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Physico-Chemical, Functional, and Sensory Properties of an Optimized Pro-Vitamin A Maize and Iron-Rich Bean Composite Flour

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Biofortification is a strategy that has been proven to not only reduce the prevalence of micro-nutrient deficiencies, but also to tackle other forms of malnutrition. Apart from increasing the concentration of the target nutrient, biofortification has also been found to improve the concentration of other nutrients in the plant. However, the effectiveness of these crops in alleviating malnutrition largely depends on consumer uptake and acceptability and this can partly be achieved by including flour from biofortified crops as major components of composite flours. This study aimed at assessing the physio-chemical, functional and sensory properties of a composite iron rich bean based

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complementary flour optimized with pro-vitamin A bio-fortified maize composite flour. The optimized composite flour was made from bio-fortified maize, sesame, soy, sorghum, wheat and beans flours. In comparison to the control, the composite flour blend containing pro-vitamin A-rich maize and iron-rich beans, had a significantly higher ($p < 0.05$) protein level of 11.9% and increased concentrations of vitamin A (1.6 µg/g), iron (6.0 mg/100g), and zinc (2.5 mg/100g) compared to the white maize-based complementary flour. The optimized flour also had lower ($p < 0.05$) anti-nutrient levels with a moisture content (10.3%), fiber (3.1%), carbohydrates (66.3%), ash (2.8%) and a fat content (5.6%). The optimized composite generally showed better functional properties. With an overall sensory acceptability score of 7.1, the optimized composite porridge showed no significant difference from the other composites. Therefore, bio-fortified maize when used as part of the components for composite flour not only increases pro-vitamin A content but also improves its overall nutrient composition and therefore help in tackling other forms of malnutrition.

Keywords: Bio-fortification; functional properties; anti-nutrients; sensory acceptability; pro-vitamin A bio-fortified maize.

1. INTRODUCTION

Globally, millions of people are affected by under nutrition (FAO et al., 2015). “Children under the age of five years and women of reproductive age are among the categories that are more predisposed to the effects of under nutrition” (Hasan et al*.,* 2022). “At the global level, an estimated 148 million (22.3%) children under five years of age were stunted while 45 million (6.8%) were wasted in 2022” (UNICEF, 2023). “Research has highlighted under nutrition as part of the primary causes of death for children under the age of five years” (Karlsson et al., 2022). Black et al. (2013) estimated that 13.6 million children die annually from malnutrition related conditions. In Africa, stunting and wasting rates are above global estimates (Amadu et al., 2021; Quamme & Iversen, 2022) with 43% and 27% of children under-five years affected by stunting and wasting respectively (UNICEF, 2023). Despite various interventions and efforts in Uganda, 26%, 10.6%, 2.9% of children below the age of five years remain stunted, underweight and wasted respectively (UBOS, 2022). Rao et al. (2016) attributed this to the continued dependence on plant-based foods and undiversified diets. Porridges based on white maize which is a poor source of micronutrients (Govender et al*.,* 2019), “remain a common complementary and weaning food in Uganda” (Ekesa et al., 2019). Therefore, the use of complementary foods like composite flours made using bio-fortified crops like maize can contribute to alleviating micro nutrient deficiencies in children (Sakala, 2021; Wasswa et al., 2022). “Various varieties of pro-vitamin A bio-fortified maize have been found to have relatively higher quantities of energy, fiber, fat, protein, iron, zinc and phosphorus content” (Beswa, 2015; Kirthee et al., 2013). Therefore, an increase in the consumption of bio-fortified maize will contribute to the alleviation of not only vitamin A deficiency but also protein-energy malnutrition deficiencies (Govender, 2014). “Though bio-fortification has been approved as a sustainable cost effective method of alleviating malnutrition, its effectiveness largely depends on the sensory acceptability of the biofortified foods within the target population” (Huey et al*.,* 2023). “The process of biofortification has been associated with visible and sensory changes in food crops. This may consequently affect consumption and acceptability of these foods. It is, therefore, important to understand how well bio-fortified foods and food products are accepted among target population groups, particularly in comparison to substitute foods made from non-biofortified foods” (Huey et al*.,* 2023). This study was therefore, aimed at evaluating the impact of substituting white maize in a bean based composite flour with pro-vitamin A bio-fortified maize, on the nutritional, functional properties and sensory acceptability of the composite flour.

2. MATERIALS AND METHODS

2.1 Sourcing and Preparation of Samples for Laboratory Analysis

Local varieties of soya beans, whole wheat, sorghum, sesame, high iron beans (Naro bean 1) were procured from Owino market, Kampala-Uganda. The pro-vitamin A bio-fortified maize (Naro maize 63 vitA) was purchased from Kisenyi market, Kampala-Uganda. The flour from the pro-vitamin A biofortified maize was prepared as described by Margaret et al. (2017). The high iron bean flour was prepared in accordance with a method described by Byarugaba et al. (2023). Sesame flour was prepared as described by

Makinde and Akinoso (2014). Soy flour was prepared in line with the method described by Udomkun et al. (2022). Whole wheat flour was prepared according to a method described by Bhat et al. (2020) while Sorghum flour was prepared according to a method described by Irondi et al. (2019).

2.2 Preparation of the Optimized Composite Flour Sample

An optimized complementary composite flour based on iron-rich beans and pro-vitamin A bio-fortified maize developed in a previous study was used in the current study. The composition of the optimized flour was maize at 57.89%, beans at 17.11%, sesame at 5.00%, soybean at 10%, wheat and sorghum at 5%.

2.3 Determination of Nutritional Properties of Provitamin A Based Composite Flour

2.3.1 Proximate composition the pro-vitamin A rich maize and high iron rich composite flour

The proximate composition of the optimized flour blend sample was determined using AOAC methods as described by Nancy, (2009). The samples were analyzed for moisture, ash, crude fiber, crude protein, and crude fat, while the carbohydrate content was calculated by difference.

2.3.1.1 Determination of moisture content of the pro-vitamin A rich maize and high iron rich composite flour

Moisture content was determined using the according to Nancy (2009) method method. About 5 g of the sample was weighed into a petri dish of a known weight. It was then dried in the oven at 105 ± 1°C for 6 hours, followed by cooling in a desiccator and weighing. The moisture content was then calculated as from;

$$\%\, moisture\ content\ = \frac{change\ in\ weight}{Weight\ of\ food\ before\ drying} \times\ 100 \qquad (1)$$

2.3.1.2 Determination of ash content of the optimized composite flour

The ash content was determined using the Nancy (2009) method. Briefly, about 2g grams of sample was weighed into a crucible and then burnt in a muffle furnace at 600 °C for 3 hours, cooled and weighed. The ash content was then calculated as follows.

$$\%\, Ash\ content\ = \frac{Weight\ of\ ash}{Weight\ of\ sample} \times\ 100 \qquad (2)$$

2.3.1.3 Determination of crude protein of pro-vitamin A rich maize and high iron rich composite flour

Protein content was determined using Kjeldahl's method, according to the procedure of Nancy, 2009). Concentrated H_2SO_4 (12 mL) and two tablets of selenium catalyst were put into a Kjeldahl's digestion flask containing 1 g of the sample. The flask was then placed in the digester in a fume cupboard, switched on and digested for 45 minutes to obtain a clear colorless solution. The digest was then distilled with 4% boric acid; a 20% sodium hydroxide solution was then automatically metered into it in the distillation equipment until distillation was completed. The distillate was then titrated with 0.1M HCl until a violet color was formed, indicating the end point. A blank was run under the same condition as with the sample. Total nitrogen content was then calculated using the equation below.

$$\%\, Protein\ = \frac{(titer\ value\ of\ sample\ blank) \times 0.01 \times 14.007 \times 6.25}{100 \times weight\ of\ sample} \times\ 100 \qquad (3)$$

2.3.1.4 Determination of crude fiber of pro-vitamin A rich maize and high iron rich composite flour

Crude fiber content was determined according to Nancy (2009) method. "About 5 g of the sample were weighed into a 500-mL Erlenmeyer flask and 100 mL of trichloroacetic acid digestion reagent added. It was then brought to boiling and refluxed for exactly 40 min counting from the start of boiling. The flask was then removed from the heater, cooled a little, and the residue filtered through a 15.0 cm what man paper. The residue was then washed with hot water stirred once with a spatula and transferred to a porcelain dish. The sample was then dried over night at 105 °C. After drying, it was transferred to a desiccator and weighed W_1 when cool. It was then incinerated in a muffle furnace at 500°C for 6 hours, allowed to cool, and reweighed W_2" (AOAC, 2005). The percentage crude fiber was calculated as shown in equation below

$$\%\, Crude\ fiber\ = \frac{W_1 - W_2}{W_0} \times\ 100 \qquad (4)$$

W_2 = Weight of crucible + fiber + ash, W_1 = Weight of crucible + ash, W_0 = Dry weight of food sample.

2.3.1.5 Determination of fat content of pro-vitamin A rich maize and high iron rich composite flour

Fat content was determined according to Nancy (2009). "About 2 g of the sample were weighed and wrapped in a filter paper. It was then placed in an extraction thimble. The extractor was cleaned, dried in an oven, and cooled in the desiccators before weighing. Then, 25 mL of N-hexane was measured into the round bottom flask. The fat content was extracted with this solvent. After extraction, the solvent was evaporated by drying in the oven. The flask and its contents were then cooled in a desiccator and weighed fat content" (AOAC, 2005). The percentage fat content was calculated as shown in equation

$$\%\,\text{Fat} = \frac{\text{Weight of fat extracted}}{\text{Weight of sample}} \times 100 \qquad (5)$$

2.3.1.6 Determination of carbohydrate content of pro-vitamin A rich maize and high iron rich composite flour

The total carbohydrate was determined by difference. The sum of percentages of moisture, ash, crude lipid, crude protein and crude fiber were subtracted from 100%.

%carbohydrate=100−(%moisture+%ash+%protein+%fat+%fiber) (6)

2.3.2 Determination of anti-nutrients content of the flour the pro-vitamin A rich maize and high iron rich composite flour

2.3.2.1 Determination of the tannin content of the pro-vitamin A rich maize and high iron rich composite flour

Tannin content was determined according to the method described by Udomkun et al. (2019). 0.5 g of a composite flour sample was weighed and then added to 5 mL of 1% (v/v) of HCl in methanol. The sample was allowed to stand at room temperature for 15 min before vortex mixing and centrifugation at 3000 rpm for 10 min. The supernatant of 2.5 mL was transferred to a 10 mL flask containing 7.5 mL of water, then 0.5 mL of Folin-Denis regent and 1 mL of sodium carbonate were added. The final volume was adjusted to 10 mL with water, and the absorbance was determined after 30 min of incubation at room temperature using a UV/Vis spectrophotometer (model Genesys G10S, USA) at 760 nm. The content of tannin was calculated from the standard curve of tannic acid solution.

2.3.2.2 Determination of the oxalate content of the pro-vitamin A rich maize and high iron rich composite flour

Oxalate composition in the composite flour was determined by a method as described by (Adebayo, 2013). 2.5 g of the sample was mixed with 75 ml of 3 M H2SO4 and stirred for 1 hour. The mixture was filtered and 25 ml of the filtrate was titrated against 0.05 M KMnO4 solution to a faint pink color that persisted for 30 s. The oxalate composition was calculated by assuming that 1 ml of 0.05 M KMnO4 is equivalent to 2.2 mg oxalate.

2.3.2.3 Determination of phytate content of pro-vitamin A rich maize and high iron rich composite flour

Phytic acid content was determined according to procedures as described by Udomkun et al. (2019).

2.3.3 Determination of the iron and zinc content provitamin A rich maize and high iron rich composite flour

The iron and zinc content of the flour was determined using Energy Dispersive X-Ray Fluorescence (EDXRF) model EDX-720 (Shimadzu - Japan).

2.3.4 Determination of vitamin A content

Total carotenoids in the composite flour were determined according to the method of Rodriguez-Amaya and Kimura (2004).

2.4 Determination of Functional Properties of the Flour

2.4.1 Determination of water absorption capacity of pro-vitamin A rich maize and high iron rich composite flour

The method described by Onwuka (2005) was used for "the determination of the water absorption capacity of the composite flour. About one gram of the composite flour was weighed into a 15 ml centrifuge tube and suspended in 10 ml water. It was then vigorously shaken on a platform tube rocker for 1 minute at room temperature. The sample was allowed to stand for about 30 minutes and centrifuged at 1200 x g for 30 minutes. The volume of free water was then be read directly from the centrifuge tube".

2.4.2 Determination of the Swelling capacity of the pro-vitamin A rich maize and high iron rich composite flour

The swelling power was determined using the method described by Oke et al. (2016). "One gram of the sample was weighed into a 50ml centrifuge tube. After which 50ml of distilled water was added and mixed gently together. The mixture was then heated in a water bath at 90ºC for 15 minutes with gentle stirring to prevent clumping of the flour. Thereafter the tube containing the paste was centrifuged at 3,000rpm for 10 minutes using a centrifuge machine. The supernatant was decanted immediately after centrifuging and the weight of the sediment was taken and recorded. The moisture content of sediment gel was then determined to get dry matter content of the gel" (Oke et al., 2016).

$$Swelling\ power\ =\ \frac{weight\ of\ wet\ mass\ sediment}{weight\ of\ dry\ matter\ in\ the\ gel}$$

2.4.3 Determination of the bulk density of the pro-vitamin A rich maize and high iron rich composite flour

The bulk density of the flour was determined basing on the method used by Baranwal and Sankhla (2019). 50g of sample was put into a 100-ml measuring cylinder. The cylinder was tapped on a laboratory bench continuously until a constant volume was obtained. Then, the volume of the sample was recorded. The bulk density was calculated according to the following formula.

Bulk density = Weight of ground flour (g)/Volume of sample (cm^3)

2.4.4 Determination of the solubility of the pro-vitamin A rich maize and high iron rich composite flour

Solubility index was determined as described by Oladele and Aina (2007). One gram of the flour was mixed with 10 ml of distilled water in a centrifuge tube and heated at 80 °C for 30 min while shaking continuously. The tube was removed from the bath, wiped dry, cooled to room temperature and centrifuged for 15 min at a RCF of 1626.24gusing a Heraeus, model: MEGA FUGE 8 laboratory centrifuge. The supernatant was evaporated, and the dried residue weighed to determine the solubility using the formula

$$\text{Solubility\%} = \frac{\text{Weight of dried sample in supernatant}}{\text{Weight of dried sample in supernatant}} \text{x100}$$

2.5 Contribution of Porridge from the Composite Flour to RDA

Percentage contribution to recommended dietary allowance was expressed as % of RDA.

$$\%\text{RDA} = \frac{\text{X}}{\text{Y}} \times\ 100$$

Where X is the amount of nutrient analyzed per 100g of the sample and Y is the RDA for a given nutrient/variable. (100g of flour are used to make 500mls of porridge sufficient for a day's consumption)

2.6 Sensory Evaluation

Consumer acceptability of porridge from the flour sample was compared to that from the white maize and a commercially available composite. Consumer acceptability tests of the porridge were carried out by a team of 30 untrained panelists using a 9-point hedonic scale (1 = dislike extremely to 9 = like extremely). Porridges from the three different flours were prepared as described by Onoja et al. (2014). For each flour, 100 g of the flour sample was mixed with 100 ml of cold water to make a paste. About 500ml of boiled water was then added to the paste and cooked for 10 minutes while stirring occasionally until cooked. About 15 ml of each of the prepared porridge was presented to panelists in identical containers, coded with random numbers. The serving order was different for each panelist who sat in individual sensory booths. Bottled drinking water was provided to rinse the mouth before and between tasting samples. Panelists were asked to score the acceptability for color, taste, flavor, mouth feel, consistency, and overall acceptability. Acceptability of the optimized porridge was compared to two other porridges prepared from commercially available composite flours.

2.7 Data Analysis

The data collected was entered and analyzed using XLSTAT software version 2019. Fischer's least significance difference test was used to separate means. All results were considered to be significant when the p value was <0.05.

3. RESULTS AND DISCUSSION

3.1 Nutritional Composition of the Flours

"The moisture content varied across all the composite flour blends as shown in Table 1. The provitamin A rich maize composite flour had the lowest moisture content (10.3%) which was equivalent to the acceptable limit of about 10% required for long term storage of flour" (Nilusha, 2021). Similar findings were observed maize containing composite flours by (Gebrezgi, 2019; Kaunda et al., 2025; Mpili et al., 2024) in Ethiopia, Malawi and Tanzania respectively. The commercial composite sample composite flour blend had the highest moisture content (13.1%). The moisture content of the provitamin A composite flour blend remained significantly lower than the other composite flour blends. This implies it has better keeping qualities than the white maize based and the commercial composite sample composites. Manley (2000) emphasized that flours having moisture content more than 14% are prone to mold growth and infestation by insects. A low moisture content enhances storage stability of powdery foods by avoiding mold growth and other unfavorable bio-chemical reactions. The high moisture content of the commercial composite sample could possibly have been caused by a higher percentage of wheat flour in this composite flour.

The protein content also varied significantly ($p \leq 0.05$) across all the composite flour blends as shown in Table 1. The provitamin A rich maize composite flour blend had a significantly ($p<0.05$) higher protein content (11.9g/100g) compared to the white maize composite flour blend (10.9g/100g). These results align with those of a study conducted by Govender (2014) who also found protein content of a biofortified maize porridge (7.77g/100g) to be higher than that of the control made using white maize porridge (6.13g/100g). In another study, Alamu et al. (2021) also found that the incorporation of biofortified maize into soybean flour improved the protein content of the flour. Additionally, Kirthee et al. (2013) found provitamin A maize to have significantly higher protein content relative to white maize. However, the results of protein content in Table 1 also contradict findings by Govender et al. (2019), who in a different study found that composite dishes made using raw white maize had an overall higher protein content of 10.22g/100g compared to the composite dishes made using provitamin A maize flour which had a protein content of 8.68g/100g. The contradiction in these results could possibly result from the nutritional composition of the different constituents of the composite. In addition different varieties of provitamin A maize have been found to have varying quantities of protein content (Kirthee et al., 2013). Therefore choice of the varieties of the components in the composite flours depending on their nutritional composition is important as different varieties of cereals and legumes have varying quantities of the same nutrient.

The bio-fortified maize composite flour had the highest ash content of 2.8g/100g as shown in Table 1. This was significantly higher than that in the white maize based composite flour and the market sample. A high ash content could be attributed to the addition of the high iron rich beans. According to Mbatchou and Dawda (2013), ash content of food has a direct correlation with the mineral contents of food. The enhancement of the flour with iron from the beans may have improved its mineral content. The ash content of provitamin A rich maize and high iron rich beans composite flour of 2.8g/100g align with those of Aderinola and Adeoye (2023) who found the ash content of another provitamin A composite flour to vary between 2.8 and 4.17g/100g. Also Aderinola and Adeoye (2023) concluded that addition of beans into a composite containing maize flour had significant improvements in the mineral compositions of the composite flours.

The biofortified maize composite flour had the highest content of fat with 5.6g/100g as shown in Table 1 and this was significantly higher than the white maize-based composite (4.4g/100g) and the commercial composite sample (2.3g/100g). Biofortified maize grains have been reported to have a higher fat content of 2.15g/100g compared to that of the white maize grains which was 2.13g/100g (Govender, 2014; Kirthee et al., 2013). "The overall high fat content of the composite flours could be as a result of the other components that were added including sesame flour which is a good source of oils" (Manikantan et al., 2015). "Fats are key nutrients because apart from being a valuable source of energy, they offer a non-polar medium required for the absorption of fat soluble vitamins such as vitamin A. Fat-soluble vitamins are emulsified and packaged in lipid-rich mixed micelles containing fatty acids, bile salt, and phospholipids during absorption" (Ofoedu et al., 2021).

The fiber content (3.1g/100g) registered in the provitamin A rich maize and high iron rich composite flour was the least, among the three flours analyzed. These results contrast with those of Govender et al. (2019) who found that replacing white maize with provitamin A maize in composite dishes had no effect on the fiber content of the composite foods.

The carbohydrate content significantly varied across all the three composite flours. However, the provitamin A rich maize and high iron rich composite flour had the lowest carbohydrate content of 66.3g/100g. This resonates with results of Alamu et al. (2021) who also found "a lower carbohydrate content in a composite flour containing biofortified maize compared to the composites made using white maize".

3.2 Contribution of Nutrient Components to the RDA of Children 6-59 Months

Assuming that 100g of the composite flour was used to prepare 500mls of porridge to be consumed per day, the provitamin A rich maize and high iron rich composite flour contributed 35.6% of the daily vitamin A requirements for children 6-12 months and also contributed more than 50% for children between 1 and 3 years of age (Table 2). The provitamin A rich maize and high iron rich composite flour blend contributed more than half of the iron requirements for children in all the 3 different age categories. In addition, the provitamin A rich maize and high iron rich composite flour blend contributed more than 50% of the RDA requirements of zinc for children in all the age groups. Generally, the contribution of the provitamin A biofortified porridge to the micro-nutrient intake for children below 5 years was above 50% apart from vitamin A for children 6-12 years. This is in line with recommendations of Global Alliance For Improved Nutrition (2008) which recommends that complementary foods should contribute at least 50% of world health organization reference nutrient intakes.

For the macronutrients, the contribution of the provitamin A rich maize and high iron rich composite flour blend to the RDA fat requirements was within the range of what is required from complementary foods for a breastfed child. According to Abeshu et al. (2016), complementary foods should contribute an average of 15–20% of fat for children 12–23 months. This implies the provitamin A porridge is a good source of fats. "Fats in the body are necessary for provision of energy and also play a vital role of transporting fat soluble vitamins such as vitamin A around the body" (Pusadkar et al., 2015). For the reduction of VAD using porridges made from biofortified vitamin A composite flour to be achieved, the fat composition of the composition must be sufficient to increase the absorption of vitamin A in the body.

"It is also required that complementary foods contribute at least 50% of the protein requirements for children" (Global Alliance For Improved Nutrition, 2008). The provitamin A maize porridge is a good source of proteins as it contributes more than 70% of the protein requirements for children 6 months to 3 years. This is above the 57% required from

Table 1. Proximate, vitamin A, iron and zinc composition of bean-based flour optimized with biofortified maize relative to the bean-based porridge made using white maize and the market sample

Component	Sample		
	Provitamin A rich maize and high iron rich beans composite flour blend	**White maize composite**	**Commercial composite sample**
Moisture (%)	$10.3^{c} \pm 0.05$	$11.1^{b} \pm 0.24$	$13.1^{a} \pm 0.12$
Protein (%)	$11.9^{a} \pm 0.16$	$10.9^{b} \pm 0.33$	$10.3^{c} \pm 0.08$
Ash (%)	$2.8^{a} \pm 0.04$	$1.2^{c} \pm 0.01$	$1.5^{b} \pm 0.02$
Fat (%)	$5.6^{a} \pm 0.04$	$4.4^{b} \pm 0.16$	$2.3^{c} \pm 0.04$
Fiber (%)	$3.1^{c} \pm 0.02$	$3.3^{b} \pm 0.02$	$3.9^{a} \pm 0.01$
Carbohydrates (%)	$66.3^{c} \pm 0.15$	$69.1^{a} \pm 0.72$	$68.9^{b} \pm 0.21$
Vitamin A (µg/g)	$1.6^{a} \pm 0.04$	$0.6^{c} \pm 0.02$	$1.0^{b} \pm 0.01$
Iron (mg/100g)	$6.0^{a} \pm 0.01$	$5.3^{c} \pm 0.01$	$5.9^{b\pm} 0.02$
Zinc(mg/100g)	$2.5^{a} \pm 0.01$	$2.1^{c} \pm 0.02$	$2.3^{b} \pm 0.02$

Values in a row with the same letter as their first superscript are not significantly different.

complementary foods (Abeshu et al., 2016). The provitamin A rich maize and high iron rich composite flour blend contributed above 60% of the carbohydrate requirements for children 6-12 months, however, its contribution to the RDA for other age categories was far below 50%.

3.3 Anti-Nutrient Composition

Biofortified maize composite had the lowest levels of all the anti-nutrients as shown in Table 3. The phytate content significantly varied across all the three different composite flours with the biofortified flour having the lowest phytate content (54.2 mg/100g). These results are similar to those of Adegunwa et al. (2020) who also evaluated the phytate content of a provitamin A biofortified maize based composite but contrast with those of Udomkun et al. (2019) who found the phytate content in a cereal legume based composite flour to be higher with. Though some anti-nutrients have been known to show beneficial physiological benefits in the body, beyond some critical values they also manifest harmful physiological effects in the body (Nath et al., 2022). According to Nissar et al. (2017), phytate consumption should be reduced to ≤ 25 mg/100 g for the best health. In addition, some countries have set their reference intakes: the UK and US accept intakes between 631- 746 mg per day. “Finland set the reference intake to 370 mg per day while Italy and Sweden set them at 219 mg per day and 180 mg per day, respectively. Phytates have been commonly reported to be present in cereals, pulses, nuts and seeds” (López-Moreno et al., 2022). “Phytates reduce the bio availability of zinc, iron and calcium by forming soluble complexes with them” (Lesjak & Srai, 2019). “Despite the negative impact of phytates, phytate-rich foods also contain fiber which can be fermented leading to a reduction in the pH of the caecum, this can improve the conversion of ferric iron to ferrous iron, consequently improving its absorption of these minerals” (Baye et al., 2017).

Table 2. Contribution of the composite porridges to the daily requirements of proteins, carbohydrates, fats, vitamin A, iron and zinc for children 6-59 months

			% Contribution to the RDA of infants and children 6-59 months		
Variable	**Age group (years)**	**RDA[a]**	**Provitamin A rich maize and high iron rich beans composite flour blend**	**White maize composite**	**Commercial composite sample**
Protein	0.5-1	12	99.2	90.8	85.8
	1-3	16	74.4	68.1	64.4
	4-8	24	49.6	45.4	42.9
Carbohydrates	0.5-1	105	63.1	65.8	65.6
	1-3	215	30.8	32.1	32.0
	4-8	220	30.1	31.4	31.3
Fats	0.5-1	30	18.7	14.7	7.7
	1-3	16.7	33.5	26.3	13.8
	4-8	23.3	24.0	18.9	9.9
Vitamin A	0.5-1	450	35.6	13.3	22.2
	1-3	300	53.3	20	33.3
	4-8	400	40	15	25
Iron	0.5-1	11	54.6	48.7	53.6
	1-3	7	85.7	75.7	84.3
	4-8	10	60	53.0	59.0
Zinc	0.5-1	3	83.3	70	76.7
	1-3	3	83.3	70	76.7
	4-8	5	50	42	46

Source: Food and nutrition board, (2003), National institute of health

The optimized biofortified maize flour had a significantly ($p<0.05$) lower oxalate content than the commercial composite sample. "However, there was no significant difference in the oxalate content of the provitamin A biofortified maize composite and the white maize composite. The observed values for the oxalate content of the optimized biofortified maize flour were low possibly because the composite flours did not have any leafy component of plants as oxalates have been found to be mostly concentrated in these leafy parts" (López-Moreno et al., 2022). "Oxalate is an end product of ascorbate, glyoxylate and glycine metabolism in mammals and they are more concentrated in leafy parts of vegetables such as spinach, chard, beet or rhubarb than in other parts" (López-Moreno et al., 2022). "Foods high in oxalates should be consumed in moderation because just like the other anti-nutrients, oxalates inhibit the absorption of nutrients especially calcium which is a critical nutrient in the diets of children" (Savage, 1999). In addition, oxalates form water-insoluble salts by binding to iron and zinc Lo et al. (2018) which are key minerals for this study.

There was a significant variation of the tannin content across all the three composite flours, the biofortified maize composite had the lowest concentration of tannins. Tannins (commonly referred to as tannic acid) are water-soluble polyphenols that are present in many plant foods (Redden et al., 2005). "They have been reported to be responsible for decreases in feed intake, growth rate. feed efficiency, net metabolizable energy, and protein digestibility in experimental animals, Tannins in the diet can generally influence the hematological iron conditions of a person" (Nath et al., 2022). Nath et al. (2022) further expressed "the need to explore how various tannin molecules interact with iron because these interactions can derail the iron enrichment strategies specified for the reduction of the prevalence of anemia deficiency such as the one under investigation in this particular study". "Tannins are also known to inhibit pancreatic lipase which can reduce lipid absorption, in higher quantities, they can be harmful to lipid nutrition" (Moreno-Córdova et al., 2020). In relation to this study, lipids are key because they enhance the absorption of Vitamin A.

3.4 Functional Properties of the Composite Flours

There was a significant ($p<0.05$) variation across the bulk densities of all the composite flours as shown in Table 4. The biofortified maize composite had the lowest bulk density of 0.8 compared to the other two composite flour samples, which is a desirable quality for composite flours. Lower bulk density indicates a lighter flour, which is often preferred for ease of mixing, cooking, and better texture in food products. A lower bulk density is expected to contribute to a lower dietary bulk, ease of packaging and transportation (Aluge et al., 2016). Alamu et al. (2021) also reported a similar trend where a composite flour made from biofortified maize and soya bean also had a low bulk density.

There was a significant ($p<0.05$) variation in the water absorption capacity of the three composite flours. However, the biofortified maize composite flour had the highest water absorption capacity. "It was hypothesized that the higher the moisture content of the flour the less room there is to add more. Conversely, the drier the flour, the more water it will absorb. This is in the line with the above results because the optimized biofortified flour had the least moisture content. This consequently increased its water absorption capacity. A high water absorption capacity is indicative of a flour that easily reconstitutes" (Ukom et al., 2019). "In addition, other factors such as the ash and protein content influence the water absorption capacity of the flour" (Sapirstein et al., 2018). The optimized flour had the highest of these attributes and this consequently explains its higher water absorption capacity.

Table 3. Anti-nutrient composition of the different composite flours

	Sample		
Anti- nutrient (mg/100g)	**Provitamin A rich maize and high iron rich beans composite flour blend**	**White maize composite**	**Commercial composite sample**
Tannins	$140.3^{c} \pm 0.16$	$149.2^{b} \pm 1.08$	$153.2^{a} \pm 0.50$
Oxalates	$29.2^{b} \pm 0.90$	$30.2^{ab} \pm 0.08$	$31.1^{a} \pm 0.21$
Phytates	$54.2^{b} \pm 0.15$	$57.9^{a} \pm 0.08$	$57.1^{a} \pm 0.12$

Figures in a row with the same letter as their first superscript are not significantly different. Figures in a row with the same letter as their second superscript are not significantly different (P < 0.05)

There was a significant variation between the solubility of the three composite flours. However, the biofortified maize composite flour had the lowest solubility compared to the white maize composite flour. This is line with results by Alamu et al. (2021) who also found that “a composite having a higher concentration of biofortified maize had a lower solubility compared to that which had no biofortified maize in it. This low solubility is indicative of the existence of strong bonding forces within the flour granules arising from coagulated protein or fat that form complexes with amylose preventing it from reaching the granules” (Sung and Stone 2003).

The optimized flour had the highest swelling power of 20.23 and this was not significantly different from that of the other two composite flours. The results of swelling power in Table 4 align with those of Alamu et al. (2021) who found that “the swelling power of a composite containing biofortified maize decreased with reduction in the quantity of biofortified maize flour in the composite”.

3.5 Pasting Properties for the Different Composite Flours

Table 5 shows that there was a significant difference in the peak viscosities of the optimized biofortified maize flour and the white maize-based flour. “Peak viscosity (PV) is the ability of starches to swell freely before their physical breakdown and indicates the strength of the pastes formed during gelatinization” (Sanni et al., 2004). “The optimized biofortified maize and bean flour had a significantly higher peak viscosity compared to the white maize composite flour. The final viscosity of the biofortified maize porridge was significantly $p<0.05$ lower than that of the commercial composite porridge. This is unexpected because it contains a higher protein content than the white maize composite flour. The presence of protein restricts starch swelling and pasting” (Alamu et al., 2021). “A lower pasting viscosity is also indicative of a lower strength of pastes formed during gelatinization” (Sanni et al., 2004). “The provitamin A biofortified maize composite had a significantly higher trough viscosity compared to the white maize composite suggesting its ability to withstand breakdown during cooling “ (Tharise et al., 2014). There was no significant difference between the breakdown viscosities of the provitamin A biofortified bean-based composite and that of the white maize based composite flour, The commercial composite sample registered the highest breakdown viscosity. The results of the breakdown viscosity of the provitamin A biofortified bean based composite flour are in line with those reported by Ndagire et al. (2015) on a supplementary bean based composite flour. The final viscosity of the biofortified maize porridge was 2446.6cP which is within the range of 1000-3000cP the consistency recommended for complementary feeding (Amagloh, 2022). “Viscosity influences the quantity of food a child can consume which can in turn affect the nutrient intake (Makame et al., 2020). Thick and viscous foods have been associated with difficulty in chewing and digestion for infants because of their limited oromotor capacity” (Cichero, 2017).

The peak time and pasting temperature of the provitamin A biofortified and the white maize-based composite were both significantly higher than that of the commercial composite sample but the vitamin A biofortified maize composite had the highest peak time and pasting temperature. These higher values followed a similar trend to that reported by Alamu et al. (2021) who also found “pasting properties of a composite blend containing biofortified maize to be higher than those blends which did not have

Table 4. Functional properties of the composite flours

Functional Property	Sample		
	Biofortified maize based optimized porridge	**White maize composite**	**Commercial composite sample**
Water absorption capacity (%)	$199.3^{a} \pm 0.09$	$186.2^{b} \pm 0.08$	$178.4^{c} \pm 0.16$
Bulk Density (g/mL)	$0.82^{c} \pm 0.01$	$0.90^{b} \pm 0.00$	$0.96^{a} \pm 0.01$
Swelling power at 90˚C g hydrated per 100g of flour.	$20.23^{a} \pm 0.12$	$18.27^{a} \pm 0.05$	$16.11^{a} \pm 0.22$
Solubility (%)	$1.9^{b} \pm 0.01$	$2.00^{a} \pm 0.01$	$1.81^{c} \pm 0.02$

Figures in a row with the same letter as their first superscript are not significantly different.

Table 5. Pasting properties for the different composite flours

Property	Sample Biofortified maize-based optimized porridge	White maize-based composite	Commercial composite sample
Peak 1 (cP)	878.7^{b} ± 5.31	781.3^{c} ± 4.50	2350.7^{a} ±7.71
Trough 1 (cP)	852.3^{b} ±5.31	763.0^{c} ± 3.27	2052.3^{a} ± 4.99
Breakdown viscosity (cP)	24.0^{b} ± 2.45	18.0^{b} ± 1.63	298.4^{a} ± 6.34
Final viscosity (cP)	2446.6^{b} ± 14.88	1454.0^{c} ± 5.10	4380.7^{a} ± 5.90
Setback viscosity (cP)	1589.7^{b} ± 4.92	646.7^{c} ± 3.40	2494.7^{a} ± 89.20
Peak time	7.0^{a} ± 0.1	6.9^{a} ± 0.1	5.9^{b} ± 0.1
Pasting temperature (^{O}C)	88.3^{a} ± 1.02	86.9^{a} ± 0.41	81.0^{b} ± 1.01

Figures in a row with the same letter as their first superscript are not significantly different. Figures in a row with the same letter as their second superscript are not significantly different (P <0.05)

biofortified maize. This is disadvantageous because a composite flour blend with a higher peak time and pasting temperature will inevitably require higher costs of fuel and also likely to have the stability of its nutrients affected by the prolonged cooking accompanied by higher cooking temperatures".

3.6 Consumer Acceptability of the Porridge from the Flours

The results in Table 6 show that the acceptability score for overall appearance ranged from 6.7 – 7.2. There was no significant difference in the acceptability score for overall appearance for the three blends. There was a significant difference in flavor for all the three blends of composite porridge, however, the flavor of the biofortified maize based flour had the highest acceptability score of 7.8 while the commercial composite sample had the lowest score of 6.3. Beswa et al. (2020) found "a similar trend where study participants gave a higher rating for biofortified based porridge relative to the white maize-based porridge for some varieties of biofortified maize. For some other varieties of biofortified maize, the flavor of their porridges was scored lower than the white maize porridges".

"The provitamin A rich maize and high iron bean composite porridge had the highest acceptability score for taste and this was significantly (P<0.05) higher than that of the white maize composite and the commercial composite sample. This is in agreement with results by Alabi (2021) who also found that food made using provitamin A biofortified maize had a better taste compared to that made using traditional maize". "Taste is often one of the most important attributes of an edible product that is looked out for" (Babayeju et al., 2017). It is defined as the sensation of flavor perceived in the mouth and the throat on contact with the substrate. It is also a critical determinant in food selection (Negri et al., 2012). This signifies that the porridge made from the biofortified maize flour has the greatest likelihood of being selected for consumption.

Table 6. Consumer acceptability scores of the different porridges

Attribute	Sample Biofortified maize optimized composite	White maize-based composite	Commercial composite sample
Overall appearance	7.2^{a} ± 1.18	7.0^{a} ± 1.21	6.7^{a} ± 1.09
Flavour	7.8^{a} ± 0.74	7.1^{b} ± 1.33	6.3^{c} ± 0.79
Taste	7.5^{a} ± 1.20	6.5^{b} ±1.48	6.5^{b} ±1.28
Mouth feel	6.8^{a} ± 1.02	6.6^{a} ± 1.47	6.7^{a} ± 1.33
Consistency	6.9^{a} ± 0.95	6.6^{a} ± 1.60	6.3^{a} ± 0.96
Colour	7.4^{a} ± 1.43	6.9^{ab} ± 1.11	6.5^{b} ± 0.66
Overall acceptability	7.1^{a} ± 0.21	7.2^{a} ± 1.05	7.1^{a} ± 1.27

Figures in a row with the same letter as their first superscript are not significantly different. Figures in a row with the same letter as their second superscript are not significantly different (P <0.05). Rows were compared to establish how different sensory attributes were between the three porridges.

There was no significant difference between the acceptability score for mouth feel of the three blends of porridge. However, the ratings for mouth feel/texture of the biofortified maize porridge were higher than the rest of the composite porridges. These findings contrast results by Beswa et al. (2020) who found lower ratings for the texture of biofortified maize porridge compared to the white maize based porridge. He attributed this to stickiness of the biofortified porridge.

The acceptability score for color of the optimized flour blend was significantly higher compared to that of the other two composite porridges. A study by Amod et al. (2016) "revealed similar results where the study participants had a positive perception about the color of a complementary food developed from two different varieties of biofortified maize". "Overall, color is an important factor in sensory evaluation as it has the ability to influence perception and preferences. Provitamin A biofortified crops such as maize have been associated with a yellow to orange color" (Katola et al., 2023). "An increase in carotenoids is associated with a change in color to a more orange hue which is a potential marketing tool for biofortified crops and their products" (Tim et al., 2015).

There was no significant difference between the overall sensory acceptability score of the three blends of the composite porridge. This resonates with the findings by Beswa et al. (2020) who also found no significant difference in overall sensory acceptability scores between stiff porridges made from provitamin A biofortified maize and those that were prepared using non biofortified provitamin A maize. Though porridge from the biofortified vitamin A maize did not numerically score highest, its score of 7.1 is higher than 7 which according to Everitt (2009), a numerical score of 7 and above is indicative of a highly acceptable product. It is also important to note Sensory quality of biofortified maize can be affected during post-harvest storage by changes in the profile of the volatile organic compounds (VOCs) because these play an important role in the sensory perception of food (Ekpa et al., 2018). It is therefore very important to use a fresh harvest or adequately stored biofortified maize for formulating products to increase sensory acceptance. Beswa et al. (2020) added on to recommend the manipulation of food product formulations to overcome the undesirable sensory attributes of provitamin A biofortified maize.

4. CONCLUSION

This study aimed at investigating the nutritional properties and the sensory acceptability of the optimized provitamin A biofortified composite flour. The study revealed that replacing white maize with provitamin A biofortified maize in the composite flour improved the vitamin A, iron, zinc, protein, ash and fat content of the composite flour. The composite porridge was as acceptable as the other composite porridges. The general improvement in nutrient content and decrease in anti-nutrient levels of the biofortified maize composite underlines its possible ability to solve micronutrient deficiencies and other types of malnutrition among children aged 6 to 59 months. Biofortified maize can, therefore, be used as an alternative to white maize when making complementary foods to alleviate both micronutrient and protein energy malnutrition among children below the age of 5 years. The moisture content of the optimized composite flour suggests that the product can remain stable on the shelf. However, further studies investing the shelf stability of the optimized complementary flour should be carried out.

ETHICAL APPROVAL

Authors declare that there are no ethical issues in this manuscript.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abeshu, M. A., Lelisa, A., & Geleta, B. (2016). Complementary feeding: Review of recommendations, feeding practices, and adequacy of homemade complementary food preparations in developing countries – Lessons from Ethiopia. *Frontiers in Nutrition, 3,* 41.

Adegunwa, A., Olatunde, G., Adebanjo, L., & Alamu, E. (2020). Quality and carotenoid compositions of extrudates produced from composite biofortified maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) flours. *Cogent Chemistry, 6*(1), 1767017.

Aderinola, T., & Adeoye, A. D. (2023). Proximate, amino acid compositions and functional properties of maize-beans composite flours. *Food Science and Engineering,* 9–19.

Alabi, D. (2021). Development and acceptability of home-made complementary food from composite flour of provitamin A biofortified maize. *FUW Trends in Science and Technology Journal, 6*, 187–190.

Alamu, G. O., Olatunde, M. O., Adegunwa, L. A., Adebanjo, O. C., Awoyinfa, J. B., Soyoye, & Yildiz, F. (2021). Carotenoid profile and functional properties of flour blends from biofortified maize and improved soybean varieties for product developments. *Cogent Food & Agriculture, 7*(1). https://doi.org/10.1080/23311932.2020.1868665

Adebayo, O., Farombi, A., & Oyekanmi, A. (2013). Proximate, mineral and anti-nutrient evaluation of pumpkin pulp (Cucurbita pepo). *Journal of applied chemistry*, *4*(4), 25-28.

Aluge, O. O., Akinola, S. A., & Osundahunsi, O. F. (2016). Effect of malted sorghum on quality characteristics of wheat-sorghum-soybean flour for potential use in confectionaries. *Food and Nutrition Sciences, 7*(13), 1241–1252.

Amadu, I., Seidu, A.-A., Duku, E., Frimpong, J. B., Jnr, J. E. H., Aboagye, R. G., Ampah, B., Adu, C., & Ahinkorah, B. O. (2021). Risk factors associated with the coexistence of stunting, underweight, and wasting in children under 5 from 31 sub-Saharan African countries. *BMJ Open, 11*(12), e052267.

Amagloh, F. K. (2022). Sweetpotato-based infant foods produce porridge with lower viscosity and aflatoxin level than cereal-based complementary blends. *PLoS One, 17*(10), e0275593.

Amod, R., Pillay, K., Siwela, M., & Kolanisi, U. (2016). Acceptance of a complementary food based on provitamin A-biofortified maize and chicken stew. *Journal of Human Ecology, 55*(3), 152–159.

Awuchi, C. G. (2019). Proximate composition and functional properties of different grain flour composites for industrial applications. *International Journal of Food Sciences, 2*(1), 43–64.*

Babayeju, A., Nmom, I., Obalowu, M., Adebisi, T., & Gbadebo, C. (2017). Sensory attributes and consumption of melon–soybean soup blends with Indian spinach vegetables in Ilorin, Kwara State, Nigeria. *Agrosearch, 17*(1), 89–100.

Baranwal, D., & Sankhla, A. (2019). Physical and functional properties of malted composite flour for biscuit production. *Journal of Pharmacognosy and Phytochemistry, 8*(2), 959–965.*

Baye, K., Guyot, J.-P., & Mouquet-Rivier, C. (2017). The unresolved role of dietary fibers on mineral absorption. *Critical Reviews in Food Science and Nutrition, 57*(5), 949–957.

Beswa, D. (2015). *Nutritional, sensory and health-promoting properties of provitamin A-biofortified maize stiff porridges and extruded snacks.*

Beswa, D., Siwela, M., Amonsou, E. O., & Kolanisi, U. (2020). Grain quality, provitamin A carotenoid profiles, and sensory quality of provitamin A-biofortified maize stiff porridges. *Foods, 9*(12). doi:10.3390/foods9121909

Bhat, N. A., Wani, I. A., & Hamdani, A. M. (2020). Tomato powder and crude lycopene as a source of natural antioxidants in whole wheat flour cookies. *Heliyon, 6*(1).

Black, R. E., Victora, C. G., Walker, S. P., Bhutta, Z. A., Christian, P., De Onis, M., Ezzati, M., Grantham-McGregor, S., Katz, J., & Martorell, R. (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet, 382*(9890), 427–451.

Byarugaba, A. N., J. M., & Mwakha, A. (2023). Effects of roasting conditions on the proximate composition and functional properties of common bean (*Phaseolus vulgaris*) flours. https://doi.org/10.4314/tjs.v49i2.23

Cichero, J. A. (2017). Unlocking opportunities in food design for infants, children, and the elderly: Understanding milestones in chewing and swallowing across the lifespan for new innovations. *Journal of Texture Studies, 48*(4), 271–279.

Ekesa, B., Nabuuma, D., & Kennedy, G. (2019). Content of iron and vitamin A in common foods given to children 12–59 months old from north western Tanzania and central Uganda. *Nutrients, 11*(3), 484.

Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V., & Linnemann, A. R. (2018). Sub-Saharan African maize-based foods: Technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Global Food Security, 17,* 48–56.

Everitt, M. (2009). Consumer-targeted sensory quality. In *Global issues in food science and technology* (pp. 117–128). Elsevier.

FAO, IFAD, & WFP. (2015). *The state of food insecurity in the world 2015: Meeting the 2015 international hunger targets: Taking stock of uneven progress.* Food and Agriculture Organization of the United Nations.

Food and nutrition board, (2003). Dietary Reference Intakes: Guiding Principles for Nutrition Labeling and Fortification. http://www.nap.edu/catalog/10872.html

Gebrezgi, D. (2019). Proximate composition of complementary food prepared from maize (*Zea mays*), soybean (*Glycine max*), and *Moringa* leaves in Tigray, Ethiopia. *Cogent Food and Agriculture, 5*(1). doi:10.1080/23311932.2019.1627779

Global Alliance for Improved Nutrition. (2008). *Nutritional guidelines for complementary foods and complementary food supplements.*

Govender, L. (2014). *Nutritional composition and acceptance of a complementary food made with provitamin A-biofortified maize.*

Govender, L., Pillay, K., Siwela, M., Modi, A. T., & Mabhaudhi, T. (2019). Improving the dietary vitamin A content of rural communities in South Africa by replacing non-biofortified white maize and sweet potato with biofortified maize and sweet potato in traditional dishes. *Nutrients, 11*(6). https://doi.org/10.3390/nu11061198

Hasan, M. M., Ahmed, S., Soares Magalhaes, R. J., Fatima, Y., Biswas, T., & Mamun, A. A. (2022). Double burden of malnutrition among women of reproductive age in 55 low- and middle-income countries: Progress achieved and opportunities for meeting the global target. *European Journal of Clinical Nutrition, 76*(2), 277–287.

Huey, B., Bhargava, A., Friesen, V., Konieczynski, E., Krisher, J., Mbuya, M., Mehta, N., Monterrosa, E., & Nyangaresi, A. M. S. (2023). Sensory acceptability of biofortified foods and food products: A systematic review. *Nutrition Reviews,* nuad100.

Irondi, E. A., Adegoke, B. M., Effion, E. S., Oyewo, S. O., Alamu, E. O., & Boligon, A. A. (2019). Enzymes inhibitory property, antioxidant activity and phenolics profile of raw and roasted red sorghum grains *in vitro. Food Science and Human Wellness, 8*(2), 142–148.

Karlsson, O., Kim, R., Hasman, A., & Subramanian, S. (2022). Age distribution of all-cause mortality among children younger than 5 years in low- and middle-income countries. *JAMA Network Open, 5*(5), e2212692–e2212692.

Katola, A. A., Stark, A. H., Ndolo, V. U., Tembo, D. T., & Katundu, M. C. (2023). Provitamin A retention and sensory acceptability of landrace orange maize (MW5021) food products among school-aged children living in rural Malawi. *Food Production, Processing and Nutrition, 5*(1), 57.

Kaunda, G., Mwangwela, A., Geresomo, N., Kaunda, E., & Simfukwe, K. (2025). Proximate composition, acceptability, and shelf life of complementary foods developed from blends of staple grains maize, soybeans, and fish in Malawi. *Cogent Food and Agriculture, 11*(1). doi:10.1080/23311932.2025.2544957

Kirthee, P., Muthulisi, S., John, D., & Frederick, J. V. (2013). Influence of biofortification with provitamin A on protein, selected micronutrient composition and grain quality of maize. *African Journal of Biotechnology, 12*(34), 5285–5293. https://doi.org/10.5897/ajb12.2920

Lesjak, M., & Srai, S. (2019). Role of dietary flavonoids in iron homeostasis. *Pharmaceuticals, 12*(3), 119.

Lo, D., Wang HsinI, W. H., Wu WanJen, W. W., & Yang RayYu, Y. R. (2018). Anti-nutrient components and their concentrations in edible parts in vegetable families.

López-Moreno, M., Garcés-Rimón, M., & Miguel, M. (2022). Antinutrients: Lectins, goitrogens, phytates and oxalates, friends or foe? *Journal of Functional Foods, 89,* 104938.

Makame, J., De Kock, H., & Emmambux, N. M. (2020). Nutrient density of common African indigenous/local complementary porridge samples. *LWT, 133,* 109978.

Makinde, F. M., & Akinoso, R. (2014). Comparison between the nutritional quality of flour obtained from raw, roasted and fermented sesame (*Sesamum indicum* L.) seed grown in Nigeria. *Acta Sci Pol Technol Aliment, 13*(3), 309–319. https://doi.org/10.17306/j.afs.2014.3.9

Manikantan, M. R., Sharma, R., Yadav, D. N., & Gupta, R. K. (2015). Selection of process parameters for producing high quality defatted sesame flour at pilot scale. *Journal of Food Science and Technology,* *52*(3), 1778–1783. https://doi.org/10.1007/s13197-013-1131-7

Manley, D. (2000). *Technology of biscuits, crackers and cookies.* Woodhead Publishing Ltd.

Margaret, S. J., Yu, N., Howe, S. R. G. J. A., Christopher, R. D., & Torbert Rocheford, S. A. T. (2017). Retention of carotenoids in biofortified maize flour and β-cryptoxanthin enhanced eggs after household cooking. https://doi.org/10.1021/acsomega.7b01202

Mbatchou, V. C., & Dawda, S. (2013). The nutritional composition of four rice varieties grown and used in different food preparations in Kassena-Nankana district, Ghana. *International Journal of Research in Chemistry and Environment, 3*(1), 308–315.

Moreno-Córdova, E. N., Arvizu-Flores, A. A., Valenzuela-Soto, E. M., García-Orozco, K. D., Wall-Medrano, A., Alvarez-Parrilla, E., Ayala-Zavala, J. F., Domínguez-Avila, J. A., & González-Aguilar, G. A. (2020). Gallotannins are uncompetitive inhibitors of pancreatic lipase activity. *Biophysical Chemistry, 264,* 106409.

Mpili, P., Vicent, V., & Rweyemamu, L. (2024). Evaluation of the proximate composition, functional, and pasting properties of ichipipi maize flour. *Applied Food Research, 4*(1), 100408. doi:10.1016/j.afres.2024.100408

Nancy T. (2009). Evaluation of Analytical Methods for the Determination of Moisture, Crude Protein, Crude Fat, and Crude Fiber in Distillers Dried Grains with Solubles, *Journal of AOAC INTERNATIONAL*, Volume 92, Issue 1, 61–73.

Nath, H., Samtiya, M., & Dhewa, T. (2022). Beneficial attributes and adverse effects of major plant-based foods anti-nutrients on health: A review. *Human Nutrition & Metabolism, 28.*

Ndagire, C. T., Muyonga, J. H., Manju, R., & Nakimbugwe, D. (2015). Optimized formulation and processing protocol for a supplementary bean-based composite flour. *Food Science & Nutrition, 3*(6), 527–538.

Negri, R., Di Feola, M., Di Domenico, S., Scala, M. G., Artesi, G., Valente, S., Smarrazzo, A., Turco, F., Morini, G., & Greco, L. (2012). Taste perception and food choices. *Journal of Pediatric Gastroenterology and Nutrition, 54*(5), 624–629. doi:10.1097/MPG.0b013e3182473308

Nilusha, R., Jayasinghe, J., Perera, O., Perera, P., & Jayasinghe, C. (2021). Proximate composition, physicochemical, functional, and antioxidant properties of flours from selected cassava (Manihot esculenta Crantz) varieties. *International Journal of Food Science*, *2021*(1), 6064545.

Nissar, J., Ahad, T., Naik, H., & Hussain, S. (2017). A review phytic acid: As antinutrient or nutraceutical. *Journal of Pharmacognosy and Phytochemistry, 6*(6), 1554–1560.

Ofoedu, C. E., Iwouno, J. O., Ofoedu, E. O., Ogueke, C. C., Igwe, V. S., Agunwah, I. M., Ofoedum, A. F., Chacha, J. S., Muobike, O. P., Agunbiade, A. O., Njoku, N. E., Nwakaudu, A. A., Odimegwu, N. E., Ndukauba, O. E., Ogbonna, C. U., Naibaho, J., Korus, M., & Okpala, C. O. R. (2021). Revisiting food-sourced vitamins for consumer diet and health needs: A perspective review, from vitamin classification, metabolic functions, absorption, utilization, to balancing nutritional requirements. *PeerJ, 9,* e11940. https://doi.org/10.7717/peerj.11940

Oke, E. K., Idowu, M. A., & Omoniyi, S. A. (2016). Proximate, functional, pasting and rheological properties of wheat-tiger nut composite flour. *Annals of Food Science and Technology, 17*(2), 411–420.

Oladele, A., & Aina, J. (2007). Chemical composition and functional properties of flour produced from two varieties of tigernut (*Cyperus esculentus*). *African Journal of Biotechnology, 6*(21).

Onoja, U. S., Akubor, P. I., & Gernar, D. I. C. C. E. (2014). Evaluation of complementary food formulated from local staples and fortified with calcium, iron and zinc. *Journal of Nutrition & Food Sciences, 4*(6). https://doi.org/10.4172/2155-9600.1000326

Onwuka, G. I. (2005). *Food analysis and instrumentation: Theory and practice.* Napthali Prints.

Pusadkar, P., Kokiladevi, E., Bonde, S., & Mohite, N. (2015). Sesame (*Sesamum indicum* L.) importance and its high quality seed oil: A review. *Trends in Biosciences, 8*(15), 3900–3906.*

Quamme, S. H., & Iversen, P. O. (2022). Prevalence of child stunting in Sub-Saharan Africa and its risk factors. *Clinical Nutrition Open Science, 42,* 49–61.

Rao, D., Higgins, C., Margot, H., Lyle, T., McFalls, S., Obeysekare, E., & Mehta, K.

(2016). Micronutrient deficiencies in the developing world: An evaluation of delivery methods. *2016 IEEE Global Humanitarian Technology Conference (GHTC).*

Redden, R., Chen, W., & Sharma, B. (2005). *Chickpea breeding and management.* United Kingdom: CABI.

Rodriguez-Amaya, D. B., & Kimura, M. (2004). *HarvestPlus handbook for carotenoid analysis* (Vol. 2). International Food Policy Research Institute (IFPRI).

Sakala, N. (2021). *Dietary quality of complementary foods for children aged 6–23 months in biofortified intervention areas of Chipata district, Zambia* [Master's thesis, The University of Zambia].

Sanni, L. O., Kosoko, S., Adebowale, A., & Adeoye, R. (2004). The influence of palm oil and chemical modification on the pasting and sensory properties of fufu flour. *International Journal of Food Properties, 7*(2), 229–237.

Sapirstein, H., Wu, Y., Koksel, F., & Graf, R. (2018). A study of factors influencing the water absorption capacity of Canadian hard red winter wheat flour. *Journal of Cereal Science, 81,* 52–59.

Savage, G. (1999). Oxalate content of foods and its effect on humans.

Sung, W.-C., & Stone, M. (2003). Characterization of various wheat starch in pasta development. *Journal of Marine Science and Technology, 11*(2), 1.

Tharise, N., Julianti, E., & Nurminah, M. (2014). Evaluation of physico-chemical and functional properties of composite flour from cassava, rice, potato, soybean and xanthan gum as alternative of wheat flour. *International Food Research Journal, 21*(4).

Tim, J., O'Hare, K., Kent, J., Fanning, I. F., & Martin, J. (2015). Zeaxanthin biofortification of sweet corn and factors affecting zeaxanthin accumulation and colour change. *Archives of Biochemistry and Biophysics.* doi:10.1016/j.abb.2015.01.015

UBOS. (2022). *Uganda Demographic and Health Survey (UDHS) 2022: Key findings.*

Udomkun, P., Masso, C., Swennen, R., Romuli, S., Innawong, B., Fotso Kuate, A., Akin-Idowu, P. E., Alakonya, A., & Vanlauwe, B. (2022). Comparative study of physicochemical, nutritional, phytochemical, and sensory properties of bread with plantain and soy flours partly replacing wheat flour. *Food Science & Nutrition, 10*(9), 3085–3097. https://doi.org/10.1002/fsn3.2907

Udomkun, P., Tirawattanawanich, C., Ilukor, J., Sridonpai, P., Njukwe, E., Nimbona, P., & Vanlauwe, B. (2019). Promoting the use of locally produced crops in making cereal-legume-based composite flours: An assessment of nutrient, antinutrient, mineral molar ratios, and aflatoxin content. *Food Chemistry, 286,* 651–658. https://doi.org/10.1016/j.foodchem.2019.02.055

Ukom, A. N., Adiegwu, E. C., Ojimelukwe, P. C., & Okwunodulu, I. N. (2019). Quality and sensory acceptability of yellow maize ogi porridge enriched with orange-fleshed sweet potato and African yam bean seed flours for infants. *Scientific African*, *6*, e00194. https://doi.org/10.1016/j.sciaf.2019.e00194

Ukom, A. N., Adiegwu, E. C., Ojimelukwe, P. C., & Okwunodulu, I. N. (2019). Quality and sensory acceptability of yellow maize ogi porridge enriched with orange-fleshed sweet.

UNICEF. (2023). *Levels and trends in child malnutrition.*

Wasswa, M., Fungo, R., & Kaaya, A. (2022). Proximate composition and sensory characteristics of refractance window dried cowpea composite porridges. *African Journal of Food, Agriculture, Nutrition and Development, 22*(10), 18965–18979.

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