Received: 12 September 2019 | Revised: 30 August 2020 | Accepted: 1 September 2020

DOI: 10.1002/leg3.62

ORIGINAL RESEARCH ARTICLE

Legume Science Open Access WILEY

Functional and pasting properties of fortified complementary foods formulated from maize (*Zea mays*) and African yam bean (*Sphenostylis stenocarpa*) flours

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Abstract

Studies were conducted on the functional, pasting and micronutrient content of complementary weaning foods from maize (*Zea mays*) and African yam bean (AYB; *Sphenostylis stenocarpa*). The complementary foods were fortified with cattle bone meal, *Brachystegia eurycoma* (achi)/potash emulisified with red palm oil and *Moringa oleifera*, to improve the micronutrient content. Maize and AYB (malted and unmalted) were processed into flours, and the fortificants were subjected to different treatments to ascertain the treatment that has the highest micronutrient contents for use in the formulation of the weaning food. Functional properties (water absorption capacity [WAC], bulk density [BD], wettability [WB]) and dispersability [DISP]), pasting properties and micronutrient contents of the formulated blends were determined using standard methods. Ashed fermented by back-slopping, dried and milled (AFDm) treatment for cattle bone meal, unfermented *B. eurycoma*/potash emulsion (PU) and fresh fermented *M. oleifera* treatment had the highest micronutrient contents. The Vitamin A and zinc contents of the formulated infant food were significantly higher ($p \leq 0.05$) than the control (Nutrend, an infant complementary cereal food product made from maize and produced by Nestle Nigeria PLC). The WAC and BD ranged from 155 to 195 g/mL for maize–AYB fermented and enriched with fortificant PU (MAFEP) and maize–AYB fermented enriched with fortificant achi emulsion (MAFEA) and 0.86 to 1.43 g/mL for MAFEA and MAFEP, respectively. The WB values ranged from 16 to 40 s for maize–AYB malt-fermented (MAMF) and MAFEP. There was no significant difference ($p \geq 0.05$) in the dispersability. There were significant differences ($p \leq 0.05$) in pasting temperature, set-back viscosity, final viscosity, peak viscosity and breakdown viscosity except for the peak time. The fortified complementary foods prepared from maize flour and malted AYB significantly improved the functional and pasting properties of the flour blends due to their high micronutrient contents and low BD which can serve as alternative to commercial products.

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KEYWORDS
African yam bean, complementary foods, fortificant, functional properties, maize, micronutrient, pasting properties, weaning food

1 | INTRODUCTION

Intake of cereal-based food products such as maize (*Zea mays*), sorghum (*Sorghum bicolor*) and millet (*Pennisetum typhoideum*) is common in developing countries. These products are mainly used as staple food (Gernah, Ariahu, & Ingbian, 2011), resulting in high incidence of protein deficiency particularly among children (Agiriga & Iwe, 2009; Oosthuizen, Napier, & Oldewage-Theron, 2006) because cereals are known to be low in protein content. Therefore complementary foods are, important in the life of a child to ensure adequate growth and prevent malnutrition, stunting, anaemia and other infectious diseases common in infancy and early childhood. When breast milk nutrients become inadequate for their growth needs, foods of high biological value must be provided to supplement the breast milk in order to meet demand for various activities of the child. The nutritional qualities of weaning foods in Nigeria, as most developing countries, are often low in protein content and devoid of vital nutrients that are required for normal child growth and development (FAO, 2004).

Complementary feeding is introduced early between the ages of 6 and 24 months of birth. Transitional foods are usually produced from cereals, and thus supplementing cereal with legume like African yam bean (AYB) may likely improve the protein content of the cereal–legume-based complementary weaning food. In spite of this and other attempts, problems associated with micronutrient inadequacies still persist and relate to deficiencies in calcium, iron, zinc and Vitamin A. It is important to note that Vitamin A deficiency is reported to be endemic in sub-Saharan African, certainly because its content in complementary foods falls below the Recommended Dietary Allowance (RDA) for infants (World Bank Nigeria, 1996). Food fortification with vitamins and minerals has been used in many countries to solve the problems of micronutrient deficiency (Canibe & Jensen, 2007; Salve, Mehrajfatema, Kadam, & More, 2011). However, the use of vitamin and mineral premix results in expensive products to the middle- and low-income earners. Uvere, Onyekwere, and Ngoddy (2010) reported that micronutrient-dense complementary foods could be produced from maize and Bambara groundnut in the ratio of 70:30 with good physical and functional characteristics and increased calcium, iron, zinc and Vitamin A contents. This was achieved by adding processed cattle bone, *Roselle calyces* and palm oil before fermentation. Incorporating processed *Moringa oleifera* leaves, cattle bone meal and red palm oil may likely increase the iron, zinc, calcium and Vitamin A contents of the maize–AYB complementary diet (Uvere et al., 2010). It is against this background the study was designed to produce a micronutrient-rich complementary diet for infants.

Functionality of a food is the property of a food ingredient that has a great impact on its utilization (Mahajan & Dua, 2002). In processing most complementary food, prominence had been given to nutritional quality and quantity while functional properties are given less attention. Functional properties are a function of consistency because consistency of complementary food aids in easy swallowing of the food by an infant. The consistency, energy density (energy per unit volume) of complementary food and regular feeding are factors that determine the extent to which an infant can meet his energy and nutrient requirements. According to WHO (2003), a good complementary diet must have high nutrient density (macroutrients and micronutrients), low bulk density (BD), viscosity, appropriate texture and consistency that allows easy consumption.

In most developing countries, complementary foods for infant are cereal- and starch-based. Cereal and starch provides the main source of energy; however, starch forms gel when heated, forming a thick and bulky diet with low energy density but liquid consistency that makes it easy to consume. The volume needed to meet the infant energy need often exceed the maximum volume the infant can ingest. Owing to the low energy and nutrient density, large volumes are usually given to meet the infant requirement without considering the infant's limited gastric capacity and number of meals offered per day.

Therefore, the general acceptability of weaning foods by infants is thus influenced by its functionality such as water absorption capacity, bulk density, wettability, dispersibility and pasting properties (peak viscosity, break down viscosity, set-back viscosity, final viscosity and pasting temperature). These functional properties are very necessary to ensure the appropriateness of the diet to the growing child (Omueti, Otegbayo, Jaiyeola, & Afolabi, 2009). Although, there have been studies on fortification of complementary foods with emphasis on nutritional content (Omueti et al., 2009). This work evaluated the functional and pasting properties of complementary weaning food products formulated from maize and AYB fortified with *M. oleifera* leaves, cattle bone meal, red palm oil, *Brachystegia eurycoma* (achi) and potash.

2 | MATERIALS AND METHODS

2.1 | Collection of food samples

Maize (*Z. mays L*) Var DMR-LSR-yellow and AYB (*Sphenostylis stenocarpa*) were used to formulate the complementary weaning food. Processed *M. oleifera*, cattle bone, *B. eurycoma* (achi), red palm oil and potash were used as fortificants. *M. oleifera* served as source of iron and zinc, cattle bone as source of calcium and emulsified palm oil as source of Vitamin A. *B. eurycoma* and potash were used to emulsifier palm oil. The food samples were purchased from Abakpa market, Abakaliki Ebonyi State, Nigeria.

2.2 | Preparation of maize flour

Maize flour was prepared according to method of Canibe and Jensen, (2007). Seven hundred grammes (700 g) of maize seeds were cleaned by winnowing and hand sorting to remove dirt and other extraneous materials. The grains were sprinkled with water for 15 s, degermed using a Bentall attrition mill (Model 200 L090, E.H. Bentall and UK) and sun dried at 28 ± 2°C to a moisture content of 10%. The dried maize grains were winnowed and milled into flour (200-µm particle size). The flour was packaged in polyethylene bags and stored in a refrigerator at 4°C prior to use.

2.3 | Preparation of AYB flour

Malting and unmalting processes were used for preparation of AYB flour.

2.4 | Malting process

The AYB seeds were cleaned by hand sorting to remove dirt, stones and other extraneous materials. Two hundred grammes (200 g) of AYB were weighed into a porous bag (25 cm × 45 cm) and malted at room temperature (28 ± 1°C) using the modified "two-step wet-steep" method as described by Etokakpan and Palmer (1990). The steeping schedule was based on the 16-h procedure for maximum water absorption by the undehulled AYB seeds. The seeds were steeped for 8 h, air rested for 6 h and resteeped in clean water for 8 h. The soaked seeds were then brought out and spread in the malting bags to germinate in a dark room for 72 h during which they were turned once every 24 h. The samples were moistened on alternate days by dipping the malting bags containing the germinating grains in water for 30 s. After 72 h, the malted grains were dried in an oven (Gallenkamp oven Model IH-150 with chamber dimensions 48 × 37 × 34 cm, England) at 50 ± 1°C for 12 h. The moisture content was reduced from 41% to 7%. The seeds were cleaned of sprouts, and hulls were removed by abrasion between the palms and winnowed. The malts were milled into flour with a particle size of 200 µm using Bentall attrition mill (Model 200 L090) and stored in polyethylene bags at 4°C.

2.5 | The preparation of unmalted AYB seeds

AYB seeds were cleaned by hand sorting. Five hundred grammes (500 g) of the AYB grains were steeped in excess water at 28°C ± 1 for 8 h. This was followed by wet dehulling by abrasion between the palms and drying in an oven (Gallenkamp oven Model IH-150, Gallenkamp, England) at 50 ± 2°C to 11% moisture content. The dried grains were milled using a mill (Foss Cyclotec 1093, Sweden), sieved through 200 µm and stored in air-tight polyethene at 4°C. The malted and unmalted AYB flour were mixed manually at 70:20 ratio separately with maize flour to obtain malt-fermented maize–AYB and fermented maize–AYB flour each. Each portion of the same quantity was used in formulation of the fortified complementary food.

2.6 | Processing of food materials used as fortificants

The food materials used as fortificants were subjected to different processing treatments in order to determine the best processing methods that would give high values of nutrients.

2.7 | Processing of cattle bone meal

The method of Uvere et al. (2010) was used in processing cattle bone meal. Two kilogrammes (2 kg) of cattle bones were cracked open using Bench Vice Ma (Model HI-Duty Vice, Paramo, England) and washed with water at 90°C to remove the marrow and oil. The product was dried in a convection Gallenkamp oven (Model IH-150 with chamber dimensions 48 × 37 × 34 cm, England) at 50°C for 12 h and transformed into bone meals. The cattle bone was subjected to nine different treatments as shown in Table 1.

2.8 | Processing of *M. oleifera* leaves

The method of Uvere et al. (2010) for processing *R. calyces* (*Hibiscus saddariffa*) was adopted. *M. oleifera* leaves were hand sorted to remove extraneous materials. The leaves were subjected to six different treatments as shown in the Table 1.

Back-slopping method was carried out by using 10% of the pervious fermented slurry as starter culture for the next fermentation as described Nout, Romboutus, and Hautvart (1989).

2.9 | Emulsification of red palm oil.

B. eurycoma (achi) seeds and potash were used differently in forming 24-h stable emulsion with red palm oil according to the method of Uvere et al. (2010). The two materials were subjected to the same type of treatment following the assessment and selection of the treatment with higher micronutrient in the two food samples (achi and potash) for use in fortifying the complementary food. *B. eurycoma* seeds were roasted at 150°C for 30 min, soaked in excess water for 3 h, dehulled by abrasion and milled into powder. The powder was used in the emulsification of red palm oil. The treatments were as follows:

1. A 24-h stable emulsion of red palm oil, water and *B. eurycoma* (1:1:2 *v*/v/w) was formed, dried at 50°C and the cake was milled into flour = *B. eurycoma* unfermented emulsion (BEU).
2. A 24-h stable emulsion of red palm oil, water and *B. eurycoma* (1:1:2 *v*/v/w) was formed and fermented by back-slopping for 72 h, dried and milled = *B. eurycoma* fermented emulsion (BEF).

TABLE 1 Processing of cattle bone meal and *Moringa oleifera* leaves

Cattle bone meal	*M. oleifera* leaves
100 g of the cattle bone was autoclaved at 121°C for 2 h, dried at 50°C and milled into powder (aDm)	100-g of fresh leaves was dried to moisture content of 10% in a convection Gallenkamp oven (Model IH-150) and ashed at 450°C for 72 h = ashed *Moringa* leaves (A)
100 g of the cattle bone was ashed at 600°C and milled (Am)	100 g of fresh leaves was fermented by back-slopping for 72 h, dried at 50°C in a convection Gallenkamp oven (Model IH-150) and the resulting cake was milled = fresh fermented *Moringa* leaves
100 g of the cattle bones was fermented by back-slopping for 72 h, dried at 50°C and milled into powder (FDm)	100 g of fresh leaves was oven-dried in a convection Gallenkamp oven (Model IH-150), fermented by back-slopping for 72 h, dried at 50°C and milled = dried fermented *Moringa* leaves
100 g of thecattle bone was fermented by back-slopping for 72 h, dried at 50°C and ashed at 600°C before milling (FDAm)	100 g of fresh leaves was sun-dried to crispy texture and milled = sundried *Moringa* leaves
100 g of the cattle bone was autoclaved at 121°C for 2 h, dried at 50°C and ashed at 600°C (aDA)	100 g of fresh leaves was shade dried and milled = shade-dried *Moringa* leaves
100 g of the cattle bone was ashed, fermented by back-slopping for 72 h, dried at 50°C and milled (AFDm)	Fresh *Moringa* leaves was milled, which served as control = fresh *Moringa* leaves (C)
100 g of the cattle bone was fermented by back-slopping for 72 h, autoclaved at 121°C for 2 h, dried at 50°C and ashed at 600°C (FaDA)	
100 g of the cattle bone was autoclaved at 121°C for 2 h, fermented by back-slopping for 72 h, dried at 50°C and then ashed at 600°C (aFDA)	
100 g of the cattle bone was autoclaved at 121°C for 2 h, dried, ashed at 600°C and fermented by back-slopping for 72 h (aDAf). Raw cattle bone was dried at 50°C and milled which served as the C	

3. Half of the emulsified and fermented emulsion was dried at 50°C, and the cake was milled in a laboratory mortar = mixture of fermented and unfermented *B. eurycoma* emulsion (BEM).

Ground potash was also used to form emulsion with palm oil under the same treatment as described for *B. eurycoma*. For potash treatment, the samples were as follows

1. PU = unfermented potash emulsion,
2. PF = fermented potash emulsion, and
3. PM = mixture of fermented and unfermented potash emulsion.

2.10 | Determination of micronutrients in the fortificants

The micronutrients (*β* carotene, iron, zinc and calcium) of the fortificants that were processed using different treatments were determined as follows:

β carotene content of the emulsified red oil was determined using the method described by Onwuka (2005). The samples were mixed with 10-ml acetone and a few crystals of anhydrous sodium sulphate were added and the mixture was allowed to settle. This process was repeated twice. The supernatant was decanted into a beaker and transferred to a separator funnel. Petroleum ether (10 ml) was added to the supernatant, mixed thoroughly and allowed to separate into two layers. The lower layer was discarded and the upper layer was collected in a 100 ml volumetric flask, and the volume was made up to a 100-ml volumetric flask with petroleum ether. The optical density (OD) of the solution was determined at 452 nm using petroleum ether as blank. The content was calculated as

$$\beta\,\text{carotene} = \frac{D \tilde{n} 13.9 \tilde{n} 10{,}000 \tilde{n} 100}{\text{Weight of sample} \tilde{n} 560 \tilde{n} 1{,}000},$$

where OD of the solution is at 452 nm.

M. oleifera samples and raw cattle bone were wet acid digested using a nitric acid and per chloric acid mixture (HNO, HCLO, 5:1 *w/v*). The total amounts of iron, zinc and calcium in the digested samples of the *M. oleifera* and cattle bone were determined by atomic absorption spectrophotometry (Thermo Elemental, model 300 VA, UK, 1969). The treatment that gave highest micronutrient in each fortificant was used in the formulation of the complementary food.

2.11 | Formulation of the complementary foods

The quantity of each of the processed food fortificants used was based on the level of the required nutrients as analysed in the processed food fortificant and the proposed RDA for infant's nutrients between 6 to 12 months of age with slight modification (Lutter & Dewey, 2003). The treatment that showed higher micronutrient in the fortificants after each method of processing were mixed in the ratio of 2.15:4.83:3.03 g (cattle bone meal:emulsified red palm oil with *B. eurycoma* or potash:*M. oleifera*) with 70:20 maize: AYB malt-fermented and unmalted AYB (Lutter & Dewey, 2003; Uvere et al., 2010). The mixture was fermented by back-slopping for 72 h

and dried at 50°C. The resulting cake was milled into flour using a hammer mill (H. Jurgens and Co., Bremen, Germany). The flour was packed in polyethylene bags, sealed and stored at 4°C.

Six complementary food formulations based on their treatments during processing as shown in the following were obtained and assessed for functional and pasting properties:

1. Maize flour + unmalted AYB flour + cattle bone meal + *M. oleifera* = maize–AYB fermented (MAF),
2. Maize flour + malted AYB flour + cattle bone meal + *M. oleifera* = maize–AYB malt-fermented (MAMF),
3. Maize flour + unmalted AYB flour + cattle bone meal + *M. oleifera* + achi emulsion = maize–AYB fermented, enriched with fortificant achi emulsion (MAFEA),
4. Maize flour + malted AYB flour + cattle bone meal + *M. oleifera* + achi emulsion = maize–AYB malted, enriched with achi emulsion (MAMEA),
5. Maize flour + unmalted AYB flour + cattle bone meal + *M. oleifera* + potash emulsion = maize–AYB fermented, enriched with fortificant potash emulsion (MAFEP), and
6. Maize flour + malted AYB flour + cattle bone meal + *M. oleifera* + potash emulsion = maize–AYB malted, enriched with potash emulsion (MAMEP).

2.12 | Determination of functional properties

2.12.1 | Bulk density

The BD was determined by the method of Mulla, Ahemed, and Al-Sharrah (2018) with slight modification. Each sample (50 g) was filled into graduated a cylinder and their weight was noted. The cylinder was tapped continuously until there was no further change in volume. The weight and final volume of flour in the cylinder was noted, and the differences in weight and volume were determined. BD was calculated as grammes per millilitre (g/mL) of the sample.

2.12.2 | Water absorption capacity

The water absorption capacity (WAC) was determined by the method of Mulla et al. (2018) with slight modification. One gramme of each sample was weighed into graduated 25-mL conical centrifuge tubes, and 10 mL of distilled water were added. The suspensions were allowed to stand 30 ± 20C for 1 h. The suspensions were centrifuged (Model No. L-708-2, Phillips Drucker, Oregon USA) at 200 rpm for 30 min. The supernatants were was decanted, and then the sample was reweighed. Change in weight was expressed as gramme per gramme (g/mL).

2.13 | Determination of WB and dispersability (DISP)

WB and dispersability were determined by the method of Onwuka (2005). WB measures the time to moisten completely 1 g of the flour after it is suspended in distilled water. Dispersability was determined by dispersing the samples in water, and particle-size distribution was determined using a laser diffraction particle size analyser (CILAS 1064 Compagnie Industrielle Des Lasers, France).

2.14 | Determination of pasting properties

Pasting properties were determined using a rapid visco analyser (RVA) Series 4 model RVA 3D + Newport scientific Pty. Ltd., Australia, with the aid of thermocline for windows (Version 1.1 Software, 1998). A 2.5 g of the compounded fortified complementary food sample was weighed into a dry empty canister, and then 25 mL of distilled water was dispensed into the canister containing the sample. The solution was thoroughly mixed, and the canister was heated from 50°C to 95°C with holding time of 2 min, followed by cooling to 50°C with 2-min holding time. The rate of heating and cooling was at a constant rate of 11.25°C per minute. PV, breakdown viscosity (BD), FV, SB, peak time and PT were read from the pasting profile with the aid of thermocline for windows software connected to a computer. The apparent viscosity was expressed in RVU (Kolawole & Okafor, 2014).

2.15 | Determination of micronutrient content of fortified maize–AYB complementary food

The micronutrient contents (β carotene, iron, zinc and calcium) of the all the six different complementary food formulations were determined as described above.

3 | STATISTICAL ANALYSIS

Each determination of the functional, pasting and micronutrient properties were carried out in triplicates. Mean values and standard deviation were obtained from each triplicate data. The results were subjected to analysis of variance using SPSS 2007 Version 16 to detect significant differences among sample means. Fisher's least significant difference was used to separate means. Significance difference was accepted at 5% confidence level.

4 | RESULTS

5 | DISCUSSION

The fortificants were subjected to different processing treatments. These treatments were carried out in order to determine the best processing methods that showed high values of nutrients. Table 2 presents the calcium contents of processed cattle bone meal. The calcium contents of the processed cattle bone (Table 2) ranged from

TABLE 2 Calcium content of processed cattle bone samples

Treatment	Calcium content (mg/100 g)	*p* value
aDm	781.56^{ab}	<.051
AM	741.48^{c}	<.001
FDm	661.32^{c}	<.001
FDAm	641.28^{c}	<.001
aDA	841.68^{ab}	<.051
AFDm	861.72^{ab}	<.001
FaDA	761.52^{bc}	<.001
aFDA	821.64^{ab}	<.051
aDAF	727.45^{c}	<.051
C	947.89^{a}	<.001
LSD	182.09	

Note. Values are the mean of triplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: aDA, autoclaved, dried and ashed; aDAf, autoclaved, dried, ashed and fermented by backslopping and milled; aDm, autoclaved, dried and milled; aFDA, autoclaved, fermented by back slopping, dried and ashed; AFDm, ashed, fermented by backslopping, dried and milled; Am, ashed and milled; C, control (raw bone); FaDA, fermented by backslopping, autoclaved, dried and ashed; FDAm, fermented by backslopping, dried, ashed and milled; FDm, fermented by back-slopping; dried and milled.

641.28 mg/100 g to 947.89 mg/100 g. The raw bone sample had the highest value of 947.89 mg/100 g, whereas FDAm sample had the lowest value of 641.28 mg/100 g. The result showed that all samples that had fermentation as their first treatment were low in calcium compared with the ones ashed before fermentation (Table 2). Ashed fermented samples had improved accessibility to calcium hydroxyapatite as a result of increased surface area provided by milling (Uvere et al., 2010). Fermentation may not be an effective method of decomposing calcium from bone meal. Statistical analysis showed significant difference ($p \leq 0.05$) between the raw bone meal and all those fermented first, but no significant difference ($p \geq 0.05$) was observed in calcium contents of all the autoclaved samples. This suggests that ashed, fermented and dried bone meal (AFDm) was the best method of choice for processing cattle bone into meal because it may be economical in terms of energy used compared with autoclaved (aDA). Hence, AFDm treatment for cattle bone meal was used in the formulation.

The β-carotene content of the red palm oil emulsified with *B. eurycoma* (Table 3) ranged from 1.71 mg/g to 2.16 mg/g. The unfermented *B. eurycoma* emulsion (BEU) had the highest value, whereas the mixture of fermented and unfermented *B. eurycoma* emulsion (BEM) had the lowest value. The red palm oil emulsified with potash emulsion ranged from 6.70 mg/g to 15.05 mg/g β carotene. The unfermented potash emulsion (PU) had the highest value, whereas the mixture of fermented and unfermented potash emulsion (PM) had the lowest value.

The result showed that emulsification of red palm oil with *B. eurycoma* or potash followed by drying at 50°C led to reduction in β-carotene content, suggesting that emulsifiers bind β carotene and drying at 50°C resulted in a loss of β carotene. The mechanism of destruction of β carotene has been reported to be through

TABLE 3 β-carotene content of processed red palm oil

Treatment	*Brachystegia eurycoma*	Potash	
β carotene (mg/100 g β carotene)			β carotene (mg/100 g β carotene)
PO	6.94^{b}	PO	6.94^{b}
BEU	2.16^{e}	PU	15.05^{a}
BEF	2.05^{e}	PF	7.20^{b}
BEM	1.71^{f}	PM	6.70^{b}
LSD	0.27	LSD	0.27

Note. Values are the mean of duplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: BEF, *B. eurycoma* fermented emulsion; BEM, mixture of fermented and unfermented *B. eurycoma* emulsion; BEU, *B. eurycoma* unfermented emulsion; PF, fermented potash emulsion; PM, mixture of fermented and unfermented potash emulsion; PO, palm oil; PU, unfermented potash emulsion.

isomerisation (conversion of all trans-β-carotene to stereoisomers having lower pro-Vitamin A activity) during heat treatment (Mahesh & Uday, 2013). Food materials contain many heat-sensitive nutrients. Cooking conditions and heat treatment caused vitamin loss (Mahesh & Uday, 2013). The unfermented potash emulsion dried at 50°C had the highest release of β carotene, suggesting that the potash may have a more effective buffering system, resulting in lower production of acid. Isomerization of trans carotenoids to less-active cis isomer during drying is promoted by acid contact which could have happened when unfermented potash emulsions were dried. Hence, the unfermented BEM with red oil and unfermented potash emulsion with red oil were used differently as fortificants in the formulation of each complementary food.

The iron contents of the processed *M. oleifera* leaves (Table 4) ranged from 47.25 mg/100 g in both sundried and ashed samples to 93.15 mg/100 g in shade-dried samples. Statistical analysis showed significant difference ($p \leq 0.05$) between the iron content of shade-dried *Moringa* leaves and iron content of other processed *M. oleifera* leaves. The significant increase in iron contents of fresh fermented

TABLE 4 Iron and zinc content of processed *Moringa oleifera* leaves

Treatment	Iron (mg/100 g)	Zinc (mg/100 g)
Shd	93.15^{a}	-
Sd	47.25^{d}	207.58^{b}
FF	76.95^{d}	279.50^{a}
DF	62.10^{c}	210.86^{b}
A	47.25^{d}	144.53^{c}
C	55.35^{cd}	225.56^{b}
LSD	8.81	19.40

Note. Values are the mean of duplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: A, ashed *Moringa* leaves; C, control (fresh *Moringa* leaves); DF, dried fermented *Moringa* leaves; FF, fresh fermented *Moringa* leaves; Sd, sundried *Moringa* leaves; Shd, shade-dried *Moringa* leaves.

and dried fermented may be attributed to freshness of the leaves and drying temperature. Increase in iron content in shade-dried may be a result of the drying temperature because drying concentrates nutrients and some microorganisms associated with fresh fermented leaves, which require iron for metabolism may have been activated during fermentation. The zinc contents of the processed *M. oleifera* leaves (Table 4) ranged from 144.53 mg/100 g in ashed *Moringa* leaves to 279.50 mg/100 g in fresh fermented *Moringa* leaves. Thecontrol (fresh *Moringa* leaves) has a value of 225.56 mg/100 g. The high value in fresh *Moringa* leaves may be due the freshness of the leaves, and no treatment was given to the sample (fresh *Moringa* leaves), resulting in no loses of zinc. Statistical analysis showed significant difference ($p \leq 0.05$) between fresh fermented and other processed samples. Increase in zinc content of fresh fermented leaves over dried fermented could be due to fermentation-induced phytate reduction (Uvere et al., 2010). The zinc contents in fresh fermented also suggest that most of the zinc requiring fermenting microorganism's associated with fresh leaves may have been eliminated during drying. Hence, *M. oleifera* leaves subjected to fresh fermentation treatment were used in the formulation of the complementary food.

5.1 | Functional properties of maize–AYB complementary food

Table 5 presents the functional properties of maize–AYB complementary food. Functional properties determine the application and uses of food material for diverse food end products. WAC obtained for maize–AYB-fortified food diets ranged from 155 to 195 g/g. The maize–AYB fermented, enriched with *B. eurycoma* (achi) emulsion (MAFEA), had the highest WAC, whereas maize–AYB fermented, enriched with potash emulsion (MAFEP), had the lowest. The values obtained in this work were higher than the values obtained by Suresh, Samsher, and Durvesh (2015). High WAC of MAFEA may be attributed to increase in amylose leaching, solubility and loss of starch crystalline structure (Suresh et al., 2015). *B. eurycoma* are high in protein content and proteins are naturally hydrophilic in nature and will absorb and bind more water while low WAC may be due less availability of polar amino acid as reported by Suresh et al. (2015). Low WAC also implies lower water absorption capacity, which is desirable for making thinner gruels with high energy density per unit volume (Omueti et al., 2009). Statistical analysis showed significant difference ($p \leq 0.05$) among the samples. The WAC is the ability of a product to associate with water under condition where water is limiting (Omueti et al., 2009). A good WAC may be useful in products where good viscosity is required.

The BD depicts the behaviour of the material in dry mixes and is an important parameter that determines the packaging requirements of products (Mohamed, Zhu, Issoufou, Fatmata, & Zhou, 2009). The BDs of the different formulations (Table 5) showed that maize–AYB fermented and enriched with fortificant potash emulsion (MAFEP) had the highest BD 1.43 g/mL, whereas maize–AYB fermented and enriched with fortificant achi emulsion (MAFEA) had the lowest BD 0.86 g/mL, followed by maize–AYB malt-fermented and enriched with potash emulsion MAMEP 0.97 g/mL. Reduction in BD on malting was a reflection of the activity of α-amylase enzymes activated during the malting process. Germination has been reported to be a useful method for the preparation of low bulk weaning foods (Okoye, Ezigbo, & Animalu, 2010). High BD may indicate greater compactness of the particles because particle size is inversely proportional to BD (Faylade & Olugbuyi, 2010). Samples with lower BDs in the diets of the complementary food may imply that more of the samples could be prepared using a small amount of water, yet giving the desired energy nutrient density and semiconsistency, which can easily be fed to an infant with ease without choking and suffocation. This observation is in agreement with the report of Ikujenola (2010) and Inyang and Zakari (2008). Low BD would be of advantage in the formulation of complementary foods. The result of BD in this study is higher than the value reported for unripe cooking banana, pigeon pea and sweet potato flour blend 0.48 g/mL to 0.92 g/mL as reported by Ehimen et al. (2017) but within the same range for maize–AYB fermented, enriched with fortificant achi emulsion (MAFEA). Diet with low BD have been reported to be poor in gelation ability (Omueti et al., 2009), hence will not form a thick gel. This is a good functional property for a complementary diet owing to the limited gastric capacity of an infant to digest thick and viscous food. According to WHO (2003), a good complementary diet is one that is neither too thick nor thin. A too thick diet will be difficult for an infant to ingest and metabolize due to

TABLE 5 Functional properties of maize–African yam bean complementary food

Formulations	WAC (g/mL)	BD (g/mL)	WB (s)	Disp (mL)
MAF	180 ± 4.24^{ab}	1.25 ± 0.03^{a}	23 ± 0.06^{a}	72 ± 2.83^{a}
MAMF	185 ± 1.41^{a}	1.20 ± 0.2^{ab}	16 ± 0.29^{b}	68 ± 2.83^{a}
MAFEA	195 ± 4.24^{ab}	0.86 ± 0.2^{b}	34 ± 0.22^{c}	68 ± 1.42^{a}
MAMEA	177 ± 2.83^{ac}	1.07 ± 0.62^{c}	19 ± 0.49^{d}	66 ± 4.24^{a}
MAFEP	155 ± 5.66^{b}	1.43 ± 0.02^{d}	40 ± 0.97^{e}	70 ± 2.83^{a}
MAMEP	180 ± 1.41^{a}	0.97 ± 0.02^{e}	28 ± 8.03^{f}	72 ± 1.42^{a}

Note. Values are the mean of duplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: BD, bulk density; DISP, dispersability; MAF, maize–AYB fermented; MAFEA, maize–AYB fermented, enriched with fortificant achi emulsion; MAFEP, maize–AYB fermented, enriched with fortificant potash emulsion; MAMEA, maize–AYB malted, enriched with achi emulsion; MAMEP, maize–AYB malted, enriched with potash emulsion; MAMF, maize–AYB malt-fermented; WAC, water absorption capacity; WB, wettability.

its limited gastric capacity, whereas a too thin diet will have a reduced energy nutrient density.

The WB values ranged from 16 to 40 s (Table 5). The maize–AYB fermented, enriched with fortificant potash emulsion (MAFEP), had the highest WB time in cold water (40 s), wheras maize–AYB malt-fermented (MAMF) had the shortest time (16 s). The WB provides useful indication of the degree to which the formulated diets are likely to possess instant characteristics (Onwuka, 2005). Complementary foods that have a higher tendency of being easily wetted makes reconstitution easier and faster. The MAMF may be reconstituted easily as a result of amylase enzyme activities that developed during the process of germination. These enzymes degrade the starch, the main constitute of the gel structure resulting in the production of a liquid gruel, thereby making reconstitution easier and faster (Ikegwu, Okechukwu, & Ekumankama, 2010). Reconstitution affects characteristics like thickness and viscosity due to hydrodynamic properties of foods.

The dispersability values ranged from 66 to 72 mL (Table 4). The maize–AYB fermented (MAF) and maize–AYB malted, enriched with potash emulsion (MAMEP), had the highest dispersability value of 72 mL, whereas maize–AYB malted, enriched with achi emulsion (MAMEA), had the lowest dispersability value of 66 mL. Dispersability describes the ease with which flour samples may be distributed as single particles over the surface and throughout the bulk of the constituting water. The MAF and MAMEP are easily dispersible. There was no significant difference among the samples at ($p \geq 0.05$).

5.2 | Pasting properties of maize–AYB complementary food

The results of the pasting properties of maize–AYB complementary diets are presented in (Table 6). Pasting properties are results of combination of processes that follow gelatinization from granule rupture to subsequent polymer alignment due to mechanical shear during the heating and cooling of starches. The PV, which is the ability of starch to swell freely before their physical breakdown, ranged from 45 to 235 RVU. The maize–AYB fermented (MAF) had the highest PV of 235 RVU. The maize–AYB malted, enriched with potash emulsion (MAMEP), had the lowest PV of 45 RVU, whereas the control had a PV of 119 RVU. Low PV implies that the weaning food will form a low viscous paste rather than a thick gel on cooking and cooling. This means that the gruel will be a high caloric density food per unit volume rather than a dietary bulk (Ikujenola & Fashakin, 2005). Statistical analysis showed significant difference ($p \leq 0.05$) among the samples. High PV of MAF is an indication of high starch content and the ratio of amylase and amylopectin and the resistance granules to swelling (Ikegwu et al., 2010), whereas low PV of MAMEP implies that the complementary diets will form a low viscous gel rather than a thick gel on cooking and cooling (Omueti et al., 2009). The PVs of the complementary diets are lower than the value reported for *pukuru*—a fermented cassava product of 362 to 430 RVU by Shittu, Lasekan, Sanni, and Oladosu (2011) and composite flour from wheat and sweet potato of 131.42 to 271.08 RVU by Odedeyi and Adeleke (2010).

The break down viscosity value is an index of the stability of starch during cooking (Tijani, Omohimi, Sanni, & Oke, 2016; Zaidhul, Hiroaki, Sun-Jn, Naoto, & Takahiro, 2006). The maize–AYB fermented (MAF) had the highest value of 127 RVU for break down viscosity, whereas the maize–AYB malted, enriched with potash emulsion MAMEP, had the lowest value of 3RVU (Table 6). Ikegwu et al., 2010 reported that the lower the break down viscosity, the higher the ability of the flour to withstand heating and shear stress during processing. High holding strength exhibited by MAF showed that the diet could withstand heating and shear stress during processing without significant change in consistence than the control. The break down viscosity reported in this work is higher than that reported by Okorie, Ikegwu, Nwobasi, Odo, and Egbedike (2016) for water yam and cowpea composite flour of 12.42 to 27.58 RVU due to varying granular association coupled with the amylose–amylopectin ratio of starches during heating and cooling. High holding exhibited by MAF represents low cooking loss and good eating quality.

The SB ranged from 61 to 90 RVU (Table 6). The maize–AYB fermented, enriched with fortificant potash emulsion (MAFEP), had the lowest SB of 61.00 RVU, whereas maize–AYB malt-fermented (MAMF) had the highest value of 90 RVU. Statistical analysis again showed significant difference ($p \leq 0.05$) among formulated samples. It

TABLE 6 Pasting properties of maize–African yam bean complementary food

Formulations	PV	BD	SB	FV	PT	Peak time
MAF	235 ± 0.06^{a}	127 ± 0.13^{a}	74 ± 0.06^{a}	183 ± 0.08^{a}	91 ± 0.05^{a}	6.25 ± 0.03^{a}
MAMF	197 ± 0.30^{b}	38 ± 70.05^{b}	90 ± 0.05^{a}	249 ± 0.10^{b}	92 ± 0.03^{b}	6.35 ± 0.03^{ab}
MAFEA	194 ± 0.07^{c}	45 ± 0.08^{c}	88 ± 0.06^{c}	237 ± 0.30^{c}	91 ± 0.03^{c}	6.09 ± 0.07^{ac}
MAMEA	135 ± 0.13^{d}	37 ± 0.14^{d}	62 ± 0.06^{d}	106 ± 0.10^{d}	90 ± 0.05^{d}	6.35 ± 0.03^{ad}
MAFEP	169 ± 0.06^{e}	6 ± 0.06^{e}	61 ± 0.08^{e}	230 ± 0.2^{e}	91 ± 0.06^{e}	6.33 ± 0.06^{ae}
MAMEP	45 ± 0.05^{f}	3 ± 0.03^{f}	65 ± 0.03^{f}	107 ± 0.02^{g}	92 ± 0.05^{f}	6.19 ± 0.05^{a}
CONTROL	119 ± 0.14^{g}	48 ± 0.06^{g}	55 ± 0.03^{g}	126 ± 0.10^{f}	92 ± 0.05^{g}	6.32 ± 0.03^{a}

Note. Values are the mean of duplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: BD (RVU), break down viscosity; FV (RVU), final viscosity; MAF, maize–AYB fermented; MAFEA, maize–AYB fermented, enriched with fortificant achi emulsion; MAFEP, maize–AYB fermented enriched with fortificant potash emulsion; MAMEA, maize–AYB malted, enriched with achi emulsion; MAMEP, maize–AYB malted, enriched with potash emulsion; MAMF, maize–AYB malt-fermented; PT (°C), pasting temperature; PV (RVU), peak viscosity; SB (RVU), set-back viscosity.

has been reported that low set-back value is an indication that the starch has a low tendency to retrograde or undergo syneresis during freezing or thawing (Ikujenola & Fashakin, 2005). This means that MAFEP and the control might be stored at low temperature with low tendency to retrograde. Low SB implies that the complementary diet on cooking will not be a cohesive gruel. This is in agreement with the work on cooking potato paste.

FV ranged from 106 to 249 RVU (Table 6). The maize–AYB malt-fermented (MAMF) had the highest value of 249RVU, whereas the maize–AYB-malted, enriched with achi emulsion (MAMEA), had the lowest value (106 RVU). There were significant differences ($p \leq 0.05$) among formulated samples. FV is the most commonly used parameter to define the quality of a particular starch-based sample as it indicates the ability of the material to form a viscous paste after cooking and cooling and the paste resistance to shear force during stirring. The highest FV value of 249 RVU for the MAMF indicates the ability to form a firm visco elastic paste or gel after cooking and cooling owing to the reassociation of starch molecules. The low FV of MAMEA implies that the complementary diets will form a low viscous paste rather than a thick gel on cooking and cooling. The control had an FV of 126 RVU.

The PT ranged from 90°C to 92 ± 1°C (Table 6), with significant difference ($p \leq 0.05$) among samples. The maize–AYB malt-fermented and maize–AYB-malted, enriched with potash emulsion, had the highest PT of 92 ± 1°C value. The maize–AYB-malted, enriched with achi emulsion MAMEA, had the lowest PT of 90 ± 1°C, whereas the control had a PT of 92 ± 1°C. PT gives an indication of the gelatinization temperature during processing. It is the temperature at which the first detectable increase in viscosity is measured and is an index characterized by initial change due to the swelling of starch. The PT indicates the minimum temperature required for cooking and gelatinization (Ikegwu et al., 2010). Low gelatinization temperature implies shorter cooking time. It has been reported that the PT is related to water-binding capacity (Ikegwu et al., 2010). A higher PT implies higher gelatinization, higher water-binding capacity and lower swelling property of starch due to a high degree of association between starch granules.

Peak times obtained from the formulated diets ranged from 6.09 to 6.35 min (Table 6). The maize–AYB malt-fermented MAMF and maize–AYB-malted, enriched with achi emulsion MAMEA, had the highest 6.35-min peak time. The maize–AYB fermented, enriched with fortificant achi emulsion MAFEA, had the lowest of 6.09 min, whereas the control had a peak time of 6.32 min. There were no significant differences ($p \geq 0.05$) among the samples in the pasting time. This may be due to high swelling index capacity of the starch granules in the flour samples. Peak time is a measure of the cooking time (Adebowale, Sanni, & Awonorin, 2005). It is the time at which the PV occurs.

5.3 | Micronutrient content of fortified maize–AYB complementary food

Table 7 presents the micronutrient contents of fortified maize–AYB complementary food. The β carotene contents of maize–AYB complementary foods ranged from 4.34 mg/100 g to 63.03 mg/100 g β carotene (Table 7). The maize–AYB-malted, enriched with potash emulsion, had the highest 63.03 mg/100 g β carotene content, whereas the maize–AYB fermented had the lowest 4.34 mg/100 g β carotene. The β-carotene content of fortified maize–AYB complementary foods were significantly ($p \leq 0.05$) higher than the unfortifed food samples and could be due to the high retinol equivalent of the palm oil of the blends (Dijkahuizen, 2003). It may also be due to the emulsifiers acting as stabilizers for the retinol formed by delaying or inhibiting oxidation of β carotene (Dijkahuizen, 2003). The β-carotene contents of the maize–AYB blends were higher than the control (Nutrend). This indicate that red palm oil is a good source of pro-Vitamin A for infant formula.

The iron content of the maize–AYB complementary food ranged from 0.06 mg/100 g to 1.80 mg/100 g (Table 7). The maize–AYB-malted, enriched with potash emulsion, had the highest iron content (1.80 mg/100 g), whereas the maize–AYB fermented had the lowest iron content (0.06 mg/100 g). The iron contents of the blends of unmalted AYB and *B. eurycoma* were significantly lower ($p \geq 0.05$) than others and the control. This could be due to the phytic acid present in unmalted legumes which has a strong binding affinity to minerals like iron and copper, as reported by Cheryan and Rackis (1980).

The zinc content (Table 7) ranged from 147.1 mg/100 g in maize–AYB fermented to 336.71 mg/100 g in maize–AYB fermented, enriched with potash emulsion. The zinc contents of the fortified maize–AYB complementary foods were significantly higher ($p \leq 0.05$)

TABLE 7 Micronutrient content of fortified maize–African yam bean complementary food

Micronutrients (mg/100 g)	Flour blends							
	MAF	MAMF	MAFEA	MAMEA	MAFEP	MAMEP	LSD	Control
β carotene	4.34^{c}	10.69^{c}	44.86^{b}	44.86^{b}	56.81^{c}	63.03^{a}	7.1	1,500 IU
Iron	0.06^{e}	0.75^{d}	1.16^{b}	0.89^{c}	0.73^{d}	1.80^{a}	0.11	10 mg/100 g
Zinc	147.11^{f}	179.79^{e}	294.21^{b}	202.68^{d}	336.71^{a}	253.35^{c}	8.22	6 mg/100 g
Calcium	320.64^{c}	300.60^{d}	340.68^{b}	326.65^{c}	360.7	340.68^{b}	18.22	390 mg/100 g

Note. Values are the mean of duplicate determinations. Values in the same column with different superscripts are significantly different ($p \leq 0.05$).
Abbreviations: MAF, maize–AYB fermented; MAFEA, maize–AYB fermented, enriched with fortificant achi emulsion; MAFEP, maize–AYB fermented enriched with fortificant ant potash emulsion; MAMEA, maize–AYB malted, enriched with achi emulsion; MAMEP, maize–AYB malted, enriched with potash emulsion; MAMF, maize–AYB malt-fermented.

than the control due to freshness of the leaves and fresh fermented *Moringa* leaves than dried *Moringa* leaves. The microorganisms associated with fresh leaves may have been eliminated during drying. High zinc content helps children fight against infections such as diarrhoea (Aggarawal, Szent, & Miller, 2007).

The calcium contents of maize–AYB complementary food ranged from 300.60 mg/100 g in maize–AYB malt-fermented to 360.7 mg/100 g in maize–AYB fermented, enriched with potash emulsion (Table 7). The calcium content of the fortified maize–AYB complementary foods were significantly higher. High calcium content could be made possible for reduction in the risk of osteoporosis and colon cancer (Meinrad, Enkoe, & Heide, 2013).

6 | CONCLUSION

The fortified complementary foods prepared from fermented maize flour and malted AYB flour significantly improved the functional and pasting properties of the formulated complementary food. Fortification of the flour blend with red palm oil, *M. oleifera* and cattle bone increased the micronutrient contents (Vitamin A, zinc and calcium) of the complementary food. Malting process led to reduction of BD, low viscous high caloric density food per unit volume rather than a dietary bulk (high volume/high viscosity diet), reduced plasticity and elasticity; hence, the diet will have a low dietary bulk, which is desirable for growing infant. The functional properties of these diets will provide an appropriate complementary diet in terms of texture, dietary bulk and caloric density. There is, therefore, a need to develop and adopt technologies that lower BDs in complementary foods. Again, this study has shown that maize and AYB-malted was the best among samples. The method for the production of these diets is simple, and the ingredients are readily available, cheap and affordable. These products are rich in micronutrient Vitamin A, zinc and calcium and will be valuable for the growing infant who is transiting from breast milk to semisolid food that will help the child fight against disease and hidden hunger. The complementary foods, therefore, could be recommended as an alternative to commercial products which are more expensive and not within the purchasing power of the poor populace.

CONFLICTS OF INTEREST

None declared.

DATA AVAILABILITY STATEMENT

The data were archived in mendeley with https://doi.org/10.17632//jxtbgc4tty.1.

AUTHOR CONTRIBUTIONS

Conceptualization: A. F. C., N. K. E. and I. O. J. Methodology: A. F. C., N. K, E., I. O. J. and N. F. N. Data collection: E. E. N. and O. G. N. Validation: N. F. N. and I. O. J. Writing original draft: A. F. C. and N. K. E. Supervision: A. F. N., N. F. N., I. O. J., A. F. C. and N. K. E. Software: A. F. C. and N. K. E. Reviewing and editing: N. K. E. and N. S. T.

ETHICS STATEMENT

This research was approved and carried out in the Department of Food Science and Technology, Ebonyi State University, P.M.B. 053 Abakaliki, Ebonyi State.

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How to cite this article: Anosike FC, Nwagu KE, Nwalo NF, et al. Functional and pasting properties of fortified complementary foods formulated from maize (*Zea mays*) and African yam bean (*Sphenostylis stenocarpa*) flours. *Legume Science*. 2020;2:e62. https://doi.org/10.1002/leg3.62