Development and quality evaluation of banana-rice-bean porridge as weaning food for older infants and young children

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Abstract
Among low-income families in developing countries, foods fed to infants and young children are rich in carbohydrates but limiting in protein and important micronutrients. Our objective was to develop a high-protein weaning food (porridge), with enhanced nutritional contents and acceptable sensory attributes. Cooked light red kidney beans and brown rice and semi-ripe Cavendish bananas were air-dried (60°C, 8–16 hr) and milled into flours to formulate seven banana-rice-bean (BRB) porridge premixes; 80:10:10, 70:10:20, 70:20:10, 60:25:15, 55:20:25, 50:30:20, and 45:40:15 BRBs, respectively. The premixes were analyzed for nutritional (protein, dietary fiber, resistant starch, minerals) and physical properties (moisture, color, density, water solubility, oil and water absorption capacity). Four prepared porridges were evaluated for selected sensory attributes by 31 African/Asian mothers. All BRB porridge premixes met the World Health Organization recommended levels of protein for complementary foods (5.70–8.52 g/100 g). Resistant starch and dietary fiber contents were 6.35–9.21 and 10.1–11.82 g/100 g, respectively. The oligosaccharide (raffinose, stachyose) ranged from 0.19 to 0.46 mg/g and 3.49–6.27 mg/g, respectively. The Tristimulus color values showed a mixed trend, with significant differences among porridges for CIE L* and a* values and Hue angle, whereas no differences were observed for CIE b* value and Chroma. The sensory quality of all prepared porridges was shown to be acceptable, with scores of 6.5–7.1, on a 9-point Hedonic scale. Twenty-nine panelists indicated that they would feed BRB porridge to a child under 5 years old. Overall, the results of this study demonstrated that the BRB porridge could be used as a nutritious weaning food.

KEYWORDS
banana-rice-beans, porridge, proximate, physical attributes, sensory quality

1 INTRODUCTION

Malnutrition is prevalent in many regions of the world, often leading to stunting and wasting. These are the most common health-related conditions in young children from underdeveloped countries, especially among children belonging to families with low income and other socioeconomic issues (Vollmer et al., 2014). UNICEF/WHO (2015) reported that stunting and wasting are estimated to affect 165 million...
and 52 million children worldwide, respectively. Stunting happens when a child’s height is too low for their respective age; specifically, “whose heights are less than two standard deviations below the median height for the age of the standard reference population” (UNICEF/WHO, 2015). This is due to the lack of essential macronutrients and micronutrients (e.g., protein, iron, and zinc) in the diet of children under 5 years old. Stunting, besides negative growth, can also lead to developmental complications, such as cognitive impairment that could last through adulthood (Dewey & Adu-Afarwuah, 2008).

Globally, approximately 5.9 million children 5 years old and under died in 2015, of which 45% of deaths were linked to malnutrition (UNICEF, 2015). Children under the age of 5 in some underdeveloped countries (e.g., Malawi) experience severe malnutrition. According to a 2015 survey, the high rate (42%) of stunting among children in this age group can be linked to malnutrition (UNICEF, 2015). Although UNICEF/WHO (2015) reported a decline in overall stunting for the year 2015, however, conversely, the number of children with stunted growth was still increasing in African continent, which has not shown any noteworthy progress in the country-specific stunting rates.

Generally, the growth rates of breast-fed infants (ages 6 months or below) in most of the developing countries are comparable with those found in the developed countries (GSS/GHS/ICF, 2015; Larrey, Manu, Brown, Peerson, & Dewey, 1999). This is, however, not the case during the weaning period for infants in developing countries. Although infants in the developed countries typically continue to grow normally during this period, stunting and wasting are observed widely among most infants in developing countries during this stage, with undernutrition being the primary reason (Amaglo et al., 2012; Larrey et al., 1999). The poor nutritional quality of the weaning foods is the primary reason for such underdevelopment in infants, along with the prevalence of infections and inadequate feeding being the two other contributing factors (Amaglo et al., 2012; Twum, Kottoh, Torby-Tetteh, Buckman, & Adu-Gyamfi, 2015).

In recent years, the use of indigenous food crops as sustainable sources is being researched as a substitute to typical fortification of existing weaning foods and also for the development of nutrient-dense novel foods for weaning infants (Shegelman et al., 2019; Twum et al., 2015). As defined by the World Health Organization (WHO), complementary feeding is the “process starting when breast milk alone is no longer sufficient to meet the nutritional requirements of infants, and therefore other foods and liquids are needed, along with breast milk.” Traditionally, cereal and legume blend is the major weaning or complementary food among low-income and food-insecure families. This choice of such blends is due to the complementary effect of amino acids, lysine that is limiting in cereals and methionine, the limiting amino acid in legumes. However, the Codex Alimentarius recommends that fruits and vegetables be added to the infant food too (CODEX, 1991). Therefore, finding ways to include and process local food crops (for example, banana, rice, and beans into ready-to-eat nutritious products and making them more shelf-stable would lessen the problem of undernutrition among children 5 years old and below, as well as add value to these traditional food crops thereby helping to minimize postharvest waste. The main objective of this study was to develop of a rice-based complementary food with improved protein content (from red kidney beans) and enhanced sensory properties (from banana) for use in developing nations. Furthermore, the results of this study will help expand the number and variety of traditional weaning foods typically available for children in developing countries.

# MATERIALS AND METHODS

## 2.1 Materials

Cavendish bananas at Stage-3 maturity (mature-to-ripe stage), light red kidney beans, and nonglutinous brown rice were procured from a local food market. The selection of Stage-3 bananas was based on USDA’s Banana Ripening Guide (USDA, 2001). All chemicals and reagents used in this study were of analytical grade and were purchased from Sigma Aldrich (St. Louis, MO, USA). Assay kits for resistant starch and dietary fiber were procured from Megazyme International (Wicklow, Ireland). All treatments and analyses were done using two replicates and results reported on wet weight basis.

## 2.2 Flour processing

Beans and brown rice were sorted and cleaned, followed by thorough washing under tap water. Beans and rice were separately soaked in four-times volume of water at 70°C for 8 hr, followed by 30-min cooking in 99.3°C water. The cooked beans and rice were cooled under 15°C water and dried in a lab-scale SD-P9000 food dehydrator (Tribest Sedona, Anaheim, CA, USA) at 60 ± 1°C for 8–10 hr. Dried beans were dehulled in a W-series hammer mill (Schutte-Buffalo, NY, USA) and sorted manually. Bananas, at Stage-3 maturity, were peeled and cut into 4-mm thick slices and treated with 34 g/L each of ascorbic acid and citric acid in distilled water, followed by subsequent draining to control enzymatic browning. The slices were then dried at 60 ± 1°C for 12–16 hr using a pilot-scale tray dryer (Proctor and Schwartz, Inc., Philadelphia, USA). The dried bananas, beans, and rice, with ~5% moisture content, were milled to 0.5 mm particle size using a UDY cyclone mill, model 3010-019 (UDY Corp., Rome, Italy). All flours were packaged/sealed in 1-mil thick polyethylene bags and stored 23 ± 1°C until analyzed or used for porridge formulation.

## 2.3 Product formulation

Banana-rice-bean (BRB) ratios used for different porridge premix treatments were as follows, respectively: 80:10:10 (Trt-1), 70:10:20 (Trt-2), 70:20:10 (Trt-3), 60:25:15 (Trt-4), 55:20:25 (Trt-5), 50:30:20 (Trt-6), 45:40:15 (Trt-7). The ratios were generally selected based on WHO recommendations for soybean flour usage in infant food (FAO/WHO, 1982) and CODEX (1991) recommendation of 6–15% of total energy requirement from protein in the complementary food and
2.4 | Chemical and nutritional analysis

2.4.1 | Proximate composition

Moisture, crude fat, and ash contents of porridge premixes were determined based on AOAC (2005) method with a slight modification for the analysis of total lipids by using of microwave-hexane extraction.

**Moisture**

About 2 g of porridge premix were weighed into dry aluminum pans, placed in a forced-air oven at 105°C for 12 hr, and then cooled to room temperature in glass desiccator. The weight of the dried samples was recorded to determine the moisture content as g/100 g.

**Ash**

About 3-g portion of porridge were added in preweighed empty crucibles with covers and placed in a muffle furnace overnight at 550°C. The samples were allowed to cool in the furnace and then transferred to glass desiccators to complete cooling at room temperature. Crucibles plus ash were weighed and ash content calculated as g/100 g.

**Crude fat**

Crude fat was extracted from 1 g of porridge in a microwave reaction system, Multiwave, model 3000 (Anton Paar, Inc., Ashland, NC, USA) using 10 ml each of acetone and hexane. The operating conditions of the extractor were: temperature ramp increased 5°C/min, 110°C final temperature; held for 10 min at 110°C; and cooled to 40°C. The extracts were filtered through glass wool into a preweighed flask, and solvent was evaporated using a rotary evaporator. Flasks containing crude fat were dried at 100°C for ~10 min, cooled in a desiccator, and weighed to determine total crude fat as g/100 g.

**Protein**

The Kjeldahl method of sample digestion and neutralization, followed by indophenol colorimetric detection of nitrogen using ammonium chloride as a standard, was used to determine protein content. Approximately 0.5 g samples were digested for 1 hr with 4 ml of hydrogen peroxide and 6 ml of sulfuric acid using a microwave extractor Multiwave, model 3000 (Anton Paar, Inc., Ashland, VA, USA). The tubes were held for 40 min followed by 20 min of cooling. Digested samples were neutralized with 1 M Na2CO3 to a pH range of 6.5–7.5. To determine nitrogen content, five working standards were prepared from 1,000 μg/ml NH4Cl stock solution and sample dilutions prepared when necessary. Two milliliters each of reagent 1 and reagent 2 were added to each tube containing 1 ml each of samples and standards (per L, reagent 1 consisted of 10 g phenol, 50 mg sodium pentacyanonitrosyl ferrate dehydrate, and reagent 2 contained 15 g NaOH, 10 mL NaOCl). All tubes were kept in a 50°C water bath for 40 min, and the absorbance was read at 640 nm using a microplate reader, model Synergy HTX Multi-Mode (BioTek, Winooski, VT, USA). Nitrogen content was quantified based on a standard curve, and 6.25 conversion factor was used for protein content determination.

**Mineral**

Sample and standard preparation for mineral analysis was done following the AOAC Official Method 999.11 (AOAC, 2005). Atomic absorption spectrophotometer, model SpectrAA 55 series (Agilent Technologies, Santa Clara, CA, USA) was used to analyze Ca, Fe, Mg, and Zn. A 0.5 g sample of porridge premix was digested for 90 min with 2 ml of H2O2 and 8 ml of nitric acid in a microwave extraction unit. Digested samples were then diluted to 25 ml with deionized water. For Ca and Mg, 5 ml of diluted digestes were additionally diluted to 20 ml for final absorbance readings. Calcium carbonate, iron metal, magnesium wire, and zinc metal strips were used to prepare Ca, Fe, Mg, and Zn standards, respectively. The working standards were prepared from the 1,000 μg/ml stock solutions for each mineral analysis.

**Total dietary fiber**

The total dietary fiber (TDF) content of porridge premixes were determined based on AOAC Method 985.29 (AOAC, 1987) using the Megazyme assay kit (Megazyme Int'l, Wicklow, Ireland). This method is based on the removal of soluble starch, insoluble starch, and protein using α-amylase, amyloglucosidase, and protease, respectively. Dietary fiber residues were precipitated using 95% ethanol at 60°C and washed successively with 78% ethanol, acetone, and 95% ethanol. The residues were corrected for residual protein and ash, and TDF was calculated following Megazyme's computation guidelines.

2.4.2 | Oligosaccharides (raffinose and stachyose)

Raffinose and stachyose contents were analyzed using the method of Kuo, Vanmiddlesworth, and Wolf (1988) by extracting porridge premix in 80% ethanol at 40°C for 16 hr. The extracted samples were analyzed by high-performance liquid chromatography, using a 6.5 × 300 mm steel cartridge, Waters Sugar-Pak carbohydrate column, WAT085188 (Waters Co., Milford, MA, USA). Quantification of raffinose and stachyose was done with Waters differential refractometer, model 410 (maintained at 35°C) using infrared detector by monitoring elution for 13 min. Concentrations of 0.13–1.34 mM (raffinose) and 0.12–1.20 mM (stachyose) were used to create standard spectra.
2.4.3 | Resistant starch

AOAC method 2002.02 was followed to quantify resistant starch using Megazyme assay kit (Megazyme International, Wicklow, Ireland; AOAC, 2005). Nonresistant starches were hydrolyzed and solubilized at 37°C for 16 hr using α-amylase and amyloglucosidase. Resistant starch was precipitated as a pellet with 99% ethanol by centrifugation at 1,500 x g for 10 min, followed by washing with 50% ethanol. The pellets were then suspended in 2 ml of 2 M KOH. The resistant starch was hydrolyzed to glucose units with amyloglucosidase and quantitatively determined by measuring absorbance at 510 nm and following Megazyme’s computation protocol.

2.5 | Physical properties

Color parameters of BRB porridge were measured using a Minolta color meter, model CR-400, equipped with a D75 light source (Konica Minolta Sensing, Inc., Osaka, Japan). About 25 g of sample were placed in a sample cup, and CIE color values were recorded as: L* (0, black; 100, white), a* (−a, greenness; +a, redness), and b* (−b, blueness; +b, yellowness). The CIE a* and b* values were used to compute Hue Angle (h) and Chroma (C*) according to method of Little (1975):

\[
\text{Chroma} = \sqrt{a^2 + b^2} \\
\text{Hue angle (h)} = \tan^{-1}\left(\frac{b}{a}\right)
\]

The method of AACC (2012) was used to determine the bulk density, by filling 50-g porridge premix into a 100-ml graduated glass cylinder. The cylinder was tapped gently few times on a lab counter to achieve a fairly constant volume and results reported as g/ml.

Water and oil absorption capacities (WAC and OAC) and water solubility index (WSI) were analyzed according to the method of AACC (2012). A 2-g sample of porridge was mixed in 20-ml distilled water for WAC and 20 ml of corn oil for OAC at 25 ± 1°C and centrifuged for 15 min at 1,000 x g. The resulting supernatants were then dried at 130°C in an oven for 2 hr, and WAC and OAC were calculated as the increase in weight of the pellet or sediment, as

\[
\text{WAC or OAC} = \frac{(\text{wt of sediment + centrifuge tube}) - (\text{wt of centrifuge tube})}{\text{wt of original sample, g}} \times 100
\]

For WSI, dried supernatant samples from WAC determination were weighed to determine WSI of porridge, as

\[
\text{WSI} = \frac{(\text{wt of supernatant, g}) + (\text{wt of dried supernatant, g})}{\text{wt of original sample, g}} \times 100
\]

2.6 | Sensory evaluation

After preliminary evaluation, four treatments were selected for final sensory evaluation of prepared porridge (PP) to prevent tasting and evaluation fatigue. Porridges had banana-rice-bean ratios, respectively, as follows: 80:10:10 (PP-1), 70:10:20 (PP-2), 60:25:15 (PP-3), and 55:20:25 (PP-4). Thirty-one mothers of African and Asian origin evaluated porridge at Sensory Evaluation Laboratory of Michigan State University.

Ready-to-serve porridge was prepared by adding 15 ml of 60°C water to 5 g of porridge premix, and served to the panelists within 10 min of preparation. Panelists were asked to evaluate the porridge for the following sensory attributes on a 9-point Hedonic scale; consistency, flavor, appearance, mouthfeel, sweetness, and overall acceptability (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely), as described by Meligaard, Civille, and Carr (1999). Panelists were also asked additional questions about some perceived attributes (beany, flavorful, raw, cooked, bland, traditional, and sweet) in porridge samples; and whether they would feed any of the porridges to their child under the age of 5 years.

2.7 | Statistical analysis

One-way analysis of variance was used to analyze the data, using SPSS version 22 (International Business Machines, New York, USA). The sensory data were collected using SIMS sensory software version 6.0 (SIMS, Berkeley Heights NJ, USA) and analyzed by analysis of variance using SAS software, version 9.3 (SAS Institute, Inc., Cary, NC, USA). The means were separated for comparison by Tukey’s honest significant difference (HSD), and the statistical significance was defined as p ≤ 0.05.

3 | RESULTS AND DISCUSSION

3.1 | Chemical/nutritional composition

3.1.1 | Proximate composition

Proximate composition of BRB porridges is shown in Table 1. The moisture content of BRB porridge ranged from 4.04 to 4.42 g/100, with no significant differences among seven treatments. The moisture levels determined in the present study were significantly (p ≤ 0.05) lower than 8.4 to 13.7 g/100 g reported by Asare, Sefa-Dedeh, Sakyi-Dawson, and Afokwa (2004) and also those of the maximum recommended by Codex Alimentarius (15.5 g/100 g) for wheat flour (CODEX, 1985). Moisture content of many food powders is 5% or less (Intipunya & Bhandari, 2010); the lower moisture content of the BRB porridge premixes could be helpful in maintaining shelf stability and improved product quality because chemical and physical deterioration are less likely to occur at such low moisture content (Intipunya & Bhandari, 2010).

Among the seven treatments, significant differences (p ≤ 0.05) were observed for protein, fat, and ash contents. The highest protein content was observed for Trt-5 porridge premix (55, 20, and 25% banana, rice, and beans, respectively). Raw light red kidney beans have...
the highest protein content (22%), followed by brown rice (7%) and banana (1%) (USDA, 2020). Therefore, increasing levels of beans in the porridge premix contributed to a significant increase in protein content of TRT-5. Protein content of porridge premixes (5.70–8.52 g/100 g) was similar to that of soybean, green bananas, and maize composite flours (5.46–8.95 g/100 g), as reported by Twum et al. (2015). Nutritionally, protein content in all treatments met recommended daily intake (RDI) for protein needed from complementary foods, like BRB porridge, which is 2 g for 6–8 months old infants and 5–6 g for 12-23 month infants (Dewey & Adu-Afarwuah, 2008).

Total fat of all porridge premixes (1.23–1.73 g/10 g) were significantly lower than the amounts recommended to meet daily lipid needs for 9–11 month old infants (3 g) and 12–23 month infants (9–13 g) (Dewey & Adu-Afarwuah, 2008). However, it is noted that porridge and similar other foods are not thought of as a conventional fat source in the diets consumed by the young children.

The TDF content of porridge premixes ranged from 10.10 g/100 g (Trt-3) to 11.82 g/100 g (Trt-5), with no significant differences (p ≥ .05) among treatments. The American Academy of Pediatrics recommends 0.5 g dietary fiber per kilogram of body weight (Aggett et al., 2003) and Codex Alimentarius recommendations are 5% (dry-basis) TDF in complementary foods (CODEX, 1991). The TDF content of all BRB porridges exceeded Codex Alimentarius standards for complementary foods; it is recommended to use beans that are fully dehulled in flour formulations in order to reduce the dietary fiber content (CODEX, 1991).

Calcium, iron, magnesium, and zinc content for BRB porridge premixes differed significantly (p ≤ .05) as shown in Table 1. The highest calcium, iron, and magnesium contents were obtained for Trt-5 (55, 20, and 25% banana, rice, and beans, respectively), whereas, Trt-7 (45, 15, and 40% banana, rice, and beans, respectively) showed the highest amount of zinc. Our results differ from those reported by Twum et al. (2015), wherein significantly lower iron (0.59 vs. 2.83 mg/100 g) and magnesium (12.6 vs. 111.61 mg/100 g) and higher zinc (2.34 vs. 1.44 mg/100 g) contents were obtained for maize composite flour. It is recommended that 50–75% of RDI of individual nutrients are derived from complementary foods (CODEX, 1991; Dewey & Adu-Afarwuah, 2008). The BRB porridge treatments were significantly lower in recommended mineral levels; however, baby foods are fortified with minerals and vitamins to meet such requirement.

### 3.1.2 Oligosaccharides and resistant starch

The oligosaccharides (raffinose and stachyose) and resistant starch (RS) content of BRB porridge premixes are presented in Table 2. Raffinose and stachyose content ranged from 0.19 to 0.46 mg/g and 3.49 to 6.27 mg/g, respectively. Trt-5, containing the most bean content (25%) exhibited the highest level of raffinose and stachyose, with some significant differences (p ≤ .05) among treatments. The raffinose and stachyose content of BRB porridge premixes were significantly lower than those reported by Jangchud and Bunnag (2001), for
cooked bean flour, that is, 5.6 mg/g raffinose and 17.9 mg/g stachyose. The lower levels of these oligosaccharides are desired for food products, which can be achieved by appropriate soaking and cooking of beans as was done in the present study. The amount of RS in BRB porridge premixes ranged from 6.38 to 9.21 g/100 g, with no differences among treatments. Bananas are rich in RS and decreasing banana flour in porridge formulations from 80% (Trt-1) to 45% (Trt-7) resulted in decreased RS content; however, this effect was not significant. Starch digestibility is an important factor in infant nutrition; our results demonstrated that 90.79 to 93.62% of BRB starch was digestible thus contributing positively to energy intake.

3.2 Physical Properties

Among various physical food properties, color is an important attribute, specifically relating to aesthetic characteristics of food products and acceptance by the consumer. The CIE color L*, a*, b* values and Chroma, and Hue Angle of BRB porridge premixes are presented in

### TABLE 2
Raffinose, stachyose, and resistant starch content of banana-rice-bean (BRB) porridge

| Treatments | Raffinose (mg/g) | Stachyose (mg/g) | Resistant starch (g/100 g) |
|------------|-----------------|-----------------|---------------------------|
| Trt-1      | 0.19 ± 0.08ₐ    | 3.53 ± 0.17ₐ    | 9.21 ± 2.20ₐ              |
| Trt-2      | 0.35 ± 0.07ₐ    | 4.62 ± 0.71ₐ    | 8.17 ± 1.18ₐ              |
| Trt-3      | 0.22 ± 0.06ₐ    | 3.49 ± 0.24ₐ    | 8.13 ± 3.35ₐ              |
| Trt-4      | 0.31 ± 0.10ₐ    | 3.99 ± 1.03ₐ    | 7.17 ± 1.8ₐ               |
| Trt-5      | 0.46 ± 0.09ₐ    | 6.27 ± 0.40ₐ    | 6.71 ± 1.30ₐ              |
| Trt-6      | 0.41 ± 0.07ₐ    | 4.92 ± 0.43ₐ    | 6.99 ± 1.6ₐ               |
| Trt-7      | 0.35 ± 0.09ₐ    | 3.95 ± 0.37ₐ    | 6.38 ± 1.4₀ₐ              |

Note. Means sharing the same subscript letter in columns are not significantly different from each other (Tukey’s HSD test, p ≤ .05).

*Treatments had banana, rice, and bean ratios, respectively, as follows: Trt-1 = 80:10:10, Trt-2 = 70:10:20, Trt-3 = 70:20:10, Trt-4 = 60:25:15, Trt-5 = 55:20:25, Trt-6 = 50:30:20, and Trt-7 = 45:40:15.

### TABLE 3
Color parameters L*, a*, b*, values and Chroma and Hue angle of banana-rice-bean (BRB) porridge

| Treatments | L*     | a*    | b*    | Chroma | Hue angle |
|------------|--------|-------|-------|--------|-----------|
| Trt-1      | 76.74 ± 1.69ₐ | 2.91 ± 0.06ₐ | 14.72 ± 1.03ₐ | 15.02 ± 0.99ₐ | 1.375 ± 0.02ₐ |
| Trt-2      | 77.31 ± 1.05ₐ | 2.72 ± 0.05ₐ | 13.89 ± 0.67ₐ | 14.15 ± 0.64ₐ | 1.377 ± 0.01ₐ |
| Trt-3      | 77.13 ± 1.04ₐ | 2.66 ± 0.11ₐ | 13.81 ± 0.8ₐ   | 14.07 ± 0.8₂ₐ | 1.379 ± 0.02ₐ |
| Trt-4      | 78.94 ± 0.75ₐ | 2.30 ± 0.08ₐ | 13.83 ± 1.6ₐ   | 14.02 ± 1.6ₐ   | 1.404 ± 0.01ₐ |
| Trt-5      | 77.67 ± 0.46ₐ | 2.65 ± 0.2ₐ   | 13.28 ± 0.3₂ₐ  | 13.54 ± 0.2ₐ   | 1.373 ± 0.02ₐ |
| Trt-6      | 79.85 ± 0.75ₐ | 1.99 ± 0.2ₐ   | 13.12 ± 1.7ₐ   | 13.27 ± 1.7ₐ   | 1.420 ± 0.00ₐ |
| Trt-7      | 78.97 ± 0.40ₐ | 2.00 ± 0.0ₐ   | 12.92 ± 0.8ₐ   | 13.07 ± 0.8ₐ   | 1.417 ± 0.00ₐ |

Note. Means sharing the same subscript letter in columns are not significantly different from each other (Tukey’s HSD test, p ≤ .05).

*Treatments had banana, rice, and bean ratios, respectively, as follows: Trt-1 = 80:10:10, Trt-2 = 70:10:20, Trt-3 = 70:20:10, Trt-4 = 60:25:15, Trt-5 = 55:20:25, Trt-6 = 50:30:20, and Trt-7 = 45:40:15.

### TABLE 4
Density, water solubility, and water and oil absorption properties of BRB porridge

| Treatments | Density (g/mL) | WSI (%) | WAC   | OAC   |
|------------|---------------|--------|-------|-------|
| Trt-1      | 0.82 ± 0.009ₐ | 28.41 ± 0.06ₐ | 2.79 ± 0.2ₐ | 1.76 ± 0.0ₐ |
| Trt-2      | 0.82 ± 0.014ₐ | 26.12 ± 0.02ₐ | 2.87 ± 0.1ₐ | 1.71 ± 0.0ₐ |
| Trt-3      | 0.81 ± 0.03ₐ  | 24.01 ± 0.05ₐ | 3.02 ± 0.1ₐ | 1.77 ± 0.0ₐ |
| Trt-4      | 0.78 ± 0.03ₐ  | 23.29 ± 0.0ₐ  | 3.03 ± 0.2ₐ | 1.75 ± 0.0ₐ |
| Trt-5      | 0.80 ± 0.00ₐ  | 22.66 ± 0.0ₐ  | 2.98 ± 0.2ₐ | 1.76 ± 0.0ₐ |
| Trt-6      | 0.81 ± 0.00ₐ  | 19.84 ± 0.3ₐ  | 3.10 ± 0.3₂ₐ | 1.75 ± 0.0ₐ |
| Trt-7      | 0.78 ± 0.03ₐ  | 17.00 ± 0.0ₐ  | 3.03 ± 0.7ₐ | 1.74 ± 0.0ₐ |

Notes. Means sharing the same subscript letter in columns are not significantly different from each other (Tukey’s HSD test, p ≤ .05).

*Abbreviations: BRB, banana-rice-bean; OAC, oil absorption capacity; WAC, water absorption capacity; WSI, water solubility index.*

*Treatments had banana, rice, and bean ratios, respectively, as follows: Trt-1 = 80:10:10, Trt-2 = 70:10:20, Trt-3 = 70:20:10, Trt-4 = 60:25:15, Trt-5 = 55:20:25, Trt-6 = 50:30:20, and Trt-7 = 45:40:15.
Table 3. The color values L* and a* differed significantly \((p \leq 0.05)\) among porridges, whereas no differences were observed for b* values. The Trt-6 premix was the lightest in color, with an L* value of 79.85. The lower L* values are considered a negative quality indicator due to enzymatic (polyphenoloxidase-induced) discoloration of banana. Asare et al. (2004) reported color L* values of 79.07 to 91.21 for blends of extruded rice-cowpea. All BRB porridge premixes had the same degree of color intensity \((p \geq 0.05)\), as shown by Chroma values, which is a better measure of overall color saturation as compared with color L*, a*, or b* values alone. With the exception of Trt-6 and Trt-7, all the other treatments had no significant differences in appearance based on Hue Angle values.

WAC and OAC is the amount of water or oil that is absorbed per gram of protein or flour (Rui & Boye, 2013). Results for BRB porridge premix density, WSI, WAC, and OAC are presented in Table 4. No differences were observed with respect to porridge premix density, WAC, and OAC among all treatments. The porridge densities of 0.78 to 0.82 mg/ml were within the range of 0.30 to 1.54 g/ml reported by Asare et al. (2004) for extruded rice-cowpea blend. The highest WSI of 28.41% was observed in Trt-1, with the least in Trt-7 (17.00%). The WSI of porridge premixes appeared to be affected by the amount of banana and rice flour in the formulation. For example, the Trt-1 containing the highest banana flour content was shown to be the most soluble whereas Trt-7 with the highest rice flour content had the lowest WSI. The WSI is linked to degree of dextrinization and gelatinization and resultant starch solubility (Nyombaire, Siddiq, & Dolan, 2011). Similarly, WAC and OAC are important physical properties that can affect the sensory quality of prepared products.

3.3 | Sensory evaluation and consumer acceptability

The results of sensory evaluation of four prepared BRB porridges, selected after preliminary taste evaluation (PP-1, PP-2, PP-3, P-4) are presented in Figure 1. Aside from sweetness, no significant \((p \geq 0.05)\) differences were noted by panelists between porridges for all other attributes, including overall acceptability. It was also observed that sweetness scores suggested a higher liking of samples, as the banana flour content was increased; PP-1 and PP-2 differed from PP-4 \((p \leq 0.05)\). Based on sensory scores ranging from 6.5 to 7.1, all porridge samples were deemed acceptable (i.e., having a score of >5). Twenty-nine panelists (out of 31) indicated they would feed any of the evaluated porridges to a child below 5 years old.

In order to obtain additional information about BRB porridge, panelists were asked additional questions and recorded their responses by selecting “all that apply” (Figure 2). Results demonstrated some differences and trends between samples for selected attributes such as flavorful, bland, beany, and raw. The percentage of panelists, who selected “flavorful” attribute, decreased with a decrease in banana flour content whereas an inverse pattern was noted for “bland” attribute. These trends could be due to an indication...
of negligible effect of the air-drying process on the flavor components of banana. There were significant differences (p ≤ .05) between porridges for “flavorful,” “sweet,” and “traditional” attributes. About 15% of the panelists noted some degree of beany flavor in PP-2 and PP-4. Most of those panelists who selected “beany” and “raw” attributes chose the porridges with the highest level of bean flour (20–25%). These results suggest an observance of rawness when bean flour content was increased in the porridge. At 10% bean flour, it appeared panelists’ perception of beany flavor and “rawness” of porridge decreased, as only one panelist reported beany flavor and “rawness.”

4 | CONCLUSIONS

Development of high-protein weaning foods (e.g., porridges) with enhanced nutritional and sensory attributes is imperative in addressing stunting and wasting in young children in underdeveloped countries. All BRB porridge premixes developed in this study contained significant levels of proteins (5.70–8.52 g/100 g) and met the RDI of protein in complementary foods. Similarly, dietary fiber levels, which ranged from 10.1 to 11.82 g/100 g for all porridges, exceeded Codex Alimentarius recommendations in complementary foods. Addition of cooked bean flour was shown to have a significant effect on most nutrients, particularly protein and digestible starch of porridge premixes, which is especially important in addressing protein energy malnutrition (PEM) issue in infants and children under 5 years old. The overall acceptability scores of all instant PPs were in the range of 6.5 to 7.1, on a 9-point Hedonic scale. Among sensory attributes, sweetness and flavorful attributes of porridge samples were affected positively by the addition of banana flour. Thus, demonstrating that banana flour could be added to traditional cereal-legume porridges to enhance flavor and sweetness that could eventually lead to avoidance of added sugars to these infant foods. It was concluded that BRB composite porridge could be included as part of children’s diet to provide balanced nutrition and help lessen PEM prevalent in many developing countries.

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CONFLICT OF INTEREST

All authors declare that no conflict of interest exists for the research reported in this article.

AUTHOR CONTRIBUTIONS

Makafui Borbi designed the experiment and conducted most of the physicochemical analysis. Kirk Dolan and Muhammad Siddiq provided scientific guidance, reviewed experimental proceedings, statistical analysis, and the manuscript. Sharon Hooper helped conduct resistant starch and dietary fiber analysis. Abdul Sami analyzed samples for selected physical properties.

ETHICAL STATEMENT

This article contains research with human subjects. Michigan State University’s Biomedical, Health Sciences Intuitional Review Board approved the study protocol for sensory evaluation.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study have been reported in this article. Part of the data is not publicly available due to privacy or ethical restrictions.

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