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Oyster Mushroom Fortification Improves Nutritional and Sensory Quality of Polished Maize-based Complementary Food

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Abstract

Polished maize-based complementary foods are widely consumed by children aged 6–24 months but are often limited in protein and micronutrient content. This study evaluated the effect of partially substituting polished maize flour with oyster mushroom flour (0%, 10%, 20%, 30%, and 40% w/w) on the nutritional composition and sensory acceptability of polished maize-mushroom composite flours. Proximate composition, mineral content, estimated nutrient contribution to recommended daily allowances (RDA), and caregiver sensory preferences were determined using standard analytical methods. Increasing oyster mushroom flour inclusion significantly improved the nutrient profile of the composites. Crude protein increased by 1.07–11.20%, while ash and crude fiber increased by up to 2.48% and 3.04%, respectively, with the highest values observed at 40% substitution. Similarly, mineral content increased significantly with mushroom flour inclusion. Iron and zinc increased by 2.7-8.88-fold and 1.9-6.0-fold, respectively, while calcium and magnesium showed percentage increases ranging from 3.5% to 55.33%, with calcium recording the highest increment. Although carbohydrate and energy contents decreased with increasing mushroom levels, all blends contributed more than 53% and 100% of the estimated energy gap for non-breastfed and breastfed children aged 6–11 months, respectively. The 40% blend contributed up to 88.9% and 78.2% of the iron RDA for children aged 6–11 and 12–24 months, respectively. Sensory scores declined significantly with increasing mushroom inclusion; however, the 10% blend was not significantly different from the control in overall acceptability. Incorporation of oyster mushroom flour, particularly at 10–20% substitution, enhances the nutrient density of polished maize-based complementary foods while maintaining acceptable sensory quality.

INTRODUCTION

Globally, micronutrient deficiencies remain a major public health concern [1]. Recent statistics indicate that more than 2 billion people suffer from micronutrient deficiencies worldwide, with 720 million cases from sub-Saharan Africa (SSA) [2]. In SSA, anemia (IDA) (about 42%) [3], zinc deficiency (ZD) (4–73%) [4], and Vitamin A [5] remain the most prevalent forms of malnutrition, disproportionately affecting children aged 6–24 months. IDA and ZD have been listed among the most prevalent severe cases among children aged 6–24 months in Uganda, leading to impaired growth, weakened immunity, and poor cognitive development [6, 7]. Iron and zinc deficiencies affect more than half of Ugandan children, with prevalence disproportionately higher in the northern region [8, 9]. These deficiencies peak during the complementary feeding period, when children aged 6 months transition from exclusive breastfeeding to family foods that are typically low in nutrient density [10].

Cereals such as maize, millet, sorghum are the major complementary food resources in many resource-constrained households in Northern Uganda due to its affordability, availability, and cultural acceptance [11]. Whole-grain maize provides valuable nutrients when used as complementary food [11, 12]. However, its utilization is limited by poor sensory acceptability among caregivers and consumers, leading to processing practices aimed at improving palatability [13, 14]. Such processing typically removes the germ and aleurone layers, which are the primary reservoirs of protein, iron, and zinc, leaving

predominantly starchy endosperm [15, 16]. This reduction in nutrient-rich fractions compromises the overall nutritional quality of polished maize flour. Furthermore, the high starch content contributes to increased viscosity and water-binding capacity, requiring large volumes of water to achieve a porridge consistency suitable for children aged 6–24 months [18]. Consequently, the dilution effect lowers the nutrient density of the porridge, thereby reducing its adequacy for meeting the dietary needs of young children. As a result, reliance on polished maize flour during complementary feeding may contributes to persistent protein-energy malnutrition and micronutrient deficiencies among children 6–24 months. Although interventions such as supplementation, industrial fortification, and biofortification have been employed to combat micronutrient deficiencies, their adoption in resource-constrained households remains limited due to cost, supply chain disruption, and consumer skepticism toward genetically modified crops [2]. These limitations emphasize the need for alternative, affordable, cultural acceptable, and sustainable household-level food-based processing approaches that not only enhance micronutrient content but also compensate for nutrient losses associated with cereal polishing processing.

Traditional household-level processing approaches such as germination, roasting, fermentation, and blending have shown potential in improving the nutritional and functional quality of cereal-based complementary foods [21]. Among these approaches, blending polished maize flour with nutrient-dense foods offers an opportunity for nutritional restitution and enrichment, particularly for protein and micronutrients such as iron and zinc, which are severely depleted during polishing process [1].

Oyster mushroom (*Pleurotus ostreatus*) is a widely consumed delicacy in Uganda, particularly in resource-constrained areas, and is naturally rich in high-quality protein, zinc, and iron [20]. Despite its nutritional potential and availability, oyster mushroom remains underutilized in complementary feeding interventions in Uganda. Blending polished maize flour with oyster mushroom flour may offers a promising strategy to restore protein and micronutrients lost during polishing, thereby improving the overall nutrient density of polished maize-based complementary foods. Beyond its nutritional contribution, mushroom fortification may enhance sensory attributes in a culturally acceptable and economically feasible manner. Nevertheless, empirical evidence on the nutritional and sensory outcomes of mushroom-enriched maize complementary foods remains limited.

Addressing this research gap, the present study examined the effect of blending polished maize flour with oyster mushroom flour on proximate composition, micronutrient content, and sensory acceptability of maize-mushroom composites. The findings are intended to provide empirical evidence supporting sustainable, culturally appropriate, and cost-effective food-based strategies to mitigate nutrient losses associated with maize polishing and to enhance the nutritional adequacy of complementary foods for children aged 6–24 months in resource-limited settings

MATERIALS AND METHODS

Study area

The study was conducted at Gulu University, Gulu-Uganda with GPS (geographical positioning system) coordinate of 2°47'14.39" N 32°19'0.60" E. Gulu is one of the cities in Uganda, located in the Northern part of the country, approximately 333km from Kampala (capital city of Uganda), and has a GPS coordinate of 2°46′54.0"N32°17'57.0"E.

Study design

The employed cross-sectional study and utilized Quantitative research design whereby laboratory analysis employed to examine nutritional composition on polished maize and composite flour whereas sensory evaluation was conducted in Gulu District to obtain information on sensory attributes and acceptability of the composites and maize flour.

Materials collection and processing

A total of 20kg of mixed-variety white maize grains were purchased from local markets in Laroo division, Gulu city. The grains were hand-sorted, winnowed three times on tarpaulin, and packed in high-density polyethylene (HDPE) bags manufactured by Klene Paks Limited. The maize grains were processed following the steps indicated in Fig. 1. The cleaned maize was then milled to a 0.25 mm particle size using a china made 20HP mill, after which the refined flour was stored in cleaned HDPE bag for composite formulation. Maize was selected as a staple ingredient due to its widespread consumption in Northern Uganda and its role as a complementary food [19].

A total of 50kg of fresh oyster mushrooms were purchased from a local producer in Gulu city practicing good agricultural practices. The mushroom was processed following the steps indicated in Fig. 1. The mushrooms were sorted, cleaned, and sliced, prior to steam blanching for 3 minutes using firewood-heat stove. Blanching was conducted to deactivate enzymes and preserve flavor, color, and texture. The blanched mushrooms were sun-dried for seven days until moisture content was reduced to below 10%. The dried product was then milled to a 0.25 mm particle size using the same 20HP mill and stored in cleaned HDPE bags at ambient temperature prior to composite formulation. Oyster mushrooms were chosen for their high protein and micronutrient content [21]

Figure 1. The process to formulate the composite from maize and mushroom and the laboratory analysis.

Blending ratios of maize-oyster mushroom composite

To obtain maize-oyster mushroom composite flour, maize and oyster mushroom flour were blended at the following ratios: 100:0; 90:10; 80:20; 70:30; 60:40 w/w, respectively. Ingredient ratios were determined using the HarvestPlus Food Composition Matrix (2011), with calculations based on energy, iron, and zinc contributions. Ratios were established to meet the minimum recommended dietary

allowance (RDA) for energy (370 kcal/100 g) and to provide approximately 66.7% of the daily requirements for key minerals, specifically iron (11 mg/100 g) and zinc (3.0 mg/100 g), for children aged 6–24 months [22]. Each composite sample was sealed in polythene bags and stored at ambient temperature. Following preparation, both the control (polished maize flour) and the maize-mushroom composites were subjected to analysis to determine: (i) proximate composition and mineral content, including zinc, calcium, iron, and magnesium; and (ii) consumer sensory ratings comparing the composites with polished maize flour (Table 1).

Table 1
Ratios of maize and oyster mushroom used in developing maize-mushroom composites

Ingredients	**maize-mushroom Composite**				
	1	**2**	**3**	**4**	**5**
white polished Maize flour (%)	100	90	80	70	60
Oyster mushroom (%)	0	10	20	30	40
formulation identity	K11	K22	K33	K44	K55

Source of information

Based on calculation using the HarvestPlus Food Composition Matrix Table 2011

Determination of nutritional composition of maize-oyster mushroom composite

The nutritional profile of polished maize flour and maize-oyster mushroom composite flours was determined through proximate and mineral analyses, employing standardized analytical procedures. All analyses were conducted in duplicate.

Proximate composition analysis

Moisture, crude protein, crude fat, ash, and crude fiber contents of polished maize flour and composite flours were determined according to methods of the Association of Official Analytical Chemists (AOAC) [23]. Moisture content was determined using the oven-drying method (AOAC Method 930.15) (hot air oven, Model 202-0A, Huanghua Faithful Instrument Co.,Ltd) at 105°C until constant weight was achieved. Crude protein content was analyzed using the Kjeldahl method (AOAC Method 984.13). Nitrogen content was determined following acid digestion, distillation, and titration, and crude protein was calculated using a nitrogen conversion factor of 6.25. Crude fat content was determined by solvent extraction using a Soxtec system HT2 fat extractor (FOSS, Hilleroed, Denmark) with hexane as the extraction solvent. Ash

content was measured by dry ashing in a Vulcan furnace (AOAC 930.15, 2000) (Thermo Scientifica T16A, USA) at 550°C until a constant weight was obtained. Crude fiber content was determined by acid and alkaline digestion in fiber Raw extractor machine (FIWE6 6place 230V/60Hz, Velp Scientifica, USA) followed by drying and ashing, in accordance with AOAC procedures [23]. Total carbohydrate content was calculated by difference as the proportion remaining after subtracting moisture, crude protein, crude fat, ash, and crude fiber from 100%. The energy value of each flour blend was calculated using Atwater conversion factors of 4 kcal g^{-1} for protein, 4 kcal g^{-1} for carbohydrate, and 9 kcal g^{-1} for fat [2]. The contribution of each composite to the recommended daily allowance (RDA) for energy was expressed as a percentage of the RDA for children aged 6–24 months.

Mineral composition analysis

The mineral contents of zinc, iron, calcium, and magnesium in maize flour and composite flours were determined according to AOAC methods [23]. Samples were dry-ashed at 550°C, and the resulting ash was dissolved in nitric acid and diluted appropriately. Mineral concentrations were quantified using an atomic absorption spectrophotometer (AAS) (Buck Scientifica, model 210 VGP, USA) under standard operating conditions. Calibration curves were prepared using certified standard solutions for each mineral element, and mineral concentrations were expressed as milligrams per 100 g of sample on a dry weight basis. The contribution of zinc and iron from each composite flour to the recommended daily allowance (RDA) was calculated as a percentage of the respective RDAs for children aged 6–24 months.

Consumer sensory evaluation of the formulated flour products

Sensory evaluation of maize-oyster mushroom composite porridges was conducted using 67 untrained caregivers from Gulu District, Uganda. Caregivers of children aged 6–24 months were selected because they are primary decision-makers in complementary feeding and capable of objectively assessing product acceptability. Participants whose children were outside the specified age range were excluded.

A multistage sampling technique was employed. Two sub-counties were randomly selected from Gulu District, followed by the random selection of two parishes from each sub-county and two villages from each parish. Households with children aged 6–24 months were then purposively identified with the assistance of local authorities.

The sample size (n = 67) was determined using the standard formula (Cochran formula) [26] for single population proportion at a 95% confidence level and 5% margin of error, considering reported prevalence rates of zinc (20–69%) and iron deficiency (53%) among children aged 6–24 months in Uganda.

Sensory evaluation was conducted according to the method followed by Alowo et al. [11] and Adoko et al. [2]. Briefly, porridge samples were prepared from four maize-mushroom composite flours and a 100% polished maize flour (control) by mixing flour with water (20% w/v) and cooking for 15 min. Samples were coded with three-digit random numbers and served warm in single-use cups. Sensory attributes

evaluated included color, aroma, taste, aftertaste, mouthfeel, and overall acceptability using a 5-point hedonic scale (1 = strongly dislike, 5 = strongly like). Prior to evaluation, participants were briefed on the meaning of each sensory attribute. Drinking water was provided for mouth rinsing between samples to minimize carry-over effects, and evaluations were conducted under conditions that minimized interaction among participants. All sensory assessments were conducted in a single session.

Statistical Analysis

Statistical Package for the Social Sciences was used to examine the data (SPSS version 25). Additionally, ANOVA and descriptive statistics were used to compare the nutritional qualities of maize flour (control) & maize-mushroom composite flour, and the rating level of each sensory characteristic of the composites and maize flour. Furthermore, mean separation was done using studentized Post Hoc Tukey test. Furthermore, bar graph was used to present sociodemographic characteristics of caregivers. A 95% confidence interval was used for the comparative analysis ($p \leq 0.05$). The results were shown as means ± standard deviation (SD).

RESULTS

Effect of blending polished maize flour with oyster mushroom on nutritional composition of maize-mushroom composite

Proximate composition of maize-mushroom composite

The proximate composition of maize-mushroom composite flours is presented in Table 2. Increasing the proportion of oyster mushroom in the composite flour formulations significantly ($p < 0.05$) affected the proximate composition of the blends but not in a uniform manner. For instance, Crude protein, crude fiber, and ash contents significantly increased ($p < 0.05$) by 11.20%, 3.04%, and 2.48%, respectively in composites with 40% oyster mushroom flour. On the other hand, total carbohydrate, crude fat, moisture, and energy contents decreased significantly ($p < 0.05$) by 13.67%, 21.82%, 46.58%, and 3.47% respectively in composites with 40% oyster mushroom flour.

Table 2
Proximate composition of the polished maize flour and different blends of maize and mushroom flour

Parameter	Sample				
	K11	**K22**	**K33**	**K44**	**K55**
Crude Protein (%)	6.67^{a}±0.69	8.74^{b}±0.35	11.04^{c}±0.09	14.23^{d}±0.21	17.87^{e}±0.14
CHO (%)	84.44^{a}±0.5	83.25^{b}±0.54	80.49^{c}± 0.07	76.31^{d}±0.36	70.77^{e}±0.44
Crude fat (%)	1.65^{a}±0.22	1.45^{b}±0.35	1.37^{c}±0.08	1.32^{c}±0.08	1.29^{d}±0.01
Crude Fiber (%)	0.54^{a}±0.01	0.76^{b}±0.13	1.21^{c}± 0.11	2.14^{d}±0.14	3. 58^{e}±0.24
MC (%)	5.86^{a}±0.63	4.67^{b}±0.12	4.23^{b}±0.22	3.57^{c}±0.08	3.13^{d}±0.28
Ash Content (%)	0.83^{a}±0.02	1.14^{ab}±0.07	1.68^{b}±0.17	2.43^{c}±0.35	3.13^{d}± 0.28
Energy (Kcal/100g)	379.31^{ac}±0.19	380.96^{ab}±0.61	378.45^{c}±0.27	374.06^{d}±0.69	366.15^{e}±1.30

Mean ± Standard deviation (n = 5) in the same row with different superscript are significantly different at $p \leq 0.05$. K11 = maize flour (control, 100%), K22 = composite of 90% maize and 10% mushroom flour, K33 = composite of 80% maize and 20% mushroom flour, K44 = composite of 70% maize and 30% mushroom flour, and K55 = composite of 60% maize and 40% mushroom flour, CHO= Carbohydrate, MC = Moisture content

Mineral composition of maize-mushroom composite flour

The mineral composition of the different maize-mushroom composite flour compared to the control is presented in Fig. 2. Increasing oyster mushroom ratio significantly ($p \leq 0.05$) increased all analyzed minerals. Zinc content increased by 1.9-6.0-fold, while iron increased by 2.7-8.88-fold, with the highest values observed at 40% mushroom inclusion. Calcium and magnesium followed similar increasing trends across substitution levels. Overall, percentage increases ranged from 3.5% to 55.33%, with calcium recording the highest increase (55.33%) and zinc the lowest (3.5%) among the minerals analyzed.

Figure 2. Effect of variation blending ratios of polished maize and oyster mushroom on concentration of selected minerals in maize flour.

Column bars with different letter superscript are significantly different at $p \leq 0.05$. Zn = Zinc, Fe = Iron, Ca = Calcium, Mg = Magnesium

Contribution of maize-mushroom composite to the recommended daily energy requirement for non-breastfed and breastfed children aged 6–24 months

Table 3 displays the contribution of various blends of maize-mushroom composite to the energy requirement for breastfed and non-breastfed children aged 6–24 months. For both non-breastfed and breastfed children, the contribution of the different composites reduced with an increase in mushroom flour ratio (Table 3). Despite the decline in energy contribution, the different blends contribute more than 53% and 100% of the energy gap for non-breastfed and breastfed children 6–11 months, respectively. However, the contribution of maize-mushroom composite to meet energy requirement for non-breastfed and breastfed children between the ages of 12 and 24 months is less than 43% and 77%, respectively.

Table 3
Contribution of maize-mushroom composite to energy requirement for non-breastfed and breastfed children 6–24 months

Sample	Energy (Kcal)	Contribution to meet energy requirement for non-breastfed infants (%)			Contribution to meet energy requirement for breastfed infants (%)		
		6–8 months	9–11 months	12–24 months	6–8 months	9–11 months	12–24 months
K11	379.31^{ac}±0.19	61.68	55.29	42.43	189.66	126.44	75.86
K22	380.96^{ab}±0.61	61.94	55.53	42.61	190.48	126.99	76.19
K33	378.45^{c}±0.27	61.54	55.17	42.33	189.23	126.15	75.69
K44	374.06^{d}±0.69	60.82	54.53	41.84	187.03	124.69	74.81
K55	366.15^{e}±1.3	59.53	53.37	40.95	183.08	122.05	73.23

Mean ± Standard deviation (n = 5) in the same column with different superscript are significantly different at $p \leq 0.05$. K11 = 100% maize flour (control), K22 = composite of 90% maize and 10% mushroom flour, K33 = composite of 80% maize and 20% mushroom flour, K44 = composite of 70% maize and 30% mushroom flour, and K55 = blend of 60% maize and 40% mushroom flour. RDA (Recommended Daily Allowance) of energy for non-breastfed infants 6–8 months, 9–11 months, and 12–24 months is 615, 689, and 894 kcal/day respectively and for breastfed infants 6–8 months, 9-11months, and 12–24 months is 200, 300, and 500 kcal/day respectively (25).

Contribution of maize-mushroom composite to Recommended Daily Allowance of zinc and iron for infants 6–24 months

The contribution of each blend of maize-mushroom composite to RDA for zinc and iron are presented in Table 4 and Table 5, respectively. As observed from Table 4, increasing oyster mushroom flour ratio greatly increased the contribution towards meeting RDA for zinc. Additionally, blend K55 with a 40% mushroom recorded the highest contribution (42%) (Table 4).

Table 4
Contribution of maize-mushroom composite to Recommended Daily Allowance of zinc for infants 6–24 months

Sample	RDA of Zn (mg/day)	Zn (mg/100g)	Contribution to RDA (%)
K11	3	$0.7^{a} \pm 0.001$	23.33
K22		$1.33^{b} \pm 0.06$	44.22
K33		$2.27^{c} \pm 0.23$	74.89
K44		$3.07^{d} \pm 0.06$	102.11
K55		$4.20^{e} \pm 1.29$	139.0

Mean ± Standard deviation (n = 5) in the same column with different superscript are significantly different at $p \leq 0.05$. K1 = maize flour (control,100%), K22 = composite of 90% maize and 10% mushroom flour, K33 = compositeof 80% maize and 20% mushroom flour, K44 = composite of 70% maize and 30% mushroom flour, and K55 = composite of 60% maize and 40% mushroom flour. RDA=Recommended Daily Allowance of zinc for infants 6–24 months = 3mg/day.

Table 5
Contribution of maize-mushroom composite to Recommended Daily Allowance of iron for infants 6–24 months

Sample	RDA of Fe (mg/day)		Analyzed Fe (mg/100g)	Contribution toward RDA of Fe (%)	
	6–11 months	9–12 months		6–11 months	12–24 months
K11	11.00	12.50	$1.1^{a} \pm 0.005$	10.00	8.80
K22			$3.03^{b} \pm 0.15$	27.50	24.24
K33			$5.6^{c} \pm 0.38$	50.90	44.80
K44			$7.83^{d} \pm 0.11$	71.10	62.26
K55			$9.77^{e} \pm 0.06$	88.90	78.16

Mean ± Standard deviation (n = 5) in the same column with different superscript are significantly different at $p \leq 0.05$. K1 = maize flour (control,100%), K22 = composite of 90% maize and 10% mushroom flour, K33 = composite of 80% maize and 20% mushroom flour, K44 = composite of 70% maize and 30% mushroom flour, and K55 = composite of 60% maize and 40% mushroom flour. RDA (Recommended Daily Allowance) of iron for infants 6–11 months and 12–24 months is 11mg/day and 12.5mg/day respectively.

A similar trend was observed with the contribution to RDA for iron (Table 5). K55 contributed more than half (88.9% and 78.16%) to the RDA of iron for children aged 6–11 months and 12–24 months, respectively.

Effect of blending polished maize with mushroom on consumer sensory preference and acceptability of maize-mushroom composites

Socio-demographic statistics of caregivers that participated in sensory evaluation

The sociodemographic data of the participants are presented in Fig. 3. The study included 67 female caregivers from Gulu District. Caregivers who were in late adulthood dominated the study, followed by those in middle- and early-adulthood (Fig. 3).

Figure 3. Socio-demographic statistics of female caregivers of Gulu district who participated in the study

Income groups were categorized according to Economic policy research center (EPRC) data on per capita daily consumption expenditure in purchasing power parity, Upper middle-class income (UG sh. 36,500 – 73,000), Lower middle income (UG Sh. 14,600 – 36,500), Below poverty line (< UG sh.7,300) (n = 67); Age group categorized based on Uganda Age Structure by Index mundi, Early Working age (15-24years), prime working age (25-54years), mature working age (> 54years).

According to the Fig. 3, more than three-quarters of the caregivers had attended school, with the majority completing their elementary education and less than 15.1% of the caregivers lacked formal education. Farmers and business caregivers made up the majority of the participants' occupation (40% and 37%, respectively), whereas only 3% and 19% of the caregivers, worked as civil servants and casual workers respectively. However, the majority of caregivers (51%) fall below the poverty line, and 33% of them are in the lower middle-income class while just a small proportion belonged to the upper middle-income class.

Comparison of caregivers’ sensory rating of different maize-mushroom composite

The sensory ratings of porridges prepared from maize-mushroom composite flours are presented in Table 6. Increasing oyster mushroom ratio significantly ($p \leq 0.05$) reduced mean scores for all evaluated sensory attributes. Aroma scores decreased by 0.54–2.39 points, with the largest reduction observed at 40% mushroom ratio; however, the 10% blend was not significantly different from the control ($p > 0.05$). Similar decreasing trends were observed for color, mouthfeel, taste, and after-taste. Notably, the composite with 10% oyster mushroom flour ratio recorded a 0.28-point higher mean color score compared to the control.

Table 6
Comparison of caregiver's sensory rating of caregivers of maize-mushroom composites

Sample	Mean sensory rating					
	Aroma	**color**	**taste**	**Mouth feel**	**After-taste**	**Overall acceptability**
K11	3.94^{a}±1.20	4.06^{a}±0.89	4.27^{a}±0.96	4.12^{a}±0.89	4.27^{a}±0.71	4.24^{a}±0.74
K22	3.40^{ab}±1.21	4.34^{b}±0.91	3.25^{b}±1.21	3.36^{b}±1.05	3.48^{b}±1.17	3.75^{a}±1.39
K33	3.01^{b}±1.27	3.18^{b}±1.03	2.84^{b}±1.59	3.39^{b}±1.24	2.90^{c}±1.44	2.95^{c}±1.45
K44	2.16^{d}±1.19	2.46^{d}±0.91	1.69^{d}±0.70	2.18^{d}±1.13	2.25^{d}±1.22	1.69^{d}±0.94
K55	1.55^{d}±1.02	3.13^{d}±0.81	1.46^{e}±0.91	1.28^{e}±0.67	1.39^{e}±0.74	1.36^{e}±0.73

Mean ± Standard deviation (n = 67) in the same column with different superscript are significantly different at $p \leq 0.05$. K11 = maize flour (control, 100%), K22 = composite of 90% maize and 10% mushroom flour, K33 = composite of 80% maize and 20% mushroom flour, K44 = composite of 70% maize and 30% mushroom flour, and K55 = composite of 60% maize and 40% mushroom flour.

Overall acceptability decreased significantly ($p \leq 0.05$) with increasing oyster mushroom flour ratios, declining by 0.49–2.88 points, with the greatest reduction observed at 40% mushroom inclusion. However, the 10% blend was not significantly different from the control ($p > 0.05$) in term of overall acceptability.

DISCUSSION

Effect of blending polished maize flour with mushroom on nutritional composition of maize-mushroom composite

The observed increase in crude protein levels after the oyster mushroom flour ratio can be attributed to the relatively high protein content in oyster mushroom (22.61%) [28]. More importantly, because maize polishing significantly reduces protein density by removing protein-rich fractions, the inclusion of mushroom effectively restores part of this lost protein. Thus, the protein increment observed in this study reflects both substitution and restitution effects. The results of the present study concur with results of previous studies of maize-mushroom composite [26], maize-button mushroom composites [27], and wheat-soy-oyster mushroom biscuit [28] had high protein content. Nonetheless, the protein values (3.3–16.8%) observed in this study were higher than those reported by Bamidele and Fasogobon [26] for maize-mushroom composites (2.3–6.9%). Variations may be linked to agro-ecological factors influencing mushroom nutrient composition [30], particularly substrate nutritional quality. From a complementary feeding perspective, the observed increase in protein content has important implications

for meeting the protein requirements of children aged 6–24 months, a period characterized by rapid growth and elevated nutrient needs. For instance, assuming typical consumption patterns of cereal-based porridges (approximately 2–3 feeding episodes per day), ratio of oyster mushroom at ≥ 20% could substantially increase the contribution of complementary foods to daily protein requirements, thereby reducing reliance on more expensive animal-source foods. At higher substitution levels (30–40%), the protein density of the composites suggests that fewer feeding episodes or smaller portion sizes may be required to achieve comparable protein intake, although this would depend on overall dietary diversity and portion sizes consumed. These findings indicate that oyster mushroom incorporation can play a meaningful role in improving protein intake among young children in resource-constrained settings. However, it is important to consider that protein adequacy is influenced not only by quantity but also by bioavailability. The presence of anti-nutritional factors such as trypsin inhibitors in oyster mushrooms [28] may affect protein digestibility. Therefore, further studies are needed to evaluate protein bioavailability and digestibility to confirm the functional nutritional benefits of the composites beyond compositional improvements.

A reduction in fat content was observed with increasing mushroom substitution. This is expected, as oyster mushroom contains considerably less fat (0.38%) compared to maize (4.16%) [31]. While this reflects a displacement effect, it also aligns with the removal of lipid-rich germ fractions during maize polishing. Despite the total fat content declined, oyster mushrooms predominantly contain unsaturated fatty acid such as oleic and linoleic acids [31], which are associated with reduced incidences of non-communicable diseases [22]. The result of the current study contradicts with results obtained by Nguyen et al. [33] in which the author reported a significant increase in lipid content of oyster mushroom-bean-barley-Dutch pea-potato formula could be attributed to high fat content in pea (26.3–36%) [34] compared to oyster mushroom (0.38%). Nevertheless, the percentage reduction (0.2%) in fat content caused by 10% oyster mushroom blending ratio observed in the present study is higher than percentage reduction (0.01%) recorded in bread by Okafor et al. [35]. The difference in the percentage reduction recorded in maize-mushroom composite flour and wheat-mushroom bread could be due to variation in nutrition profiles of mushroom species used. Furthermore, difference could be attributed to variations in nutrition profiles of cereals used. Notably, the fat content of wheat (2.97–3.54%) [36] is higher compared to that of maize (1.65%). Nevertheless, the relatively low-fat content (1.29–1.45%) observed in the composites were below CODEX maximum limits (3.3%) for complementary foods, and may enhance oxidative stability and storage safety. However, since dietary fat contributes to energy density and palatability, future formulation strategies may consider controlled lipid optimization to balance nutrient density and sensory appeal.

The increase in fiber content of the different blend of maize-mushroom composites is attributable to the higher dietary fiber fraction of oyster mushroom, particularly insoluble fiber [26, 37]. Unlike polished maize flour, which is fiber-depleted due to removal of bran, oyster mushroom flour incorporation reintroduces structural polysaccharides into the composite. Moreover, majority of the fiber in oyster mushroom flour are insoluble (12-21g/100g) [38]. Insoluble fiber has numerous health benefits such as increasing the bulkiness, and thickness of stool resulting in reduced occurrences of functional gastro-

intestinal disorders such as irritable bowel syndrome characterized by constipation [39, 40]. This will probably have a favorable impact on the gut health of children taking into account the fact that sufficient amount of fiber in complementary foods has been observed as effective in alleviation of constipation in children as lactulose [2]. Furthermore, sufficient amount of fiber plays a crucial role in establishment of healthy micro-flora population during first year of growth and development [41, 42]. In comparison, for 30 and 40% oyster mushroom flour inclusion rate in the Siyame et al. [31] study, the percentage increment (7.67–9.27%) in fiber content reported is higher than the percentage increment (1.6–3.04%) in the present study. The difference could be attributed geographical location effect on mushroom nutrient quality and typed of maize flour used. Though, the increase in fiber content in the present study is similar to results obtained by Gemede [43], the fiber content (0.76–3.58%) of different maize-mushroom composites is lower than CODEX threshold (5%) in complementary foods. Although fiber levels (0.76–3.58%) remained below the CODEX upper threshold, moderate fiber inclusion may promote gut health and support microbiota development during early childhood, without excessively impairing nutrient absorption. Therefore, mushroom enrichment appears to re-balance the refined carbohydrate nature of polished maize without exceeding tolerable fiber levels for young children.

The reduction in carbohydrate content in the maize-mushroom composites reflects the lower starch concentration of mushroom (67.32μg/100g) relative to maize [45]. Given that polished maize flour is approximately 65.46–73.3% starch [45], its dilution through mushroom substitution decreases total carbohydrate proportion. The carbohydrate content (ranged from 83.25–70.77%) observed in the current study is higher than the carbohydrate content (64.25%) recorded in NUTREND developed by Nwadi and Uvere [46]. The difference in carbohydrate content in maize-mushroom composites in the current study and NUTREND could be due to effect of germination on the carbohydrate composition of maize grains used to develop NUTREND. In fact, during germination, the catalytic activity of alpha amylase increase, hence more starch is hydrolyzed to simpler and absorbable monomers which is utilized by seedling at an early start of germination [47]. Additionally, the carbohydrate contents observed in the different blends of maize and mushroom in the present study are above the CODEX standard (range 64–75%) for complementary flour. The implication of this is that the different blends are adequate to meet the energy requirement of children 6–24 months.

Although energy density declined slightly with reduced carbohydrate content, the composites still have the potential to meet substantial proportions of the energy gap for both breastfed (70%) and non-breastfed (40%) children. Importantly, the modest carbohydrate dilution enhances overall nutrient density by reducing excessive starch dominance, a key limitation of polished maize porridges. This result demonstrates the potential of different maize-mushroom composites in meeting the physiological energy need of children 6–24 months.

Moisture content decreased of the composites with mushroom blending ratios. Polished maize flour contains high starch fractions (73%) capable of significant water binding due to abundant hydroxyl groups on starch granules [48]. Replacing part of this starch with oyster mushroom flour reduces water-binding capacity, resulting in lower moisture levels observed in this study. The moisture content

observed in this study was lower compared to moisture content reported by Fikiru et al.[49] in maize-roasted pea-malted barley composite. This could be attributed to the difference in starch granules composition between the product developed in the current study and the aforementioned product. It is noteworthy that the lower starch granules composition, the lower moisture content of any products. Lower moisture content improves storage stability and reduces susceptibility to microbial spoilage, which is critical in resource-constrained settings lacking refrigeration. Thus, mushroom inclusion may confer both nutritional and shelf-life advantages. Moreover, lower moisture content implies that maize-mushroom composite are more shelf-stable and less prone to storage microbial spoilage.

Ash content increased proportionally with oyster mushroom ratio, reflecting its high mineral composition (8.8%) [21]. This is particularly significant because minerals such as iron and zinc are concentrated in the outer layers of maize kernels, which are removed during polishing. Consequently, polished maize flour is inherently micronutrient-poor. This result corroborates with results obtained in previous studies. For instance, Farzana and Mohajan [28] reported that incorporation of mushroom and soy in wheat had a favorable impact on the total ash content of the composite. This is majorly due to the high mineral content of mushroom and soybean. Nonetheless, the increase (37.3-277.1%) recorded in this study is higher than the increase (11.0–17%) observed in maize-pea-anchote composite reported by Gemede [43]. This could be attributed to difference in total mineral composition of oyster mushroom used in this study and pea & anchote used in the aforementioned product. In fact, oyster mushroom has higher ash content (6.37%) [50] compared to pea and anchor which has 2.56% and 3.87% ash content, respectively. The high ash content implies that mushroom could be more suitable for enhancing total mineral contents of maize than legumes.

The increase in the level of total minerals in the different maize-mushroom composites indicate that these composites would contribute to the children's overall micronutrient intake. For instance, calcium, zinc, iron, and Magnesium levels were found to be greater in composites containing mushroom [26]. This is plausible due to high concentration of calcium, magnesium, iron, phosphorus, and zinc in mushroom [28]. The nutrient levels were analyzed in the flour rather than in the prepared porridge; consequently, the potential effects of cooking and food preparation on nutrient retention were not assessed. Future research should therefore investigate how processing and preparation methods influence the nutrient composition of maize–mushroom composites.

Complementary foods should supply 30 to 97% of the overall daily requirement of micronutrients [27]. The increase in zinc and iron content observed in this study therefore represents a targeted correction of polishing-induced micronutrient depletion. Consumption of 100 g of blends containing 10% and 20% mushroom provided 44.22% and 74.89% of the recommended dietary allowance (RDA) for zinc, respectively. This suggests that oyster mushroom enrichment may substantially reduce zinc deficiency risk among children aged 6–24 months. The findings concur with the conclusions of earlier research. Common examples are studies that showed a strong positive correlation between increase in zinc concentration and the percentage of substitution effect of mushroom in the various blends [51].

Although iron contribution from 10–20% substitution was below 51% RDA, higher inclusion levels demonstrated superior performance compared to maize-legume malt composites [46], indicating that mushroom may be a more effective iron enhancer than some traditional plant-based fortificants. This could be attributed to the higher iron content in oyster mushroom compared to cowpea and bambara ground nut malt. This implies that oyster mushroom is more effective in enhancing the iron content of maize-based complementary foods than bambara ground nut and cowpea. However, the bioavailability of iron and zinc may be influenced by residual anti-nutritional factors such as phytates from maize. Future research should evaluate mineral bioaccessibility following porridge preparation, as thermal processing and dilution may alter micronutrient retention.

Overall, the findings demonstrate that oyster mushroom flour incorporation into polished maize flour acts as a processing-sensitive enrichment strategy, restoring protein and micronutrients lost during milling while modestly moderating excessive starch content. This positions mushroom enrichment as a feasible, household-level nutritional restitution approach in maize-dependent communities. Extrapolating from this, it might be hypothesized that the promotion of consumption of maize flour blended with oyster mushroom flour may increase intake of proteins and key micro-nutrients such as iron and zinc by children 6–24 months.

Effect of blending polished maize flour with mushroom on sensory attributes of maize-mushroom composite

Consumer acceptability is a crucial variable that has been linked to the success of food-based nutritional innovations in society [54]. The degree of consumer preference for the specific sensory qualities of food product is a major determinant of acceptability. While mushroom flour inclusion improved nutritional density, it negatively influenced several sensory attributes, particularly color, aroma, taste, and overall acceptability at higher inclusion levels.

The results on color contradicts with the results reported by Farzana and Mohajan [28], where consumers liked the color of soy-mushroom biscuits. The difference in the findings could be due to the masking effect of soybean used in that study on mushroom. Thus, porridge of maize-mushroom composites had a poor color compared to the control which could negatively affect its consumption among children 6–24 months.

Aroma is sensory quality that can sometimes have a significant impact on how well-liked foods are, and it is influenced by the ingredient used in the formulation [53]. The aroma that comes from mushroom is less liked by people [56]. Therefore, lower aroma scores may be attributed to volatile sulfur-containing compounds such as lanthionine and S-alkyl cysteine derivatives [55], which are characteristic of mushrooms. These compounds might have negatively altered the aroma of the composites. Furthermore, Furthermore, reduced fat content may have limited flavor retention and mouthfeel enhancement, as lipids contribute significantly to sensory perception [56].

The taste of any product is the main determinant of its acceptability and has the greatest influence on its likelihood of commercial success. According to Teferra et al.[57], the sensation of taste is a chemical process that involves stimulation of taste receptors by taste stimuli. Therefore, the higher starch content of maize flour [62] and the associated chemical processes as a result of heat treatment could be the cause of higher scores for taste observed in the control compared to the composites. Additionally, the lower sensory score for taste could be explained by the intense aroma of mushroom. The lower rating of after-taste of the maize-mushroom composites could be due to slight bitter after-taste of mushroom as reported by the caregivers.

The lower mouthfeel ratings observed in the present study may be attributed to the characteristic flavor profile of oyster mushroom and the reduced fat content of the composites, both of which influence texture perception. Similar findings have been reported by Okafor et al.[59], where mushroom incorporation negatively affected the sensory attributes and overall acceptability of wheat-based products. This aligns with the current study, which showed a significant decline in overall acceptability with increasing mushroom inclusion. However, at lower substitution levels, particularly 10%, no significant difference in overall acceptability was observed compared to the control, corroborating findings by Adeoye et al.[35] in that 10% mushroom ratio did not affect overall acceptability of the composite. Furthermore, blends containing ≤ 20% mushroom consistently achieved higher sensory ratings than those with higher inclusion levels, indicating a nutritional-sensory optimization threshold.

From a nutritional standpoint, the 10% mushroom blend (K22), which maintained acceptable sensory properties, contributed 27.5% and 24.24% of the recommended daily allowance (RDA) for iron for children aged 6–11 and 12–24 months, respectively, and 44.22% of zinc requirements for children aged 6–24 months. While these contributions do not fully meet daily micronutrient requirements, they represent a substantial proportion, particularly for zinc. Considering typical complementary feeding practices of 2–3 meals per day, consumption of this blend across multiple feeding episodes could cumulatively meet or approach daily micronutrient requirements without compromising acceptability. Alternatively, modest increases in portion size could further enhance nutrient intake, provided that feeding frequency and child appetite are taken into account. These findings suggest that although higher mushroom inclusion levels yield greater micronutrient density, lower inclusion levels (10–20%) may offer a more practical balance between nutritional improvement and sensory acceptability. Therefore, optimizing feeding frequency and portion size using acceptable formulations could serve as a feasible strategy for improving iron and zinc intake among children in resource-constrained settings, while maintaining caregiver and child preference. The trade-off between nutritional enhancement and sensory acceptability emphasizes the need for formulation refinement, possibly through flavor masking strategies, controlled roasting, or partial fat optimization. As dietary adoption is driven more strongly by sensory appeal than nutritional value alone [64], future studies should explore processing modifications to enhance palatability without compromising nutrient restitution benefits.

Conclusion

The results demonstrate that mushroom incorporation into polished maize flour is not simply a compositional adjustment but a strategic response to nutrient losses caused by cereal polishing. Maize-mushroom composites offer the optimal macro-and micro-nutrient contents for children aged 6-24 months. By restoring protein, iron, zinc, and mineral content while maintaining acceptable energy levels, maize-mushroom composites present a promising, locally adaptable intervention for improving complementary feeding in polished maize-dependent communities. The sensory quality of the composites, specifically their color, aroma, taste, aftertaste, and mouthfeel, were greatly reduced, but this did not lower overall acceptability of the composite with 10% mushroom flour which was comparable to polished maize porridge commonly consumed by the participants studied. Therefore, the inclusion of mushrooms should not be more than 20% of the composite in order to produce an acceptable maize-mushroom composites that is nutritionally enriched. Furthermore, optimizing sensory characteristics remains essential to ensure sustained household adoption.

Abbreviation

ID	Iron deficiency
ZD	Zinc deficiency
VAD	Vitamin A deficiency
GPS	Geographical Positioning System
AOAC	Association of official Analytical chemists
MC	Moisture Content
SSA	Sub-Saharan Africa
RDA	Recommended Daily Allowance
AAS	Atomic Absorption Spectrophotometer
GUREC	Gulu University Research Ethic Committee
CAO	Chief Administrative Officer

Declarations

Ethical considerations

The study followed the ethical research standards such as free & informed consent, privacy & confidentiality, ethical approval, and risks & benefits of conducting research, in accordance with the Declaration of Helsinki [61]. The study was approved by Gulu University Research Ethics Committee (GUREC-2022-207). The products were handled with extreme care during laboratory analysis. Permission from the CAO (Chief Administrative Officer) of the Gulu district was requested in order to conduct research in the community of Gulu district. Prior to taking part in the study, informed consent of the

caregivers who participated in the study was obtained, in accordance with the Declaration of Helsinki standards [61]. Caregivers were fully informed about the study's objectives, procedures, potential risks, and benefits before providing their consent. In the study, there was no chance of injury or discomfort. This was because there was no allergic reaction. Caregivers who are allergic or had allergic reaction in the past, however, were not permitted to take part in the sensory evaluation, in accordance with the Declaration of Helsinki standard [61]. Additionally, because the sensory evaluation was conducted in a hospital setting, medical personnel were on hand to assist the participant if they had any discomfort while tasting the various composite formulae. In this study, clinical trial number was not applicable. Also, the final version of this manuscript has been read and approved by all listed co-authors.

Consent for Publication

Not applicable

Data and Material availability

The data will be made available from corresponding author on reasonable request

Competing interest

We declare that there are no competing interests that could influence the integrity of this study.

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Credit authorship contribution statement

GK contributed to the study through conceptualization, data curation, formal analysis, investigation, methodology, validation, writing of the original draft, and writing for review and editing. DA was involved in conceptualization, formal analysis, methodology, supervision, validation, and writing for review and editing. SO participated in conceptualization, formal analysis, methodology, supervision, validation, and writing for review and editing.

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Figures

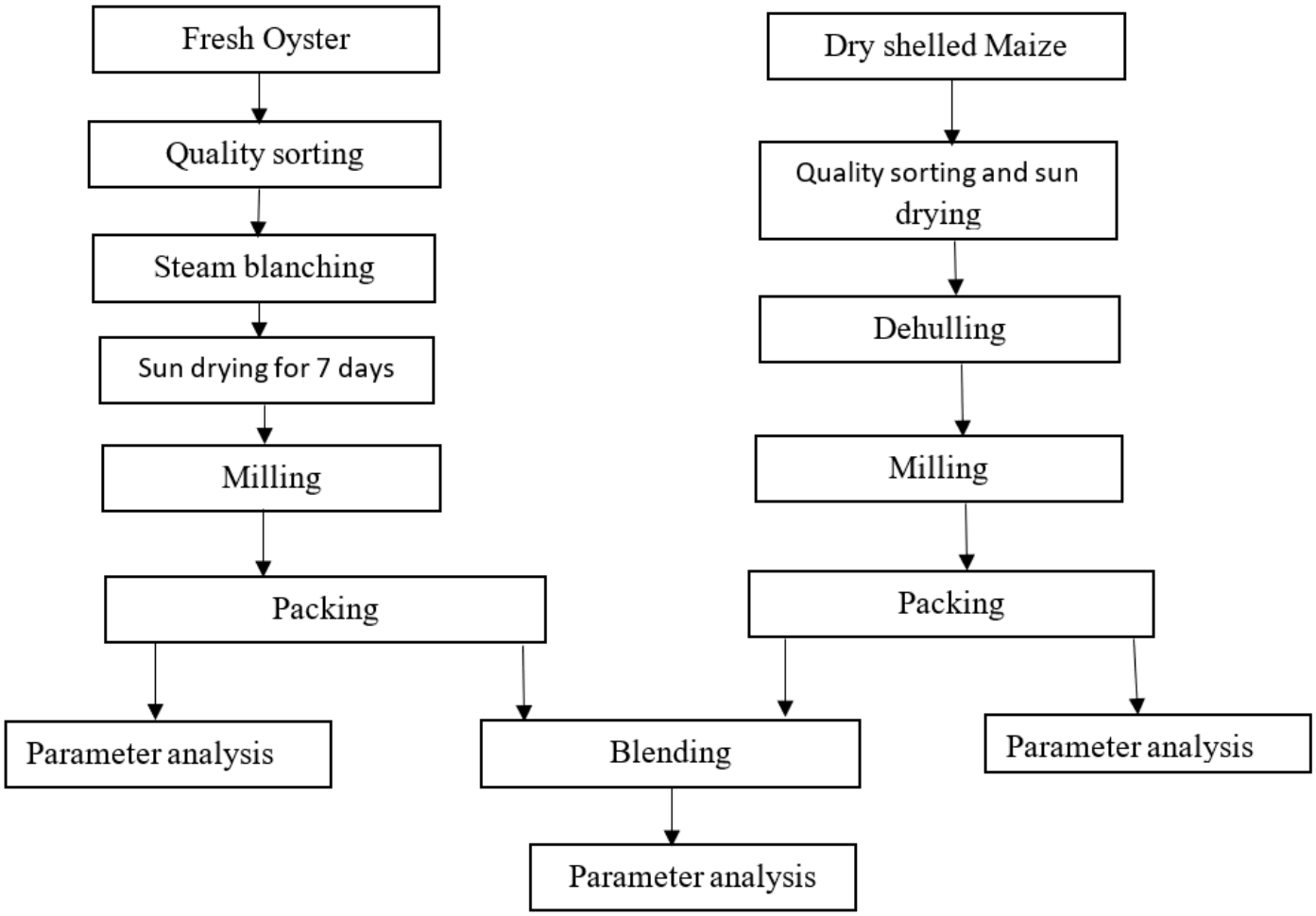


Figure 1

The process to formulate the composite from maize and mushroom and the laboratory analysis.

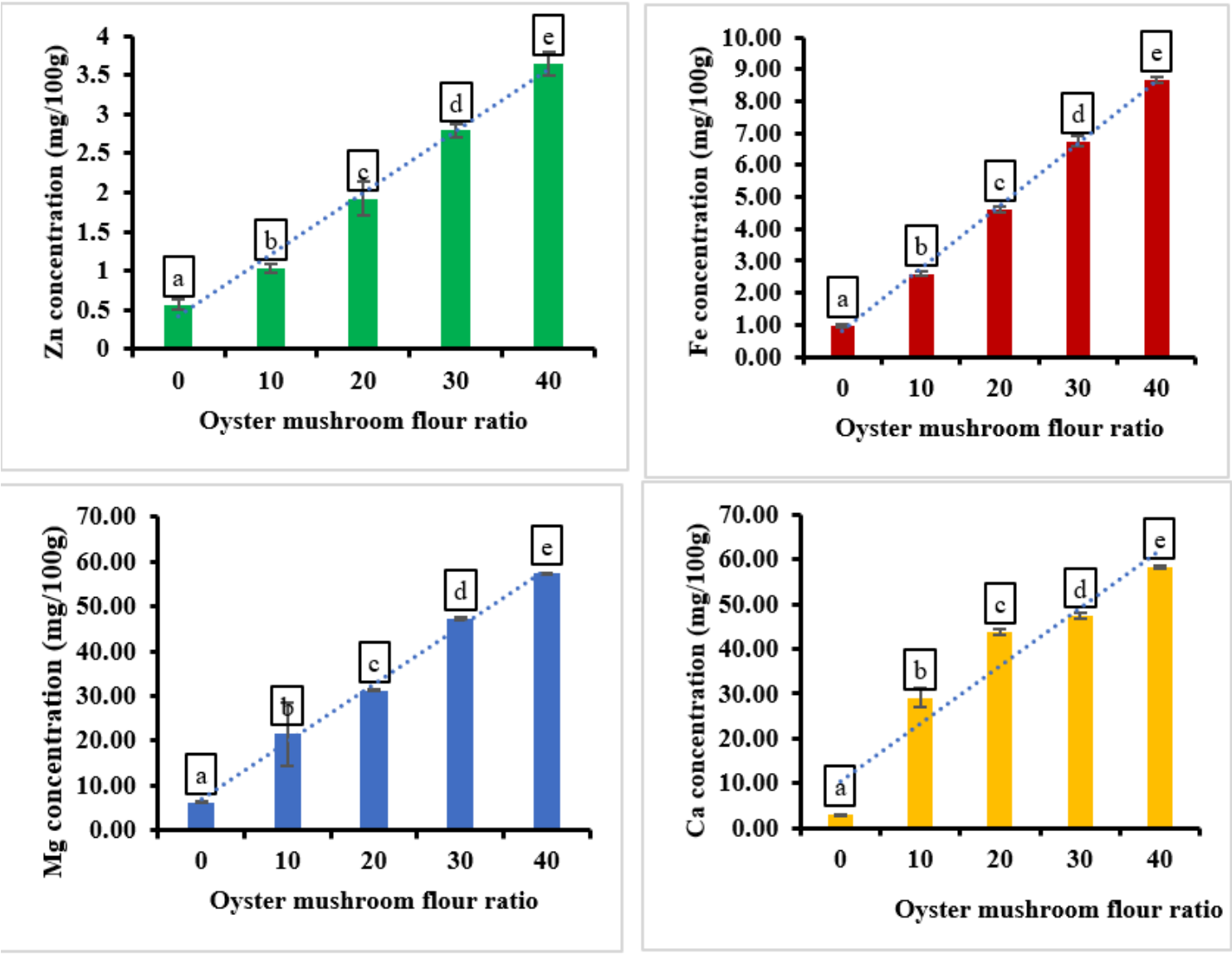


Figure 2

Effect of variation blending ratios of polished maize and oyster mushroom on concentration of selected minerals in maize flour.

Column bars with different letter superscript are significantly different at p≤0.05. Zn = Zinc, Fe = Iron, Ca = Calcium, Mg = Magnesium

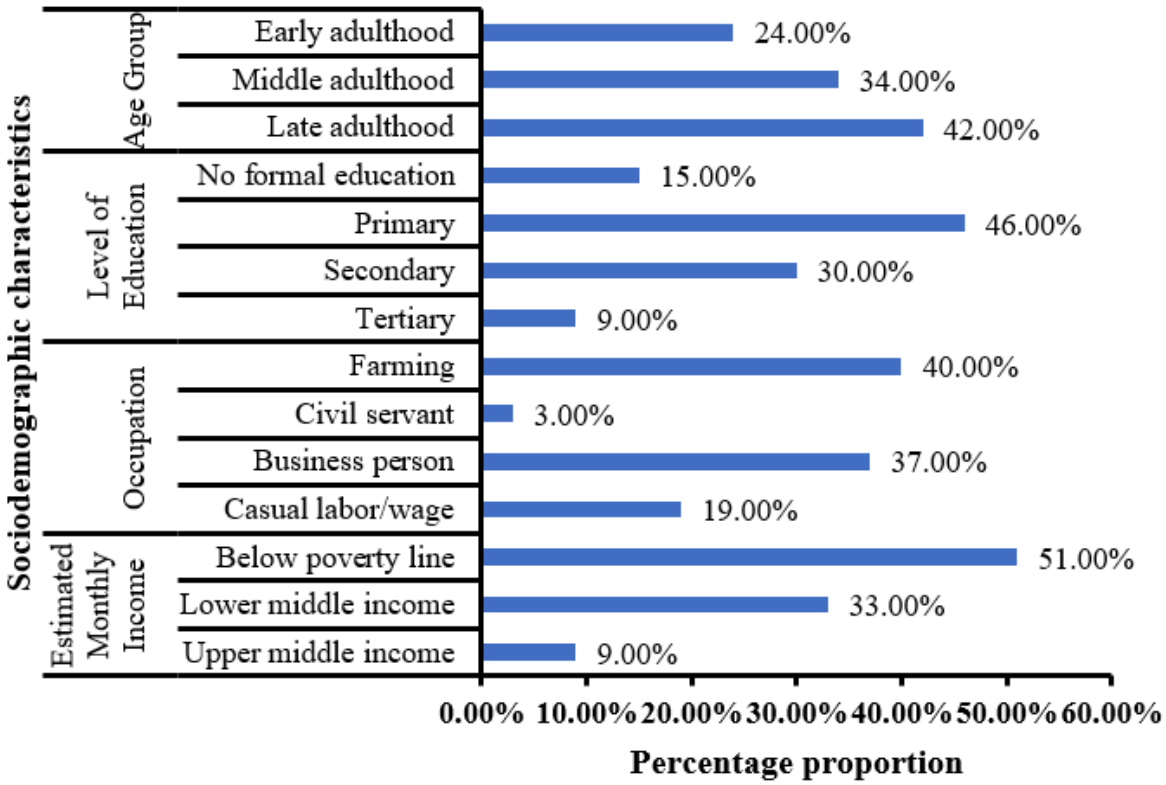


Figure 3

Socio-demographic statistics of female caregivers of Gulu district who participated in the study