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A dual food-to-food fortification with moringa (*Moringa oleifera* Lam.) leaf powder and baobab (*Adansonia digitata* L.) fruit pulp increases micronutrients solubility in sorghum porridge

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Malnutrition is one of the most serious problems throughout the world and children are especially vulnerable. This research aimed at designing a fermented sorghum porridge food-fortified with moringa leaf powder and baobab fruit pulp and assessing mineral bio-accessibility. The food fortification rate was defined according to local population practices and literature. In-Vitro Solubility of minerals was assessed to simulate gastro-intestinal digestion. Acceptability test of the fortified fermented sorghum porridge was assessed both with children (using the facial expression) and their mothers (using sensory attributes). Results (expressed in dry weight) indicate that food fortification increases significantly ($p<0.05$) fermented sorghum porridge calcium content from 43.6±1.9 mg/100 g to 3454.5±86.4 mg/100 g, iron content from 7.3±0.2 mg/100 g to 88.4±1.2 mg/100 g, zinc content from 88.2±3.8 mg/100 g to 202.4±3.1 mg/100 g. Soluble minerals of the porridge after fortification increase significantly ($p<0.05$) from 10.5±0.0 mg/100 g to 162.2±4.6 mg/100 g for calcium, from 0.3±0.0 mg/100 g to 1.8±0.1 mg/100 g for iron, from 0.4±0.1 mg/100 g to 4.2±0.2 mg/100 g for zinc. The fermented sorghum porridge dual food-fortified with moringa leaf powder and baobab fruit pulp (fortification rate, 17.0%, dry weight) was the most preferred by mothers while their under-five-years old children found no significant difference between those at food fortification rate 17.0% dry weight and at 29.0% dry weight. Food fortification using moringa leaf powder and baobab fruit pulp could be a good alternative for micronutrient deficiency alleviation.

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Abbreviations

ANF	Anti-Nutritional Factors
BFP	Baobab Fruit Pulp
CNERS	Comité National d'Ethique pour la Recherche en Santé
dw	dry weight
EARs	Estimated Average Requirements
IVS	*in vitro* solubility
PFMo	Moringa leaf powder
wb	Wet basis

Introduction

Minerals contribute significantly to body functioning and human growth. Indeed, calcium is essential for cellular structure, intracellular and intercellular metabolic function as well as muscle contractions [1]. Iron serves as an oxygen carrier from lungs to tissues [2] whereas zinc ensures growth [3]. Worldwide, more than 2 billion people are deficient in key vitamins and minerals, especially vitamin A, iodine, iron and zinc [4]. Among them, children are highly vulnerable because of their rapid growth which requires high mineral intake that inadequate dietary practices are unable to supply [5]. It is estimated that 46% of Africans are anemic [6]. In Benin, iron as well as zinc deficiencies highly prevail among rural children before and after (harvesting seasons 33 and 49% respectively) [7]. Food fortification is known as a potent and highly cost-effective strategy for micronutrient delivery to large populations and for reducing nutritional concerns in under five-years-old children[8]. However, in developing countries, mass and targeted classical food fortifications are poorly sustainable and hardly implementable because only synthetic nutrients are used and they are not always available. The alternative of food-to-food fortification is more and more promoted in these countries due to the availability of nutritious and accepted food ingredients. Successful experiences of the use of local food products as food fortificants in food-to-food fortification have been reported in Africa. Moringa leaf powder and baobab fruit pulp individually used to fortify maize-ogi and yoghurt [9–12] improving their calcium, iron, zinc, vitamin A and/or protein contents. Indeed, *Moringa oleifera* leaf powder (per 100 g dry weight) is rich in calcium (1443.9 ± 11.0 mg), magnesium (176.7 ± 0.7 mg), iron (53.8 ± 5.1 mg), zinc (17.6 ± 0.9 mg) and β-carotene (624.4 ± 0.4 μg ER) [13]. Baobab fruit pulp (per 100 g dry weight) contains 390.0–700.9 mg of calcium and up to 350 mg of vitamin C [14]. Sorghum grains (100 g) contain 24 mg of calcium, 3.7 mg of iron, 1.79 mg of zinc, 311 mg of magnesium, 297 mg of phosphorus and 0.38 mg of copper [15]. In certain regions of Benin, sorghum porridge is believed to be the best complementary food [16]. When fermented, sorghum porridge scored as the most important porridge traditionally moringa leaf powder or baobab fruit pulp fortified in Northern Benin (unpublished data). More generally, porridges (maize porridge, sorghum porridge, soya porridge, millet sorghum) are sometimes single food-fortified with moringa leaf powder or baobab fruit pulp for consumption by infants [17] while dual food-to-food fortification was not reported so far. The association of moringa leaf powder with baobab fruit pulp would increase the final content of the fermented sorghum porridge in vitamin C and minerals, and consequently enhance the in-vitro solubility of the latter.

Considering that high nutrient content does not mean much when digestibility and bioavailability is low [18,19], this study aimed at designing a fermented sorghum porridge rich in bioaccessible iron, calcium and zinc through a moringa leaf powder and baobab fruit pulp dual food-to-food fortification. Therefore, what is the content in crude and soluble minerals of the moringa leaf powder and baobab fruit pulp fortified fermented sorghum porridge? How acceptable is the moringa leaf powder and baobab fruit pulp fortified fermented sorghum porridge for consumers? When rich in biaccessible minerals and accepted by infants and mothers, the designed dual food-fortified porridge could contribute to micronutrient deficiency alleviation among under-five-years old children.

Material and methods

Fermented sorghum porridge was produced by processors in their households, food-fortified with moringa leaf powder and baobab fruit pulp in laboratory, analysed for various parameters and tested for acceptability on the field. Finally, the contribution of the food-fortified fermented sorghum porridge to iron, calcium and zinc Estimated Average Requirements (EARs) for children was computed.

The study was approved by the National Ethical Committee for Health related Research in Benin (approval N°: 08 of March, 29th, 2017, Comité National d'Ethique pour la Recherche en Santé, CNERS).

Production of the fermented sorghum porridge

Fermented sorghum porridge processing scheme was documented by following three productions done separately by three (3) experienced female processors from Tanguieta (northern Benin) where the food-fortified fermented sorghum ogi porridge is the most consumed (unpublished data). Each of the three (3) processors produced the porridge once using the same technology. Therefore, they were considered as replicates. Successive weighting was performed at each processing step. The fermented sorghum porridge was sampled, packed in plastic containers and kept under ice until it reaches the laboratory for analysis the same day. Prior fortification in the laboratory, the three samples of fermented sorghum porridge

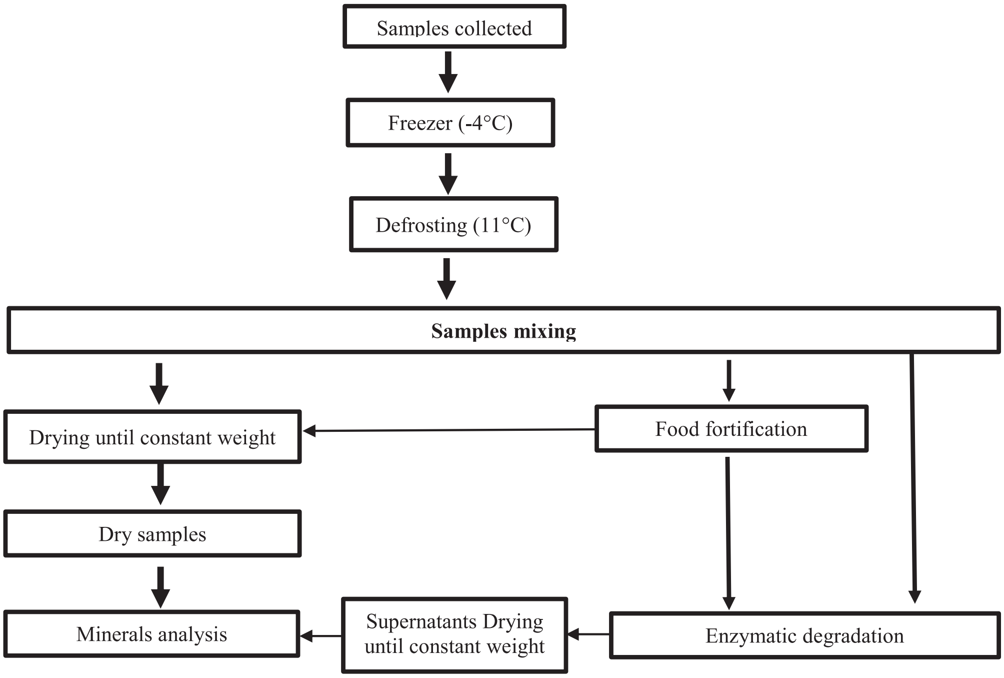

Fig. 1. Pretreatment plan of samples for laboratory analysis.

from these female experienced processors were mixed. Pretreatment plan of samples for laboratory analysis is presented in Fig. 1.

Pilot fortification assays

Fortification rate was defined based on traditional fortification practices (unpublished data) and fortificant amounts successfully used in literature (15 g of a designed mix of moringa leaf powder and baobab fruit pulp) for daily consumption by under-five-years old children [20,21]. Indeed, a designed mix of 15 g of moringa leaf powder and baobab fruit pulp were mixed with 100 g of fermented sorghum porridge. This fortification rate was further adjusted in order to fit the palatability of the food-fortified porridge with consumer taste. Therefore, two formulas were tested for acceptability.

Characterization of the fortificants, food fortified and unfortified fermented sorghum porridge

Food-fortified (15 g of a designed mix of moringa leaf powder and baobab fruit pulp mixed with 100 g of fermented sorghum porridge) and unfortified fermented sorghum porridge were analysed for their dry matter, minerals contents as well as their *in vitro* solubility (IVS) while food fortificants (moringa leaf powder and baobab fruit pulp) were analysed for their minerals contents. All analyses were performed in duplicate. Dry matter content and *in vitro* digestibility were assessed in the Laboratory of Food Sciences, University of Abomey-Calavi (Benin). Mineral (Ca, Fe, Zn, Cu, Mg and P) content determination were done in the laboratory of Soil Sciences, Wageningen University (Netherlands). The latter samples (for mineral content analyses) as described in Fig. 1, were dried and packed in Greiner tubes for air transportation to the Netherlands.

Dry matter content, expressed in g per 100 g of sample, was assessed by thermo-gravimetric method according with [22].

Approximately 0.4 g of food fortified and unfortified fermented sorghum porridge was digested using hydrofluoric acid (40%) and concentrated nitric acid (65% w/w). Next, the concentrations of Ca, Fe Zn, Cu, Mg and P were analysed by Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES, Elan 6000, Perkin Elmer, USA) [23]. 0.15 ml of concentrated nitric acid (HNO3 65%) was added to samples obtained from *in vitro* digestion (food fortified and unfortified fermented sorghum porridge) in 15 ml tubes. These samples were analysed by the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS, Elan 6000, Perkin Elmer, USA) [23]. Analyses were performed in duplicate. Minerals contents were expressed in mg /100 g dry weight (dw).

Minerals IVS, used as an estimate of their bioaccessibility, was assessed as described by [24], slightly modified by [25]. Indeed, duplicate food fortified and unfortified fermented sorghum porridge (approximately 2 g) were suspended in 30 mL distilled water and were digested under simulated gastro-intestinal conditions with the use of artificial saliva containing human saliva α-amylase (A6948,0500), artificial gastric juice containing lipase (AY30), pepsin (A4289,0025), artificial pancreatic solution consisting of pancreatin (A0585,0100) and bile (Sigma B-3883–100 G). In short, the mixture of food-to-food

Table 1
formulas used for acceptability test.

Quantity of sorghum porridge (g)	Quantity of designed mix of PFMo & BFP (g)	Fortification rate (%), wb	Fortification rate (%), dw
100	3.75	3.61	**29.02**
100	1.875	1.84	**16.98**

dw: Dry weight, wb: Wet basis, PFMo: Moringa leaf powder, BFP: Baobab Fruit Pulp.

formula with water Erlenmeyer was kept in a 37 °C water bath while shaking (about 400–500 rpm) for 5–10 min. 2 mL artificial saliva was added after 30 min of incubation while shaking, the Erlenmeyer was put on ice. pH was measured and adjusted to pH = 4 using 5 M HCl. After about 5 min of incubation at 37 °C in the water bath, 8 mL artificial gastric juice was added followed by 60 min incubation while shaking; the Erlenmeyer was afterwards put on ice; pH was noted and adjusted to pH 6 using 3 M NaHCO3; the samples were further incubated at 37 °C for about 5 min and 10 mL pancreatic solution was added and they were incubated for 30 min while shaking. After digestion, the suspension was kept on ice and centrifuged for 40 min at 20,292 x g at 4 °C (centrifuge –EBA21 Zentrifugen Heltich). The supernatant was recovered and the pellet was washed twice with 20 mL distilled water and centrifuged again. A blank consisting of 30 mL distilled water was digested and centrifuged as mentioned above. The amounts of Ca, Fe, Zn, Mg, P and Cu (expressed as mg/100 g dry matter of digested sample) in supernatant were regarded as dissolved minerals. Percentage of dissolved mineral was calculated as:

$$\text{In} - \text{VitroSolubility}(\text{IVS}, \%) = \frac{(\text{minerals contents in supernatant} - -\text{minerals contents in blank})}{\text{minerals contents in undigested samples}} \times 100$$

Assessment of acceptability of the fortified fermented sorghum porridge

The food fortification assay formula (15 g of a designed mix of moringa leaf powder and baobab fruit pulp mixed with 100 g of fermented sorghum porridge) was too thick and visually unacceptable. A dilution with porridge was performed and end up with two formulas (Table 1) which were tested for acceptability for under-five-years old children and their mothers. Fifty (50) under-five years old children-mothers couples were randomly selected on voluntary basis (approval and consent of mothers) in a community where people are accustomed with the consumption of fermented sorghum porridge. The facial expressions of children were gathered to express their acceptability level using a scale of five (05) levels of facial expressions (**0:** very bad, **1:** bad, **2:** maybe good or bad, **3:** good, **4:** very good) as described by [26]. Mothers have appreciated the porridges according to the sensorial attributes under evaluation.

Consumption frequency survey and consumed quantities of fermented sorghum porridge by the under five years old children

A consumption frequency survey was performed at Tanguieta (Northern Benin) where people are accustomed with the consumption of fermented sorghum porridge traditionally fortified with moringa leaf powder and/or baobab fruit pulp. The number of children considered for consumption frequency survey was determined using a spot check with 50 randomly selected under-five-years old children. The spot check estimated the proportion of children who consume fermented sorghum porridge with baobab fruit pulp and/or moringa leaf powder. This proportion was used to compute the sample size (Ni) of children for frequency of consumption, using the following formula, $\text{Ni} = \frac{4\text{Pi}(1-\text{Pi})}{\text{d}^2}$ [27] where: Ni: the total number of children under five to be considered for consumption frequency; Pi: the proportion of children who consume fermented sorghum porridge with baobab fruit pulp and/or moringa leaf powder among 50 selected children; d: the expected error margin which was fixed at 0.07. As Pi value was found to be 0.92, a sample size (Ni) of 60 under five years old children was considered. This sample included 20 (33.33%) of children aged of 6 - 12 months, 27 (45%) of children aged of 12 - 36 months and 13 (21.66%) of children aged of 36 - 59 months. The consumption frequency survey covered the 7 days preceding the day of the survey and was performed using a questionnaire. Over this period, the mothers were asked for the number of day that children consume a fermented sorghum porridge with baobab fruit pulp and/or moringa leaf powder and consumed quantities. Consumed quantities were estimated using reference containers with previously assessed capacity. Capacity of the reference containers showed to the mothers was determined in grams as the mean weight of the fermented sorghum porridge collected from six (6) randomly processors - vendors.

Contribution of the food fortified fermented sorghum porridge to iron, calcium and zinc estimated average requirements (EARs) for children

The contribution (cover rate in percentage) of the food fortified fermented sorghum porridge to the most important minerals (iron, calcium and zinc) Estimated Average Requirements (EARs) was computed. Iron EARs are respectively 6.9 mg/d, 3 mg/d and 4.1 mg/d for children aged 6–12months, 12–36months and 36–59months. For zinc, it is 2.5 mg/d for children aged 6–12months, 12–36months and 4 mg/d for children aged 36–59months. As far as calcium is concerned, it is 0.5 g/d for children aged 12–36 months and 0.8 g/d for children aged 36–59 months [28]. Cover rates were computed based daily consumption levels of the fermented sorghum porridge (recorded through the consumption frequency survey), the minerals (calcium, iron and zinc) contents and the IVS of calcium, iron and zinc in the fortified fermented sorghum porridge. Indeed, the soluble minerals was determined in the portion of food fortified fermented sorghum porridge daily consumed by children. This soluble minerals allowed computing the cover rate as mentioned bellow.

$$\boldsymbol{Coverrate}(\%) = \frac{\textbf{Fe, Ca or Zn soluble i}\text{n the portion of food fortified sorghum porridge daily consumed}}{\textbf{Fe, Ca or Zn EARs}} \times \mathbf{100}$$

Data processing and statistical analysis

The statistical analyses were performed using R software version 3.4.4 (2018–03–15) under agricolae and lawstat packages. The difference in minerals content and IVS between food fortified and unfortified fermented sorghum porridge formula was apprehended through an ANOVA followed by a turkey test at a significance level of 0.05. The two samples t-test and Welch test (in case of inequality of variance) were performed to assess the difference between formulas in term of their acceptability by both children and mothers.

Results

Flow diagram for production fermented sorghum porridge

Fig. 2 summarizes the main steps for producing fermented sorghum porridge commonly food fortified with moringa leaves powder and baobab fruit pulp. It encompasses mainly: washing, soaking, grinding, humid sieving, fermentation and cooking. Fermentation and cooking are key unit operations in this process. Fermentation was performed naturally after obtaining ogi of sorghum. This ogi was put in a plastic and covered with another plastic at room temperature during 18 ± 8.5 h. Cooking was performed by putting fermented sorghum ogi (326±56 g) in boiling water (1034±212 g) and the mix was stirred during 4±2minutes. From 1000 g of sorghum, 4695 g of fermented sorghum porridge was obtained (wet basis). After cooking, the porridge is mixed with moringa leaf and baobab fruit pulp (15 g of a designed mix of moringa leaf powder and baobab fruit pulp for 100 g of fermented sorghum porridge meaning 13.0% fortification rate wet basis and 62.1% fortification rate dry basis).

Characteristics of the food fortificants, food fortified and unfortified fermented sorghum porridge

Baobab fruit pulp contained (per 100 g dw) 260 mg of calcium, 13.04 mg of iron, 0.7 mg of zinc, 0.47 mg of copper, 135.04 mg of magnesium and 68.68 mg of phosphorus while moringa leaf powder (per 100 g dw) contained 1729 mg of calcium, 36.61 mg of iron, 2.58 mg of zinc, 0.67 mg of copper, 545.76 mg of magnesium and 404.27 mg of phosphorus.

After food fortification, dry matter content of the fermented sorghum porridge increased significantly from 8.1±1.7 to 19.9±0.1. The dual food fortification with moringa leaf powder and baobab fruit pulp increased significantly ($p<0.05$) the mineral contents of the fermented sorghum porridge except for copper. Mainly for 100 g dw, mineral content increased from 43.6±1.9 mg to 3454.5±86.4 mg for calcium, from 7.3±0.2 mg to 88.4 ± 1.2 mg for iron, from 88.2±3.8 mg to 202.4±3.1 mg for zinc, from 260±50 mg to 1540±20 g for magnesium and from 490±90 mg to 1620±50 mg for phosphorus.

A significant increase ($p<0.05$) of In -Vitro Solubility (IVS) after fortification was observed only for zinc (from 0.5±0.1% to 2.1±0.1%). Soluble mineral contents in fermented sorghum porridge after fortification increased significantly ($p<0.05$) per 100 g dw from 10.5±0.0 mg to 162.2±4.6 mg for calcium, from 0.3±0.0 mg to 1.8±0.1 mg/100 g dw for iron, from 0.4±0.1 mg to 4.2±0.2 mg for zinc and from 102.0±9 mg to 138.3±17.4 mg for magnesium (Table 2). The increase rates after food fortification are over 100% for mineral content (107.1±2.8% to **7**827.8±156.1%**)** and ranged from 36.8±29.1% to 1441.7±45.2% for soluble mineral after food fortification.

Food-fortified fermented porridge is obtained from incorporation of 15 g of the designed moringa leaf powder and baobab fruit pulp mixture in 100 g of fermented sorghum porridge; Means (±standard deviation) with the same letter on the same line are not significantly different ($p>0.05$); ND: Not Determined; coefficient of variation (in%) are in the brackets. All analyses were performed in duplicate.

Acceptability of food fortified fermented sorghum porridge by the under-five-years old children and their mothers

The food fortification assay formula (15 g of a designed mix of moringa leaf powder and baobab fruit pulp mixed with 100 g of fermented sorghum porridge) was too thick and visually unacceptable. A dilution with porridge was performed and end up with two formulas (fortification rate, 29.0% dw and fortification rate, 17.0% dw) which were tested for acceptability. Fig. 3 shows the acceptability level of the fermented sorghum porridge dually fortified with moringa leaf powder and baobab fruit pulp (fortification rate, 29.0% dw and fortification rate, 17.0% dw) by mothers and children. Indeed, 51.5% of mothers found sorghum porridge food fortified with PFMo and baobab fruit pulp (food fortification rate, 29.0 dw; formula SPFMoB29 meaning 100 g of fermented sorghum ogi porridge mixed with 3.75 g of a designed mix of moringa leaf and baobab fruit pulp) pleasant (from good to very good). The same appreciation was given by 78.8% of mothers for the sorghum porridge

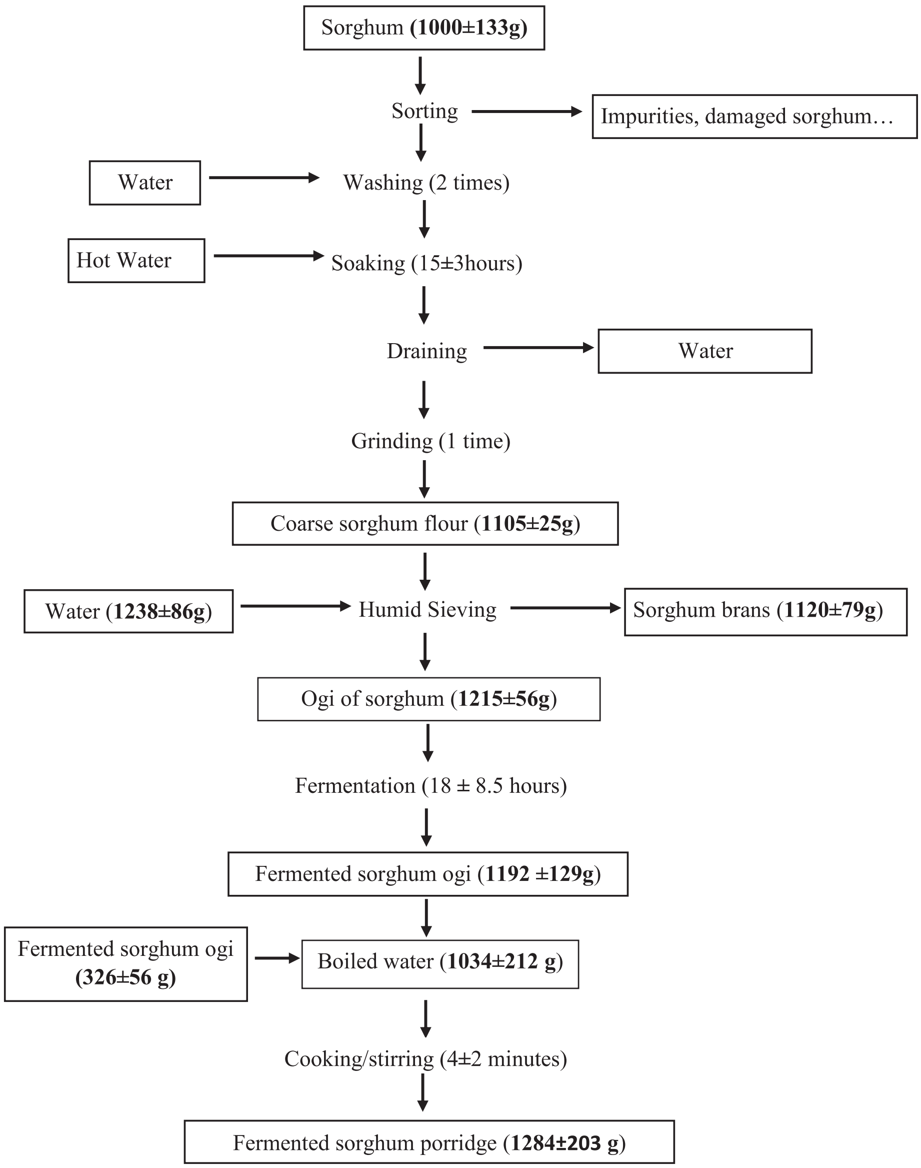

Fig. 2. Flow diagram for the processing of fermented sorghum porridge (obtaining once from three female experienced processors, meaning 3 separate productions).

food fortified with PFMo and baobab fruit pulp (food fortification rate, 17.0% dw; formula SPFMoB17 meaning 100 g of fermented sorghum ogi porridge mixed with 1.875 g of a designed mix of moringa leaf and baobab fruit pulp). Children involved in the acceptability test were either male (53.6%) or female (46.4%). 43.0% of children showed a positive appreciation (from good to very good) towards sorghum porridge food fortified with PFMo and baobab fruit pulp (fortification rate, 29.0%) and 57.3% of children give the same appreciation towards sorghum porridge food fortified with PFMo and baobab fruit pulp (fortification rate, 17.0% dw).

The two samples t-test shows that there is a significant difference between the global appreciation score of the two tested formulas ($p\text{-value} = 0.009392 < 0.05$) for mothers. The average global appreciation score is respectively 3.1±0.7 for sorghum porridge food fortified with PFMo and baobab fruit pulp (food fortification rate, 17.0% dw; formula SPFMoB17) and 2.6±0.7 for sorghum porridge food fortified with PFMo and baobab fruit pulp (fortification rate, 29.0 dw; formula SPFMoB29). Nevertheless, Welch test performed on the two sensory attributes under evaluation shows that there is no significant difference between formulas in term of color ($p\text{-value} = p\text{-value} = 0.2544 > 0.05$) and taste ($p\text{-value} = 0.06841 > 0.05$). Therefore, both formulas are equally accepted by mothers as good.

The two samples t-test performed shows that there is no significant difference ($p\text{-value} = 0.5043 > 0.05$) between formulas in term of appreciation score for children. Therefore, both formulas are equally accepted by half of the children.

Table 2
Characteristics of the food-fortified and unfortified fermented sorghum porridge.

Minerals	Treatment	Unfortified	Food-fortified	Increase rate after fortification (%)	p-value
Ca	Sorghum porridge (mg/100 g dw)	43.6 ±1.9^{a} (4.47)	3454.5±86.4 ^{b} (2.5)	7827.8±156.1	<0.001
	IVS (%)	24.2±1.0 ^{a} (4.39)	4.7±0.2 ^{b} (5.35)	ND	0.002
	Soluble Ca (mg/100 g dw)	10.5±0.0 ^{a} (0.1)	162.2±4.6 ^{b} (2.9)	1441.7±45.2	<0.001
Fe	Sorghum porridge (mg/100 g dw)	7.3±0.2 ^{a} (3.07)	88.4±1.2 ^{b} (1.34)	1105.7±20.8	<0.001
	IVS (%)	3.8±0.4 ^{a} (4.39)	2.0±0.2 ^{b} (5.35)	ND	0.03
	Soluble iron (mg/100 g dw)	0.3±0.0 ^{a} (7.8)	1.8±0.1 ^{b} (8)	535.8±1.4	0.004
Zn	Sorghum porridge (mg/100 g dw)	88.26±3.8 ^{a} (4.29)	202.4±3.1 ^{b} (1.54)	129.7±6.3	0.001
	IVS (%)	0.5±0.1 ^{a} (19.11)	2.1±0.1 ^{b} (3.75)	ND	0.003
	Soluble Zn (mg/100 g dw)	0.4±0.1 ^{a} (14.9)	4.2±0.2 ^{b} (5.3)	905.2±201.9	0.002
Cu	Sorghum porridge (mg/100 g dw)	157.6±29.1 ^{a} (18.48)	326.8±64.7 ^{a} (19.8)	107.1±2.8	0.078
	IVS (%)	8.4±2.5 ^{a} (29.58)	1.6±0.8 ^{a} (51.05)	ND	0.068
	Soluble Cu (mg/100 g dw)	13.6±6.4 ^{a} (46.8)	5.7±3.8 ^{a} (67.4)	ND	0.271
Mg	Sorghum porridge (mg/100 g dw)	260±50 ^{a} (18.14)	1540±20 ^{b} (1.01)	503.2±115.4	0.001
	IVS (%)	39.7±3.7 ^{a} (9.39)	9.0±1.0 ^{b} (11.59)	ND	0.008
	Soluble Mg (mg/100 g dw)	102.0±9 ^{a} (8.8)	138.3±17.4 ^{a} (12.6)	36.8±29.1	0.120
P	Sorghum porridge (mg/100 g dw)	490±90 ^{a} (8.12)	1620±50 ^{b} (3.36)	236.6±72.1	0.004
	IVS (%)	28.9±4.4 ^{a} (15.33)	7.1±2.6 ^{b} (36.6)	ND	<0.001
	Soluble P (mg/100 g dw)	140.1±4.0 ^{a} (2.83)	115.4±45.8 ^{a} (39.72)	ND	0.527

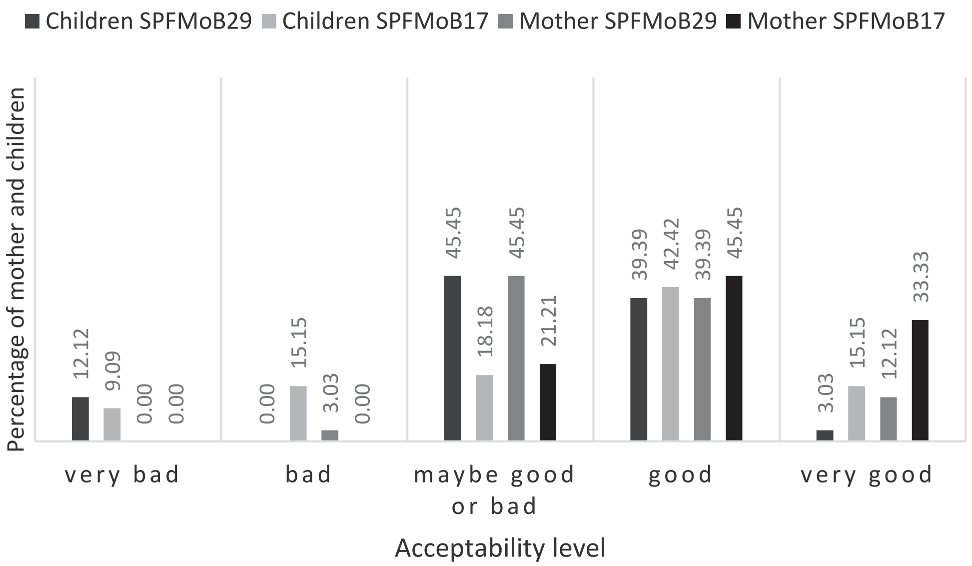

Fig. 3. Mothers' and children' acceptability of fermented sorghum porridges dually food fortified with PFMo and BFP

Table 3
Contribution of the food fortified sorghum porridge to the iron, calcium and zinc Estimated Average Requirements (EARs).

Fortified food	Target children	Daily porridge intake (g)	Iron EAR (mg/d)	Iron cover rate (%)	Calcium EAR (g/d)	Calcium cover rate (%)	Zinc EAR (mg/d)	Zinc cover rate (%)
Sorghum porridge fortified with PFMo and BFP	6–12 m	522	6.9	**26.7**	NA	**ND**	2.5	**176.3**
	12 –36 m	466	3.0	**54.9**	0.5	**29.8**	2.5	**157.4**
	36–59 m	306	4.1	**26.4**	0.8	**12.2**	4.0	**64.6**

PFMo: Moringa leaf powder, BFP: Baobab fruit Pulp, ND: Not determined, NA: Not Available, m: month.

Contribution of food fortified fermented sorghum porridge consumption to mineral EARs for children

Food consumption frequency survey reveals that children aged 6 to 12 months, 12 to 36 months and 36 to 59 months consumed in average fermented sorghum porridge respectively 3 times, 2 times and 1 time per day with the consumed quantities per time estimated at 174 g, 233 g and 306 g. Consequently, the children aged 6 to 12 months, 12 to 36 months and 36 to 59 months respectively consume 522 g, 466 g and 306 g of fermented sorghum porridge per day (Table 3). These estimated amount of food fortified porridge daily consumed by each child covers more than 50% of the iron needs of 12–36 months children whereas it covers less than 30% of their daily needs when aged 6–12 months or 36–59 months. The calcium cover rate is approximately 30% for children aged 12 –36 months and 12.2% for children aged 36–59 months. For zinc, the estimated food fortified fermented sorghum porridge daily consumed by each child would cover over 100% of the needs of children aged 6–12 months and children aged 12 −36 months while it covers 64.6% for children aged 36–59 months (Table 3). The consumption of the dual food fortified fermented sorghum porridge using moringa leaf powder and baobab fruit pulp for porridge can be promoted to fight against zinc deficiencies among children aged 6–12 months and children aged 12 −36 months.

Discussion

Dual food fortification using moringa leaf powder and baobab fruit pulp allows an increase in mineral content of the fermented sorghum porridge. Food-to-food fortification approach was shown to be successful in this study. Food fortification was defined as a deliberate increase of the content of essential micronutrients in a food to improve the nutritional quality of the supplied food and to provide a public health benefit with minimal risk to health. In addition, for food-to-food fortification, the fortificants are natural [29]. The use of moringa leaf powder to enrich maize-ogi or cheese and the use of baobab fruit pulp to fortify yoghurt [10] or maize ogi improved the essential micronutrients (calcium, iron zinc), vitamin A and protein contents of used food vehicles [10–12]. The increase of the minerals content of the food fortified fermented sorghum porridge is due to the high micronutrient content of the used fortificants [13,30]. Indeed, Baobab fruit pulp used in this study contained (per 100 g dw) 260 mg of calcium, 13.04 mg of iron, 0.7 mg of zinc while moringa leaf powder (per 100 g dw) contained 1729 mg of calcium, 36.61 mg of iron, 2.58 mg of zinc. Food-to-food fortification using moringa leaf powder and baobab fruit pulp may be promoted to fight against micronutrients deficiencies that remains a great nutritional challenge especially among under five years old children in developing countries. Nevertheless, high nutrient content is not enough when bioavailability is low [18,19].

In Vitro Solubility (IVS) is an estimate of nutrient bioaccessibility, and in this case minerals. It represents the quantity of minerals potentially available for absorption after ingestion of foods and depends on the food matrices and the digestion process [31]. It is also considered as the fraction of a compound that is released from its matrix in the gastrointestinal tract and thus becomes available for intestinal absorption. It includes the entire sequence of events that take place during the digestive transformation of food into materials that can be assimilated by the body, the absorption/assimilation into the cells of the intestinal epithelium and lastly the metabolism [32]. Food fortifying sorghum porridge with moringa leaf powder and baobab fruit pulp does not improve calcium, iron, copper, magnesium and phosphorus IVS. The decrease in iron and calcium IVS could probably be due to the presence of antinutrients in moringa leaf powder as a binding factors. *Moringa oleifera* leaves are rich (g/100 g dw) in phytate (1.58 ± 0.02), tannin (0.05±0.01) and phenolic compounds (0.12±0.001) [33]. The digestibility of zinc and iron in fourteen fermented millet porridge collected in Burkina-Faso was 13.1±2.8% for zinc IVS and 10.9±4.5% for iron IVS [34]. These values are higher than those found in this study for fermented sorghum porridge. This difference observed can be due to the food matrices used and the digestibility method applied by the authors. In fact, [34] has performed the digestibility study according to [35] method modified by [36–38] which differs from [24] method. The difference between these methods is relative to the incubation times, solution used to adjust pH, amount of product used for digestion and amount of enzymatic solution used.

The calcium, iron and zinc IVS of food fortified and unfortified sorghum porridge is relatively low. That could be due to the Anti-Nutritional Factors (ANF[1]) that contain sorghum. Indeed, it was well known that cereals contain high ANF such as phytates and polyphenols compound which reduce the bioavailability of micronutrients [34,39]. It was reported that sorghum contains from 0.7 to 1.4% of phytates and from 0.2 to 10.3% of polyphenols [34]. Despite the process (fermentation, soaking, cooking) applied, the IVS are relatively low for minerals. These low IVS in both food fortified and unfortified fermented sorghum porridge let hypothesize that antinutritional factors were not highly eliminated through the applied process and that was possibly due to the duration of this process. Soluble minerals of the fermented sorghum porridge after food fortification increased significantly ($p<0.05$) for calcium, iron and zinc though no increasing of calcium and iron IVS was observed. This underlined the nutritional value of the food fortified fermented sorghum porridge. It comes out that soluble minerals is due both by the IVS and the nutritional value of the food. Indeed, a low mineral IVS product can have a high soluble mineral due to its high mineral content. That could explain the high cover rate recorded for calcium, iron and especially for zinc.

It is expected that in sorghum porridge dual food fortified with moringa leaf powder and baobab fruit pulp, iron IVS can be high, probably due to high vitamin C content of baobab fruit pulp up to 350 mg/100 g dw [14]. But no IVS increase was observed. It was reported that an ascorbic acid (vitamin C) to- iron molar ratio of 4:1 is needed to increase iron absorption from diets high in phytic acid [39]. In this study, sorghum porridge food fortified with moringa leaf powder and baobab fruit pulp had ascorbic acid (vitamin C) to-iron molar ratio of 0.04:1 (personal data) far less than 4:1 molar ratio; that is probably the reason why no iron IVS increasing was observed. Further study can be designed for other options for food fortification rate as a pathway to optimize iron bioaccessibility.

Several authors tackle the acceptability of food fortified with moringa leaf powder or baobab fruit pulp but a food fortified with moringa leaf powder and baobab fruit pulp acceptability was not investigated so far. Indeed, sorghum porridge food fortified with moringa leaf powder and baobab fruit pulp (fortification rate, 17.0% dry weight) is the most preferred by

[1] Anti-Nutritional Factors

the mothers. Nevertheless, [10] find that maize ogi food fortified with baobab fruit pulp at substitution levels of 0, 10, 20 and 50% were acceptable while “ogi” produced from maize food fortified with moringa leaves powder was accepted until 10% dry weight of food fortification rate [11]. Despite the addition of *Moringa oleifera* leaf powder tended to color porridges very green, the sorghum porridge dual food fortified with moringa leaf powder and baobab fruit pulp was accepted up to 17.0% food fortification rate. This relatively high acceptability level of the dual food fortified sorghum porridge is possibly due to baobab fruit pulp that may improve the taste of sorghum ogi porridge. Indeed, baobab fruit pulp is known as an acidulant and consequently could possibly affect the taste of food (enhancement of their acidity). According to the mothers, there is a significant difference between both tested food fortified sorghum porridges formulas (food fortification rate 17% and food fortification rate 29%). It can be expected that this difference be find out by the children after gathering their facial expression. Indeed, mothers are willing to predict their children food acceptability. But in this study, no significant difference was underlined by children between the two dually food fortified sorghum porridges (food fortification rate 17% and food fortification rate 29%). This observation possibly underlined the limit of the facial expression. According to [40] during the face scale test, very young children (6 years and younger) can be distracted and can even be disturbed by the mean look of the frowning face and the scales may add undesirable and possibly complex visual and conceptual variables to the test situation. Autonomic reactivity, respiration and heart rate [26] could be used instead of facial expression but they are not appropriate as the acceptability test was performed in field. Nevertheless, additionally to facial expression, differential ingestion test can be performed to assess the acceptability level of the food fortified fermented sorghum porridge. This can be further addressed. The significant difference between the global appreciation score of the tested formulas for mothers was not explained by the sensory attributes under evaluation (color and taste) because no significant difference was observed between formula considering the color and the taste attributes. Other attributes, mainly smelling and consistency could probably explain this difference between the formulas considering the global appreciation score for mothers. Further sensory experiments could be designed to find out the sensory attributes that explain the difference between formulas.

Conclusion

The present study allows proposing fermented sorghum porridge dual food fortified with moringa leaf powder and baobab fruit pulp for under five years old children. Food fortification with moringa leaf powder and baobab fruit pulp improve significantly the micronutrients content (calcium, iron and zinc) of the fermented sorghum porridge as soon as the soluble minerals (calcium, iron and zinc). Dual food-to-food fortification using moringa leaf powder and baobab fruit pulp for fermented sorghum porridge can be promoted to fight against minerals deficient that remains a great nutritional challenge especially among under five years old children in developing countries.

Author contribution

Marius Affonfere contributed to study design, field data collection, laboratory analysis, data analysis and drafted the manuscript. He approved the submitted version. Yann Eméric Madodé contributed to study design, laboratory analysis, data analysis and manuscript writing. He also reviewed the manuscript and approved submitted version. Flora Josiane Chadaré contributed to study design, data analysis, reviewed the drafted manuscript and approved the submitted version. Paulin Azokpota and Djidjoho Joseph Hounhouigan reviewed the drafted manuscript and approved the submitted version.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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