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*Research Article*

# Nutritional Quality of Three Iron-Rich Porridges Blended with *Moringa oleifera*, *Hibiscus sabdariffa*, and *Solanum aethiopicum* to Combat Iron Deficiency Anemia among Children

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Iron deficiency anemia has been a public health issue in children under five years of age in Cameroon. Very limited attempts have been carried out to develop an iron-rich food using local ingredients. The study aimed at developing functional porridges from local ingredients for iron-deficient children aged 6–23 months. Leaves of *Moringa oleifera, Hibiscus sabdariffa, and Solanum aethiopicum* were harvested as sources of iron, dried, ground into powder, and screened for their water and iron contents. Each vegetable powder was mixed with the other ingredients (dry whole milk, brown sugar, yellow maize flour, and refined soybean oil) to obtain three powdered porridges using linear programming (LP). Protein, lipid, carbohydrate, iron, energy, water, ash, crude fiber, and vitamin C contents, expressed in dry weight, were determined on powdered porridges. Powdered porridges were cooked in boiled water (ratio 2 : 7%w/w) for 5 min. Hedonic tests were conducted using cooked porridges with 50 untrained panelists. Leaf powders contained iron varying between 5.39 and 5.98 mg/100 g. LP models of the three porridges satisfied the nutritional requirements of children aged 6–23 months in terms of iron, lipid, protein, carbohydrate, and caloric daily intake. Protein, lipid, carbohydrate, iron, energy, water, ash, crude fiber, and vitamin C contents were, respectively, between 11.37 and 13.83 g/100g, 30.79 and 32.94 g/100g, 45.97 to 46.81 g/100g, 5.14 and 6.15 mg/100g, 509.93 and 517.48 kcal/100g, 6.42 to 7.62 g/100g, 2.20 and 2.88 g/100g, 1.65 and 2.44 g/100g, and 46.49 and 163.38 mg/100g. The cost of powdered porridges varied between 0.40 and 0.49 USD/100g. The sensory analysis showed that the moringa leaf-based porridge (82%) was the most appreciated followed by eggplant leaf-based porridge (80%) and folere leaf-based porridge (70%). Hence, these results showed that moringa, folere, and eggplant leaves can be used in functional foods to alleviate iron deficiency among children aged 6–23 months.

## 1. Introduction

Malnutrition is a supreme public health issue that disturbs many children worldwide and can be due to micronutrient deficiencies among other causes. Iron deficiency is one of the most devastating and widespread micronutrient deficiencies, affecting about a third of the world's population [1]. It is one of the most common causes of anemia [2]. It affects both the developed and developing world, especially children since they are the most vulnerable groups due to the high iron demand for proper growth and development. Anemia increases the risk of morbidity and mortality among children. Children with anemia have a 4.3 times greater risk of death than nonanemic children [3]. About 47.4% of children under five suffer from anemia worldwide [4, 5]. In developing countries, it affects 46–66% of children aged under five years. About 67.6% of children under five in Africa are suffering from anemia [6].

The Global Nutrition Report classifies Cameroon as experiencing three forms of malnutrition; overweight, anemia, and stunting [7]. Precisely in Cameroon, the prevalence of anemia in children below five years of age is high, 68% [8]. About 50% of anemia in Cameroon is attributable to iron deficiency [9]. In Cameroon, the national prevalence of iron deficiency anemia in children under 59 months has increased from 58% (2004) to 60% (2014) [10]. Although iron deficiency is one of the main causes of anemia, other factors, such as early weaning, poor health of pregnant women, insufficient safe drinking water, inadequate hygiene, sanitary conditions, and poverty may add to the growth of this condition. Also, food insecurity could be one of the major causes of this illness especially in areas faced by crises where agriculture is the main activity of these areas [11].

Functional foods and nutraceuticals have been identified as one of the leading food categories where research and development efforts are concentrated. Functional foods contain added ingredients, which provide health benefits beyond the effect of common typical food products [12]. Fortification of complementary foods and staple foods with micronutrients can be a cost-effective intervention to combat hidden hunger in children, young people, and women [13]. Complementary feeding should be timely (start receiving from 6 months onward) and adequate in amounts, frequency, consistency, and using a variety of foods. The foods should be prepared and given safely in a way that is appropriate (foods are of appropriate texture for the child's age) and responsive feeding should be applied by following the principles of psychosocial care [14]. Maize porridge, which is a bulky food low in nutrient density, is used as a complementary food in many African countries [15–17]. A balance of nutrients may be obtained by the integration of cereals and vegetables in the number of products [18].

The leaves of *M. oleifera* are the most nutritious part of the plant, being a significant source of B vitamins, vitamin C, provitamin A as beta-carotene, vitamin K, manganese, and protein, among other essential nutrients [19, 20]. *M. oleifera* has been used as a food fortificant in many food products such as amala (stiff dough), ogi (maize gruel), bread, biscuits, yoghurt, and cheese, and in making soups [21]. Moringa leaf powder has been successfully incorporated into wholegrain maize porridge to improve iron and zinc bioaccessibility [22].

*Hibiscus sabdariffa* calyces were found to contain a higher amount of iron (164.78 mg/kg) [23]. Naturlan [24] reported an iron content of 5 mg/100 g dry weight in *Hibiscus sabdariffa* leaves. The plant is also found to be rich in minerals, especially potassium and magnesium. Vitamins (ascorbic acid, niacin, and pyridoxine) were also present in appreciable amounts [25]. The fruits of *Solanum aethiopicum* were reported to contain high amount of calcium, magnesium, potassium, sodium, manganese, iron, copper, zinc, and phosphorus [26]. Achikanu et al. [27] reported an iron content in *S. aethiopicum* leaves of 36.86 mg/100g. Although *Hibiscus sabdariffa* and *Solanum aethiopicum* leaves are rich in the iron content, no attempts have been made for their incorporation into porridge or their use as food fortificant.

As part of the efforts in curbing iron deficiency anemia, the current study aimed at developing the most acceptable nutrient-dense porridges rich in iron targeting children between 6 and 23 months of age using three vegetables, namely, *Hibiscus sabdariffa*, *Solanum aethiopicum*, and *Moringa oleifera*.

## 2. Materials and Methods

*2.1. Selection of Ingredients.* In this study, the ingredients to be used for the development of iron-rich porridges were selected based on their nutritional value, availability, price, and Bamenda cultural acceptance and preference. Dry whole milk, brown sugar, yellow maize flour, and refined soybean oil were purchased from the Bamenda main market (Mezam division, North West Region, Cameroon). Fresh moringa leaves (*Moringa oleifera*), folere leaves (*Hibiscus sabdariffa*), and eggplant leaves (*Solanum aethiopicum*) were harvested from the farm around the city of Bamenda. They were transported in plastic bags to the laboratory of Biochemistry at the University of Bamenda prior to further processing.

*2.2. Processing of Leaves into Powder.* A total of 1 kg of each vegetable leaf was weighed using a precision balance (SF-400, China) and placed in a preheated ventilated oven (PEC MEDICAL, USA). The oven was kept at 50°C for 24 hours. The dried vegetable leaves were removed and cooled down at room temperature. The dried leaves were crushed in a grinder (silver crest, Germany) and filtered using a 250-$\mu$m-diameter sieve. The recovered powders were kept in labelled linear low-density polyethylene bags at room temperature prior to being used for the formulations and also for the various nutritional screenings.

*2.3. Determination of the Water and Iron Contents of the Vegetable Leaf Powders.* The water and iron content of the leaves of *Moringa oleifera*, *Hibiscus*. A total weight of 5 g of each vegetable leaf powder (*Moringa oleifera, Hibiscus sabdariffa, and Solanum aethiopicum)* was weighed separately and oven-dried at 105°C for 2 hours to determine the water content as described by AOAC [28]. The iron content was determined as described by Pauwels et al. [29]. One Gram of each vegetable leaf was ashed at 550°C for 2 hours. The ashes were mixed with 0.2 N nitric acid and allowed to stand for 10 min. A volume of 2 mL of the ash extract, 2 mL of 10% ascorbic acid, 3 mL of a 60% ammonium acetate buffer solution, and 2 mL of ortho-phenanthroline 0.5% were successively introduced in a 50-ml volumetric flask and made up with distilled water to the gauge line. The iron

Table 1: Food composition for 100 g and cost of the ingredients used to develop the 3 formulated flours.

| Ingredients | Energy (cal) | Carbohydrates (g) | Proteins (g) | Lipids (g) | Iron (mg) | Cost/100 g (F CFA) |
|---|---|---|---|---|---|---|
| Yellow maize flour | 370 | 79 | 7 | 1.8 | 1.1 | 100 |
| Dry whole milk | 496 | 38 | 26 | 27 | 0.5 | 500 |
| Brown sugar | 380 | 98 | 0.1 | 0 | 0.7 | 100 |
| Soya bean oil | 884 | 0 | 0 | 100 | 0.1 | 200 |
| Moringa leaves' powder | 300 | 40 | 25 | 8 | 65.66 | 500 |
| Egg plant leaves' powder | 347.26 | 65.75 | 14.45 | 2.94 | 68.89 | 400 |
| Folere leaves' powder | 220 | 30.82 | 21 | 1.5 | 41.86 | 350 |

content in the mixture was assessed using a Jasco V-630 molecular absorption spectrophotometer at 510 nm against a blank. The results were expressed in mg/100 g dry weight (DW) for the iron content and in g/100 g dry weight for the water content.

*2.4. Development of Porridge Flours.* The creation of a database for the ingredients' composition in an MS Excel spreadsheet was first performed prior to the optimization (Table 1). Information about the composition of each ingredient was extracted from the USDA food composition databases [30] (https://ndb.nal.usda.gov/ndb/), West Africa Food table composition [31] (https://www.fao.org/infoods/infoods/tables-et-bases-de-donnees/afrique/fr/), and the paper of Fokwen et al. [32]. For each ingredient, the nutrient content, cost for 100 g, and maximum weight allowed for use in the formulation were included in the Excel spreadsheet.

The nutritional constraints for the differently formulated porridges were based on the technical specifications for ready-to-use supplementary foods for children aged 6–59 months [33] except for the iron content, which was set to be half of the recommended constraints for ready-to-use supplementary foods. The specifications were as follows:

Energy should be between 510 Cal and 560 Cal;

Protein content should vary between 11 g and 16 g;

Lipid content should range between 26 g and 36 g;

Iron content should be between 5 mg and 7 mg;

The final weight of the product should be 100 g;

The final mass for maize flour should be between 25 g and 35 g;

The final mass for dry whole milk should be between 20 g and 40 g;

The final mass for sugar should vary between 5 g and 15 g.

To minimize the cost of formulation, the linear programming (LP) model is used, which can be expressed as follows:

$$Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n, \quad (1)$$

where $Z$ is the formulation cost. $C_1$, $C_2$, …, $C_n$ are objective function coefficients. $X_1$, $X_2$, …, $X_n$ are decision variables (DV). In the formula, C is defined as the cost per 100 g and $X$ is the weight of food ingredients. Linear constraints set the limitations of the optimization process. These constraints are imposed on the DVs to ensure that the formulation meets nutritional constraints and does not exceed the lower or the upper limits. Fulfilling all constraints is a prerequisite to the design of a proper formulation. The cost of formulation in this study stands for raw material expenses that refer to the cost of the components that go into a final manufactured product (powdered porridge).

After the LP model was developed and the data layout was created in a spreadsheet, optimization was performed using Microsoft Excel 2019 Solver Add-in (Microsoft, Inc., Redmond, WA, USA). First, the objective function (OF), decision variables (DV), and constraints were keyed into the software. Solver was allotted to minimize the OF. Solver's default mode was assigned for the optimization. In the default mode, the maximum time to solve the problem was 100 sec, with iterations of 100. The calculation was carried out at a precision of 0.000001 with a tolerance of 5% and a convergence of 0.0001.

*2.5. Preparation of the Three Porridge Flours.* The various raw materials for each porridge sample were weighed using an electronic scale (SF-400, China) according to the values given by the Solver for 100 g of powdered porridge (Figure 1). All dried ingredients such as the yellow maize flour, dry milk powder, brown sugar, and vegetable flour (either *Moringa oleifera*, *Solanum aethiopicum,* or *Hibiscus sabdariffa*) were weighed separately and mixed in three different well-cleaned dishes. Lastly, the mixtures were mixed with the soya bean oil.

*2.6. Determination of the Nutritive Value of the Porridge Flours.* The nutritional composition of the formulated porridge flours, containing *Moringa oleifera*, *Hibiscus sabdariffa*, and *Solanum aethiopicum* was carried out to determine the water, lipid, ash, crude fiber, carbohydrate, and the caloric contents using the AOAC methods [28]. The protein content was determined by the Kjeldahl method [34] coupled with the method described by Devani et al. [35]. The iron content was determined as described by Pauwels et al. [29]. The vitamin C content was determined using the method reported by Mohanad et al. [36]. To determine the vitamin C content, each sample (2 g) was diluted with distilled water to a final volume of 10 mL. Then, the mixture was titrated with dichlorophenol indophenol $5 \times 10^{-4}$ mol/L solution until a pink tint appears that persists for about 30 seconds. Water and iron contents were determined as previously described in Section 2.3. Lipids were exhaustively extracted in a Soxhlet extractor from the

(a) (b) (c)

Figure 1: Powdered porridges fortified with *Moringa oleifera* (a), *Hibiscus sabdariffa* (b), *Solanum aethiopicum* (c) leaves.

three porridge flours (2 g each) using hexane at 65 °C for 8 hours, and the content was determined by the gravimetric method. Ash was obtained by incineration (550°C) of the samples (1 g each) for 2 hours in a muffle furnace, and the content was determined by the gravimetric method. Crude fiber was determined using the gravimetric method. Each fat-free sample (3 g) was digested with 0.26 N hot sulfuric acid for 30 min, and 0.23 N sodium hydroxide was added. The mixtures were filtered with a Whatman paper, and the filtered samples were washed with acetone and oven-dried at 105°C for 8 hours before being ashed at 550°C for 3 hours. The ash content was calculated using the gravimetric method. Concerning the protein content, 1 g of each sample was heated in mineralization flasks with a pinch of nitrogen catalyst (200 g $NaSO_4$ + 3.5 g of selenium + 3.2 g of $CuSO_4$) and 10 mL of concentrated sulfuric acid. 1.2 mL of sodium acetate (0.08 g/mL) and 1.2 mL of reactive solution (mixture of 37% (v/v) formaldehyde, acetylacetone, and distilled water) were successively added to the 0.1 mL of the mineralized content in test tubes. The tubes were immersed in boiling water (97.5°C) for 15 min and then cooled in cold water to lower the temperature to 30°C. Distilled water (7.1 mL) was added to each tube, and absorbances were read at 412 nm against a blank. The nitrogen content was obtained by extrapolating the absorbance of each test on the nitrogen calibration curve, and the calculation of the protein content was made using the following formula:

$$Xp\,(g/100g\ DM) = \frac{Yp \times Ve \times F\ d \times 6,25}{1000000 \times Pe \times DM\ C}, \tag{2}$$

where *Xp* is the protein content (g/100 g DM); Yp is the nitrogen content obtained by the spectrophotometer ($\mu$g/100 g DM); Ve is the total volume of the extract (in mL); Fd is the dilution factor; Pe is the test portion for mineralization (g); 1000000 is the conversion factor to convert from $\mu$g to g/100 g DM; and DMC is the dry matter content.

Carbohydrate contents of the porridge flours were determined as the difference between 100 and the sum of the moisture, ash, lipid, and protein contents of the samples. The caloric contents of the porridge flours were determined as kcal per 100 g based on the energy conversion factors:

Caloric value = 4 × protein content + 9 × lipid content + 4 × (carbohydrate content − crude fiber content).

*2.7. Cooking of Porridges.* For each 100 g of formulated flour, a total of 250 g of water was used for cooking the different porridges. Water was introduced in a pot and allowed to boil, after which the flour was added and stirred continuously with a cooking spoon for 5 minutes for it to get ready. It was then removed from a pot into a dish and allowed to cool down prior to the sensory analyses.

*2.8. Sensory Analysis.* A total of 50 untrained panelists of both sexes, aged over 20 years, were recruited randomly to assess the acceptability of the 3 porridges using a structured-scale quantitative acceptance scoring test. These panelists had been fasting for at least an hour. The descriptors used were colour, smell, taste, after taste, and texture. A 9-point rating scale was used, namely, (1) extremely unpleasant, (2) very unpleasant, (3) moderately unpleasant, (4) slightly unpleasant, (5) neither unpleasant/nor pleasant, (6) slightly pleasant, (7) moderately pleasant, (8) very pleasant, and (9) extremely pleasant. The final decision of the panelists was assessed using the like and dislike rating scale. For each sample of porridge, 30 ml was placed in a brown plastic cup. During the test, it was important to take a three-minute break and drink water between tastings, to eliminate any taste interference. The samples were anonymized with 3-digit codes.

*2.9. Statistical Analysis.* Optimization of the different porridge flours was carried out in MS Excel 2019 sheets using the Solver Add-in. The sensitivity analysis was performed to understand the effect of changing the objective coefficients of the model in the optimal solutions. Lab data were expressed in terms of mean ± standard deviation. One-way ANOVA (analysis of variance) coupled with the Tukey test was used to compare iron and water contents of vegetable flours on one hand, and the nutritive values (water, ash, fiber, and vitamin C contents) of the three porridges on the other hand. A one-sided one-sample *t*-test was used to compare the experimental means of nutritive values of the porridges with reference values. Differences between comparable sets of results were considered significant at $p < 0.05$. Statistical tests were performed using the Statistical Package for Social Science (SPSS) version 26. The figure was graphed using MS Excel 2019.

## 3. Results

*3.1. Water and Iron Contents of Selected Leaf Powders.* Powders of *Moringa oleifera*, *Hibiscus sabdariffa*, and *Solanum aethiopicum* leaves used had water contents of 9.33 mg/100 g DW, 9.20 mg/100 g DW, and 9.47 mg/100 g DW respectively. No statistical difference was observed among the three water contents. The iron content of the leaf powders of folere, moringa, and eggplant leaves was 5.14 mg/100 g DW, 5.40 mg/100 g DW, and 6.15 mg/100 g DW, respectively. Moringa powder had statistically the lowest content of iron and eggplant powder the highest content.

*3.2. Modeling of Formulated Porridge Flours.* All ingredients for the three formulations were selected to satisfy all constraints (Table 2). The amount of 25 g of yellow maize flour, 40 g of dry whole milk, 9.5 g of brown sugar, 17.6 g of refined soyabean oil, and 7.9 g of eggplant powder for the formulation of eggplant leaf-based flour provided optimal results (Table 2). For folere leaf-based flour, the optimal formulation consisted of 32.5 g of yellow maize flour, 24 g of dry whole milk, 7 g of brown sugar, 24.7 g of refined soyabean oil, and 11.9 g of folere powder for the formulation of folere leaf-based flour. For moringa leaf-based flour, the optimal conditions were met with 30.2 g of yellow maize flour, 31 g of dry whole milk, 10 g of brown sugar, 20.6 g of refined soyabean oil, and 8.3 g of moringa powder. All the constraints related to ingredient weights were satisfied in the three formulations (Table 2). The total costs of the optimized formulations of moringa leaf-based flour, eggplant leaf-based flour, and folere leaf-based flour were 277.60 F cfa, 301.29 F cfa, and 250.13 F cfa, respectively. Regarding the reduced cost of moringa leaf-based flour, if the unit cost of dry whole milk is increased by 377.74 F cfa or more, the optimal solution changes. Regarding eggplant leaf-based flour, if the unit cost of dry whole milk is increased by 377.26 F cfa or more, the optimal solution changes. In the case of folere leaf-based flour, if the unit cost of brown sugar is increased by 121.41 F cfa or more, the optimal solution changes. The unit cost of the other ingredients of the three flours, not mentioned above, had no tolerance to change as their reduced cost was zero. In this study, the allowable increase and decrease were nonzero for almost all variables and had considerable figures. This means that the final values of ingredients remain optimal even if the objective coefficient drastically changes. The limits report (lower and upper limits) was also obtained from the Solver. For the final values, the lower and the upper limits were the same, which shows that to meet the constraints the variable cannot be changed.

*3.3. Validation of the Predicted Content of the Formulated Porridges.* All the nutritional constraints were satisfied in the three formulations (Table 3). The nutrient and energy contents were statistically greater than the allowed lower limits except for energy contents of eggplant leaf- and folere leaf-based flours that were statistically identical to the lower limit. The energy content of moringa leaf-based flour was still lower than the allowed upper limit of 560 Cal.

*3.4. Cost Contribution of Each Ingredient of the Formulated Porridges.* Dry whole milk was the main contributor to the overall cost of the three powdered porridges (Table 4). Dry whole milk represented 47.9% for folere leaf-based porridge, 55.8% for moringa leaf-based porridge, and 66.4% for eggplant leaf-based porridge. The eggplant, moringa, and folere leaf powders represented 10.5%, 14.9%, and 16.5% of the overall cost of their respective porridges. Sugar was the least contributor to the overall cost.

*3.5. Other Nutrient Contents of Powdered Porridges.* Additional macronutrients (ash, water, and crude fiber) and a micronutrient (vitamin C) were assessed, and the results are shown in Table 5. The water contents of the three flours varied from 6.42 to 7.62 g/100g DW, and the ash contents ranged between 2.22 and 2.88 g/100g DW. The fiber contents were found to be between 1.65 and 2.44 g/100g DW, and the vitamin C contents fluctuated between 46.49 g/100g DW and 163.38 g/100g DW. Moringa leaf-based flour had the highest water and vitamin C contents. Eggplant leaf-based flour had the highest ash content, and folere leaf-based flour exhibited the highest fiber content.

*3.6. Sensory Analysis of Cooked Porridges.* Figure 2 shows the assessment of the 50 untrained panelists in terms of 5 descriptors, namely, colour, aroma, taste, after taste, and texture. The colour of folere leaf-based porridge was slightly unpleasant (score = 3.96), whereas the colours of porridges supplemented with eggplant leaf and moringa leaf flours were neither unpleasant nor pleasant (scores around 5), respectively. The aroma, taste, after taste, and texture of the three porridges were slightly pleasant (all scores around 6). The final appreciation of panelists based on the like and dislike rating scale showed that porridges fortified with moringa leaves' flour received the highest number of likes (82%) followed by the one supplemented by eggplant leaves' flour (80%) and that of folere leaves' flour (70%).

## 4. Discussion

In the results, eggplant leaf powder (*Solanum aethiopicum*), folere leaf powder (*Hibiscus sabdariffa*), and moringa leaf powder (*Moringa oleifera)* had statistically different amounts of iron. The iron content of moringa leaf powder was lower than that of Joshi and Mehta [37] who reported a value of 19 mg/100g DW after oven-drying moringa leaves. However, its iron content was greater than 3.5 mg/100g DW from the study by Sahay et al. [38]. The leaves of *Solanum aethiopicum* in this study exhibited a low iron content compared to the level (36.86 mg/100g DW) recorded by Achikanu et al. [27]. The iron content of *Hibiscus sabdariffa* leaves was found to be greater than the 5 mg/100g DW reported by Naturlan [24].

Table 2: Results of LP optimization and sensitivity analysis of the three formulated flours.

| Ingredients | Final value (g) | Reduced cost | Objective coefficient | Allowance increase (g) | Allowance decrease (g) | Lower limit | Upper limit |
|---|---|---|---|---|---|---|---|
| Moringa leaf-based flour | | | | | | | |
| Yellow maize flour | 30.173 | 0 | 100 | 0.504 | $10^{30}$ | 30.173 | 30.173 |
| Dry whole milk | 31.000 | 377.74 | 500 | $10^{30}$ | 377.765 | 31.000 | 31.000 |
| Brown sugar | 10.000 | 0.49 | 100 | $10^{30}$ | 0.498 | 10.000 | 10.000 |
| Soya bean oil | 20.568 | 0 | 200 | 26.68 | 106.195 | 20.568 | 20.568 |
| Moringa powder | 8.258 | 0 | 500 | $10^{30}$ | 84.253 | 8.258 | 8.258 |
| Total cost | 277.60 F cfa | | | | | | |
| Eggplant leaf-based flour | | | | | | | |
| Yellow maize flour | 25.000 | 0.24 | 100 | $10^{30}$ | 0.239 | 25.000 | 25.000 |
| Dry whole milk | 40.000 | 377.26 | 500 | $10^{30}$ | 377.262 | 40.000 | 40.000 |
| Brown sugar | 9.506 | 0 | 100 | 0.23 | $10^{30}$ | 9.506 | 9.506 |
| Soya bean oil | 17.596 | 0 | 200 | 1639.56 | 12.261 | 17.596 | 17.596 |
| Eggplant powder | 7.898 | 0 | 400 | 41.92 | 306.496 | 7.898 | 7.898 |
| Total cost | 301.29 F cfa | | | | | | |
| Folere leaf-based flour | | | | | | | |
| Yellow maize flour | 32.530 | 0 | 100 | 72.95 | $10^{30}$ | 32.530 | 32.530 |
| Dry whole milk | 23.974 | 0 | 500 | 108.20 | 377.93 | 23.974 | 23.974 |
| Brown sugar | 7.000 | 121.41 | 100 | $10^{30}$ | 121.41 | 7.000 | 7.000 |
| Soya bean oil | 24.674 | 0 | 200 | 1288.84 | 144.13 | 24.674 | 24.674 |
| Folere powder | 11.822 | 0 | 350 | $10^{30}$ | 62.45 | 11.822 | 11.822 |
| Total cost | 250.13 F cfa | | | | | | |

Table 3: Validation of the predicted protein, iron, lipid, and energy contents of the formulated flours.

| Flour | Nutritive values | Content | Lower limit | Student t | $p$-value |
|---|---|---|---|---|---|
| Eggplant | Iron content (mg/100g) | $6.15 \pm 0.16^*$ | 5 | 12.405 | 0.006 |
| | Protein content (g/100g) | $13.83 \pm 0.30^*$ | 10 | 22.077 | 0.002 |
| | Lipid content (g/100g) | $30.91 \pm 0.80^*$ | 26 | 10.640 | 0.009 |
| | Energy (cal) | $509.93 \pm 4.80$ | 510 | −0.023 | 0.984 |
| Folere | Iron content (mg/100g) | $5.14 \pm 0.03^*$ | 5 | 8.083 | 0.015 |
| | Protein content (g/100g) | $11.37 \pm 0.61$ | 10 | 3.905 | 0.060 |
| | Lipid content (g/100g) | $32.94 \pm 0.34^*$ | 26 | 35.244 | 0.004 |
| | Energy (cal) | $517.48 \pm 1.51^*$ | 510 | 8.568 | 0.013 |
| Moringa | Iron content (mg/100g) | $5.40 \pm 0.03^*$ | 5 | 21.732 | 0.002 |
| | Protein content (g/100g) | $12.54 \pm 0.86^*$ | 10 | 5.102 | 0.036 |
| | Lipid content (g/100g) | $30.79 \pm 0.60^*$ | 26 | 13.889 | 0.005 |
| | Energy (cal) | $511.76 \pm 5.18$ | 510 | −1.576 | 0.256 |

*The nutritive values carrying the superscript were statistically different from the lower limit ($p < 0.05$).

The three linear programming models were able to satisfy all constraints (ingredients and nutrients) using the proposed ingredients. Cooking, which is required when preparing the suggested porridges, generally influences nutrient composition [39]. In this case, the bioavailability of the targeted mineral, that is, iron, should not be affected by heat as shown by Miller [40]. However, a study conducted by Macharia-Mutie et al. [41] revealed that maize porridge fortified with amaranth grain flour did not improve the iron status of preschool children despite a large increase in iron intake likely due to the high ratio of phytic acid: iron in the meal. Thus, various research should be investigated in the future, prior to cooking, to enhance iron bioavailability such as germination, microbial fermentation, or soaking to reduce the phytate and polyphenol contents of unrefined cereal porridges [42]. The iron contents of the three powdered porridges varied between 5.14 mg/100 g DW and 6.15 mg/100 g DW. A weight of 100 g of these three powdered will easily cover the iron needs of children aged 12 to 24 months with the recommended intakes set at 5.8 mg/day to 7 mg/day by the World Health Organization [43]. A minimum amount of 152 g of the three porridges will be needed to meet the iron needs of children aged 6 to 12 months with the recommended intake set at 9.3 mg/day by the World Health Organization [44].

Table 4: Cost contribution of each ingredient to the total cost of each porridge.

| Ingredients | Cost (F CFA) | | |
|---|---|---|---|
| | Moringa leaf-based porridge | Eggplant leaf-based porridge | Folere leaf-based porridge |
| Maize flour | 30.173 | 25 | 32.530 |
| Milk powder | 155 | 200 | 119.872 |
| Sugar | 10 | 9,506 | 7 |
| Soyabean oil | 41.136 | 35.193 | 49.348 |
| Leaf powder | 41.292 | 31.592 | 41.376 |
| Total | 277.602 | 301.290 | 250.126 |

Table 5: Water, ash, fiber, and vitamin C contents of formulated flours.

| Content (for 100 g DW) | Eggplant leaf-based flour | Folere leaf-based flour | Moringa leaf-based flour |
|---|---|---|---|
| Water content (g) | $6.42 \pm 0.14^{a}$ | $7.16 \pm 0.24^{b}$ | $7.62 \pm 0.03^{c}$ |
| Ash content (g) | $2.88 \pm 0.11^{b}$ | $2.20 \pm 0.12^{a}$ | $2.25 \pm 0.02^{a}$ |
| Crude fiber content (g) | $1.86 \pm 0.21^{a}$ | $2.44 \pm 0.18^{b}$ | $1.65 \pm 0.27^{a}$ |
| Vitamin C (mg) | $75.34 \pm 5.21^{b}$ | $46.49 \pm 5.75^{a}$ | $163.38 \pm 11.31^{c}$ |

The values carrying different letters on the same row are statistically different ($p < 0.05$).

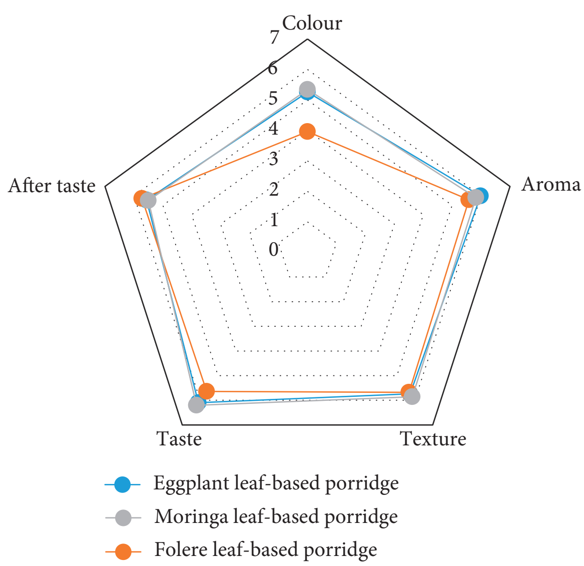


Figure 2: Hedonic appreciation of the three porridges based on five descriptors.

Vitamin C is known to be easily degraded and sensitive to high temperatures, oxygen, and light [45]. Thus, vitamin C contents in the three powdered porridges are likely to reduce during the cooking process. The amount of vitamin C found in the three powdered porridges was largely greater than the reference values (RNI) for vitamin C intake for children aged 6–23 months as recommended by WHO, which is 20 mg/day [46]. Vitamin C is particularly valuable in assisting the absorption of non-haem iron from vegetables [47].

The protein contents of the three powdered porridges varied from 11.37 g/100g DW to 13.83 g/100g DW. In these food formulas, the main supplier of proteins was dry whole milk with protein contributions between 56.67% and 78.19% of the total protein contents. Milk is a good source of many essential amino acids, and milk proteins are currently the main source of many biologically active peptides [48]. This suggests that the powdered porridges should provide proteins of good quality to children aged 6–23 months. However, the powdered porridges are not meant to be consumed as such but should be cooked in boiling water for 5 min. Proteins go through numerous chemical and physical alterations upon heating, namely, denaturation, glycation, b-elimination reactions, racemisation, iso-peptide bonds formation, etc., which are significant for nutrition. Environmental conditions of heat thermal treatment influence its harmful effect on nutrients [49].

The three powdered porridges had lipid contents of 30.79 g/100 g DW, 30.91 g/100 g DW, and 32.94 g/100 g DW. The main lipid contributor in the three powdered porridges is soyabean oil with lipid contents of 17.60 g/100 g, 20.57 g/100 g, and 24.67 g/100 g. Fortuitously, cooking conditions of the powdered porridges should have a minimal damaging effect on soybean oil as oils rich in polyunsaturated fatty acids (PUFA) and low in saturated fatty acids (SFA) values are recommended for food preparation [50].

Water content in the three powdered porridges varied between 6.42 g/100 g DW and 7.62 g/100 g DW. The dried foodstuffs are more proper for keeping quality when the water content is less than 10% [51]. The microorganisms cannot develop when the water content is below 8% in dehydrated foods [52]. Thus, the water content of the three powdered porridges developed in this study should prevent the growth of microorganisms.

The ash contents of the three powdered porridges were similar to the three porridges developed by Mahgoub et al. [53] with ash contents of 1.86 g/100 g DW, 2.01 g/100 g DW, and 2.17 g/100 g DW. The fiber contents of the three powdered porridges varied from 1.65 g/100 g DW to 2.44 g/100 g DW. These values were comparable to that of Nestle Cerelac (2.27 g/100 g) as reported by Ikese et al. [54]. There is very little evidence for the effects of dietary fiber in young children and current dietary guidelines are based on assumptions and data extrapolated from studies in adults. However, the first years of life may be critical for the establishment of healthy colonic microflora, as well as good eating habits [55].

The cost for 100 g of the different powdered porridges fortified with folere, moringa, and eggplant leaves was 250.13 F CFA (0.40 USD), 277.60 F CFA (0.45 USD), and 301.29 F CFA (0.49 USD), respectively. These overall costs are challenging in an economy where 37.5% of the population was still living below the national poverty line in 2014 (ECAM4), especially in conflict-affected areas [56]. Considering the monetary poverty threshold of USD 1.90 (~1143 F CFA) per person per day and the fact that a woman has an average of 4.8 children in Cameroon [56, 57], these overall costs are unsustainable. Thus, the low-cost ingredients should be investigated. For example, dry whole milk was the main contributor to the overall costs (between 47.9% and 66.4%) and also the main source of proteins (between 56.67% and 78.19%). It is necessary to consider another ingredient with comparable protein content and less expensive such as legumes that could be used in porridge formulation as described by De Carvalho et al. [39] and Gitau et al. [58].

Eighty-two percent of untrained panelists like the cooked porridge fortified with 8.26% of *Moringa oleifera*. Consistent results (82%) were reported by Mahan et al. [59] with their porridge containing 15% of *M. oleifera* (EE 09 formula).

## 5. Conclusions

Leaves of eggplant, folere, and moringa cultivated in the North West Region had a high content of iron, between 5.14 and 6.15 mg/100 g DW. Porridges fortified with flours of folere, moringa, and eggplant leaves were successfully formulated to satisfy the recommended nutrient intakes (RNI) of children aged 6 to 23 months, namely, energy content (510 to 560 Cal/100 g), protein content (11 to 16 g/100 g), and lipid content (26 to 36 g/100 g). The iron content that was set to be half of the RNI, that is, 5 to 7 mg/100 g, was met by the linear programming modeling. The different powdered porridges had a very low amount of water (6.42 to 7.62%), low ash content (2.2 to 2.88%), and low fiber content (1.65 to 2.44%) with a high vitamin C content (46.49 to 163.38 mg/100 g DW). The three formulated porridges were found to be appreciated by the panelists (From 70% to 82%). Thus, the three porridges have the potential to address iron deficiency anemia among children aged 6 to 23 months. However, the cost of powdered porridges, between 250.13 F CFA (0.40 USD) and 301.29 F CFA (0.49 USD), was unreasonably high because of the inclusion of dry whole milk. Reasonable cost requires the investigation of budget-friendly protein-rich ingredients.

## Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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