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Phytochemical Composition and Functional Properties of Millet (*Pennisetum glaucum*) Flours Fortified with Sesame (*Sesamum indicum*) and *Moringa* (*Moringa oleifera*) as a Weaning Food

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Authors' contributions

This work was carried out in collaboration between all authors. Authors WKD, MBF and LPK designed the study, performed the statistical analysis, wrote the protocol and managed the analyses. Authors WKD, MJG and FMTK wrote the first draft of the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to produce local foods made from millet (*Pennisetum glaucum*) flour weaning food enriched with sesame (*Sesamum indicum*) seed flour and *Moringa* (*Moringa oleifera*) leaf powder to prevent various forms of malnutrition.
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Methodology: Seven weaning food blends were formulated using fermented millet, germinated millet, sesame and *Moringa* in the following proportions: 90-10-0-0 (*Mi100*), 60-10-0-30 (*MiMo*), 60-10-30-0 (*MiS*), 60-10-25-5 (*MiSMo5*), 60-10-20-10 (*MiSMo10*), 60-10-15-15 (*MiSMo15*) and 60-10-10-20 (*MiSMo20*). Standardized methods were adopted for proximate, phytochemical, antioxidant activity and functional properties evaluation of these formulated diets.
Results: A significant difference (P<0.05) was observed between all biochemical properties measured except for the oxalate content of samples. The moisture, ash, protein, fiber, carbohydrate, total phenolic compounds, flavonoid and tannin contents increased significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame in different formulated diets, whereas energy value, fat and phytate contents were found to decrease. The nutritional composition of most formulated foods tested is within the recommended standard for weaning foods. The best antioxidant activity was obtained with the formulated diet fortified with 15% sesame and 15% *Moringa*. Regarding the functional properties, water and oil absorption capacities, foam capacity and dispersibility increased significantly (P<0.05) with *Moringa* incorporation, while bulk density decreased.
Conclusion: The incorporation of sesame and *Moringa* as food supplements provides products with improved nutritional and functional properties, a good source of phytochemicals and a good antioxidant activity, useful for infants.

Keywords: Weaning food blend; Sesamum indicum; Moringa oleifera; nutritional content; functional properties; antioxidant properties.

1. INTRODUCTION

Chronic malnutrition remains a persistent problem for young children in sub-Saharan Africa [1]. Children in developing countries are the most vulnerable and most affected by malnutrition. The World Health Organization (WHO) recommends exclusive breastfeeding for the first six months of life. Then, from 6 months to 2 years of age, the addition of complementary foods (known as complementary weaning foods) is coupled with continuous breastfeeding [2]. During this period, it is necessary to feed the child with liquid or semi-liquid food to complement the mother's milk [3]. These complement foods should bring, in balanced proportion, major nutrients such as proteins, lipids and carbohydrates.

In most parts of Africa, the traditional weaning food which supplements breast-feeding are gruels, watery suspension cereals such as millet, maize, rice, sorghum and other available. Previous studies showed that millet has several potential health benefits, partly attributed to its polyphenol and dietary fiber contents [4]. However, cereals have low quality proteins because of their poverty in some essential amino acids such as lysine and tryptophan [3], which are indispensable for the child growth and contribute to 45% of dietary proteins [1]. In this context, supplementation with grain legumes and leaf powder rich in bio-available nutrients is a promising strategy to address essential nutrients deficiency among the children [5]. High consumption of fruits and vegetables in childhood protect against cancer in adulthood [6]. Moreover, the low intake of fruits and vegetables has as a consequence the increment of childhood obesity [7].

Moringa oleifera, native to India, has become naturalized in the tropic countries and is the most widely cultivated species of a monogeneric family, the Moringaceae [8]. Its leaves, seeds and flowers have good nutritional, therapeutic and prophylactic properties. Some studies have shown that leaves are used to prevent or treat protein-energy malnutrition and other nutritional diseases [8]. *Moringa oleifera* leaves contain low fat and carbohydrate but are an excellent source of vitamins, various antioxidant compounds, proteins and amino acids with all essential amino acids [8], particularly sulphur-containing amino acids (methionine and cystine) which are often in short supply in cereals and other plant-based foods [9].

Sesame (*Sesamum indicum*) belongs to the *Pedaliaceae* family and it is an oldest cultivated plants in several countries such as USA, India, China, Burma, Sudan and Nigeria [10]. Sesame seeds were found to be good sources of edible oil, protein and minerals like potassium, phosphorus, magnesium and calcium [11]. Sesame has been used as food for ages and has been valued as a healthy food additive preventing diseases and promoting well-being. Its nutraceutical uses include cancer prevention (myristic acid), heart disease prevention (fiber), antioxidant activity and hepatoprotective property (lecithin) [10]. In addition, sesame oil contains high levels of unsaturated fatty acids, especially oleic and linoleic acids, which are suitable for the body and without cholesterol [11].

In Côte d'Ivoire, sesame and *Moringa* are available, but adults consume them in traditional form. However, their nutritional potentials could be an asset to fight against malnutrition in Côte d'Ivoire. So, the aim of the present study was to produce a millet flour weaning food enriched with sesame (*S. indicum*) seed flour and *Moringa* (*M. oleifera*) leaf powder. Then, the nutrient composition, phytochemical contents, antioxidant activity and functional properties of this new weaning food were investigated.

2. MATERIALS AND METHODS

2.1 Materials

Seeds of millet (*Pennisetum glaucum*) were purchased from Abobo market (Abidjan-Côte d'Ivoire). *Moringa oleifera* leaves were obtained from a producer of Abobo-Baoulé locality (Abidjan, Côte d'Ivoire), while the sesame *(Sesamum indicum)* seeds were from the Meagui locality (South-West region of Côte d'Ivoire). All other chemicals and reagents used were of analytical grade and purchased from Sigma Chemical Co. (St. Louis, MO).

2.2 Sample Preparation and Processing

2.2.1 Processing of fermented millet seed flour

The millet seeds were sorted to eliminate plant debris, defects and infested. Then sorted seeds were washed and one (1) kg of seeds were soaked for 24 hours in 3 L of water. The soaked seeds were put again in water to start the fermentation for 3 days. The fermented seeds were washed with distilled water, dried in an oven at 45ºC for 2 days. Then, the dried seeds were milled and sieved through 0.25 mm wire mesh before packing in a sealed airtight plastic container and storage at 4ºC prior to formulation and analysis.

2.2.2 Processing of germinated millet seed flour

The millet seeds were sorted, washed and soaked for 24 hours. The soaked seeds were kept on a cotton cloth and allowed to germinate in the dark at room temperature for 3 days. Then, the germinated seeds were dried in an oven at 45ºC for 2 days and degerminated by hand. The dried seeds were milled, sieved, packed and stored at 4ºC as before.

2.2.3 Processing of sesame seed flour

The mature and dry sesame seeds were sorted to remove infested seeds and washed in clean tap water before draining at room temperature. Samples of seeds (200 g) were boiled in water (in stainless steel container) for 5 min, oven dried at 45ºC for 2 days. Then, the dried seeds were roasted (oven-cooking) for 10 min at a soft fire and cooled at room temperature. The roasted seeds were ground into flour using a blender equipped with a 0.50 mm mesh sieve. The ground material obtained was stored at 4°C in a clean dry airtight sample bottle until required formulation and analysis.

2.2.4 Processing of *Moringa* leaf powder

Moringa oleifera leaves were sorted and washed in clean tap water containing 1% NaClO. Then, they were dried at room temperature for 4 days, grounded into powder using a blender and sieved with a fine sieve of 0.25 mm. The resulting powder was packaged in black polyethene bags and stored in airtight plastic containers away in the dark until formulation and analysis.

2.2.5 Preparation of methanolic extract

The methanolic extract necessary to quantify the phytochemical constituents was prepared according to the Singleton et al. [12] method. Blend sample (1 g) was soaked in 10 mL of methanol 70% (v/v) and centrifuged at 1000 rpm for 10 min. The residue was then re-extracted with 10 mL of methanol 70% (v/v) before centrifuged at 1000 rpm for 10 min. The resulting extracts were combined and stored at 4°C until analyses.

2.3 Weaning Food Blend Formulation

The weaning food blends containing fermented millet, germinated millet, sesame and *Moringa* were formulated using different proportions of individual ingredients as shown in Table 1.

2.4 Proximate Analysis

Nutrient (moisture, ash, protein, fat, fiber and carbohydrate) content was determined according

Table 1. Composition of designed formulations

Ingredient (%)	*Mi100*	*MiMo*	*MiS*	*MiSMo5*	*MiSMo10*	*MiSMo15*	*MiSMo20*
Fermented millet flour	90	60	60	60	60	60	60
Germinated millet flour	10	10	10	10	10	10	10
Sesame flour	0	0	30	25	20	15	10
Moringa powder	0	30	0	5	10	15	20

to standard methods of AOAC [13]. Carbohydrate content was determined by the difference that is by deducing the mean values of other parameters that were determined from 100. Energy value was estimated using the Atwater's conversion factors [14].

2.5 Phytochemical Analysis

The content of total phenolic compounds was determined using the Folin–Ciocalteu reagent method [12]. The absorbance of gallic acid as standard and the methanolic extract was measured at 765 nm using a spectrophotometer.

Flavonoid quantification was carried out using aluminium chloride colorimetric method [15]. The absorbance of standard (quercetin) and the methanolic extract was measured spectrophotometrically at 415 nm.

Tannins of samples were quantified using vanillin reagent method [16]. The absorbance was measured at 500 nm using a tannic acid as standard.

Phytate (phytic acid) content was measured by the colorimetric method using Wade's reagent [17]. The absorbance at 490 nm was measured using sodium phytate as standard.

Oxalate was determined using the titrimetric method of Day and Underwood [18].

2.6 Antioxidant Assay

Antioxidant activity assay was carried out using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) photometric assay [19]. About 1 mL of a 0.3 mM DPPH solution in methanol was added to 2.5 mL of sample solution (1 g of dried powdered sample mixed in 10 mL of methanol), filtered through Whatman No.4 filter paper and allowed to react at room temperature. After 30 min, the absorbance (*Ab*) values were measured at 517 nm with a spectrophotometer. The average absorbance values were converted into the percentage of antioxidant activity using the following equation:

$$Antioxidant\ activity(\%) = 100 - \frac{(Ab\ of\ sample - Ab\ of\ blank) \times 100}{Ab\ of\ positive\ control}$$

Methanol (1 mL) plus plant extract solution (2.5 mL) was used as a blank, while DPPH solution plus methanol was used as a positive control. Vitamin C (50 µg/mL) was used as the standard.

2.7 Functional Properties Analysis

The bulk density (BD) of flours was evaluated according to the Narayana and Narasinga [20] method. The water (WAC) and oil (OAC) absorption capacities of flours were determined as described by Phillips et al. [21] and Eke and Akobundu [22], respectively. The foaming capacity (FC) of flours was measured by the Coffman and Garcia [23] method and the flour dispersibility by the Kulkarni et al. [24] method.

2.8 Data Analysis

All analyses were performed in triplicate and data were expressed as the mean ± standard deviation (SD). Mean values were carried out using Duncan's Multiple Range Test ($P<0.05$), with the STATISCA Software version 7.1.

3. RESULTS AND DISCUSSION

3.1 Biochemical Composition

Results from the biochemical analyses of formulated diets are compiled in Table 2. Moisture content increases significantly ($P<0.05$) with increasing proportions of *Moringa* leaf powder and decreasing sesame seed flour in different formulations. Indeed, compared to formulation with 100% millet (*Mi100*), incorporation with 30% sesame in millet flour (*MiS*) exhibited the low moisture level (3.54 ± 0.65%), whereas that of *Moringa* powder (*MiMo*) exhibited a high level (6.46 ± 0.29%). These values were similar to the finding of Achidi et al. [2] and Tiencheu et al. [25]. Except for *MiMo* flour, the moisture content of the different food products used in this study was within the recommended range (≤5%) for suitable storage of dehydrated foodstuff [26]. It is well established that low moisture content of complementary foods increase the nutrient composition [27] and inhibits biochemical activities of invading microorganisms, and thereby prevent food spoilage during storage [2].

Regerding the ash content, there is a significant difference (P<0.05) between all samples. The ash content ranged between 0.58 ± 0.04 (*Mi100*) to 3.14 ± 0.03% (*MiMo*). It was found to increase significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame. However, these values were within the recommended norms (≤3%) [26]. Samples containing a sufficient amount of ash imply that they are rich in mineral elements.

According to Table 2, the protein content varied from 9.53 ± 0.12 (*Mi100*) to 16.47 ± 0.06% (*MiMo*) for formulated diets. These values were also found to increase significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame. The presence of *Moringa* leaf powder and/or sesame seed flour could explain the high protein content of the different formulations [5]. In addition, except for *Mi100* diet, the protein level of other formulated diets was within the recommended standards for weaning foods (11-21%) [28]. Proteins play a role in the body defending and cover nitrogen expenditure caused by the renewal of tissues and the synthesis of some compounds involved in the proper body functioning (enzymes, hormones) [29].

Fat was higher (P<0.05) in formulations containing sesame flour (10.82 ± 0.03 to 21.56 ± 0.06%) as compared to formulations *Mi100* (4.68 ± 0.03%) and *MiMo* (5.43 ± 0.08%). Sesame seeds contribute to the high fat amount in different formulations. Indeed, the fat content of formulated diets decreases significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame. However, the fat content obtained in this study fall within the recommended norms for infants (10-25%) [26]. High fat values have been reported in formulations used for the treatment of moderate acute malnutrition in Uganda [30]. Fat is important in diets because it is a high-energy nutrient and promotes fat-soluble vitamins absorption [30].

The formulated diets showed a significant difference (P<0.05) in crude fiber contents. Thus, the lowest fiber content (3.83 ± 0.24%) was found in *Mi100* diet, while the highest (7.94 ± 0.19%) in *MiMo* diet. These values were lower than those of some selected Cameroonian local baby flours (2.01-2.83%) [29]. Results showed that the fiber content increases significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame. But, only *Mi100*, *MiS* and *MiSMo5* displayed a fiber content within the recommended norms for infants (≤5%) [26]. Fibers regulate intestinal transit and capture some of the lipids and carbohydrates, thus regulating part of the blood sugar and avoiding excess cholesterol. Due to their high saturation degree, these fibers exert a positive effect against overweight and metabolic diseases [29].

Regarding the carbohydrate content, flour containing 100% millet (*Mi100*) had the highest value (81.38 ± 0.33%) while *MiS* flour exhibited the lowest value (59.28 ± 0.64%). These values are significantly (P<0.05) different, and increase with increasing proportions of *Moringa* and decreasing sesame. Except *for Mi100* diet, all formulated diets met values close to the recommended value (64 ± 4%) [26]. Carbohydrates have an essentially energetic role; they are the main source of energy from the body and are involved in protein anabolism. Some carbohydrates come in the composition of fundamental tissues of the body (cartilage, acids nucleic, mucous, antigenic substances) [29].

Energy value in foods is provided by proteins, fats and carbohydrates [27]. In this study, there is a significant difference (P<0.05) in the energy content of different diets. The lowest values were measured in *MiMo* (382.83 ± 1.00 kcal/100g) and *Mi100* (405.72 ± 0.54 kcal/100g) flours; whereas the highest values (416.90 ± 0.32 to 483.50 ± 1.07 kcal/100g) were recorded in formulations containing sesame seed flours. These high levels could probably be due to the relatively high fat content of sesame seeds. However, all formulated diets have values close to that recommended (400-425 kcal/100 g) by FAO/OMS [26]. According to Brown et al. [31], infant and children foods are energy-dense because low energy-dense foods tend to limit total energy intake and the use of other nutrients.

3.2 Phytochemical Composition

The phytochemical composition of the food formulations is presented in Table 3. Results revealed that total phenolic exhibited the higher phytochemical content with 198.55 ± 2.8 to 904.32 ± 3.20 mg/100g of dry matter (DM).

Table 2. Proximate composition of formulated diets

Diets	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Crude fiber (%)	Carbohydrates (%)	Energy (Kcal/100g)
Mi100	4.34 ± 0.35^{b}	0.58 ± 0.04^{a}	9.53 ± 0.12^{a}	4.68 ± 0.03^{a}	3.83 ± 0.24^{a}	81.38 ± 0.33^{g}	405.72 ± 0.54^{b}
MiMo	6.46 ± 0.29^{d}	3.14 ± 0.03^{g}	16.47 ± 0.06^{e}	5.43 ± 0.08^{b}	7.94 ± 0.19^{g}	67.01 ± 0.12^{f}	382.83 ± 1.00^{a}
MiS	3.54 ± 0.65^{a}	1.79 ± 0.02^{b}	13.08 ± 0.76^{b}	21.56 ± 0.06^{g}	4.30 ± 0.17^{b}	59.28 ± 0.64^{a}	483.50 ± 1.07^{g}
MiSMo5	3.77 ± 1.30^{a}	2.04 ± 0.01^{c}	13.48 ± 0.07^{b}	18.72 ± 0.05^{f}	4.80 ± 0.10^{c}	60.97 ± 0.22^{b}	466.23 ± 0.13^{f}
MiSMo10	4.25 ± 0.47^{b}	2.20 ± 0.01^{d}	14.65 ± 0.44^{c}	16.15 ± 0.03^{e}	5.36 ± 0.17^{d}	61.64 ± 0.65^{c}	450.53 ± 0.61^{e}
MiSMo15	4.46 ± 0.19^{b}	2.45 ± 0.03^{e}	15.24 ± 0.06^{d}	13.47 ± 0.00^{d}	5.99 ± 0.10^{e}	62.86 ± 0.13^{d}	433.61 ± 0.26^{d}
MiSMo20	5.08 ± 0.92^{c}	2.69 ± 0.04^{f}	15.64 ± 0.06^{d}	10.82 ± 0.03^{c}	6.62 ± 0.11^{f}	64.24 ± 0.08^{e}	416.90 ± 0.32^{c}

Values are mean ± standard deviation of triplicate measurements and those bearing different letter within a columns are significantly different (P<0.05). Mi100: 100% Millet (90 % Millet fermented and 10% Millet germinated); MiMo: 60 % Millet fermented, 10% Millet germinated and 30% Moringa; MiS: 60% Millet fermented, 10% Millet germinated and 30% Sesame; MiSMo5: 60% Millet fermented, 10% Millet germinated, 25% Sesame and 5% Moringa; MiSMo10: 60% Millet fermented, 10% Millet germinated, 20% Sesame and 10% Moringa; MiSMo15: 60% Millet fermented, 10% Millet germinated, 15% Sesame and 15% Moringa; MiSMo20: 60% Millet fermented, 10% Millet germinated, 10% Sesame and 20% Moringa

Total phenolic, flavonoid and tannin contents increased significantly (P<0.05) with fortification by *Moringa* leaf powder in different formulated diets studied.

The health properties of phenolic compounds have been extensively studied from an epidemiological point of view by studying directly their effect on enzymatic systems and/or on physiological functions. Phenol and other phytochemicals found in fruits, vegetables and legumes are bioactive compounds which are able to neutralize free radicals and that play a role in several diseases prevention [32]. In addition, research has shown that consumption of flavonoid-rich foods protects humans against diseases associated with oxidative stress [33]. Flavonoids are natural secondary metabolites of plants with rich antioxidant properties and are able to interact and scavenge the free radicals that can damage cell membranes and biological molecules [34]. Most of the beneficial effects of flavonoids on health are related to their antioxidant and synergistic properties with other antioxidants. Concerning tannins, the obtained values (19.62 ± 1.36 to 75.63 ± 1.24 mg/100 g DM) are well below the limit values of 760 to 900 mg/100 g DM indicated by Aletor [35]. The tannin content of flours may have a significant role in antioxidant activity. They have vasculoprotective, healing and anti-diarrheal properties. Also, tannins have been considered to be anti-inflammatory, anti-carcinogenic and anti-mutagenic agents [36]. This property attributes to tannins an important and beneficial nutritional interest in the children nutrition and the health of people at risk.

The bioavailability of food nutrients is reduced by the presence of some of the anti-nutrients such as oxalates and phytates. Indeed, these compounds form insoluble complexes with vitamins, proteins and minerals making them unavailable for the body [37]. The value of oxalates and phytates in different food formulations studied is shown in Table 3. Except for the formulated diet with 100% millet flour (*Mi100*), there is no significant difference (P>0.05) in oxalate content of the other formulations. The oxalate content in different food formulated ranged from 120.79 ± 15.58 to 236.37 ± 22.34 mg/100 g DM. These values were within the normal dietary intake of 50-200 mg of oxalates/day and below the minimum lethal dose of 4-5 g total oxalates/day [38]. As for phytate content, a significant difference (P<0.05) is observed between the different formulations. The phytate values ranged from 17.96 ± 0.29 to 23.22 ± 0.41 mg/100g DM. These values are also well below the tolerable maximum phytate dose in the body (250 to 500 mg/100 g) [39]. Therefore, phytate levels observed in this study may be considered safe.

3.3 Antioxidant Activity

The antioxidant activity studied in different formulations showed that the methanolic extracts of flours have some abilities to quench the free radical DPPH, with rates ranging from 21.32 ± 3.63 to 69.64 ± 5.66% (Fig. 1). These results indicated that the formulated diet fortified with 15% sesame and 15% *Moringa* (*MiSMo15*) exhibited the best antioxidant activity. Phytochemicals provide health benefits associated with their ability to prevent damage due to biological degeneration. Levels of individual antioxidants in food do not necessarily reflect their total antioxidant capacity, which could also depend on synergic and redox interactions among the different antioxidant molecules (phytochemicals, vitamins and minerals) present in foods. Among the phytochemicals, phenolic compounds are reported to be the main contributor of antioxidant activity in plant extracts due to their higher value in total content [40]; their interaction and redox property [41] and their synergistic effectiveness as hydrogen donors, reducing agents and free radical scavengers [42].

3.4 Functional Properties

Table 4 shows the functional properties of the different formulated diets. The bulk density (BD) of these diets decreased significantly (P<0.05) with the incorporation of *Moringa* and/or sesame (0.65 ± 0.01 to 0.71 ± 0.01 g/mL) compared to the control diet *Mi100* (0.75 ± 0.02 g/mL). BD of formulated diets was lower than those (0.80 to 0.83 g/mL) reported from corn, papaya, red beans and mackerel [25]. According to Oulai et al. [43], BD is a measure of flour heaviness and an important parameter for determining packaging requirements, material handling and application in the wet processing in the food industry. A low BD would also be desirable in the weaning foods. This is because lower BD values lead to higher quantities of flour particles that can remain together and thus increase the energy content of these diets [25]. As a result, more samples could be prepared using a small amount of water while providing the desired energy nutrient density and semi-solid consistency that can be easily administered to an infant.

Regarding the water absorption capacity (WAC) of the different formulations, it ranged between 108.31 ± 0.90 (*MiS*) to 236.22 ± 0.78% (*MiMo*). WAC values increase significantly (P<0.05) with increase *in Moringa* incorporation and a decrease in sesame. These values were comparable to those of instant weaning food processed by Kouakou et al. [3] (92-133%) and by Tiencheu et al. [25] (200-330%). According to this author, WAC gives an indication of the amount of water absorbed by starch and available for gelatinization. Higher WAC indicates higher protein content in the formulations, which absorbs and binds with more water [3]. Scientific research has shown that high WAC indicates that food samples hold a large volume of water during cooking into gruels, to yield voluminous low energy and nutrient food [25].

Table 3. Phytochemical composition (mg/100 g DM) of formulated diets

Diets	Total phenolics	Flavonoids	Tannins	Oxalates	Phytates
Mi100	207.17 ± 2.10^{b}	0.29 ± 0.03^{a}	19.62 ± 1.36^{a}	120.79 ± 15.58^{a}	23.22 ± 0.41^{g}
MiMo	904.32 ± 3.20^{g}	86.26 ± 0.14^{f}	75.63 ± 1.24^{g}	236.37 ± 22.34^{b}	17.96 ± 0.29^{a}
MiS	198.55 ± 2.80^{a}	0.74 ± 0.04^{a}	41.32 ± 0.39^{b}	202.33 ± 21.72^{b}	19.40 ± 0.30^{f}
MiSMo5	311.22 ± 2.98^{c}	14.56 ± 1.13^{b}	51.33 ± 1.73^{c}	206.41 ± 21.67^{b}	19.03 ± 0.29^{e}
MiSMo10	427.52 ± 1.47^{d}	28.59 ± 0.24^{c}	58.88 ± 0.51^{d}	212.54 ± 21.83^{b}	18.85 ± 0.29^{d}
MiSMo15	542.71 ± 1.89^{e}	42.60 ± 0.29^{d}	65.18 ± 5.64^{e}	217.62 ± 21.88^{b}	18.57 ± 0.29^{c}
MiSMo20	661.21 ± 3.41^{f}	56.92 ± 0.47^{e}	70.24 ± 1.87^{f}	223.66 ± 22.02^{b}	18.36 ± 0.29^{b}

Values are mean ± standard deviation of triplicate measurements and those bearing different letter within a column are significantly different (P<0.05)

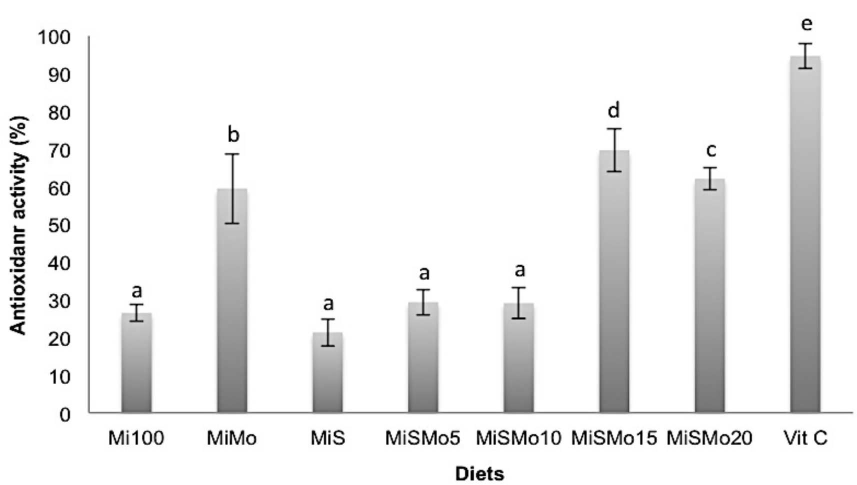

Fig. 1. Antioxidant activity of formulated diets

Table 4. Functional properties of formulated diets

Diets	BD (g/mL)	WAC (%)	OAC (%)	FC (%)	Dispersibility (%)
Mi100	0.75 ± 0.02^{c}	122.59 ± 1.89^{b}	195.87 ± 3.51^{e}	6.76 ± 0.81^{a}	72.05 ± 0.00^{g}
MiMo	0.65 ± 0.01^{a}	236.22 ± 0.78^{f}	206.80 ± 3.34^{f}	9.85 ± 0.95^{c}	68.75 ± 0.00^{e}
MiS	0.71 ± 0.01^{b}	108.31 ± 0.90^{a}	178.07 ± 3.93^{a}	7.29 ± 1.80^{a}	71.87 ± 0.18^{f}
MiSMo5	0.67 ± 0.01^{a}	124.00 ± 0.96^{b}	182.53 ± 6.77^{b}	8.33 ± 0.90^{b}	68.67 ± 0.56^{d}
MiSMo10	0.67 ± 0.02^{a}	141.37 ± 0.75^{c}	188.00 ± 0.72^{c}	8.25 ± 0.97^{b}	67.03 ± 0.22^{b}
MiSMo15	0.66 ± 0.01^{a}	165.16 ± 0.81^{d}	192.20 ± 1.60^{d}	8.21 ± 0.89^{b}	64.94 ± 0.31^{a}
MiSMo20	0.65 ± 0.01^{a}	184.12 ± 0.38^{e}	191.20 ± 3.86^{d}	8.69 ± 0.00^{b}	67.26 ± 1.14^{c}

Values are mean ± standard deviation of triplicate measurements and those bearing different letter within a columns are significantly different (P<0.05)

The oil absorption capacity (OAC) of the different formulations varied from 178.07 ± 3.93 to 206.80 ± 3.34%. The increase in *Moringa* leaf powder increased significantly (P<0.05) the OAC of the formulated diets. *MiMo* diet was found to have the highest OAC value with 206.80 ± 3.34%. OAC is an important property in food formulations because fats improve the flavour and mouthfeel of foods, especially bread and other baked foods [44]. It is also important because of the storage stability and particularly in the rancidity development [45]. The observed variations in OAC of different flours depend on the presence of non-polar side chains, which bind the hydrocarbon side chain of oil. The mechanism of oil absorption may be explained as a physical entrapment of oil related to the non-polar side chains of proteins [46]. Indeed, the major chemical component affecting OAC is a protein which is composed of both hydrophilic and hydrophobic parts. Non-polar amino acid side chains can form hydrophobic interaction with hydrocarbon chains of lipids.

The foaming capacity (FC) of the different weaning foods increases significantly (P<0.05) with an increase in the proportion of *Moringa* leaf powder and with a decrease in sesame flour. These values ranged between 6.76 ± 0.81 (*Mi100*) and 9.85 ± 0.95% (*MiMo*). Similar results were obtained for weaning food formulated by Achidi et al. [2] (7.62-13.56%). FC is the ability of a substance to produce foam after stirring or vigorously shaking. Foams are used to improve texture, consistency and appearance of foods [46]. According to Tiencheu et al. [25], proteins are denatured and aggregated during cooking and agitation leading to foam formation. Moreover, the low or absence of FC from certain meals could affect their stability during storage.

Concerning dispersibility, there is a significant difference (P<0.05) between the different formulated diets studied and values were ranged from 64.94 ± 0.31 (*MiSMo15*) to 72.05 ± 0.00% (*Mi100*). These results were in accordance with those found from different formulations (61.50-75%) [2,24]. The dispersibility decreased significantly (P<0.05) with increasing proportions of *Moringa* and decreasing sesame. Flour dispersibility gives an indication of particles suspensibility in water, which is a useful functional parameter in various food product formulations [43]. The diet dispersibility in water also indicates its reconstitutability. The higher the diet dispersibility value, the better is the diet. Therefore, the formulated diets would be more suitable in preparing weaning foods due to their high dispersibility values.

4. CONCLUSION

This study has developed seven weaning food blends and assessed their nutritional and functional properties. Regarding the functional properties studied, it appears clearly that the formulations enriched with a mixture of sesame seed flour and *Moringa* leaf powder have the best attribute. The formulated diets *MiSMo5* and *MiSMo10* have good nutritional quality and would be more efficient in addressing the nutritional problems. However, the best formulation is *MiMo5*, because it is the more in conformity with the different recommendations required by FAO for weaning foods. The use of millet, sesame and *Moringa* in complementary food formulations provides products with improved nutritional and functional properties, a good source of phytochemicals and high antioxidant capacity. This makes them potentially effective in addressing some of the nutritional problems faced by infants and children in Côte d'Ivoire.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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