**Nutritional content, functional and sensory characteristics of complementary flours formulated from orange sweet potato and sesame seed fortified with carrot, baobab pulp, and Moringa leaves**

# Abstract

Protein-energy malnutrition and micronutrient deficiency in young children remain a significant concern in developing countries. Inadequate complementary feeding practices, especially the low quality of homemade complementary foods represent a major contributing factor. The main objective of this study was to use locally available plant foods to produce complementary flours that would meet the energy and nutrient requirements of young children. To achieve this goal, orange sweet potato was fermented with *Lactobacillus planctarum* at 45°C for 48 hours, sesame seeds were soaked and germinated, carrot and Moringa leaves were steam blanched, and baobab pulp was obtained without any treatment. The pre-treated ingredients were then dried and ground to obtain individual flours, which were blended in various proportions to formulate four complementary flours (FM1, FM2, FM3, FM4). The macro and micronutrient composition of these flours was then determined including the moisture content, total ash, total carbohydrates, soluble sugar, crude protein, crude fat, crude fibre, iron, calcium, zinc, vitamins A and C, as well as their energy value and functional properties including water absorption capacity, water solubility index, and bulk density. Gruels were prepared from the flours and their energy density, viscosity, and sensory properties were evaluated. The results indicate that except for iron, the nutrient content (Protein 10.77-14.06%; Carbohydrate 65.73-67.10%; Calcium 250.43-301.10 mg; Zinc 3.85-4.51 mg; Vitamin A 770-970 µg RE; Vitamin C 30.25-31.16 mg) and energy value (403.73-417.25 kcal) of the flours formulated met the standards set by the World Food Programme for 100 g of infant flour. All the flours demonstrated favourable water absorption capacity, solubility index, and bulk density, intriguing functional properties for complementary flours. The gruels prepared with these flours exhibited satisfactory viscosity and energy density, yet their organoleptic characteristics, particularly colour, and mouthfeel, were not particularly well-received. In light of the aforementioned findings, the flours produced could be recommended as complementary flours, albeit with the caveat that they require to be fortified with iron.

**Keywords**: Young child feeding; Complementary flour; Food processing; Food quality; Food characterization; Sensory evaluation.

# Introduction

The prevalence of protein-energy malnutrition and micronutrient deficiency, particularly vitamin A and iron deficiency, remains high in many developing countries, particularly in sub-Saharan Africa, where approximately 170 million children under the age of five are affected. Cameroon is facing a significant public health challenge, with a prevalence of 29% of children under five years old suffering from protein-energy malnutrition [1]. Additionally, 57% of children are affected by anaemia caused by iron deficiency, and 35% are suffering from vitamin A deficiency [2]. Malnutrition in children is a prevalent issue from the age of six months onwards, coinciding with the introduction of complementary feeding practices.

Indeed from four to six months of age, breast milk alone is no longer sufficient to meet the nutritional demands of the young child, necessitating the introduction of complementary foods into the diet as nutritional needs increase [3]. Despite the availability of commercial complementary foods in urban areas in Came roon, the majority of households rely on homemade porridges and purées made from cereal or tuber flours, either alone or with other ingredients such as vegetables and legumes [4]. However, these porridges are frequently of insufficient nutritional and functional quality since mothers lack the requisite knowledge and control over certain technological and technical aspects. Indeed, due to their high starch content, cereals, tubers, and starchy foods tend to result in porridges that are thick and difficult for the child to swallow, this forces mothers to add water to dilute them, which subsequently diminishes the nutritional density of the porridge [5]. Moreover, vegetables and legumes contain several antinutritional factors such as phytate, raffinose family oligosaccharides, trypsin inhibitors, lectins, and tannins which restrict mineral bioavailability and protein digestion [6]. Consequently, the nutrient density of porridges provided to children is low, as is the digestibility of macronutrients and the bioavailability of micronutrients.

To address these issues, foods can be subjected to several processing techniques, including soaking, germination, fermentation, heating, and roasting [7]. These treatments facilitate the hydrolysis of starch into soluble sugars, which reduces viscosity and enhances digestive processes. Additionally, they reduce the concentration of antinutrients, thereby increasing the bioavailability of micronutrients and the digestibility of proteins [8,9]. Consequently, numerous studies have focused on the development of complementary foods derived from local Cameroonian ingredients and subjected to the requisite processing.

A purée was formulated from fermented melon, soaked and roasted soybeans, and steam-blanched spinach leaves [10]. The same treatments were applied to the same ingredients to produce flours [11]. A flour was produced from germinated and cooked yellow maize, soaked and roasted cashew almonds, and baobab pulp [5]. The formulation of flours based on rice, yellow corn, Irish potatoes, cassava, soya bean, crayfish, carrot, and groundnut was conducted [12]. Three flours were developed from pre-cooked plantain fortified with roasted sesame, roasted cashew nut, and soaked and roasted soybean [13]. Despite the extensive research conducted on infant and young child nutrition, there is still much to be done in this field, particularly given the abundance of plant foods in the Cameroonian ecosystem that could be utilized in the production of complementary foods.

Talking about plant foods, sweet potato (*Ipomoea batatas*) is one of the most consumed tubers in Cameroon, with an estimated annual yield of approximately 440,012 tonnes [14]. It is a rich source of carbohydrates, which constitute a primary source of energy for the body, and its orange flesh variety contains β-carotene, a precursor to vitamin A that plays a role in maintaining eyesight and cell differentiation [15]. However, sweet potato's high starch content can result in difficulties with the viscosity of the porridge, this necessitates the hydrolysis of the starch. To this end, the bacterial strain *Lactobacillus plantarum* has demonstrated efficacy in the hydrolysis of starchy matrices during fermentation [16].

Sesame (*Sesamum indicum* L.) is a rich source of proteins that promote growth and development, omega-3 and omega-6 unsaturated fatty acids which have anti-inflammatory properties, iron which is an essential component of haemoglobin and plays a pivotal role in the development of the child's immune system, and calcium which is involved in the process of ossification, which is crucial for skeletal development [17]. Nevertheless, the presence of antinutrients such as phytic and oxalic acids and tannins reduces the bioavailability of minerals [17]. Fortunately, studies have demonstrated that treatments such as soaking and germination can effectively reduce antinutrient levels in plant foods [7].

Carrot (*Daucus carota*) is one of the most popular vegetables grown and consumed in numerous countries all over the world. When included in the diet, carrot is a good source of dietary antioxidants and provitamin A. Carrots are believed to possess various health benefits due to their nutritional composition and antioxidant capacity, including the potential to prevent cardiovascular disease and certain types of cancers [18]. It is a vegetable with a high level of dietary fibre which is associated with favourable gastrointestinal, immune, and metabolic health outcomes when consumed at sufficient levels [19].

Baobab pulp (*Adansonia digitata* L.) contains substantial quantities of iron and zinc, both of which serve as cofactors in a multitude of immunological processes and act as antioxidants. Additionally, it is a rich source of calcium, a mineral essential for bone and tooth development, and can contain up to 350 mg of vitamin C (ascorbic acid) [20]. This vitamin C, in addition to its antioxidant properties, aids in the absorption of non-heme vegetal iron in the body [21]. Consequently, baobab pulp represents an optimal source of essential minerals and vitamins, which are vital for the development of healthy bones and a robust immune system in children.

Moringa leaves (*Moringa oleifera* Lam.) are notable for their high nutritional value, particularly their high protein and soluble fibre content. Moringa leaves have been found to contain magnesium, phosphorus, potassium, iron, vitamins B1, B2, B3, C, and E, as well as carotenoids [22,23]. However, it also contains antinutrients such as phytic and oxalic acids, but their level can be reduced by a heat treatment like steam blanching as previously demonstrated on spinach leaves [24].

Based on all this information, the overarching objective of this study was to use fermented orange sweet potato, soaked/roasted sesame seeds, steam-blanched Moringa leaves, carrot, and baobab pulp to develop complementary flours that could contribute to alleviating toddlers' protein energy malnutrition and micronutrients deficiency in Cameroon.

# 2. Materials and methods

## 2.1. Sampling of raw materials

The assortment of biological materials including orange sweet potato (*Ipomoea batatas*) tubers, sesame seeds (*Sesamum indicum* L.), carrot (*Daucus carota*), baobab pulp (*Adansonia digitata* L.), and Moringa leaves (*Moringa oleifera* Lam.) was procured from a main market in Ngaoundere town, Cameroon. The raw material was subsequently dispatched to the Food Biophysics, Biochemistry, and Nutrition laboratory at the University of Ngaoundéré's National School of Agro-industrial Sciences for further analysis.

## 2.2. Production of individual flours and powders

Figure 1 depicts the methodology employed to produce individual flours. Sweet potato tubers were sifted to remove infected tubers and foreign bodies. They were then rinsed with potable water to remove mud and minimise microbial contamination. They were subsequently peeled and grated (Figure 1A). The dough was cooked at 95°C for 30 mins in a cooker (Magimix, Surrey, UK), and fermented for 48 hours at 45°C with *Lactobacillus plantarum* strain. Subsequently, the material was dried at 45°C for 24 hrs in a vented dryer ((Rivière & Bar QD105A, Paris, France), then ground with a crusher (Culatti Micro Hammer Mill DCFH 48, Lutoslawskiego Witolda, Poland), and sieved. This resulted in fermented sweet potato flour with a particle size ≤ 355 µm.

The production of sesame flour was carried out by the modified process of Jiokap et al. [25], as illustrated in Figure 1B. The sesame seeds were subjected to a sifting, rinsing, and soaking process at room temperature for 24 hours, with a ratio of 1:3 (m/v), and the soaking water was replaced every 12 hrs. Subsequently, the seeds were drained for approximately four hrs and germinated on racks positioned on shelves at room temperature in the absence of light, with occasional watering to maintain optimal humidity. The germination was stopped after three days, and the rootlets were removed by rubbing the seeds against metal plates. Subsequently, the germinated seeds were subjected to a drying process at 45°C for 48 hrs in a vented drier. Following this, the seeds were crushed and sieved, resulting in the production of malted sesame flour with a particle size ≤ 355 µm.

Grating

Used water

sorting

Washing

Clean water

Cooking

(95°C/30 mins)

Fermentation

(45°C/48 hrs)

Peeling

Peels

Drying

45°C/24 hrs

Grinding

Sieving (Ø≤355μm)

Bran

Draining

Used water

sorting

Washing

Clean water

Germination

(72 hrs)

Drying

(45°C/48 hrs)

Soaking

(24 hrs)

Soaking water

Grinding

Sieving (Ø≤355μm)

Bran

Clean water

**(A)**

**(B)**

**Figure 1.** Process diagram of orange sweet potato **(A)** and sesame **(B)** flour production

The production of powders was conducted following the flow diagrams presented in Figure 2. The baobab pulp powder was obtained by the process depicted in Figure 2A and previously described by Ngaha et al. [5]. The baobab pulp was subjected to a sorting process to remove residual fruit shell debris, funiculus, and other extraneous matter. It was then pitted and ground in a mortar. The coarse powder was then subjected to a sieving process, with the objective of obtaining a baobab powder with a particle size ≤ 355 µm.

Cores

sorting

Stoning

Crushing

Sieving (Ø≤355 μm)

Bran

Slicing

(1 mm)

Used water

sorting

Washing

Clean water

Cooking

(95°C/10 mins)

Peeling

Peels

Drying

45°C/24 hrs

Grinding

Sieving (Ø≤355μm)

Bran

Used water

sorting

Washing

Clean water

Steam blanching

(95°C/5 mins)

Picking

Stems

Drying

45°C/10 hrs

Grinding

Sieving (Ø≤355μm)

Bran

**(A)**

**(B)**

**(C)**

**Figure 2.** Process diagram of baobab pulp (A), carrot (B), and Moringa pulp (C) powders production

The carrot powder was produced following the process illustrated in Figure 2B. The carrots were sorted, washed, and peeled. The carrots were sliced into 1 mm-thick piece and cooked at 95°C for 10 minutes to denature the enzymes responsible for altering the colour. Subsequently, the cooked carrots were subjected to a 24-hour drying process at 45°C in a ventilated dryer, after which they were crushed and sieved at 355 µm to obtain the desired carrot powder.

As illustrated in Figure 2C, Moringa leaves were sorted, cut, and subjected to a five-minute steam blanching process at 95°C using a steam cooker. (Magimix, Surrey, UK). The moringa powder was obtained by subjecting the blanched leaves to a drying process at 45°C for a period of 10 hrs in a ventilated dryer, followed by a crushing and sieving process at 355 µm.

The resulting flours and powders were packaged and stored for subsequent analysis and formulation of complementary flours.

## 2.3. Physicochemical characterization

The determination of proximate composition including moisture content, total ash, total carbohydrate, crude protein, crude fat, and crude fibre was conducted using the standard procedures previously outlined by Ngaha et al. [13]. Soluble sugar content was measured as reported by Tedom et al. [16]. Iron content was quantified through a colorimetric approach using orthophenanthroline, while the calcium level was determined through a titrimetric method [16]. The zinc concentration was evaluated using the flame photometric method, as described by Cowling and Miller [26]. The initial evaluation of vitamin A content entailed the determination of carotenoid content, followed by the application of the conversion factor, which stipulates that 12 µg of carotenoids equates to 1 µg of vitamin A. This approach was described by Ngaha et al. [13] and was employed to estimate the quantity of vitamin A. The concentration of vitamin C was evaluated using the titrimetric method described by Da Silva et al. [27]. The aforementioned analyses encompassed a range of ingredients, including maize and sesame flours, carrot, Moringa leaves, and baobab pulp powders, in addition to formulated complementary flours.

## 2.4. Energy value of complementary flour and micronutrient mix

The energy value (EV) (kcal) for 100 g of flour was calculated using Formula 1, based on the dry matter (Q), carbohydrate, protein, and fat contents of the formulation.

(1)

## 2.5. Formulation of complementary flours

To formulate the complementary flours, all of the flours and powders produced were blended following the proportions determined by the Design Expert 11.0 program, which was based on their biochemical composition. The World Food Programme's (WFP) recommendations for sugar (65-68%), protein (8-16%), and vitamin A (350-1250 µg RE) levels in 100 g of infant flour were used as responses [28]. The software generated 15 formulations that satisfied the WFP recommendations in terms of total sugar and protein content, but only four having the highest levels of these nutrients were retained for further investigations, with the proportions of the ingredients presented in Table 1 (FM1, FM2, FM3, and FM4).

**Table1.** Proportions of ingredients used for complementary flour formulations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Runs | Sweet potato (%) | Sesame (%) | Carrot (%) | Moringa leaves (%) | Baobab pulp (%) |
| FM1 | 47.5 | 17.5 | 25 | 8.5 | 1.5 |
| FM2 | 51 | 19 | 21.5 | 7 | 1.5 |
| FM3 | 52 | 19.5 | 20.5 | 6.5 | 1.5 |
| FM4 | 55 | 20 | 18 | 5.5 | 1.5 |

## 2.6. Functional characterization of flour and mix

To ascertain the water absorption capacity and solubility index of the flours produced, a mass of 1 g of flour (M0) was combined with 10 mL of distilled water. The mixture was then shaken for 30 mins and subsequently centrifuged at 2500 rpm for a further 30 mins. Subsequently, the wet pellet was weighed (M2) and then subjected to drying at 105°C for 24 hrs, after which it was weighed again (M1). The apparent water absorption capacity (aWAC), the real water absorption capacity (rWAC), and the water solubility index (WSI) were calculated following formulas 2,3, and 4 as described by Ngaha *et al.* [5].

The mass of the residue obtained after drying the supernatant is designated as M3.

(4)

(3)

(2)

Bulk density (BD) was determined by introducing 2 g (m) of flour into a measured cylinder flask of 10 mL, followed by vibration for 1 minute (Vortex RS Lab\_6Pro). The volume (V in mL) occupied by the flour following vibration was recorded, and equation 5 was employed to calculate the bulk density (BD) as reported by Tedom *et al.* [11].

(5)

## 2.7. Microbiological analysis

The objective of the search for total flora following NF ISO 4833 (2003) is to predict the quality of the foodstuff by evaluating its total microbial load. The search and enumeration of faecal coliforms and *Escherichia coli* were conducted on a selective EMB (Eosin Methyl Blue) medium. The search for yeasts and moulds was conducted on a selective Sabouraud medium with chloramphenicol. Concerning the enumeration of Salmonella, the pre-enriched samples (25 g of flour in 225 mL of peptone water) were subjected to enrichment in a selective broth (selenite broth, 37°C/18 to 24 hrs) before isolation for enumeration on a selective medium (SS Agar, 37°C/24 to 48 hrs).

## 2.8. Preparation and characterization of gruels from formulated flours

Gruels were prepared from formulated complementary flours following the methodology delineated by Ngaha et al. [5]. Each of the selected flours (100 g) was mixed with 250 mL of boiled potable water and transferred into a plate containing 250 mL of boiling water to prevent the formation of clots. The mixture was then stirred for approximately 2-3 mins. At the end of the preparation process, 6% table sugar was incorporated to enhance the palatability of the gruel, which was then cooled to approximately 45°C and utilized for the functional and sensory assessments.

The viscosity of the gruel was determined using a Bostwick viscometer (Standard Model ASTM F1080-93, United Kingdom) which allows for the measurement of the flow behaviour of fluids. The gruel was cooled at 45°C and allowed to flow for 30 seconds. The distance traversed by the gruel is indicative of the viscosity (fluidity) observed, expressed in cm/s. A conversion table was employed to convert cm/s to Pa.s. The energy value (EV) of the flour and the quantity of flour (Q) used to prepare 100 mL of gruel were known; therefore, the energy density (ED) (kcal/100ml) of the gruel was calculated using Formula 6.

## 2.9. Sensory assessment

(6)

A sensory assessment was conducted following the ethical guidelines set forth by the Ethics Committee of the Postdoctoral Training Unit in Food Science and Nutrition of the National School of Agro-Industrial Science (University of Ngaoundere, Cameroon). The assessment was carried out within the Food Sensory Laboratory of the aforementioned institution. A nine-point hedonic scale (with endpoints labeled 1 and 9, respectively) was employed for the assessment of the sensory properties of the gruels. The samples were evaluated by a panel of 32 mothers, aged between 18 and 35 years old, selected from among women residing in Ngaoundere who were familiar with complementary flours. The participants were trained on how to use the nine-point hedonic scale to evaluate the samples. The sensory attributes that were sought included colour, flavour, viscosity, aroma, mouthfeel, and overall acceptability. The samples were prepared as gruels using the formulated flours, while a gruel prepared using commercially available flour served as a positive control. The samples were simultaneously and randomly presented to the participants. The randomization sequence was carried out using XLSTAT version 2016 (Addinsoft, Paris, France) which allowed to obtain a randomized design matrix of 5 (samples) by 6 (sensory attributes) for the 32 evaluators (configurations). This aimed to present different samples to the participants in a completely random order, ensuring that no sample systematically appears first, last or in a specific position, in order to minimize the biases caused by the presentation order and to allow a more accurate assessment of the sensory attributes of the product. The panelists were instructed to rinse their mouths with drinking water between samples and to assess the next sample after 4 mins. The sensory evaluation was conducted at room temperature under controlled environmental conditions. To prevent any communication between panelists, they were seated in individual boxes illuminated by white light to prevent any changes in sample colour. The initial parameter to be evaluated was the visual aspect. Moreover, to guarantee the safety of the panelists, they were informed in advance of the composition of the gruels, thus ensuring that they were not allergic to any of the ingredients.

## 2.10. Statistical tools and analysis

The results were expressed as means ± standard deviations derived from three determinations using Microsoft Excel 2016 software. The data normality was checked for, and they were subjected to analysis of variance (ANOVA) to ascertain whether there was a significant difference (p < 0.05) using Statgraphics Centurion software. The Duncan multiple range test was employed to separate the means.

# Results and Discussion

## Physicochemical characteristics of raw materials

Table 2 illustrates the nutritional composition of the raw materials utilized and the impact of the implemented treatments. The data show that the water content of the individual flours exhibited considerable variation, with Moringa leaf powder displaying a value of 4.13% and baobab pulp powder exhibiting a value of 7.91%. The water content of all samples was less than 10%, which suggests a favourable shelf life for the flours produced. Flours with a low water content have been demonstrated to have an extended shelf life, which is linked to the inactivation of microorganisms and the decrease of metabolic reactions [29]. These water contents are similar to those reported in other studies examining food flours derived from tubers, legumes, fruits, and vegetables [5,11,30].

The ash content of fruits and vegetables was considerable, with values reaching 7.7% in carrots, 8.2% in baobab pulp, and 9.6% in Moringa leaves. Furthermore, sesame, and more specifically its sprouted form, was found to have a significant ash content (4.8%). These elevated ash levels indicate that these matrices are significant sources of minerals [31]. The ash content of the carrot reported in this study is in close agreement with the 7.01% value previously documented by Izuwa [32]. In contrast, the ash content of Moringa leaves is lower than that reported by Mutayaba *et al.* [33]. This discrepancy could be attributed to the maturity state of the leaves, the soil type, and the climatic conditions, which could vary considerably between studies [34]. The notable increase (p<0.05) in sesame ash content from 3.95 to 4.83% following seed treatment is comparable to the findings of Jiokap *et al*. [25]. This phenomenon may be attributed to the concentration of nutrients in the seed due to the loss of water and fibre, the hydrolysis of complex organic compounds (endogenous enzyme), and the subsequent release of antinutrients during soaking, germination, and drying. Furthermore, Makinde and Akinoso [35] demonstrated that the germination and roasting of sesame seeds markedly (p < 0.05) elevates the ash content.

Concerning macronutrients, Table 2 illustrates that among the raw materials employed, sesame represents the most significant source of lipids and proteins. The process of germination was observed to result in a reduction in the lipid content of the seeds, from 52.2 to 47.2 g/100 g DM. This outcome aligns with the findings of Kouamé *et al*. [36], who demonstrated that the lipid content of sesame seeds exhibited a statistically significant decline (p<0.05) with the progression of germination time. This phenomenon may be explained by an increase in the activity of lipolytic enzymes during the germination process, which hydrolyse fatty compounds into free fatty acids and glycerol for the synthesis of carbohydrates [37].

The protein content of germinated sesame exhibited a statistically significant increase (p<0.05), rising from 20.35 to 24.09 g/100 g DM. This outcome aligns with the findings of Kouamé *et al*. [36]. This increase can be attributed to the synthesis of cellular constituents and enzymes that facilitate the degradation of other seed constituents during germination [38]. Similarly, during germination, metabolic enzymes such as proteinases are activated, which could result in the release of specific amino acids and peptides to facilitate the synthesis or formation of new protein molecules [39]. This is also attributable to the degradation of carbohydrates and lipids, which provide the amino acids necessary for biochemical processes and the growth of germinating seeds [39].

Concerning carbohydrates, the sweet potato exhibited the highest total sugar content (67.52 g/100 g DM), representing the primary source of carbohydrates among the utilized ingredients. The content increased significantly (p<0.05) following fermentation, reaching 73.37 g/100 g DM. The soluble sugar content of the sweet potato also exhibited a significant increase (p<0.05) following fermentation with *L. plantarum*, rising from 10.24 to 43.49 g/100 g DM. The observed increase in soluble sugar content can be attributed to the amylolytic properties of *L. plantarum* which facilitate the cleavage of long polysaccharide chains of sweet potato starch into shorter chains and monosaccharides. Furthermore, the fermentation of sweet potato results in a notable reduction in fibre content, which may also be attributed to the activity of *L. plantarum*. Indeed, the bacteria possess β-amylases capable of digesting fibres, particularly cellulose, into cellulobiose and ultimately glucose [16]. This may also explain the observed increase in soluble and total sugars in fermented sweet potato flour. Furthermore, the literature indicates comparable outcomes during melon fermentation by the same bacterial strain [16].

The hydrolysis of starch and fibre by *L. plantarum* contributes to the increased soluble sugar content of cooked and fermented sweet potato flour, rendering it a more suitable ingredient for infant formulations. A reduction in the fibre content of fermented sweet potato flour is advantageous for the absorption of vitamin A. High fibre levels have been demonstrated to lower the bioavailability of vitamin A, either by complexing it or by interacting with bile acids, which results in the faecal excretion of fat-soluble substances [40]. Furthermore, the fermentation of fibres by bacteria produces short-chain fatty acids, including acetic, butyric, and propionic acids, which are beneficial in preventing colon cancer and lowering blood cholesterol levels [41].

Table 2 illustrates that fruit (baobab pulp) and vegetables (carrot and moringa) are the primary sources of minerals, with the highest concentrations typically found in these food items. This is exemplified by iron, with a content of 5.7 mg/100 g DM in carrots, 12.3 mg/100 g DM in baobab pulp, and 24.7 mg/100 g DM in Moringa leaves. A similar trend is observed for zinc, with levels ranging from 3.1 to 7.6 mg/100 g DM in carrot and baobab pulp respectively. Furthermore, calcium levels in Moringa leaf reach 1213 mg/100 g DM. However, sesame exhibits calcium levels of 1180 mg/100 g DM and iron levels of 8 mg/100 g DM. Furthermore, Moringa leaves are a significant source of minerals with 5 mg/100 g DM and 3.15 mg/100 g DM of zinc and iron respectively. These high mineral contents indicate that Moringa leaves can be used in infant formulations to fortify mineral-limited starch matrices. These results are in line with those of numerous studies on the mineral composition of leafy vegetables [22-24, 34], baobab pulp [20], and carrots [18, 19].

Concerning vitamins, the results in Table 2 indicate that carrots are the most important source of vitamin A (1725.7 µg/100 g DM). However, with respective vitamin A contents of 605 µg/100 g DM for orange sweet potato and 113 µg/100 g DM for Moringa leaf, these two foods also represent interesting sources of vitamin A. These results are similar to those of numerous previous studies that have reported high vitamin A content in carrots [18,19], Moringa leaf [22,23], and orange sweet potato [15].

The results in Table 2 for vitamin C indicate that baobab pulp is the most important source, with an average content of 301 mg/100 g DM. This result is consistent with the existing literature, which indicates that baobab pulp is a rich source of vitamin C [5,20]. The vitamin C content of 25.3 mg/100 g DM obtained from carrots is relatively low in comparison to the data presented in the literature [18], which could be attributed to the blanching treatment applied to the carrots in this study. Vitamin C is a thermolabile vitamin, and therefore susceptible to destruction by heat treatments exceeding 55°C [42,43]. It can be reasonably deduced that the application of blanching at 95°C for 10 mins would have resulted in a reduction of the vitamin C content of the carrot.

**Table 2.** Physicochemical composition of untreated and treated raw materials (for 100g DM)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | Untreated potato | Treated  Potato\* | Untreated sesame | Treated sesame+ | Carrot° | Moringa leaves | Baobab  pulp |
| Moisture content (%) | 4.14±0.15a | 4.90±0.31d | 5.07±0.15e | 4.33±0.03b | 4.50±0.14c | 4.13±0.19a | 7.91±0.29f |
| Total ash (%) | 3.65±0.06b | 3.17 ± 0.01a | 3.95±0.041c | 4.83±0.08d | 7.7±0.11e | 9.56±0.04g | 8.17±0.16f |
| Total carbohydrate (g) | 67.52±1.47e | 73.37±2.53f | 4.61±0.07b | 2.59±0.03a | 34.46±0.21d | 25.66±0.53c | 56.25±0.13g |
| Soluble sugar (g) | 10.24±0.88e | 43.49 ± 0.74g | 0.55±0.01a | 1.1±0.52b | 6.37±0.15d | 4.77±0.05c | 11.81±0.12f |
| Crude fat (g) | 3.09 ± 0.56b | 3.61± 0.89b | 52.18±0.93d | 47.23±0.11c | 2.2±0.30a | 3.65±0.32b | 1.7±0.28a |
| Crude protein (g) | 4.67 ± 0.12b | 5.33±0.28c | 20.35±0.15d | 24.09±0.02e | 3.9±0.01a | 20.99±0.02d | 4.72±0.27b |
| Crude fiber (g) | 7.54±0.05d | 4.34±0.05b | 4.50±0.05c | 4.03±0.035a | 12.93±0.41f | 9.63±0.05e | 7.42±0.09d |
| Iron (mg) | 0.78±0.02a | 0.81±0.05a | 4.30±0.09b | 8.5±0.07d | 5.7±0.02c | 24.66±0.28f | 12.3±0.13e |
| Calcium (mg) | 22.6±0.64a | 23.80±0.88a | 1180±0.13d | 1297±0.48f | 210.54±0.03b | 1213±0.34e | 539.4±0.38c |
| Zinc (mg) | 0.59±0.05a | 0.69±0.06a | 1.93±0.02b | 3.15±0.20c | 3.07±0.03c | 3.98±0.05d | 7.61±0.04e |
| Vitamin C (mg) | 11.83±0.35e | 8.35±0.50d | 6.57±0.55b | 2.57±0.73a | 25.3±0.65f | 7.30±0.97c | 301.99±0.55g |
| Vitamin A (µg RE) | 605.31±9.07f | 572±10.21e | 9.67±0.18c | 9.29±0.31b | 1725.7±15.51g | 113.1±0.014d | 5.70±0.02a |

\*cooked and fermented; + Soaked and germinated; ° Steam blanched; Values in the same line with different superscript letters differ significantly (p < 0.05).

## **Nutritional content of flour**

Table 3 presents the nutritional composition of the formulated flour samples. The water content of all samples is in close alignment with the 5% recommended for infant flours, with a range of 5.01% for FM4 to 5.98% for FM1. This low water content confers an advantage upon the flours produced. Indeed, the storage of a product is contingent upon its water content, which serves to regulate the activity of enzymes and microorganisms. A low water content has the effect of slowing down the metabolic processes and inhibiting microbial growth and proliferation, which in turn results in a longer product shelf life [29]. In light of the aforementioned arguments, it can be posited that the flours produced are suitable for preservation. Similar outcomes have been observed with a range of complementary floors formulated from starch matrices including plantain, pumpkin, and maize [5,11,13].

Furthermore, the ash content of all flours produced complies with the standards indicated for this type of food product, with an ash content >2% for all the samples. The ash content of the samples demonstrates a notable decline from FM1 (3.87%) to FM4 (2.72%). This reduction can be attributed to the decrease in the proportion of fruit and vegetables (moringa leaves, baobab pulp, and carrot) from 30% in FM1 to 25% in FM4, as results in Table 2 show that carrot, moringa leaves and baobab pulp have the highest level of ash content. This result is analogous to that reported by Tedom *et al*. [11], who observed a decline in ash content with the reduction in the quantity of spinach leaves in the formulation of complementary flours. Given that a high ash content is typically indicative of the mineral richness of a feed [44], FM1 flour can be considered the richest in minerals.

Table 3 also demonstrates that, with a total sugar content between 65 and 68%, all the flours formulated satisfied the WFP standard. However, there was a notable increase in the total sugar content from FM1 (65.7%) to FM4 (67.1%), which can be attributed to the variation in the amount of sweet potato used during the formulation process as it arises from Table 2 that sweet potato is the main source of carbohydrate. FM4 flour exhibited the highest proportion of sweet potato (55%), contributing to this observed increase. Furthermore, several studies on the formulation of complementary foods have also reported an increase in total sugar content with increasing starch matrix [5,13].

The soluble sugar content of the formulated flours exhibited a range from 38.83% for FM1 to 39.63% for FM4. Nevertheless, it is of greater significance to ascertain the ratio of soluble sugar to the total sugar content of the flour. This ratio is about 0.59 for the four formulated flours, lower than 0.87 obtained for fermented melon-based foods [10,11], and 0.61 obtained for malted maize-based flour [5]. These results indicate that the fermentation time could perhaps have been increased to further hydrolyse the potato polysaccharides in the present study. Nevertheless, given that fermentation products include organic acids that may result in a more acidic product with potentially adverse effects on organoleptic quality, it would be preferable to determine the optimal conditions for fermenting sweet potato with *L. plantarum* for use in toddler formulations.

The protein content of the formulated flours exhibits a range from 10.77% for FM1 to 14.06% for FM4, with an observed increase in proportion to the inclusion of sesame, the main source of protein in the formulations (See Table 2). These protein contents are noteworthy in that they fall within the 8-16% range recommended by the WFP for toddler flours. These findings are consistent with those of previous studies on infant formulations that have employed sesame and other legumes, including soybean and cashew almonds to produce flours that meet the established protein content standards [5,11,13].

The lipid content of the flours exhibited a range from 9.64% for FM1 to 11.09% for FM4, which can be attributed to the proportion of sesame in the flours. Indeed, the results of the raw material characterisation demonstrated that sesame seeds constituted the primary source of lipids among the ingredients employed (see Table 2). The lipid contents obtained are in close alignment with the standards indicated for young infant flours [28], and are also comparable to those reported by other authors who have employed sesame and other legumes in the formulation of complementary foods [5,11,13,45].

The fibre content of the flours produced is in close alignment with the recommended range for infant flours. The fibre content decreases progressively from FM1 to FM4, corresponding to the lower proportion of Moringa leaves in the formulations and also to the low proportion of baobab pulp. This is because the characterisation of the raw materials showed that these two ingredients were the richest in fibre (see Table 2). These findings align with those of Tedom *et al*. [11] and Ngaha *et al*. [5], who observed a decrease in fibre content in infant foods as the proportion of spinach (leafy vegetable) decreased. The presence of sufficient quantities of fibre in the diet is essential, as the influence of fibre intake on the intestinal microbiome, metabolic diseases (obesity and diabetes), neurological aspects, cardiovascular diseases, autoimmune diseases, and cancer prevention has been demonstrated [46]. However, excessive consumption of fibre can impede the absorption of fat-soluble vitamins by forming complexes with bile acids, which are essential for the digestion and absorption of fats and fat-soluble compounds [40].

The content of some minerals and vitamins in the formulated flours was also evaluated, and the results are presented in Table 3. The results demonstrate that, except for the iron content of the flours which fell below the established norm, all other quantified minerals and vitamins were following the WFP recommendations.

The low iron content of the flours (5.99 to 6.69 mg/100 g) can be attributed to the low quantities of Moringa leaves (5.5 to 8.5%) and baobab pulp (1.5%) which are the main sources of iron as recorded in Table 2. Indeed, preliminary sensory tests demonstrated that an elevated incorporation of Moringa leaves resulted in a pronounced green colouration of the flours, whereas an elevated incorporation of baobab pulp imparted a more acidic taste, leading to rejection by panelists. However, these values are higher than the average iron content of 5 mg/100g reported for flour with baobab pulp as an iron source [5]. This discrepancy may be explained by the fact that in the present work, baobab pulp was not the sole iron source, but was associated with Moringa leaves. However, these values are lower than the 10 mg/100 g iron content reported for a puree with spinach leaves as the iron source [10]. This discrepancy can be attributed to two factors: firstly, spinach leaves are richer in iron than Moringa leaves and baobab pulp used in this study; secondly, a proportion of 10% spinach leaves was used in the production of the puree, compared with 5.5-8.5% moringa leaves and 1.5% baobab pulp in the present study.

The calcium content of formulated flours is worthy of note, with values reaching 301 mg/100 g of flour. Calcium is a mineral that plays an essential role in the growth and development of young children, particularly in the formation, development, and maintenance of bones and teeth. The findings indicated that FM4 exhibited the highest calcium content, which can be attributed to its higher proportion of processed sesame which exhibited the highest calcium content (See Table 2). Indeed, the characterisation of the raw materials revealed that the processed sesame seeds were the ingredient with the highest calcium content. The maximum calcium content obtained in this study (301.1 mg/100 g) is higher than that reported in previous work on an infant flour fortified with baobab (182 mg/100 g) [5]. This discrepancy can be attributed to the type of fortifier employed. Indeed, the sesame used in the present study is approximately 2.5 times richer in calcium than baobab pulp (see Table 2).

The zinc levels observed ranged from 3.85 to 4.51 mg/100 g of flour, which is close to the 4.2-14 mg/100 g range indicated by WFP. These findings suggest that when consumed regularly, formulated flours, particularly FM1 and FM2, can provide young children with an adequate intake of zinc to bolster their immune system, engage in antioxidant processes (zinc is a crucial cofactor in metabolic reactions), facilitate cell synthesis for growth, and prevent and manage diarrhoea [47].

The vitamin C content of formulations ranges from 30.25 to 31.16 mg/100 g of flour, which falls within the 30-60 mg range recommended for infant flours. This constitutes a significant advantage for formulated flours, given the importance of vitamin C in human nutrition. In addition to its antioxidant properties, vitamin C (ascorbic acid) facilitates the conversion of non-heme iron (Fe³⁺) into iron (Fe²⁺), which is more readily and rapidly absorbed in the small intestine [21,48].

With regard to vitamin A, the four flours produced were found to meet the WFP recommendations, with levels ranging from 770 to 970 µg RE/ 100 g of flour. This content declines in a stepwise manner from FM1 to FM4, a consequence of the diminished proportion of carrots in the blends. Nevertheless, despite the reduction in the proportion of carrots, the results in Table 2 indicate that orange-fleshed sweet potato is also a valuable source of provitamin A. This may explain why the vitamin A level of the FM4 formulation remains aligned with the standard, despite the decline in the contribution of carrot. The flours produced are rich in vitamin A, which may confer benefits for vision (retinal), protein synthesis, and cell differentiation, thereby maintaining the health of epithelial tissues and the skin (retinoic acid), and supporting growth [49]. Indeed, children suffering from vitamin A deficiency are prone to stunted growth [50]. The results demonstrate that the vitamin A content of the formulated flours is higher than the average contents of 240 and 340 µg/100 g respectively obtained with plantain, sesame, cashew nut, and soy [13], and with maize, cashew nut and baobab pulp [5]. Conversely, it is less than the mean of 2000 µg/100 g derived from melon, spinach leaves and soybeans [11]. This discrepancy may be attributed to the differing sources of vitamin A employed in the various studies.

**Table 3.** Nutritional composition of the formulated flours (For 100 g of flour)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Components | FM1 | FM2 | FM3 | FM4 | Standard\* |
| Moisture content (%) | 5.98±0.40b | 5.71±0.42ab | 5.72±0.38ab | 5.01±0.41a | <5 |
| Total ash (%) | 3.87±0.03d | 3.78±0.02c | 3.12±0.08b | 2.72±0.05a | >2 |
| Total carbohydrate (%) | 65.73±1.15a | 66.02±0.65b | 66.97±0.82b | 67.10±0.67c | 65-68 |
| Soluble sugar (%) | 38.83±0.68a | 38.95±0.38a | 39.49±0.48ab | 39.63±0.40b | - |
| Crude protein (%) | 10.77±0.41a | 12.6±0.39b | 13.34±0.43c | 14.06±0.51d | 8-16 |
| Crude fat (%) | 9.64±0.26a | 10.25±0.30b | 10.63±0.45bc | 11.09±0.51c | 9-10 |
| Crude fiber (%) | 4.94±0.51b | 4.46±0.37b | 4.09±0.53ab | 3.77±0.36a | <3 |
| Iron (mg) | 6.69±0.09c | 6.22±0.10b | 6.09±0.08ab | 5.99±0.11a | 11.6-23 |
| Calcium (mg) | 250.43±3.06a | 279.66±4.12b | 288.02±5.03c | 301.1±3.11d | 260-420 |
| Zinc (mg) | 4.51±0.21b | 4.13±0.14a | 4.02±0.23a | 3.85±0.19a | 4.2-14 |
| Vitamin C (mg) | 31.16±0.70a | 30.93±0.61a | 30.61±0.44a | 30.25±0.57a | 30-60 |
| Vitamin A (mg RE) | 0.97±0.11a | 0.93±0.12a | 0.84±0.10a | 0.77±0.16a | 0.3-1.25 |

\* Acceptable levels of the nutritional components recommended by World Food Program for infant flours [28]; FM1: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (47.5/17.5/25/8.5/1.5); FM2: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (51/19/21.5/7/1.5); FM3: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (52/19.5/20.5/6.5/1.5); FM4: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (55/20/18/5.5/1.5); Values in the same line with different superscript letters differ significantly (p < 0.05).

## Microbial quality of flour

The microbial quality of the flours produced was evaluated, and the findings are presented in Table 4. The results demonstrate the absence of faecal coliforms, *Escherichia coli*, yeasts, moulds, and salmonella. Similarly, the number of aerobic mesophilic bacteria in the formulated flours was found to be below the standard set for pre-cooked infant foods [51]. This outcome may be attributed to the thermal treatments applied to the raw materials, which have effectively reduced the number of microorganisms that are likely to proliferate. This outcome is also indicative of the adherence to hygiene protocols throughout the production process, thereby ensuring that these flours are fit for consumption without any risk of microbial contamination.

**Table 4.** Microbial characteristics of formulated flours

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Germs (UFC/g) | FM1 | FM2 | FM3 | FM4 | Norms |
| MAB | 88 | 70 | 105 | 95 | <104 |
| Faecal coliforms | 0 | 0 | 0 | 0 | <20 |
| *Escherichia coli* | 0 | 0 | 0 | 0 | <2 |
| Yeast and moulds | 0 | 0 | 0 | 0 | Non precise |
| *Salmonellas* | 0 | 0 | 0 | 0 | Absent in 25 g of finished product |

FM1: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (47.5/17.5/25/8.5/1.5); FM2: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (51/19/21.5/7/1.5); FM3: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (52/19.5/20.5/6.5/1.5); FM4: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (55/20/18/5.5/1.5); MAB: Mesophilic Aerobic Bacteria.

## Functional and caloric characteristics of flour and gruels

Table 5 presents the functional and energy characteristics of the flours formulated and the gruels prepared from them. The results demonstrate that there was no statistically significant difference (p>0.05) between the various parameters evaluated for all flour and powder samples. In terms of water absorption capacity, the formulated flours demonstrated the ability to absorb three times their weight. This phenomenon can be attributed to the pre-gelatinisation of the sweet potato, a principal component of the formulated flour. During this process, amylose and amylopectin, the constituents of starch, are released, thereby enhancing the flour's capacity to bind water [52]. This result is consistent with the findings of numerous studies on infant flour formulations with starchy matrices [5,11,13]. The high water absorption capacity may also be attributed to the presence of proteins derived from sesame and Moringa leaves in the formulated flours. Indeed, the presence of proteins, particularly hydrophilic proteins, in food matrices has been demonstrated to enhance their capacity to absorb water [53].

Furthermore, the flours display noteworthy solubility indices and bulk density, aligning with the findings of numerous preceding studies [5,11,13]. The bulk density of the four formulated flours, which range between 0.51 and 0.55, indicate that they are densely packed, thereby making them nutrient-dense. This is due to their capacity to concentrate in a limited volume [54].

The energy value of formulated flours falls within the range of 403.73 to 417.25 kcal/100 g, which aligns with the recommendations set forth by WFP (400-420 kcal/100 g as the optimal energy value for infant flours). This also applies to the energy density of gruels prepared from produced flours which lies between 99.99 and 108 kcal/100 ml, falling within the 80-120 kcal/100 ml range recommended. These findings are consistent with those of multiple studies on infant formulations [5,11,13] and indicate that the gruels prepared can provide an adequate quantity of energy to meet the toddler’s needs.

With regard to the viscosity of the gruels, the range is from 2504 mPa.s for FM1 to 2590 mPa.s for FM4. These values fall within the reference range of 2500-3500 mPa.s, which is recommended for infant foods [55], and suggest that the gruels can be easily swallowed by the intended young consumers. Furthermore, a combination of low viscosity and high energy density is an important factor in ensuring that children consume sufficient calories. These findings are consistent with those of previous studies, which also demonstrated viscosities that met the recommended standards for infant porridges [5,11]. However, these outcomes differ from those of Ngaha *et al*. [13], who obtained viscosity ranging from 4222 to 4840 mPa.s for porridges prepared from plantain flour. This discrepancy can be attributed to the fact that in the study conducted by Ngaha et al. [13], the plantain was not subjected to any processing, whereas in the present study, the sweet potato underwent fermentation by the bacterial strain *L. plantarum*. Indeed, it has been demonstrated that during fermentation by *L. plantarum*, partial hydrolysis of polysaccharides (starch and fibre) occurs, resulting in the production of soluble sugars reducing significantly the viscosity of slurries [11,16].

**Tableau 5.** Functional and energetic characteristics of formulated flours and prepared gruels

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Formulated flours** | | | | |
| Parameters | FM1 | FM2 | FM3 | FM4 |
| aWAC (%) | 293.48± 9.08a | 295.51±8.82a | 298.24±9.16a | 299.72±8.17a |
| rWAC (%) | 343.97±8.76a | 346.67±8.53a | 348.94±8.61a | 349.24±9.36a |
| WSI (%) | 7.54±0.20a | 7.57±0.19a | 7.60±0.23a | 7.64±0.21a |
| Bulk density (%) | 0.51±0.06a | 0.53±0.05a | 0.54±0.07a | 0.55±0.06a |
| Energy value (kcal/100 g)\* | 403.73±10.15a | 408.99±11.03a | 410,88±11.22a | 417.25±12.10a |
| **Prepared gruels** | | | | |
|  | FM1 | FM2 | FM3 | FM4 |
| Viscosity (mPa.s) | 2534.00±18.32a | 2549.50±13.44a | 2553.00±15.55a | 2570.00±17.32a |
| Energy density (kcal/100 ml)\*\* | 99.99± 8.32a | 103.75± 9.02a | 104.50± 7.53a | 108.00± 5.02a |

\*Standard: 400-420 kcal/100 g; \*\*Standard 80-120 kcal/100 mL; FM1: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (47.5/17.5/25/8.5/1.5); FM2: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (51/19/21.5/7/1.5); FM3: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (52/19.5/20.5/6.5/1.5); FM4: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (55/20/18/5.5/1.5); Values in the same line with different superscript letters differ significantly (p < 0.05). WAC: Water Absorption Capacity; a: apparent; r: real; WSI: Water Solubility Index; BD: Bulk Density.

## Sensory characteristics of gruels

While the nutritional value of food products is undoubtedly a crucial factor in consumer health, it is equally important to consider their organoleptic characteristics, including colour, flavour, aroma, mouthfeel, viscosity, and general acceptability. These attributes significantly influence consumer purchasing decisions, with positive organoleptic characteristics increasing the likelihood of a consumer purchasing a product again. To achieve this objective, Table 6 presents the results of the hedonic test conducted on gruels prepared from formulated flours and an imported commercial flour that was used as a control.

The results demonstrate that the flavour, viscosity, and aroma of all prepared gruels were deemed favourable by the mothers on the panel, as these attributes achieved a rating of 6 or above on a scale of 9 for all the gruels. In contrast, the mouthfeel was deemed satisfactory by only two of the gruels FM3 and FM1, while the colour was rated poorly for all of the samples. Ultimately, in terms of general acceptability, the flour formulated with FM3 was the most highly rated of the four.

The elevated scores assigned to flavour and aroma can be attributed to the fermentation process applied to sweet potatoes. Indeed, studies have demonstrated that during the fermentation process, chemical compounds such as those responsible for developing new flavours and aromas are produced, thereby enhancing the organoleptic quality of fermented products [56,57]. Furthermore, the fermentation process, carried out by *L. planctarum*, an amylolytic bacterium, results in the hydrolysis of polysaccharides to produce soluble sugars [16], reducing significantly the viscosity, and therefore improving the mouthfeel of gruels.

It is noteworthy that the four formulated flours obtained exhibited significantly lower scores (p < 0.05) for all sensory parameters when compared to the commercial flour used as a control. This result is analogous to that obtained by Tedom *et al.* [11], indicating the necessity to enhance the organoleptic attributes of formulated flours, as they exert a pivotal influence on mothers' decisions to purchase complementary foods and in children's consumption.

**Table 6.** Sensory characteristics of gruels prepared from formulated flours

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Gruels | Colour | Flavour | Viscosity | Aroma | Mouthfeel | Overall acceptance |
| FM1 | 4.98±0.75a | 6.64±0.92a | 6.55±0.69a | 6.74±0.79a | 6.46±0.34b | 6.53±0.56a |
| FM2 | 4.74±0.71a | 6.23±0.91a | 6.82±0.40a | 6.27±0.62a | 5.91±0.30a | 5.77±0.83a |
| FM3 | 5.56±0.81a | 6.58±0.77a | 7.82±0.75ab | 6.95±0.89a | 7.09±0.45b | 6.90±0.67a |
| FM4 | 4.29±0.83a | 7.55±0.69ab | 6.73±0.91a | 6.84±0.76a | 5.73±0.37a | 6.16±0.69a |
| Control | 8.39±0.43b | 8.51±0.32b | 8.70±0.43b | 8.87±0.22b | 8.82±0.23c | 8.35±0.13b |

FM1: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (47.5/17.5/25/8.5/1.5); FM2: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (51/19/21.5/7/1.5); FM3: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (52/19.5/20.5/6.5/1.5); FM4: Sweet potato/Sesame/Carrot/Moringa leaves/Baobab pulp (55/20/18/5.5/1.5); Values in the same column with different superscript letters differ significantly (p < 0.05).

# Conclusion

Upon completion of this process, blends of orange sweet potato, sesame seed, carrot, Moringa leaves and baobab pulp were produced, resulting in four complementary flours with favorable nutritional and functional characteristics rendering them suitable for the preparation of gruels for young children. Concerning their energy value, protein content, mineral (except iron) and vitamin composition, these flours meet the criteria set out by the WFP. The gruels prepared from these flours exhibit a satisfactory energy density and viscosity. The most appreciated formulation among the produced flours is FM3 with 52% cooked and fermented sweet potato, 19.5% soaked and germinated sesame, 20.5% steam-blanched carrot, 6.5% steam blanched moringa leaves, and 1.5% baobab pulp. Nevertheless, the low score obtained in the sensory assessment, particularly concerning colour and mouthfeel attributes, highlights the necessity for enhancements to be made to their organoleptic properties, maybe by altering the proportions of ingredients or exploring processing modifications. Furthermore, the low iron levels observed in all the formulated flours indicate the necessity for fortification with another iron source such as sweet potato leaves or micronutrient mixes. It will also be judicious to assess the *in vivo* digestibility of the formulated flours and their pasting properties to provide some relevant information on the cooking behaviours. This result could contribute to alleviating protein-energy malnutrition and micronutrient deficiency in Cameroon and other developing countries, as the food material used is locally available and the technology may be transferred to the population.

**Ethical statement and consent**

The study was conducted following the ethical standards outlined in the Declaration of Helsinki, and all the procedures involving human subjects were approved by the ethical clearance certificate number 28 - / 2024 delivered by the ethics committee of the postdoctoral training unit in food science and nutrition of the University of Ngaoundere. As the food materials used in the study were already known and consumed by the participants, informed consent was obtained from them orally for the sensory assessment. The verbal consent was witnessed and formally recorded. The anonymity of the participants was assured, as was the confidentiality of the data collected. Furthermore, measures were implemented to guarantee that all participants were free from illness and allergic to the foodstuffs utilized in the formulations.

**CRediT authorship contribution statement**

**Waha Nouwe Lyzette Aurelie:** Investigation, Methodology, Formal analysis, Data curation. **Ngaha Damndja Wilfred:** Conceptualization, Supervision, Resources, Methodology, Software, Writing – review & editing. **Agume Ntso Aurelie Solange:** Resources, Software, Data curation, Writing – original draft. **Ejoh Aba Richard:** Conceptualization, Supervision, Validation

**Declaration of competing interest**

The authors declare that there is no conflict of interest.

**Data availability**

Data will be made available on request

# References

[1] World Health Organization (WHO), Infant Physiological Development and its Implications for Complementary Feeding. In: Geneva: The WHO Scientific Journal (2020) 111p.

[2] World Food Programme (WFP), Nutrition Research Review 22 (2022) 193-220.

[3] World Health Organization (WHO), Guiding Principles for Feeding Non-Breastfed Children 6-24 Months of Age. WHO Press. Geneva, Switzerland (2019) 1-42.

[4] K. Brou, E.J. Kouadio, E.A. Due, S.K. Kouame, K. Tano, G. Dago, Effects of processing method and blend on some physicochemical properties and digestibility of flours made from selected cereals and legumes, Int. J. Biol. Chem. Sci. 3 (2009) (5) 1151-1160.

[5] W.D. Ngaha, A.S.N. Agume, T.J.M. Ngatchic, H.N. Djello, Physicochemical, Functional, Microbial, and Sensory Characteristics of Precooked Complementary Flour Produced from Yellow Maize Enriched with Roasted Cashew Almonds and Baobab Pulp, Journal of Food Quality (2024) 1579963, 10 p https://doi.org/10.1155/2024/1579963

[6] S. Lisciani, S. Marconi, C. Le Donne, E. Camilli, A. Aguzzi, P. Gabrielli, M. Ferrari, (2024). Legumes and common beans in sustainable diets: nutritional quality, environmental benefits, spread and use in food preparations, Frontiers in Nutrition 11 (2024) 1385232.

[7] W.D. Ngaha, R.A. Ejoh, E.N. Fombang, W.D. Tedom, (2020). Nutritional quality of formulated complementary foods and their biological effects for tackling malnutrition in Sub-Saharan Africa (SSA) countries, European Journal of Nutrition and Food Safety 12 (2020) (12) 91-103. https://doi.org/10.9734/EJNFS/2020/v12i1230339.

[8] J. Sánchez-García, S. Muñoz-Pina, J. García-Hernández, A. Tárrega, A. Heredia, A. Andrés, Protein digestibility and ACE inhibitory activity of fermented flours in older adults and standard gastrointestinal simulation, Food Research International 180 (2024) 114080.

[9] H.N. Moyo, The Impact of Food Processing Techniques on Nutrient Retention and Bioavailability, IRE Journals 8 (2024) (2).

[10] W.D. Ngaha, J.A.A. Assiene, A.S.N Agume, W.D. Tedom, R.A. Ejoh, Nutritional, functional and sensory characteristics of an infant puree food from pre-treated pumpkin flesh (Curcubita pepo L.), soybean (Glycine max L.) and spinach leaves (Spinacia oleracea), Journal of Agriculture and Food Research 16 (2024) 101183 https://doi.org/10.1016/j.jafr.2024.101183.

[11] W.D. Tedom, W.D. Ngaha, A.S.N. Agume, R.A. Ejoh, Formulation of complementary flours from pretreated pumpkin pulp, soybeans and spinach leaves: Nutritional, functional and sensory characterization, Heliyon. 10 (2024) e37604 https://doi.org/10.1016/j.heliyon.2024.e37604.

[12] D.V. Harouna, Y. Vandi, N.M. Caris, Formulation and Evaluation of Complementary Foods for Children from Six to Twenty-four Months Prepared from Potential Locally Available Foodstuffs in Tubah Sub Division of Cameroon, Food Science & Nutrition Technology, 8 (2023) (3) 1-9 https://doi.org/10.23880/fsnt-16000302.

[13] W.D. Ngaha, E.S. Ngangoum, C. Saidou, S. Mohamadou, Formulation of three infant foods from plantain flour fortified with sesame (Sesamum indicum), Soya bean (Glycine max) and Cashew nut (Anacardium occidentale L.), Food Chemistry Advances, 3(2023) 4-6 https://doi.org/10.1016/j.focha.2023.100313.

[14] AGRI-STAT N0 009, Yearbook of agricultural sector statistics, 2012/2016 campaign, Publication of the agricultural studies and projects division: survey and statistics units, Yaoundé, Cameroon (2017). [15] D. Abewoy, H.G. Megersa, D.T. Banjaw, D.T. Lemma, Major Nutritional Content of Orange Fleshed Sweet Potato (OFSP) and Its Importance, Global Academic Journal of Agriculture and Biosciences, 6(2024) 1-7. https://doi.org/10.36348/gajab.2024.v06i01.001.

[16] W.D. Tedom, E.D. Fombang, W.D. Ngaha, R.A. Ejoh, Optimal conditions for production of fermented flour from pumpkin (Cucurbita pepo L.) for infant foods, European Journal of Nutrition and Food Safety, 10(2019) (2) 125-136. https://doi.org/10.9734/EJNFS/2019/v10i230105.

[17] N.B. Thatwale, Y.R. Patil, S.A. Alde, Sesame (Sesamum indicum L.): a review of nutritional value, phytochemical composition, and health benefits, World Journal of Pharmaceutical Research, 13(2024) (12) 1167-1176.

[18] G.S. Nagraj, S. Jaiswal, N. Harper, A.K. Jaiswal, Carrot. Nutritional Composition and Antioxidant Properties of Fruits and Vegetables, (2020) 323-337.

[19] N. Basuray, E.C. Deehan, F.T. Vieira, H.M. Avedzi, R.L. Duke, E. Colín-Ramírez, ..., A.M. Haqq, Dichotomous effect of dietary fiber in pediatrics: a narrative review of the health benefits and tolerance of fiber, European Journal of Clinical Nutrition, (2024) 1-12.

[20] B. Stadlmayr, J. Wanangwe, C.G. Waruhiu, R. Jamnadass, K. Kehlenbeck, Nutritional composition of baobab (Adansonia digitata L.) fruit pulp sampled at different geographical locations in Kenya, Journal of Food Composition and Analysis, 94(2020) 103617.

[21] S. Ramachandran, R. Manthena, C. Gopi, M.D. Dhanaraju, Enhancement of non-heme iron absorption from vegetable foods by using Vitamin-C supplements in Wistar rats, Research Journal of Pharmacy and Technology, 17(2024) (5) 2224-2228.

[22] E.P. Masitlha, E. Seifu, D. Teketay, Nutritional composition and mineral profile of leaves of Moringa oleifera provenances grown in Gaborone, Botswana, Food Production, Processing and Nutrition, 6(2024) (1) 3.

[23] A.M. Putri, I. Rosidah, S.A. Amelia, L.F. Feriska, R.H.U. Puspitasari, Strategy to increase the economic value: the potential of Moringa oleifera leaf powder, In Faculty of Economics and Business International Conference (FEBIC), (2024) 18-23.

[24] W.D. Tedom, E.N. Fombang, R.A. Ejoh, W.D. Ngaha, Optimal conditions of steam blanching of spinach (Spinacia oleracea), a leafy vegetable consumed in Cameroon, International Journal of Nutritional Science and Food Technology, 6(2020) (4).

[25] Y. Jiokap, C. Maka, F. Abunde, C. Kapseu, Multi-response optimization of the energy value and rheological parameters in the formulation of a complementary flour for infant porridge, African Journal of Food Sciences 11(2017) (8) 278-290.

[26] H. Cowling, E. Miller, Determination of small amounts of zinc in plant materials-A photometric Dithizone method, Industrial & Engineering Chemistry Analytical Edition, 13(1941) (3) 145-149. [27] T.L. Da Silva, E. Aguiar-Oliveira, M. Mazalli, E. Kamimura, R. Maldonado, Comparison between titrimetric and spectrophotometric methods for quantification of vitamin C, Food Chemistry, 224(2017) 92-96.

[28] World Food Program (WFP), World Food Programme (WFP) Strategic Plan 2017–2021, Second Regular Session of the Executive Board, Rome, 52 (2017).

[29] A.A. D’Souza, D. Kumari, R. Banerjee, (2017). Nanocomposite biosensors for point-of-care evaluation of food quality and safety. In A. M. Grumezescu (Ed.), Nanobiosensors (2017) 629-676. Academic Press. https://doi.org/10.1016/B978-0-12-804301-1.00015-1.

[30] W.D. Ngaha, W. Tchabo, R.S. Matsinkou, L.K. Nyame, E.N. Fombang, Formulation of low glycaemic index biscuits suitable for diabetics from unripe banana, okra, and stevia leaves/jujube fruit, Food Production, Processing and Nutrition, (2023) 5:32 https://doi.org/10.1186/s43014-023-00148-x.

[31] M.A. Valdez-Solana, V.Y. Mejía-García, A. Téllez-Valencia, G. García-Arenas, J. Salas-Pacheco, J.J. Alba-Romero, E. Sierra-Campos, Nutritional content and elemental and phytochemical analyzes of Moringa oleifera grown in Mexico, J. Chem., (2015) 860381.

[34] A.J.A. Assiene, E.N. Fombang, C.M. Mbofung, In vitro protein digestibility and iron bioavailability according to agro-ecological zone and stage of maturity of Moringa oleifera Lam leaves, European Journal of Nutrition and Food Safety, 12(2020) (11) 90-103.

[40] V.K. Maurya, J. Singh, V. Ranjan, K.M. Gothandam, T. Bohn, S. Pareek, Factors affecting the fate of β-carotene in the human gastrointestinal tract: a narrative review, Int. J. Vitam. Nutr. Res., 92 (2022) 385-405 https://doi.org/10.1024/0300-9831/a000674.

[41] S.D. Gomes, C.S. Oliveira, J. Azevedo-Silva, M.R. Casanova, J. Barreto, H. Pereira, ... A. Preto, The role of diet-related short-chain fatty acids in colorectal cancer metabolism and survival: prevention and therapeutic implications, Current medicinal chemistry, 27(2020) (24) 4087-4108.

[42] M.I. Hussain, A. Hamza, M.A. Rashid, Estimation of vitamin C in carrot before cooking and after cooking, Journal of Food and Nutrition Sciences, 4(2016) (4) 108-112 https://doi.org/10.11648/j.jfns.20160404.16.

[43] A. Mditshwa, L.S. Magwaza, S.Z. Tesfay, U.L. Opara, Postharvest factors affecting vitamin C content of citrus fruits: A review, Scientia Horticulturae, 218(2017) 95-104.

[44] P.T. Nurhaliza, L.L. Masniary, Z. Lubis, Effect of Kweni mango juice addition and percentage of carboxymethyl cellulose (CMC) on the physicochemical characteristics of watermelon albedo fruitghurt, E3s Web of Conferences, 332(2021) 08002, https://doi.org/10.1051/E3sconf/202133208002.

[45] T.G. Yohannes, A.O. Makokha, J.K. Okoth, M.W Tenagashaw, Developing and nutritional quality evaluation of complementary diets produced from selected cereals and legumes cultivated in Gondar province, Ethiopia, Current Research in Nutrition and Food Science Journal, 8(2020) (1), 291-302.

[46] C.B. Ioniță-Mîndrican, K. Ziani, M. Mititelu, E. Oprea, S.M. Neacșu, E. Moroșan, ... C. Negrei, Therapeutic benefits and dietary restrictions of fiber intake: A state of the art review, Nutrients, 14(2022) (13), 2641.

[47] C.T. Chasapis, P.S.A. Ntoupa, C.A. Spiliopoulou, M.E. Stefanidou, Recent aspects of the effects of zinc on human health, Archives of toxicology, 94(2020) 1443-1460.

[48] A.C. Carr, S. Maggini, Vitamin C, and immune function. Nutrients, 9(2017) (11) 1211.

[49] M.S. Menezes, C.M. Almeida, Structural, functional, nutritional and clinical aspects of vitamin A: a review Pharma Nutrition, (2024) 100383.

[50] E.M. Wiseman, S. Bar-El Dadon, R. Reifen, The vicious cycle of vitamin a deficiency: A review, Critical Reviews in Food Science and Nutrition, 57(2017) (17) 3703-3714 https://doi.org/10.1080/10408398.2016.1160362.

[51] A. Ballata, A. Shtembari, Study of microbiological quality of different varieties of wheat for processing flour, International Journal of Ecosystems & Ecology Sciences, 13(2023) (2).

[52] C. Li, S. Dhital, R.G. Gilbert, M.J. Gidley, High-amylose wheat starch: Structural basis for water absorption and pasting properties, Carbohydrate polymers, 245(2020) 116557.

[53] A. Heddam, N. Kaci Aissa, Manufacturing process, evaluation of the technological quality of soft wheat flours and trial of the development of a dietetic bran bread, Doctoral dissertation, Mouloud Mammeri University (2021).

[54] S.M. El-Sayed, Use of spinach powder as a functional ingredient in the manufacture of UF-Soft cheese, Heliyon, 6 (2020) 1, https://doi.org/10.1016/j.heliyon.2020.e03278.

[55] Codex, Alimentarius (2019). Codex standard for processed cereal-based foods for infants and children. CXS 74-1981, Adopted in 1981. Revised in 2006. Amended in 2017, 4 (2019).

[56] M. Verni, E. Pontonio, M. Montemurro, C. Giuseppe Rizzello, Fermentation as strategy for improving nutritional, functional, technological, and sensory properties of vegetables. In Vegetables Research, 2(2022).

[57] D. Senanayake, P.J. Torley, J. Chandrapala, N.S. Terefe, Microbial fermentation for improving the sensory, nutritional and functional attributes of vegetables, Fermentation, 9(2023) (7) 635.