


Research Article

Sensory Evaluation of Fortified Sorghum Porridges with Underutilized Tropical Plant Foods for Improved Iron Content and Consumer Acceptability in Western Kenya

Erich Midigo^{1*}, James Otieno^{2*}, Peter Akomo¹, Oscar Kambona³, Sylus Okumu², Augustine Majiwa¹, Nyambura Kogi¹, Lilian Adongo¹, Charchil Ayodo¹, George Ayodo²

Abstract

Sorghum (*Sorghum bicolor*) is a major staple cereal in sub-Saharan Africa, valued for its resilience and suitability for low-input farming systems, but limited by the low bioavailability of key micronutrients, particularly iron. Food-to-food fortification (FtFF) using locally available, underutilized tropical plant foods offers a culturally appropriate strategy that can potentially improve both nutrient density and sensory quality of sorghum-based foods. This study evaluated FtFF by blending red sorghum with orange-fleshed sweet potato (OFSP), amaranth grains, pumpkin seeds, mango, and guava. Composite flours were prepared in varied ratios of the fortificants, while the control contained only sorghum flour. Five formulations (one control, four fortified) were produced. The two best-performing fortified samples were selected for detailed analysis. Porridges were prepared under standardized laboratory conditions and evaluated by 120 panelists (trained and untrained) using a nine-point hedonic scale to assess appearance, color, taste, aroma, thickness, and overall acceptability. Iron content was determined using AOAC Official Method 999.11. Fortification did not compromise appearance, aroma, or thickness, while significantly improving taste ($p < 0.05$) and overall acceptability ($p < 0.05$). Iron content increased by 362–428% compared to the control, meeting or exceeding the Recommended Dietary Allowance (RDA) for preschool and school going children (102–190% of RDA) and contributing substantially to maternal requirements (42–49% of RDA). These results demonstrate that FtFF using locally available plant foods can produce a culturally acceptable, iron-rich sorghum porridge with enhanced sensory and nutritional qualities, offering a scalable approach to improve nutritional intake among at-risk consumers of staple cereal diets.

Keywords: Sensory evaluation; Sorghum; Food-to-food fortification; Iron content

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a major staple cereal across sub-Saharan Africa (SSA), valued for its drought resistance and suitability for low-input farming systems (Anyango et al., 2021). Despite its resilience and widespread consumption, sorghum-based porridges are limited by poor bioavailability of key micronutrients, particularly iron, due to the presence of inhibitors such as phytates (Oduro et al., 2018). Low mineral and nutrient bioavailability contribute to “hidden hunger,” particularly among infants, young children, and women of reproductive age from rural, low-income

Affiliation:

¹Ndaloh Heritage Organization, Bondo, Kenya

²Centre for Community Health and Wellbeing, Jaramogi Oginga Odinga University of Science and Technology, Bondo, Kenya.

³County Government of Siaya, Department of Health and Sanitation (Nutrition Unit), Siaya, Kenya.

*Corresponding author:

1. Erich Midigo Ndaloh Heritage Organization, Bondo, Kenya.

2. James Otieno, Centre for Community Health and Wellbeing, Jaramogi Oginga Odinga University of Science and Technology, Bondo, Kenya.

Citation: Erich Midigo, James Otieno, Peter Akomo, Oscar Kambona, Sylus Okumu, Augustine Majiwa, Nyambura Kogi, Lilian Adongo, Charchil Ayodo, George Ayodo. Sensory Evaluation of Fortified Sorghum Porridges with Underutilized Tropical Plant Foods for Improved Iron Content and Consumer Acceptability in Western Kenya. *Journal of Food Science and Nutrition Research*. 9 (2026): 38-47.

Received: March 30, 2026

Accepted: April 13, 2026

Published: June 17, 2026

households who rely heavily on cereal-based diets with limited dietary diversity (Low et al., 2017). Enhancing both the nutrient density and sensory quality of sorghum porridges represents a strategic pathway to strengthen nutrition security among at-risk populations in SSA.

Food-to-food fortification (FtFF) is emerging as a sustainable, culturally appropriate, and food-system-sensitive approach to improving the micronutrient quality and sensory properties of staple diets, particularly in low-income settings where access to industrial fortification or supplements is limited (Thompson, 2007; Olney, Rawat & Ruel, 2012). By combining staple foods with locally available, micronutrient-dense ingredients, FtFF leverages indigenous food resources and culinary practices to enhance nutrient density and bioavailability while maintaining dietary acceptability. Ingredients such as orange-fleshed sweet potato (OFSP), mango, guava, pumpkin seeds, and amaranth grains are naturally rich in provitamin A carotenoids, essential minerals, dietary fiber, and health-promoting lipids, making them suitable fortificants within traditional food systems (Abong et al., 2010; Low et al., 2017). Their integration into sorghum porridges can simultaneously address nutrient deficiencies and enhance sensory attributes such as appearance, color, taste, and aroma, which are key determinants of consumer acceptability (Anyango et al., 2021; Oduro et al., 2018).

Previous research has shown that OFSP and mango improve the visual appeal and color intensity of cereal-based foods due to their β -carotene and natural pigment content (Low et al., 2017). Similarly, guava and mango provide natural sweetness and characteristic fruity aromas that enhance consumer preference (Abong et al., 2010). Amaranth grains and pumpkin seeds contribute minerals, high-quality proteins, and desirable nutty flavors, positively influencing taste and texture (Oduro et al., 2018; Oluwamukomi et al., 2011). However, despite growing interest in FtFF, few studies have comprehensively evaluated the combined sensory performance and nutrient enhancement resulting from multi-ingredient blends incorporating cereals, fruits, and seeds.

The present study, therefore, examined the sensory attributes and iron content of fortified sorghum porridges developed by blending red sorghum flour with OFSP, amaranth grains, pumpkin seeds, mango, and guava flours. Furthermore, the study evaluated the potential of sorghum porridge food-to-food fortification (FtFF) using underutilized tropical plant foods, assessing both acceptability and iron content. Generating this evidence is essential for designing nutrient-dense, culturally acceptable, and locally scalable fortified porridge formulations that can strengthen nutritional adequacy and dietary quality among

children and women and support resilient community-based food systems.

Materials and Methods

Study design and description of the study site

This study employed an experimental laboratory-based food formulation and sensory evaluation design. Composite sorghum porridges were developed using underutilized, locally available tropical plant foods, followed by consumer acceptability and descriptive sensory evaluation, as well as laboratory determination of iron content in selected formulations. The study followed a completely randomized design (CRD) with five porridge formulations (one control and four fortified), with sensory attributes and iron content as outcome variables.

The study was conducted in Siaya County, western Kenya, with raw materials sourced from smallholder farmers in Gem and Rarieda sub-counties. Located within the Lake Victoria Basin, Siaya County is predominantly rural, with sorghum serving as a major staple crop. The county experiences periodic food insecurity and a high burden of malnutrition. According to the Kenya Demographic and Health Survey (KDHS, 2022), moderate stunting in children was 19.2 %, above the national estimate of 17.5 %, severe stunting was 5.3 % compared with 4.2 % nationally, and severe underweight affected 1.1 % of children, higher than the national figure of 0.6 % (KDHS, 2022).

Materials for composite sorghum porridges

Red sorghum (*Sorghum bicolor*), amaranth grain (*Amaranthus* spp.), orange-fleshed sweet potato (*Ipomoea batatas*), pumpkin seeds (*Cucurbita pepo*), ripe mangoes (*Mangifera indica*), and guavas (*Psidium guajava*)—used as sources of natural sugars, organic acids, and flavour-enhancing compounds—were obtained from demonstration farms and smallholder farmers in Gem and Rarieda sub-counties, Siaya County, Kenya. All raw materials were transported to the laboratory and stored at optimum temperatures in tightly sealed zip bags until further analysis.

Preparation of fortified sorghum composite flours and porridges

Sorghum grains were first cleaned, sorted, washed, and soaked in clean water, and finally germinated for 4 days at ambient temperature (25–30 °C). After germination, the grains were washed, sun-dried, and lightly roasted to enhance flavor and reduce antinutritional factors. Amaranth grains were cleaned and roasted, sun dried while pumpkin seeds were soaked, dried, and roasted to improve flavor and nutrient availability. Orange-fleshed sweet potato (OFSP), mangoes, and guavas were processed into dried flours through washing, peeling (where applicable), slicing, and drying.

All processed materials were milled into fine flours using a laboratory mill. Composite flour blends were then prepared by combining sorghum flour with the nutrient-dense plant-based ingredients (amaranth, pumpkin seeds, OFSP, mango, and guava) in predetermined ratios designed to enhance micronutrient content while maintaining sensory acceptability. The control formulation contained only sorghum flour, while the other blends incorporated additional plant-based ingredients to enhance micronutrient content, as shown in table 1.

Porridge Preparation and Sensory Evaluation

For sensory and nutritional evaluation, the composite flours were cooked into porridge using standard household methods. Each flour blend was mixed with water at a ratio of approximately 1-part flour to 3 parts water to achieve a smooth, uniform consistency. The mixtures were heated while stirring until fully cooked, ensuring all samples had a consistent texture. Porridges were then allowed to cool to a suitable temperature prior to consumption. The sequence of composite flour preparation and the corresponding porridge formulations is illustrated in Sensory evaluation was conducted under standardized laboratory conditions using 120 panelists, comprising 60 trained and 60 untrained participants. The trained panelists were students from the Commonwealth University of Medical Sciences, Kisumu, with prior exposure to basic sensory evaluation procedures. The untrained panelists consisted of women of reproductive age from Gem and Rarieda sub-counties, representing potential end-users and acting as proxies for caregivers of young children within the first 1,000 days of life.

A nine-point hedonic scale was used to assess general appearance, colour, taste, aroma, thickness, and overall acceptability (1 = dislike extremely, 9 = like extremely). All preparation, serving, and evaluation procedures were standardized to ensure comparability of results across formulations.



Figure 1: Composite flours and porridge formulations.

Iron Content analysis of selected samples

Based on the results of sensory evaluation, three formulations (Sample 1, Sample 4, and Sample 5) were selected for iron analysis due to their higher overall acceptability. Iron content was determined using AOAC Official Method 999.11 (Association of Official Analytical Chemists [AOAC], 2002)

Composite flour samples were analysed in triplicate, and iron concentration was expressed as milligrams per 100 g of dry weight (mg/100 g). The iron content of the fortified formulations was compared with that of the control sample (Sample 1), and percentage increases in iron content were calculated. To assess the nutritional relevance of the formulations, iron values were further expressed as the percentage contributions for pregnant women and children aged 7 months to 3 years.

Statistical Analysis

Sensory evaluation data were analyzed using the Statistical Package for Social Sciences (SPSS) version 21. Mean scores and standard deviations were calculated for each sensory attribute. One-way analysis of variance (ANOVA) was performed to determine significant differences among samples. Where significant differences were observed, mean separation was conducted using Tukey's test or the Games-Howell test as appropriate. Statistical significance

Table 1: Composition of Fortified Sorghum Composite Flour Formulations

Formulation	Ingredients					
	Sorghum	OFSP	Amaranth	Pumpkin seeds	Guava	Mango
Sample1 (Control)	✓	-	-	-	-	-
Sample 2	✓	✓	✓	✓	✓	✓
Sample 3	✓	✓	✓	✓	✓	-
Sample 4	✓	✓	✓	✓	✓	✓
Sample 5	✓	✓	✓	✓	✓	✓

*OFSP = Orange-Fleshed Sweet Potato: ✓ indicates ingredient inclusion, – indicates absence.

was considered at $p < 0.05$. Iron content data were analyzed descriptively and expressed as: mean iron content (mg/100 g), percentage increase relative to the control formulation, and percentage contribution to the RDA for pregnant women and children aged 7 months to 3 years.

Ethical Approval Statement

The County Health Research Committee of the Siaya County Government reviewed and approved the request to conduct this project as part of an initiative aimed at improving household food security, nutrition, and socioeconomic empowerment among rural households in Siaya County, Kenya, implemented by Ndaloh Heritage Organization. The Committee determined that the activity is exempt from human subjects oversight, and formal authorization for ethics exemption was granted. The project activities were conducted under the oversight of the County Nutrition Officer and the respective Sub-County Nutrition Officers.

Results

Sensory Evaluation of Fortified Sorghum Porridge

Sensory characteristics of the fortified sorghum porridge formulations were evaluated by both trained and untrained panelists to assess product acceptability and consumer preference. The trained panelists provided analytical assessments based on prior exposure to sensory evaluation techniques, while the untrained panelists represented potential end-users and reflected typical consumer perceptions. All attributes—general appearance, colour, taste, aroma, thickness, and overall acceptability—were rated using a nine-point hedonic scale. Mean scores, standard deviations, and descriptive statistical analyses for each formulation are presented in Tables 2 and 3.

The combined use of trained and untrained panelists allowed for a comprehensive interpretation of sensory quality by capturing both subtle analytical differences and practical consumer acceptance.

General Appearance

General appearance is a critical sensory attribute because it strongly influences first impressions and consumers' willingness to try a food product. Across all formulations, mean appearance scores were above the midpoint of the hedonic scale for both trained and untrained panelists, indicating good overall visual acceptability of the porridges.

Among trained panelists (Table 2), mean general appearance scores ranged from 6.17 ± 0.94 to 6.50 ± 1.09 . Sample 4 received the highest score (6.50 ± 1.09), followed by Sample 1 (6.25 ± 1.86) and Sample 5 (6.17 ± 0.94). However, no statistically significant differences were observed among the formulations ($p > 0.05$), suggesting that trained assessors perceived the visual attributes of the porridges as largely comparable.

Similarly, among untrained panelists (Table 3), mean scores ranged from 5.83 ± 1.64 to 7.08 ± 0.90 . Sample 5 recorded the highest appearance score (7.08 ± 0.90), followed by Sample 4 (6.33 ± 1.50), while Sample 1 received the lowest score (5.83 ± 1.64). As with the trained panel, these differences were not statistically significant ($p > 0.05$).

Thus, the consistently acceptable appearance scores across both panels indicate that food-to-food fortification with the locally sourced ingredients did not negatively affect the visual quality of sorghum porridge. This is particularly important for consumer acceptance, as appearance is a key determinant of initial product appeal for cereal-based staple foods.

Colour

Colour is a key sensory attribute that contributes to visual appeal and strongly influences consumer expectations prior to tasting. Differences in colour perception can therefore affect product acceptability, particularly in fortified cereal-based foods.

Table 2: Mean sensory scores of fortified sorghum porridge evaluated by trained panelists.

Sample	General appearance	Color	Taste	Aroma	Thickness	Overall acceptability
Sample 1	$6.25^a \pm 1.86$	$6.75^a \pm 0.97$	$5.08^a \pm 1.56$	$6.75^a \pm 1.71$	$5.25^a \pm 1.96$	$6.02^a \pm 0.85$
Sample 4	$6.50^a \pm 1.09$	$6.25^a \pm 0.75$	$6.08^{ab} \pm 1.31$	$7.00^a \pm 1.60$	$6.08^a \pm 1.51$	$6.38^a \pm 0.58$
Sample 5	$6.17^a \pm 0.94$	$8.00^b \pm 0.43$	$7.17^b \pm 0.72$	$6.83^a \pm 0.58$	$6.17^a \pm 0.72$	$6.87^b \pm 0.35$

Means with different superscript letters within a column are significantly different ($p < 0.05$). Values are mean \pm standard deviation ($n = 60$).

Table 3: Mean sensory scores of fortified sorghum porridge evaluated by untrained panelists

Sample	General appearance	Color	Taste	Aroma	Thickness	Overall acceptability
Sample 1	$5.83^a \pm 1.64$	$6.67^a \pm 1.37$	$4.92^a \pm 1.31$	$6.50^a \pm 1.62$	$6.92^a \pm 1.51$	$6.17^a \pm 0.64$
Sample 4	$6.33^a \pm 1.50$	$6.33^a \pm 0.78$	$6.83^b \pm 0.94$	$6.92^a \pm 1.62$	$6.33^a \pm 1.44$	$6.55^b \pm 0.67$
Sample 5	$7.08^a \pm 0.90$	$6.75^a \pm 0.62$	$7.08^b \pm 1.51$	$6.67^a \pm 0.98$	$6.00^a \pm 0.60$	$6.72^b \pm 0.44$

Means with different superscript letters within a column are significantly different ($p < 0.05$). Values are mean \pm standard deviation ($n = 60$).

Among trained panelists (Table 2), mean colour scores ranged from 6.25 ± 0.75 to 8.00 ± 0.43 . Sample 5 recorded the highest colour score (8.00 ± 0.43), followed by Sample 1 (6.75 ± 0.97), while Sample 4 received the lowest score (6.25 ± 0.75). These differences were statistically significant ($p < 0.05$), indicating that fortification significantly influenced colour perception among trained assessors, who are typically more sensitive to subtle visual variations.

In contrast, among untrained panelists (Table 3), mean colour scores ranged from 6.33 ± 0.78 to 6.75 ± 0.62 . Sample 5 again recorded the highest score (6.75 ± 0.62), followed by Sample 1 (6.67 ± 1.37), while Sample 4 had the lowest score (6.33 ± 0.78). However, these differences were not statistically significant ($p > 0.05$), suggesting that although trained panelists detected distinct colour variations, these differences were not sufficiently pronounced to influence colour preference among general consumers.

The results indicate that food-to-food fortification enhanced the visual colour attributes of sorghum porridge without compromising consumer acceptability. The greater sensitivity observed among trained panelists highlights the role of panel expertise in detecting formulation-driven colour changes, while the consistently acceptable scores among untrained panelists suggest favourable market-level acceptance.

Taste

Taste is a critical determinant of food acceptance and consumer preference, particularly for staple foods consumed regularly. In this study, taste emerged as a key attribute differentiating fortified formulations from the control among both trained and untrained panelists. Among trained panelists (Table 2), mean taste scores ranged from 5.08 ± 1.56 to 7.17 ± 0.72 . Sample 5 recorded the highest score (7.17 ± 0.72), followed by Sample 4 (6.08 ± 1.31), while Sample 1 (control) received the lowest score (5.08 ± 1.56). The difference between the highest-scoring fortified formulation and the control was statistically significant ($p < 0.05$), indicating that food-to-food fortification positively influenced taste perception among trained assessors. Similarly, among untrained panelists (Table 3), mean taste scores ranged from 4.92 ± 1.31 to 7.08 ± 1.51 . Sample 5 achieved the highest score (7.08 ± 1.51), followed by Sample 4 (6.83 ± 0.94), while Sample 1 recorded the lowest score (4.92 ± 1.31). Both Sample 4 and Sample 5 were rated significantly higher than the control ($p < 0.05$).

The consistency in taste preference patterns across trained and untrained panelists indicates that flavour improvements introduced through food-to-food fortification were not only perceptible to trained assessors but also meaningful and acceptable to potential consumers.

Aroma

Aroma is an important sensory attribute that influences initial consumer perception and overall acceptability of porridge. In this study, aroma scores were generally similar across all formulations. Among trained panelists (Table 2), mean aroma scores ranged from 6.75 ± 1.71 to 7.00 ± 1.60 . Sample 4 recorded the highest score (7.00 ± 1.60), followed closely by Sample 5 (6.83 ± 0.58), while Sample 1 received the lowest score (6.75 ± 1.71). However, no statistically significant differences were observed among formulations ($p > 0.05$).

Likewise, among untrained panelists (Table 3), aroma scores ranged from 6.50 ± 1.62 to 6.92 ± 1.62 , with Sample 4 recording the highest score and Sample 1 the lowest. These differences were also not statistically significant ($p > 0.05$).

The similarity in aroma scores across both panelist groups suggests that food-to-food fortification preserved the characteristic aroma of sorghum porridge, thereby maintaining familiarity and overall sensory acceptability.

Thickness

Thickness is an important quality attribute of porridge, influencing texture perception, mouthfeel, and ease of consumption. Thickness scores did not differ significantly among formulations for either group of panelists. Among trained panelists (Table 2), mean thickness scores ranged from 5.25 ± 1.96 to 6.17 ± 0.72 . Sample 5 recorded the highest score (6.17 ± 0.72), followed by Sample 4 (6.08 ± 1.51), while Sample 1 received the lowest score (5.25 ± 1.96). These differences were not statistically significant ($p > 0.05$). Similarly, among untrained panelists (Table 3), thickness scores ranged from 6.00 ± 0.60 to 6.92 ± 1.51 . Sample 1 recorded the highest score (6.92 ± 1.51), followed by Sample 4 (6.33 ± 1.44), while Sample 5 recorded the lowest score (6.00 ± 0.60). No significant differences were observed among formulations ($p > 0.05$).

The absence of significant differences in thickness indicates that food-to-food fortification did not compromise porridge texture—an attribute closely linked to cultural expectations, ease of feeding, and habitual consumption of cereal-based porridges.

Overall acceptability

Overall acceptability represents the combined sensory response of panelists to all evaluated attributes and provides an integrated measure of product preference. Among trained panelists (Table 2), mean overall acceptability scores ranged from 6.02 ± 0.85 to 6.87 ± 0.35 . Sample 5 recorded the highest score (6.87 ± 0.35), followed by Sample 4 (6.38 ± 0.58), while Sample 1 (control) received the lowest score (6.02 ± 0.85). These differences were statistically significant

($p < 0.05$), indicating a clear preference for the fortified formulations over the control.

Similarly, among untrained panelists (Table 3), overall acceptability scores ranged from 6.17 ± 0.64 to 6.72 ± 0.44 . Sample 5 achieved the highest score (6.72 ± 0.44), followed by Sample 4 (6.55 ± 0.67), while Sample 1 recorded the lowest score (6.17 ± 0.64). Both Sample 4 and Sample 5 were rated significantly higher than the control ($p < 0.05$).

The comparable preference patterns observed among trained and untrained panelists suggest that the fortified porridges were not only sensorially superior under controlled evaluation but are also likely to be well accepted by consumers in real-life consumption settings. The integrated sensory performance of the selected formulations is further illustrated using a radar chart (Figure 2), which visually compares mean scores across all evaluated attributes. Sample 1 (control) exhibited a narrower sensory profile, reflecting lower mean scores across several attributes. In contrast, Sample 5 demonstrated a broader sensory profile, with pronounced extensions along the colour and taste axes, corresponding to its higher ratings for these attributes. Sample 4 displayed a more evenly distributed sensory profile, indicating balanced performance across appearance, aroma, taste, colour, and thickness.

Overall, the radar chart confirms that food-to-food fortification enhanced key sensory attributes—particularly taste and colour—while maintaining acceptable appearance, aroma, and thickness. The expanded and balanced sensory profiles observed for Sample 4 and Sample 5 are consistent with their significantly higher overall acceptability scores compared with the control formulation.

Iron content analysis

Based on the results of sensory evaluation, three

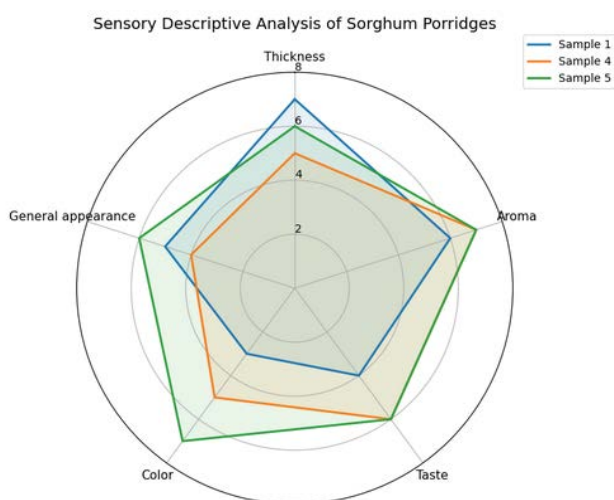


Figure 2: Mean sensory scores of selected fortified sorghum porridge formulations ($n = 60$).

formulations (Sample 1, Sample 4, and Sample 5) were selected for iron analysis due to their higher overall acceptability. Iron content was determined using AOAC Official Method 999.11 (Association of Official Analytical Chemists [AOAC], 2002). The iron content of the selected formulations, expressed as milligrams per 100 g of dry weight (DW), and the percentage increase relative to the control sample are presented in table 4.

Table 4: Iron content of selected sorghum formulations and percentage increase in iron across the formulations.

Formulation	Mean Fe content (mg/100g DW) ¹	% iron increase compared to the control
Sample 1 (control) ³	3.11	-
Sample 4	11.255	361.897
Sample 5	13.32422	428.424

Values represent single analyses on a DW basis, with a quality control (in-house control sample) included in each set and/or batch of samples analysed.

¹DW; Dry weight

²Iron content was determined using AOAC Official Method 999.11

³Control was used as a reference for the other porridge samples

As shown in table 4, the control formulation, Sample 1, recorded the lowest iron content at 3.110 mg/100g DW. In comparison, Sample 4 had an iron content of 11.255 mg/100g DW, representing a 361.90% increase relative to the control. Sample 5 recorded the highest iron content at 13.324 mg/100g DW, corresponding to a 428.42% increase above Sample 1.

Contribution of Iron Content to Recommended Dietary Allowances (RDA)

To further quantify the nutritional contribution of the fortified sorghum formulations, the iron content of the selected samples was expressed as a percentage contribution to the RDA for pregnant women and young children. Percentage contributions for pregnant women and children aged 7 months to 3 years. The percentage contribution of iron from each formulation to the respective RDAs are presented in table 5.

As presented in table 5, Sample 1 contributed 11.52% of the iron RDA for pregnant women, 28.27% for children aged 7–12 months, and 44.43% for children aged 1–3 years. Higher contributions were observed for the fortified formulations. Sample 4 contributed 41.69% of the iron RDA for pregnant women, 102.32% for children aged 7–12 months, and 160.79% for children aged 1–3 years. Sample 5 contributed 49.35% of the iron RDA for pregnant women, 121.13% for children aged 7–12 months, and 190.32% for children aged 1–3 years.

The lab analysis showed that food-to-food fortification

Table 5: Iron content of the three sorghum formulations and the % RDA contribution for pregnant women and children aged 7 months to 3 years.

Formulation	Fe content (mg/100g DW)	% RDA pregnant women	% RDA children 7 - 12 months	% RDA children 1 - 3 years
Sample 1	3.11	11.519	28.273	44.429
Sample 4	11.255	41.685	102.318	160.786
Sample 5	13.324	49.348	121.127	190.323

*Fe RDA: pregnant women = 27mg/day, children 7 -12 months = 11mg/day, children 1 -3 years = 7mg/day; DW; Dry weight

Values represent single analyses on a DW basis, with a quality control (in-house control sample) included in each set and/or batch of samples analysed.

increased the iron content of sorghum porridge, which may potentially help support the iron requirements of children and pregnant women.

Discussion

The present study demonstrates that food-to-food fortification of sorghum flours using underutilized tropical plant foods can enhance micronutrient content while maintaining acceptable sensory characteristics. In line with formulation and sensory evaluation literature, the findings confirm that successful fortified cereal products must achieve a balance between nutritional enhancement and consumer acceptability, particularly when targeting nutritionally vulnerable populations such as pregnant women and young children (Muhimbula et al., 2011; Okoth et al., 2017).

The absence of significant differences in general appearance, aroma, and thickness across formulations indicates that the inclusion of amaranth, orange-fleshed sweet potato (OFSP), pumpkin seeds, mango, and guava did not adversely affect the core sensory attributes of sorghum flour-based porridges. Similar outcomes have been reported in composite flour studies, where incorporation of legumes, seeds, and fruits maintained acceptable appearance and consistency when ingredient proportions were appropriately optimized (Muhimbula et al., 2011; Oluwamukomi et al., 2011). This is particularly important for cereal-based porridges, as undesirable changes in viscosity or visual appeal are common barriers to adoption of fortified products.

Significant differences observed for colour, taste, and overall acceptability highlight the influence of ingredient functionality on consumer perception. Formulations with higher proportions of OFSP and mango flour, particularly Sample 5, achieved superior colour scores among trained panelists. This finding is consistent with previous sensory formulation studies attributing improved colour intensity and visual appeal to natural carotenoid pigments present in OFSP and fruits (Low et al., 2017; Tumuhimbise et al., 2019). Colour has been shown to strongly shape perceived quality and willingness to consume cereal-based foods, especially among adult caregivers who make household feeding decisions (Muhimbula et al., 2011).

Taste emerged as a critical determinant of acceptability across both trained and untrained panelists. Higher taste scores recorded for Sample 4 and Sample 5 are likely due to the combined contribution of mango flour, pumpkin seed flour, and amaranth, which impart natural sweetness, improved mouthfeel, and mild nutty flavours. Comparable trends have been reported in composite flour studies, where moderate inclusion of fruits and lipid-rich seeds enhances palatability and reduces the bland or astringent characteristics often associated with sorghum-based products (Sengev et al., 2012; Habiba et al., 2021). The consistency in preference patterns between trained and untrained panelists further suggests that these formulations align with general consumer expectations rather than expert-only sensory perceptions.

Overall acceptability reflected the combined influence of individual sensory attributes and followed a pattern similar to that observed for taste and color. The higher acceptability scores for fortified formulations, particularly Sample 5, indicate that nutritional enhancement did not compromise consumer preference. This observation supports findings from formulation studies emphasizing that acceptability is maximized when nutrient-dense ingredients are incorporated at levels that enhance, rather than overwhelm, the sensory profile of the base cereal (Muhimbula et al., 2011; Anyango et al., 2021).

Beyond sensory quality, the fortified formulations demonstrated marked improvements in iron content, highlighting the nutritional significance of the formulation approach. The higher iron levels observed in Sample 4 and Sample 5 can be attributed to the inclusion of iron-dense ingredients such as amaranth leaves, pumpkin seeds, and selected fruit components, which are recognized sources of dietary iron. In addition, processing techniques applied in this study, including germination and roasting, are known to reduce antinutritional factors—particularly phytates—and thereby increase measurable mineral content and potential bioaccessibility (Egli, 2001; Mohamed et al., 2007). Comparable increases in iron content have been reported in cereal-based composite foods fortified with legumes, seeds, and fruits rich in minerals and organic acids, supporting the effectiveness of multi-ingredient formulation strategies for improving micronutrient density (Okoth et al., 2017; Oduro et al., 2018).

The contribution of fortified formulations to the recommended dietary allowance for iron highlights their potential nutritional impact among vulnerable groups. The ability of Sample 4 and Sample 5 to meet or exceed daily iron requirements for young children, while providing substantial proportions of maternal iron needs, supports the use of food-based strategies for addressing iron deficiency. Compared with supplementation, food-based approaches offer advantages, including habitual consumption, cultural familiarity, and a reduced risk of excessive intake (Bailey et al., 2015).

The inclusion of provitamin A-rich ingredients such as OFSP, mango, and guava is particularly relevant for pregnant women. High-dose vitamin A supplementation is generally discouraged during pregnancy due to potential teratogenic risks associated with preformed vitamin A, whereas provitamin A carotenoids from plant sources are considered safe because their conversion to active vitamin A is physiologically regulated (FAO/WHO, 2004; Allen, 2012). Consequently, the formulation approach adopted in this study provides a nutritionally appropriate means of improving vitamin A intake through regular dietary practices rather than pharmacological intervention.

The findings in this study align with the formulation and sensory evaluation research by Muhimbula et al., (2011) demonstrating that multi-ingredient composite flours can deliver meaningful nutritional benefits while maintaining sensory acceptability when ingredient selection and proportions are carefully optimized. The superior performance of Sample 5 underscores the importance of balancing cereals, fruits, and seeds to produce formulations that are nutritionally valuable, culturally acceptable, and suitable for integration into community-based nutrition.

This study had several limitations that should be considered when interpreting the findings. First, the iron analysis quantified the total iron content of the fortified sorghum formulations but did not directly assess iron bioavailability or absorption. Although the formulation strategy incorporated ingredients and processing methods known to enhance non-heme iron bioavailability, such as the inclusion of vitamin C-rich fruits and the use of plant-based ingredients with reduced antinutritional factors, the extent to which the measured iron would be absorbed and utilized *in vivo* was not determined. Future studies incorporating *in vitro* or *in vivo* bioavailability assessments are therefore recommended.

Second, sensory evaluation was conducted among trained panelists and adult untrained consumers, rather than across all population groups targeted by the fortified porridge formulations within the first 1,000 days of life. While adult participants adequately represented women of reproductive age, pregnant, and lactating women, direct sensory evaluation by young children aged 0–3 years was not feasible due to

ethical and practical constraints. Consequently, caregiver perception was used as a proxy for child acceptability, which may not fully reflect infant and young child feeding responses.

Third, although the number of trained and untrained panelists was adequate for detecting differences in sensory acceptability among formulations, the findings may not be generalizable beyond the study population and setting. Sensory preferences can vary across different cultural and socio-economic contexts, and broader consumer testing may be required to confirm acceptability at the population level.

Finally, the sensory evaluation was conducted under controlled preparation and evaluation conditions, which may differ from typical household preparation practices. Variations in preparation methods at the household level could influence porridge consistency, flavor, and overall acceptability.

Despite these limitations, the study provides valuable evidence on the potential of fortified sorghum-based porridges to enhance iron content while maintaining acceptable sensory qualities, supporting their further development and evaluation for use among nutritionally vulnerable populations.

Conclusions and Recommendations

This study demonstrates that food-to-food fortification of sorghum porridge using underutilized, locally available plant ingredients such as amaranth grains, orange-fleshed sweet potatoes, pumpkin seeds, mangoes, and guava can substantially enhance mineral content without compromising sensory acceptability. The fortified porridges show strong potential to contribute substantially to recommended dietary iron intakes for young children and women of reproductive age, underscoring their relevance for addressing micronutrient deficiencies in staple cereal-dependent communities.

Further research is recommended to evaluate iron bioavailability using *in vitro* and *in vivo* methods, assess long-term consumer adoption and cost-effectiveness, and determine impacts on broader malnutrition indicators such as anaemia prevalence and anthropometric outcomes, including weight-for-age, height-for-age, and weight-for-height.

“Scaling up these culturally appropriate, nutrition-sensitive interventions could contribute meaningfully to improved micronutrient status and household nutritional adequacy and dietary quality at both county and national levels.

Policy implication

The findings of this study have important implications for strengthening nutrition security through food-based approaches in cereal-dependent settings. The demonstrated sensory acceptability and enhanced micronutrient content of food-to-food fortified sorghum porridges support their inclusion within county-led maternal, infant, and young

child nutrition (MIYCN) programmes, particularly in regions experiencing a high burden of multiple micronutrient deficiencies, including iron, zinc, and vitamin A.

Incorporating food-to-food fortification strategies into existing public nutrition platforms, such as antenatal and postnatal nutrition counselling, community health outreach, and early childhood feeding programmes, could improve dietary quality without requiring major shifts in food preferences or consumption patterns. Because the approach relies on familiar staple foods and locally recognizable plant ingredients, it aligns well with culturally appropriate and sustainable nutrition interventions.

At the policy level, these findings reinforce the need to move beyond calorie adequacy toward nutrition-sensitive programming that emphasizes micronutrient density, dietary diversity, and acceptability. County and national nutrition strategies may therefore consider food-to-food fortification as a complementary approach to supplementation and commercial fortification, particularly in low-resource and rural contexts where access to fortified foods or supplements may be inconsistent. Finally, integrating food-to-food fortification concepts into nutrition education, extension services, and formulation guidelines could support household-level adoption and inform the development of context-specific dietary recommendations aimed at improving nutritional adequacy and dietary quality among vulnerable populations.”

Finally, integrating food-to-food fortification concepts into nutrition education, extension services, and formulation guidelines could support household-level adoption and inform the development of context-specific dietary recommendations aimed at improving nutrition security among vulnerable populations.

Acknowledgment

Authors are extremely thankful to the project funders, Grand Challenges Canada and Seeding the Future Foundation, the County Government of Siaya, and smallholder farmers.

Declaration of interest statement

There was no conflict of interest among authors and project partners.

References

- Anyango JO, Njoroge DM, Abong' GO, et al. Effect of improved sorghum varieties on the sensory acceptability of sorghum porridge. *Food Research International* 140 (2021): 110036.
- Oduro I, Ellis WO, Dzogbefia VP, et al. Food fortification and product development using local fruits. *International Journal of Food Science and Nutrition* 3 (2018): 45–56.
- Low JW, Mwangi ROM, Andrade M, et al. Tackling vitamin A deficiency with biofortified sweetpotato in sub-Saharan Africa. *Global Food Security* 14 (2017): 23–30.
- Thompson B. Combating iron deficiency: Food-based approaches. In: Thompson B, Amoroso L, eds. *Combating micronutrient deficiencies: Food-based approaches*. Food and Agriculture Organization of the United Nations (2010): 20–21.
- Olney DK, Rawat R, Ruel MT. Identifying potential programs and platforms to deliver multiple micronutrient interventions. *Journal of Nutrition* 142 (2012): 178S–185S.
- Abong' GO, Okoth MW, Karuri EG, et al. Potential for orange-fleshed sweet potato in processed food products in urban Kenya. *International Potato Center* (2010).
- Oluwamukomi MO, Oluwalana IB, Akinbowale OF. Physico-chemical and sensory properties of wheat–cassava composite biscuit enriched with soy flour. *African Journal of Food Science* 5 (2011): 50–56.
- Kenya National Bureau of Statistics, ICF. *Kenya Demographic and Health Survey 2022*. KNBS and ICF (2023).
- Association of Official Analytical Chemists. *AOAC official method 999.11: Determination of lead, cadmium, copper, iron, and zinc in food by atomic absorption spectrophotometry after dry ashing*. AOAC International (2002).
- Muhimbula HS, Issa-Zacharia A, Kinabo J. Formulation and sensory evaluation of complementary foods from local, cheap and readily available cereals and legumes in Iringa, Tanzania. *African Journal of Food Science* 5 (2011): 26–31.
- Okoth JK, Ochola S, Gikonyo NK, et al. Optimization of amaranth–sorghum blends for production of nutritious complementary foods. *Food Science & Nutrition* 5 (2017): 86–93.
- Mitzner K, Scrimshaw NS, Morgan RG. Improving the nutritional status of weaning-age children. *Nutrition Reviews* 42 (1984): 293–298.
- Masmoudi M, Besbes S, Chaabouni M, et al. Physicochemical and sensory properties of wheat–date biscuits. *Journal of Food Quality* 31 (2008): 88–102.
- Abioye AO. Effect of composite flour on functional and sensory properties of weaning food. *African Journal of Food Science* 9 (2015): 123–129.
- Walker AF, Pavitt F. Energy density and nutrient content of Third World weaning foods. *The Lancet* 309 (2007): 701–703.
- Tumuhimbise GA, Tumwine G, Kyamuhangire W. Effect of processing techniques on nutritional composition and

- physicochemical properties of orange-fleshed sweet potato flour. *Food Science & Nutrition* 7 (2019): 1191–1199.
17. Sengev IA, Akpapunam MA, Ingbian EK. Production and evaluation of breakfast cereal from blends of maize, bambara groundnut and mango mesocarp flours. *Nigerian Food Journal* 30 (2012): 59–65.
 18. Habiba U, Robin A, Hasan M, et al. Nutritional and functional properties of pumpkin seed flour for food application. *Journal of Food Science and Technology* 58 (2021): 1808–1816.
 19. Lakshminarayana S, Subhadra NV, Subramanyam H. Organic acid composition of mango fruit (*Mangifera indica* L.). *Journal of Food Science* 35 (1970): 794–796.
 20. Sogi DS, Siddiq M, Greiby I, et al. Total phenolics, antioxidant activity and functional properties of guava purees. *Journal of Food Science* 77 (2012): C954–C959.
 21. Egli IM. Traditional food processing methods to increase mineral bioavailability from cereal- and legume-based weaning foods. ETH Zurich (2001).
 22. Mohamed ME, Amro BH, Mashier AS, et al. Effect of processing followed by fermentation on anti-nutritional factors of pearl millet (*Pennisetum glaucum*). *Research Journal of Agriculture and Biological Sciences* 3 (2007): 876–880.
 23. Helland M, Wicklund T, Narvhus JA. Effect of germination on alpha-amylase production and viscosity of maize porridge. *Food Research International* 35 (2002): 315–321.
 24. Han W, Shen T, Lou H. Dietary organic acids and their roles in enhancing mineral bioavailability. *Food Chemistry* 311 (2020): 125944.
 25. Bailey RL, West KP, Black RE. The epidemiology of global micronutrient deficiencies. *Annals of Nutrition and Metabolism* 66 (2015): 22–33.
 26. Dewey KG, Brown KH. Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs. *Food and Nutrition Bulletin* 24 (2003): 5–28.
 27. Food and Agriculture Organization of the United Nations, World Health Organization. Human vitamin and mineral requirements. FAO/WHO (2004).
 28. Allen LH. Guidelines on nutrition during pregnancy. World Health Organization (2012).



This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC-BY\) license 4.0](https://creativecommons.org/licenses/by/4.0/)