage reduction in protein after enzymatic digestion.

$$\text{IVPD} = \frac{A - B}{A}$$

where; A is the % of protein in the sample before digestion and B is the % of the protein in the sample after enzymatic digestion.

Mineral content and bioavailability (Fe and Zn)

Total iron and zinc contents were determined after acid digestion using the procedure of [46], and quantified by Microwave Plasma-Atomic Emission Spectroscopy (MP-AES). In-vitro bioavailability of iron and zinc was evaluated using simulated gastric and pancreatic digestion [47], and expressed as the proportion of dialyzable iron or zinc relative to the total mineral content.

Functional properties

Water absorption capacity (WAC) and Oil absorption capacity (OAC) were analyzed by dispersing samples in

water or oil respectively, centrifuging, and calculating the absorbed volume as [48]. Bulk density was determined using the method by Ikuenlola and Fashakin [49] with some amendments. This was determined by filling and tapping flour in a measuring cylinder, while pH was measured in a slurry of sample and distilled water using a calibrated pH meter (eco Testr pH 2, Eutech Instruments, Made in Malaysia).

Anti-nutritional factors

Phytates, tannins, polyphenols, and trypsin inhibitors were quantified, as these compounds influence mineral bioavailability and protein utilization [16, 37]. Phytates were determined using the colorimetric method of Beta et al. [50], polyphenols by the Folin–Ciocalteu assay [51], tannins using the Folin–Denis method [52, 53], and trypsin inhibitors by the ISO 14902 enzymatic assay [54].

Statistical analysis

All data were entered in Microsoft Excel (Version 24) and analyzed using SPSS (Version 24). Descriptive statistics were used to summarize caregivers' socio-demographic

characteristics. One-way ANOVA was applied to compare sensory perception mean scores between malted and unmalted samples at a 5% significance level ($p \leq 0.05$). Multivariate Analysis of Variance (ANOVA) (Two-way) was used to compare proximate composition, zinc and iron levels, protein digestibility, mineral bioavailability,

functional properties, and anti-nutritional factors of the composite formulae, also at $p \leq 0.05$. However, where significant differences were observed, Tukey's Honest Significant Difference (HSD) post-hoc test was applied to separate treatment means, and the results are presented using superscript letters in the tables.

Table 2 Socio demographic characteristics of caregivers/ mothers disaggregated by district (n is the number of participants = 124)

Socio demographic characteristics	Amuru (n = 60)		Nwoya (n = 64)	
	n	%	n	%
Sex of the child				
Female	32	53.3	32	50.0
Male	28	46.7	32	50.0
Child's age				
6–11 Months	21	35.0	21	32.8
12–24 Months	39	65.0	43	67.2
Mothers/Caregivers age				
15–25 years	34	56.7	29	45.3
26–45 years	25	41.7	33	51.6
45–65 years	1	1.7	2	3.1
Education level of the caregivers				
No formal schooling	5	8.3	11	17.2
Primary	49	81.7	41	64.1
Secondary	6	10.0	8	12.5
Tertiary	0	0.0	4	6.2
Occupation of care givers/mothers				
Unemployed	0	0.0	1	1.6
Employed/Salary earner	0	0.0	1	1.6
Small scale trading	5	8.3	5	7.8
Farming	55	91.7	57	89.1

Results

Socio-demographic characteristics of study participant

The results showed that in both Amuru and Nwoya districts, females constituted the majority of the children recruited, with slightly more in Amuru (53.3%) than in Nwoya (50%) (Table 2). Most children in Amuru (65%) were between 6–11 months, while in Nwoya (67.2%), the majority were aged 12–24 months. With regard to caregivers, over half in Amuru (56.7%) and in Nwoya (51.6%) fell within the age ranges of 15–25 and 26–45 years, respectively. Furthermore, a higher proportion of caregivers in Amuru (81.7%) had attained primary education compared to those in Nwoya (64.1%). Farming was the predominant occupation in both districts, where 91.7% of caregivers in Amuru and 89.1% in Nwoya reported being engaged in agricultural activities.

Sensory perceptions of the mothers/caregivers for broken Rice-Iron rich beans composite

The findings (Table 3) indicate that for children aged 6–11 months, there were no statistically significant differences in the caregivers' ratings for appearance, aroma, taste, texture, and overall acceptability between the malted (Composite A) and unmalted (Composite E) formulations ($p > 0.05$). However, Composite E (unmalted) consistently received higher mean scores than both Composite A (malted) and the control (Composite I) for

Table 3 Caregivers' scores for sensory attributes and overall acceptability of malted and un-malted broken rice-iron rich beans composite segregated by age category

Sensory Attribute	Age category								
	Children 6–11 Months				Children 12–24 Months				Control
	A	E	B	F	C	G	D	H	
Appearance	4.19 ± 1.10 ^{ab}	4.18 ± 1.10 ^{ab}	1.78 ± 0.92 ^b	3.24 ± 1.18 ^{ba}	4.36 ± 0.77 ^{ab}	3.67 ± 1.18 ^{ab}	2.18 ± 1.10 ^b	2.93 ± 1.27 ^{ab}	3.29 ± 1.61 ^a
Aroma	4.10 ± 1.13 ^{ab}	4.09 ± 1.11 ^{ab}	1.91 ± 0.98 ^b	3.38 ± 1.23 ^{ba}	4.30 ± 0.87 ^{ab}	3.59 ± 1.25 ^{ba}	2.24 ± 1.10 ^b	2.96 ± 1.22 ^{ab}	3.07 ± 1.63 ^a
Taste	4.07 ± 1.00 ^{ab}	4.25 ± 1.13 ^{ab}	1.68 ± 0.81 ^b	3.30 ± 1.27 ^{ba}	4.54 ± 0.82 ^{ab}	3.73 ± 1.23 ^{ba}	2.09 ± 1.00 ^b	3.01 ± 1.32 ^{ab}	2.93 ± 1.49 ^a
Texture	4.01 ± 1.09 ^{aa}	4.06 ± 1.15 ^{aa}	2.44 ± 1.23 ^{ab}	3.15 ± 1.26 ^{bb}	3.98 ± 1.15 ^{aa}	3.58 ± 1.10 ^{ba}	2.66 ± 1.30 ^b	3.06 ± 1.32 ^{ab}	3.82 ± 1.55 ^a
General Acceptability	4.28 ± 0.94 ^{ab}	4.39 ± 0.96 ^{ab}	1.75 ± 0.94 ^b	3.25 ± 1.22 ^{ba}	4.48 ± 0.88 ^{ab}	3.75 ± 1.21 ^{ba}	2.08 ± 1.06 ^b	2.92 ± 1.31 ^{ab}	3.12 ± 1.57 ^a

Values are presented as mean ± standard deviation (n = 5). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice + 30% malted beans), B (30% broken rice + 70% malted beans), C (60% broken rice + 40% malted beans), D (40% broken rice + 60% malted beans), E (70% broken rice + 30% unmalted beans), F (30% broken rice + 70% unmalted beans), G (60% broken rice + 40% unmalted beans), H (40% broken rice + 60% unmalted beans), and I (100% broken rice as the control)

all sensory attributes ($p \leq 0.05$). Additionally, for children aged 6–11 months, Composite F (unmalted) was rated significantly higher than Composite B (malted) for appearance, aroma, taste, texture, and overall acceptability ($p \leq 0.05$). Similarly, Composite F also scored significantly higher than both Composite B and the control (Composite I) in aroma, taste, and general acceptability for the same age group ($p \leq 0.05$).

Among children aged 12–24 months, Composite C (malted) recorded significantly higher scores in aroma, taste, texture, and overall acceptability compared to Composite G (unmalted) and the control ($p \leq 0.05$). However, Composite D (malted) scored significantly lower in taste, texture, and overall acceptability than Composite H (unmalted) and the control for this age group ($p < 0.05$). Overall, Composite E (unmalted) was the most preferred formulation for children aged 6–11 months, while Composite C (malted) was most preferred for children aged 12–24 months (Table 3).

Effect of malted iron rich bean flour on nutrient composition and functional properties of broken rice-iron rich bean composite

The results (Table 4) show that for children aged 6–11 months, there were no significant differences in most proximate components between the malted (Composite A) and unmalted (Composite E) samples ($p > 0.05$), except for crude fat, which was significantly higher in the unmalted composite (Composite E) ($p \leq 0.05$).

For children aged 12–24 months, the control (Composite I) showed significantly higher carbohydrate content than both the malted composite (Composite C) and the unmalted composite (Composite G) ($p \leq 0.05$). Conversely, crude fiber, crude protein, and ash contents were significantly higher in the malted composite (Composite

C) compared to Composite G and the control ($p \leq 0.05$). Additionally, the unmalted composite (Composite G) exhibited significantly higher crude fat and moisture content than Composite C and the control ($p \leq 0.05$).

Micronutrient profile of the broken rice-iron rich bean composite formulas

Focusing on zinc, calcium, iron, magnesium, and potassium (Table 5), the results indicate that for children aged 6–11 months, the malted composite (Composite A) showed significantly higher levels of magnesium and potassium compared to the unmalted composite (Composite E) and the control (Composite I) ($p \leq 0.05$). Conversely, calcium content was significantly higher in Composite E (unmalted) than in Composite A (malted) and the control ($p \leq 0.05$). There was no significant difference observed between Composites A and E in zinc and iron content ($p > 0.05$). However, both composites recorded significantly higher iron levels than the control for the same age group ($p \leq 0.05$).

For children aged 12–24 months, Composite C (malted) exhibited significantly higher levels of zinc, calcium, iron, magnesium, and potassium compared to the unmalted Composite G and the control (Composite I) ($p \leq 0.05$).

The effect of malted iron rich bean flour on the functional properties of broken rice-iron rich bean composite

Results for the functional properties of the composite formulations by age category (Table 6) indicate that for children aged 6–11 months, the unmalted composite (Composite E) exhibited significantly higher WAC, bulk density, and pH compared to the malted composite (Composite A) and the control ($p \leq 0.05$). Conversely, the malted composite (Composite A) showed significantly

Table 4 Proximate composition of malted and unmalted broken rice-iron rich beans composite formulae segregated by age category

Proximate Composition	Age category				
	Children 6–11 Months		Children 12–24 Months Control		
	A	E	C	G	I
Carbohydrate (%)	86.19 ± 0.42 ^{ab}	83.23 ± 1.00 ^{ab}	85.21 ± 0.31 ^{ab}	82.87 ± 0.38 ^{bb}	91.72 ± 0.04 ^a
Crude fat (%)	0.15 ± 0.08 ^{aa}	1.79 ± 0.17 ^{bb}	0.50 ± 0.13 ^{ab}	1.17 ± 0.03 ^{bb}	0.17 ± 0.01 ^a
Crude fibre (%)	1.67 ± 0.42 ^{aa}	1.08 ± 0.06 ^{aa}	1.14 ± 0.03 ^{aa}	0.27 ± 0.01 ^{ba}	0.87 ± 0.21 ^a
Crude protein (%)	8.63 ± 0.54 ^{ab}	8.84 ± 0.14 ^{ab}	10.89 ± 0.35 ^{ab}	10.05 ± 0.07 ^{bb}	5.14 ± 0.11 ^a
Moisture (%)	2.30 ± 0.37 ^{aa}	1.31 ± 0.24 ^{bb}	1.20 ± 0.002 ^{ab}	3.00 ± 0.12 ^{bb}	1.91 ± 0.10 ^a
Ash (%)	1.45 ± 0.08 ^{ab}	1.52 ± 0.12 ^{ab}	2.28 ± 0.69 ^{ab}	1.76 ± 0.01 ^{bb}	0.47 ± 0.02 ^a

Values are presented as mean ± standard deviation ($n = 5$). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice + 30% malted beans), B (30% broken rice + 70% malted beans), C (60% broken rice + 40% malted beans), D (40% broken rice + 60% malted beans), E (70% broken rice + 30% unmalted beans), F (30% broken rice + 70% unmalted beans), G (60% broken rice + 40% unmalted beans), H (40% broken rice + 60% unmalted beans), and I (100% broken rice as the control)

Table 5 Mean micronutrient composition of malted and unmalted broken rice-iron rich beans composite formulae segregated by age category

Micronutrient content	Age Category				
	Children 6–11 Months		Children 12–24 Months Control		
	A	E	C	G	I
Zn (mg/100 g)	1.66 ± 0.52 ^{ab}	1.39 ± 2.00 ^{ab}	1.46 ± 1.12 ^{ab}	0.72 ± 0.32 ^{ba}	0.72 ± 1.61 ^a
Ca (mg/100 g)	221.0 ± 1.06 ^{ab}	242.0 ± 2.24 ^{bb}	331.0 ± 15.65 ^{ab}	270.0 ± 2.04 ^{bb}	63.3 ± 5.60 ^a
Fe (mg/100 g)	10.26 ± 7.36 ^{aa}	8.47 ± 11.73 ^{aa}	12.20 ± 5.24 ^{ab}	9.47 ± 0.04 ^{ba}	8.45 ± 12.71 ^a
Mg (mg/100 g)	457.7 ± 3.30 ^{ab}	420.8 ± 4.80 ^{bb}	604.2 ± 2.33 ^{ab}	519.4 ± 4.41 ^{bb}	112.6 ± 0.43 ^a
K (mg/100 g)	325.94 ± 16.84 ^{ab}	288.78 ± 27.68 ^{bb}	424.75 ± 111.79 ^{ab}	370.78 ± 104.64 ^{bb}	35.41 ± 4.01 ^a

Values are presented as mean ± standard deviation ($n=5$). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice +30% malted beans), B (30% broken rice +70% malted beans), C (60% broken rice +40% malted beans), D (40% broken rice +60% malted beans), E (70% broken rice +30% unmalted beans), F (30% broken rice +70% unmalted beans), G (60% broken rice +40% unmalted beans), H (40% broken rice +60% unmalted beans), and I (100% broken rice as the control)

Table 6 Functional properties of malted and unmalted broken rice-iron rich beans composite formulae segregated by age category

Functional properties	Age category				
	Children 6–11 months		Children 12–24 months control		
	A	E	C	G	I
Water absorption capacity (%)	5.01 ± 0.07 ^{ab}	5.5 ± 0.00 ^{bb}	4.75 ± 0.35 ^{aa}	5.00 ± 0.00 ^{ab}	4.53 ± 0.035 ^a
Oil absorption capacity (%)	3.50 ± 0.00 ^{aa}	2.75 ± 0.35 ^{ba}	3.05 ± 0.07 ^{aa}	4.50 ± 0.00 ^{ab}	3.35 ± 0.21 ^a
Bulk density (unit)	0.28 ± 0.006 ^{aa}	0.44 ± 0.01 ^{bb}	0.453 ± 0.00 ^{ab}	0.46 ± 0.007 ^{ab}	0.28 ± 0.00 ^a
pH	5.8 ± 0.00 ^{aa}	6.2 ± 0.00 ^{ba}	6.0 ± 0.07 ^{ab}	6.3 ± 0.01 ^{ba}	6.4 ± 0.02 ^a

Values are presented as mean ± standard deviation ($n=5$). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice +30% malted beans), B (30% broken rice +70% malted beans), C (60% broken rice +40% malted beans), D (40% broken rice +60% malted beans), E (70% broken rice +30% unmalted beans), F (30% broken rice +70% unmalted beans), G (60% broken rice +40% unmalted beans), H (40% broken rice +60% unmalted beans), and I (100% broken rice as the control)

higher oil absorption capacity (OAC) than Composite E ($p \leq 0.05$), while no significant difference in OAC was observed between Composite A and the control ($p > 0.05$). However, the control displayed significantly higher OAC than Composite E ($p \leq 0.05$).

For the 12–24 months age category, the pH of the malted composite (Composite C) was significantly higher than that of the unmalted composite (Composite G) and the control ($p \leq 0.05$). Other functional properties between Composites C and G did not differ significantly ($p > 0.05$). When compared to the control, Composite C had a significantly higher bulk density ($p \leq 0.05$), while no significant differences were observed for WAC and OAC ($p > 0.05$). In contrast, Composite G recorded significantly higher WAC, OAC, and bulk density than the control ($p \leq 0.05$), although their pH values were statistically similar ($p > 0.05$).

Effect of malted iron rich bean flour on the selected anti-nutritional factors and in-vitro bioavailability of selected nutrients in broken rice-iron rich beans composite

As shown in Table 7, for children aged 6–11 months, the malted composite (Composite A) contained significantly higher levels of polyphenols and tannins compared to the unmalted composite (Composite E) and the control ($p \leq 0.05$). In contrast, phytate and trypsin inhibitor levels were significantly lower in Composite A than in Composite E and the control ($p \leq 0.05$).

Among children aged 12–24 months, the malted composite (Composite C) exhibited significantly higher levels of polyphenols, phytates, and tannins compared to the unmalted composite (Composite G) and the control ($p \leq 0.05$). However, Composite C showed significantly lower trypsin inhibitor content than Composite G and the control for this age group ($p \leq 0.05$).

Table 7 Content of selected anti-nutritional factors in the malted and unmalted broken Rice-Iron rich beans composite formulae segregated by age category

Anti-nutritional factor	Age category				
	Children 6-11 months		Children 12-24 months		Control
	A	E	C	G	I
Polyphenols/Gallic acid equivalent (mg/g)	27.13 ± 2.75 ^{ab}	14.35 ± 0.92 ^{ba}	29.63 ± 0.52 ^{ab}	15.56 ± 1.05 ^{ba}	11.57 ± 0.65 ^a
Phytates (mg/g)	50.27 ± 8.36 ^{aa}	114.82 ± 30.21 ^{ba}	63.45 ± 11.57 ^{ab}	42.55 ± 1.29 ^{aa}	53.91 ± 13.50 ^a
Trypsin inhibitor (TIU)/mg	53.10 ± 0.42 ^{ab}	54.60 ± 1.70 ^{ba}	54.30 ± 0.42 ^{aa}	55.90 ± 0.42 ^{ba}	55.00 ± 0.28 ^a
Tannins (mg/g)	23.38 ± 0.53 ^{ab}	11.13 ± 0.88 ^{ba}	14.50 ± 1.41 ^{ab}	10.50 ± 0.35 ^{ba}	11.25 ± 0.35 ^a

Values are presented as mean ± standard deviation ($n=5$). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice +30% malted beans), B (30% broken rice +70% malted beans), C (60% broken rice +40% malted beans), D (40% broken rice +60% malted beans), E (70% broken rice +30% unmalted beans), F (30% broken rice +70% unmalted beans), G (60% broken rice +40% unmalted beans), H (40% broken rice +60% unmalted beans), and I (100% broken rice as the control)

Effect of malting on the in-vitro protein digestibility and bioavailability of zinc, iron and calcium of broken rice-iron rich beans composite

Table 8 shows that t IVPD and bioavailability of zinc, iron, and calcium in malted composite formulas (Composite A) for children aged 6-11 months had significantly higher digestible protein than the unmalted composite (Composite E) ($p \leq 0.05$). Similarly, for children aged 12-24 months, digestible protein was higher in Composite C (malted) than in Composite G (unmalted), although this difference was not statistically significant ($p > 0.05$). However, protein digestibility was significantly higher in the control (Composite I) compared to both malted and unmalted composites for the respective age groups ($p \leq 0.05$).

Regarding zinc bioavailability, Composite A (malted) had significantly lower bioavailable zinc than Composite E (unmalted) and the control in children aged 6-11 months ($p \leq 0.05$). Bioavailable iron and calcium

did not differ significantly between Composites A and E for the same age group ($p > 0.05$), although iron levels were significantly lower in the control compared to both composites ($p \leq 0.05$). For children aged 12-24 months, bioavailable iron was significantly higher in Composite C (malted) than in Composite G (unmalted) and the control ($p \leq 0.05$). In contrast, the control showed significantly higher bioavailable calcium compared to both malted and unmalted composites across the age categories ($p > 0.05$).

Discussion

Effect of malting on consumer sensory preference and acceptability of broken rice-iron rich bean composite flour

Food processing alters sensory characteristics, influencing acceptability and intake [55–57]. Sensory evaluation is therefore crucial in assessing consumer acceptance, especially when using locally available ingredients [58].

Table 8 In-vitro protein digestibility and bioavailability of zinc, iron and calcium in the malted and unmalted formulae segregated by age category

Parameter	Age category				
	Children 6-11 months		Children 12-24 months control		
	A	E	C	G	I
Protein digestibility (%)	33.16 ± 0.83 ^{ab}	14.36 ± 1.41 ^{bb}	12.35 ± 3.61 ^{ab}	8.71 ± 2.19 ^{ab}	95.29 ± 0.60 ^a
Zinc bioavailability (%)	4.72 ± 0.15 ^{aa}	10.66 ± 1.39 ^{bb}	4.14 ± 0.15 ^{aa}	10.70 ± 0.57 ^{ab}	0.06 ± 0.02 ^a
Iron bioavailability (%)	0.13 ± 0.01 ^{ab}	0.11 ± 0.02 ^{ab}	0.15 ± 0.01 ^{ab}	0.11 ± 0.00 ^{bb}	0.06 ± 0.02 ^a
Calcium bioavailability (%)	1.04 ± 0.05 ^{ab}	0.85 ± 0.02 ^{ab}	1.02 ± 0.09 ^{ab}	0.10 ± 0.02 ^{ab}	2.52 ± 0.49 ^a

Values are presented as mean ± standard deviation ($n=5$). Differences among means were determined using one-way analysis of variance (ANOVA), and where significant differences were observed, Tukey's HSD post-hoc test was applied at a significance level of $p \leq 0.05$. Within each row, means followed by different superscript letters indicate statistically significant differences, whereas means sharing the same superscript letter are not significantly different from each other. The composite flour formulations evaluated included: A (70% broken rice +30% malted beans), B (30% broken rice +70% malted beans), C (60% broken rice +40% malted beans), D (40% broken rice +60% malted beans), E (70% broken rice +30% unmalted beans), F (30% broken rice +70% unmalted beans), G (60% broken rice +40% unmalted beans), H (40% broken rice +60% unmalted beans), and I (100% broken rice as the control)

In the present study (Table 3), caregivers evaluated eight composite formulations based on appearance, aroma, taste, texture, and overall acceptability. For children aged 6-11 months, malted Composite A and unmalted Composite E were the most preferred, while for children aged 12-24 months, malted Composite C and unmalted Composite G were favored. The higher preference for these composites is likely due to their higher proportion of rice, which imparts an attractive light brown color with reddish undertones [59]. Similar results were reported by Adeyede [60], where cookies with 85% rice flour and 15% soybean flour were the most preferred.

The enhanced aroma in malted composites A and C can be attributed to malting, roasting, and extrusion, which reduce the beany odor and improve flavor [61–63]. Malting activates hydrolytic enzymes, producing volatile compounds that enhance aroma and palatability, consistent with findings by previous authors [64, 65]. Taste scores were highest for malted Composite C, likely due to its 60:40 rice-to-bean ratio, coupled with malting and roasting, improving palatability. This aligns with the findings of the previous studies [66], who reported improved taste in malting-processed soybean bread, and [67], where malting reduced bitterness in bean and cereal composites. Texture, a key determinant of palatability [68, 69], was significantly improved in malted Composite C for children aged 12-24 months compared to its unmalted counterpart ($p \leq 0.05$), while no difference was observed in the younger age group. These findings align with the findings of the previous studies by [70] and [71], who noted improved textural quality in malted finger millet flour and cassava, maize, and sorghum blends, respectively. Overall acceptability scores indicated that unmalted Composite E (6-11 months) and malted Composite C (12-24 months) were most preferred. Malting improves appearance, flavor, and color through enzyme activity and Maillard reactions [62, 72, 73]. These results highlight that malting can enhance sensory qualities and acceptability of complementary foods, though awareness and utilization in rural communities remain low to realize routine consumption.

Effect of malting on proximate profile and micronutrient composition of broken rice-iron rich beans composite

Proximate composition informs the nutritional contribution of complementary foods to recommended daily allowances [74, 75]. Malting significantly ($p \leq 0.05$) reduced moisture and crude fat in Composite C compared to unmalted Composite G and control I for children aged 12-24 months (Table 4), likely due to enzymatic and hydrolytic reactions and extrusion [76, 77]. Low moisture enhances shelf life by reducing microbial activity [78], while reduced fat may result from lipase activity,

hydrolyzing fats into glycerol and fatty acids [79]. Control I had significantly higher carbohydrates than Composites A and E for 6-11 months, possibly due to α -amylase inactivation during gelatinization [24]. Conversely, malted Composite C showed higher crude protein, fiber, ash, and carbohydrates compared to unmalted Composite G for 12-24 months ($p \leq 0.05$), consistent with findings of Shiriki et al. [80]. Increased fiber and protein are attributable to higher bean content, supporting growth and digestion in children [81, 82]. High fiber, however, may reduce micronutrient absorption and should be balanced [83].

Malting significantly increased magnesium and potassium in Composite A (6-11 months) and zinc, calcium, iron, magnesium, and potassium in Composite C (12-24 months) compared to unmalted composites and control ($p \leq 0.05$) (Table 5). This increase is likely due to macronutrient breakdown by microbial activity during malting, releasing minerals for bioavailability [84]. This increase may be due to breakdown of complex food structures during malting by micro-organisms, which makes minerals more available, as well as the contribution from iron-rich beans [84]. However, it is important to note that these values represent mineral concentrations per 100 g of product and not actual dietary intake. Therefore, the extent to which they meet RDAs depends on assumed daily consumption levels and bioavailability. Based on typical complementary feeding portion sizes for children aged 6-24 months, the observed mineral densities suggest that these formulations could contribute meaningfully toward meeting daily requirements when consumed in adequate quantities. Moreover, adequate intake of these minerals supports cognitive development, immune function, bone growth, and enzymatic function [40, 85, 86]. In Acholi sub-region that is affected by high prevalence of micronutrient and protein deficiencies, this composite provides a practical way to mitigate child undernutrition especially during complementary feeding.

Effect of malting on functional properties of broken rice-iron rich beans composite

Functional properties influence the quality, acceptability, and nutrient behavior of foods during processing and storage [56]. For infants aged 6-11 months, malted Composite A exhibited higher OAC but lower WAC, bulk density, and pH compared to unmalted Composite E ($p \leq 0.05$) (Table 6). Low WAC and bulk density facilitate the preparation of energy-dense, easy-to-swallow gruels, making the composite suitable for complementary feeding of young children [87, 88], while high OAC enhances flavor, texture, and mouthfeel [89]. For children aged 12-24 months, malted Composite C had significantly higher pH, likely due to ash and alkaline components

formed during malting [90, 91]. Although higher pH may favour microbial growth, lower pH in other composites can inhibit pathogens, improving shelf stability [92]. The observed functional changes suggest that malting improves the suitability of these composites as complementary foods by producing energy-dense, palatable, and safe gruels that are easier for infants and young children to consume. However, the microbial safety of these formulations should be further evaluated.

Effect of malting on anti-nutritional factors in the broken rice-iron rich beans composite

Anti-nutritional factors reduce nutrient bioavailability and interfere with protein digestion [93, 94]. In this study, malting, roasting, and extrusion reduced trypsin inhibitors and phytates in Composites A and C, though polyphenols and tannins increased in some composites (Table 7). High polyphenols in malted composites may result from roasting, which releases bound phenolic compounds and forms Maillard reaction products [63, 95]. Decreased phytates in Composite A may be due to phytase activation during malting, enhancing mineral bioavailability [56, 96]. Increased tannins in malted composites may reduce protein digestibility and micronutrient availability [24, 63, 97]. Trypsin inhibitor reduction is attributable to proteolytic enzyme activation and heat treatment during extrusion, improving protein digestibility [98]. Overall, traditional processing methods reduced some, but not all, anti-nutritional factors. However, our findings underscore an important contribution of the composite flour for improving nutrition status of children in regions of low socio-economic status such as Acholi. Future research should optimize malting conditions to further reduce polyphenols, tannins, and phytates, thereby maximizing nutrient bioavailability in complementary foods for children aged 6-24 months.

Effect of malting on the in-vitro protein digestibility and bioavailability of zinc, iron and calcium of broken rice-iron rich beans composite

Malting of broken rice-iron-rich bean composites improved IVPD and iron bioavailability, particularly in younger children (6-11 months) and children (12-24 months) (Table 8). Malted composites exhibited higher IVPD than unmalted ones, likely due to protease activation during malting that hydrolyzes complex proteins into more digestible forms [60, 71, 99]. However, the rice control exhibited the highest IVPD (95.29%) as shown in Table 8, which can be attributed to its simpler protein matrix and minimal anti-nutritional interference, resulting in easier enzymatic hydrolysis. In contrast, the incorporation of iron-rich bean flour in the composites

likely increased protein-protein interactions and structural complexity, thereby reducing enzyme accessibility and overall digestibility despite improved amino acid composition [100]. Iron bioavailability increased in malted composites, especially for older children, consistent with reduced phytic acid and enhanced mineral release [63, 97, 101]. Conversely, zinc bioavailability decreased in malted composites for younger children despite the increase in total mineral content, likely due to enhanced binding of zinc by polyphenols and tannins formed or released during germination, which can reduce mineral solubility and absorption [97, 102]. In contrast, calcium remained most bioavailable in the rice control, which may be associated with its lower levels of these chelating compounds and a simpler food matrix [103]. These findings suggest that malting may improve protein digestibility and may also enhance iron availability based on the in-vitro results, which could contribute to better nutritional quality of the food. However, the lower zinc and calcium bioaccessibility observed indicates that some nutrients may still be limited in how well they can be absorbed, meaning that additional approaches such as fortification or improved formulation may be needed. While the malted rice-bean composites show promise as nutrient-dense complementary foods based on in-vitro evidence, their nutritional benefits in children require confirmation through well-designed clinical feeding trials. Future studies should therefore evaluate the in-vivo bioavailability of these nutrients and their effects on child growth and nutritional status.

Strengths and limitations of the study

This study has several strengths. It used locally available broken rice and iron-rich beans to develop affordable and culturally acceptable complementary foods. Standard laboratory methods were applied to assess proximate composition, minerals, anti-nutritional factors, and in-vitro digestibility, and the formulations were evaluated for two child age groups (6-11 and 12-24 months). Sensory evaluation also provided useful insights into acceptability. However, there are some limitations such as the findings being based on in-vitro analyses, which may not fully reflect nutrient absorption in children. Acceptability was based on caregiver feedback, and only malting was assessed without comparing other processing methods. The study also did not examine long-term outcomes such as growth or hemoglobin status, and variation in raw materials may affect consistency. In addition, laboratory analyses were carried out in duplicate due to limited resources, which may slightly reduce statistical precision. Further studies using in-vivo and longitudinal designs are needed to confirm these findings.

Conclusions

This study demonstrated that malting broken rice and iron-rich beans improved the nutritional quality of complementary foods by enhancing protein digestibility, increasing the in-vitro bioaccessibility of iron, magnesium, and potassium, and reducing anti-nutritional factors such as phytates and trypsin inhibitors. Sensory evaluation also showed good acceptability, with malted composites being more preferred for children aged 12–24 months, while unmalted composites were better accepted for those aged 6–11 months. These findings highlight the potential of locally available, low-cost ingredients processed through malting to improve the nutritional quality of culturally acceptable complementary foods. The improved in-vitro iron availability suggests that these formulations could contribute to better dietary iron intake among young children. To maximize these benefits, malting should be promoted at household and community levels through nutrition education, practical demonstrations, and Infant and Young Child Feeding counselling. Caregivers should also be encouraged to combine the composite with zinc- and calcium-rich foods, such as groundnuts, sesame seeds, silver fish, and dark green leafy vegetables, to improve the overall nutritional quality of complementary diets. Integrating these composite flours into early childhood feeding programmes could further support improved infant and young child nutrition. However, because these findings are based on in-vitro analyses, their effects on iron status, growth, and overall child health require confirmation through clinical feeding trials. Future research should therefore include feeding studies, growth monitoring, and haemoglobin assessment to establish long-term effectiveness and generate evidence to inform policy and wider community adoption.

Abbreviations

AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of Variance
CRD	Completely Randomized Design
HDPE	High-Density Polyethylene
ICF	Inner City Fund
IVPD	In-vitro Protein Digestibility
ISO	International Organization for Standardization
LC1	Local Council One
NaCRRI	National Crops Resources Research Institute
NARO Bean 3	National Agricultural Research Organization Bean 3
RDA	Recommended Dietary Allowance
UBOS	Uganda Bureau of Statistics
WHO	World Health Organization

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Authors' contributions

****CA:**** Conception and design, data collection, analysis and interpretation, drafting of the manuscript. ****SMO:**** Conception and design, analysis and interpretation, drafting of the manuscript, review and editing. ****CM:**** Conceptualization, data curation, formal analysis, software, supervision, writing, review and editing. ****BM:**** Critical review of the concept, supervision, review, editing and final approval of the draft manuscript for publication.

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Data availability

The datasets generated and/or analyzed during this study are not publicly available to protect participant confidentiality but can be obtained from the corresponding author on [sundaymarkoyet@gmail.com] (mailto:sundaymarkoyet@gmail.com) upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). Ethical clearance was obtained from the Gulu University Research Ethical Committee (GUREC) (Application No. GUREC-030–20). Permission was sought from the Chief Administrative Officers (CAOs) of the study districts, Senior Assistant Accountants of the respective sub-counties, and Local Council Ones (LC1s) of the respective villages. Verbal consent was obtained from all participants before enrollment, and participants were informed of their right to withdraw at any time without penalty. Additionally, the health and well-being of participants were prioritized throughout the study, with measures taken to ensure that participation posed no risk to their physical or nutritional health.

Consent for publication

Not applicable. This manuscript does not contain any identifiable personal information from participants, including images or videos, in any form.

Competing interests

The authors declare no competing interests.

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