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Research Article

Biochemical functional and physical characterization of Bambara groundnut [*Vigna subterranea* (L.) Verdc. Fabaceae] seeds grown in septentrional area of Cameroon

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Abstract

Bambara groundnuts ~~is~~ are adapted to varied agro-ecological conditions. Due to its great diversity and high nutritional content, Bambara groundnuts contribute to a healthy and balanced diet. The objective of this study is to carry out a physico-chemical and functional characterization of 20 Bambara groundnuts morphotypes to determine their nutritive potential. Bambara groundnuts morphotypes were collected in the septentrional area of Cameroon. The results of the surveys show that Bambara groundnuts are a legume used for both food and the treatment of certain diseases, making it a medicinal product. The seed colours of the Bambara groundnut morphotypes differed significantly (P= 0.00). The lipid contents ranged from 7.06 to 9.05% and with energy values between 396.78±2.64 and 405.90±2.84 Kcal/100g but these parameters were not significantly different. The total carbohydrate content and the average protein contents varied between 53.05 and 64.03% dry matter respectively and were significantly different. Thus, the seeds of these morphotypes are mainly rich in proteins and carbohydrates. Five morphotypes CM/AD/MC/32, CM/EN/DW/27, CM/EN/MC/13, CM/EN/DW/12, CM/EN/MC/30 are shown to be particularly interesting and can be exploited to obtain other more efficient varieties. The vegetable proteins contained in these seeds can relieve a large part of the population exposed to malnutrition due to protein deficiency.

1. Introduction

Several food plants considered as protein~~s~~ sources exist in nature, among which are seed legumes [1] that have ~~an~~ the advantage of being widely cultivated by rural populations. Among these legumes, Bambara groundnuts [*Vigna subterranea* (L.) Verdcourt] ranks third after groundnut and cowpea [2], but it is part of the long list of neglected and under-exploited species that have been cultivated for millennia and contribute to the food security of the world's poorest populations [3-6]. It is a complete food for its high nutritional value and a hardy crop for its drought tolerance and ability to grow ~~up~~ on soils considered less fertile for the cultivation of other species [7]. In the context of climate change, plants such as Bambara groundnuts is one of the plants relevant for food and nutrition security [8-9]. The annual production of Bambara groundnut is estimated to be 0.2 million tonnes from an area of 0.25 million hectares worldwide [4]. Sub-Saharan Africa is the largest producer of Bambara groundnut, while a small quantity is produced in Southeast Asia [10-11]. The proteins contained in Bambara groundnuts seeds have a high lysine content and their association with cereals in the diet constitutes a nutritional supplement for many local populations which cannot afford the high costs of animal proteins [12]. Modern production technologies and value chains are yet to be developed in Africa to achieve economic gains from Bambara groundnut production, product development, and commercialization. There ~~is~~ are limited research and development efforts globally on Bambara groundnut [13]. In Cameroon, Bambara groundnuts is mainly cultivated by women, in pure culture ~~on~~ in small areas and without improved techniques, whereas improving the production of this crop can help ensure food security [14]. The recent decades have seen an increase in the prevalence of hunger, childhood overweight, and adult obesity. Should we continue with our current production and consumption patterns, we are unlikely to achieve the United Nations Sustainable Development Goal (SDG) of Zero Hunger by 2030 [15]. To meet the SDG of zero hunger by 2030 and to end malnutrition in all its forms, the target is to increase the availability and accessibility to nutrients, not just calories. Adoption of a diversified healthy diet, with emphasis on affordable nutrient-rich plant-based foods such as fruits, vegetables, whole grains, and legumes can contribute to sustainable food and nutrition security [16-17] and ~~to~~ the achievement of SDG2. The seed of ninety-five accessions of Bambara groundnuts seeds obtained from the genetic resource center of the International Institute of Tropical Agriculture (IITA), Ibadan contain 50.6–69.3, 0.76–6.39, 2.88–13.55,12.51–26.72 and 3.19–9.88 of the carbohydrate, ash, moisture, protein and fat respectively [18]. Due to its good nutritional contents of proteins, fats, carbohydrates, and minerals, Bambara groundnut is regarded as a completely balanced diet [19-20]. The seed contains 53-70% carbohydrates, 18-25 % proteins, 3-9.7% lipids, 3-12 % fiber and 3-5% ash [21-23]. Diallo et al., 2015 in Côte d'Ivoire also evaluated the biochemical composition of seven Bambara groundnuts cultivars, with showed 7.35 to 9.02 %, 2.55 to 2.98 %, 2.57 to 4.08 %, 14.61 to 20.74 % and 7.69 to 8.55 % of moisture, ash, crude fiber, protein and lipid respectively. However, orphan crop species have received limited research and development attention by researchers and policymakers and, hence, their economic value, production methods, product development, and commercialization have not yet been fully explored [24]. In Cameroon, some studies concerning physicochemical and functional characterization have previously been carried out with Bambara groundnuts flours [25-27]. Very few results are available on the nutritional and functional properties of the existing Bambara groundnuts morphotypes in Cameroon. Several Bambara groundnuts accessions collected in different regions of Cameroon have contrasting [28-29]. The use of high-performance accessions, combined with well-distributed rainfall and a well-managed technical itinerary ~~are~~ is necessary to obtain good yields [30]. The aim of the present investigation is to highlight the biochemical, functional and physical characteristics of the flours of 20 Bambara groundnuts morphotypes collected in septentrional area of Cameroon. The results of this analysis will provide basic information on the nutritional quality of this collection.

2. Materials and methods

2.1. Colour characterisation of the different Bambara groundnuts morphotypes collected

The CIE L*a*b* colour space, defined by the International Commission on illumination [31], is a three-dimensional space with uniform chromatic differences. The physical colour parameters of the flours were evaluated in the CIELab colour system using the method described in OIV-MA-AS2-11: R2006 with a colorimeter (KONICA MINOLTA OPTICS CS10, No 40212027, Japan) and a light source. *Principle:* This colour system or CIELab space is based

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on a Cartesian sequential or continuous representation on 3 orthogonal axes L*, a* and b*. The L* coordinate denotes lightness (L* = 0 black and L* = 100 colourless), a* denotes the red/green colour component (a*>0 red, a*<0 green) and b* the yellow/blue colour component (b*>0 yellow, b*<0 blue). The CIE L*a*b* coordinates of each sample were then determined. The following coordinates were used to calculate the whiteness index:

$$\mathbf{IB} = 100 - \sqrt{(100-L)^2 \times a^2 + b^2}$$

2.2. Biochemical characterization of the flours of 20 Bambara groundnuts morphotypes

The twenty morphotypes of Bambara groundnuts seeds (Fig. 1) collected during prospecting in the Northern Cameroon (Far North, North and Adamawa) were brought back to the laboratory. Each 200g batch was carefully sorted to remove impurities, mouldy, immature and very small seeds. Samples were coded as follows: country initials/collection region/ collector/sequential number.

Figure 1. Pictures of the seeds of twenty Bambara groundnuts morphotypes collected in Northern Cameroon [14]

The dried seeds were ground into flour in a mobile hammer mill (Culatti, polymix, France) and then sieved through a 500µm mesh sieve. The flours obtained were sealed in polyethylene papers and stored at 4°C for analyses. These flours were used for biochemical and functional analyses at the Food and Nutrition Research Centre in Yaounde (CRAN).

2.2.1. Determination of moisture and dry matter content

The dry matter was determined using the AFNOR method [32]. First of all, the vacuum crucible was cleaned, dried and weighed. After this, the crucible containing the mass sample (0.5g) was weighed again and then placed in the oven (PROLABO) at 105°C for 24 hours.

2.2.2. Determination of total ash content

Total ashes were quantified by the method described in [33]. It consisted ~~in~~ of completely incinerating a sample until white ash was obtained in a muffle furnace (HERAEUS, Germany) set at 550°C.

2.2.3. Determination of total nitrogen and crude protein content

Total nitrogen is determined after the mineralization of samples according to the Kjeldahl method [34] (French Normalization Association), and the dosage according to the colorimetric technique [35].

2.2.4. Determination of total lipid content

Total lipids were determined by the method of Bourely [36]. The dried test sample of mass (1g) was wrapped in filter paper (Whatman No. 1) previously dried and weighed. The whole (paper + test sample) was steamed at 105°C for 5 hours and reweighed.

2.2.5. Determination of total carbohydrate content

The total carbohydrates were determined by difference, since flour contains water, minerals, carbohydrates, protein, and fat. According to the (AOAC) method [37], it was calculated by subtracting the sum of the moisture (H), fat (F), protein (P) and ash (A) contained in the sample from 100.

2.2.6. Determination of the energy value (EV)

The energy value was calculated considering Atwater's coefficients.

2.3. Evaluation of the functional properties of 20 Bambara groundnuts morphotypes

2.3.1. Determination of the water absorption capacity of powders

The method used is the one described by [38] 1 g of powder is mixed in 10 ml of distilled water, the whole

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Table 1. Uses of Bambara groundnuts seeds in the study area

Use	Method of seed preparation	Purpose	Regions*
Food	Grilled as an aperitif	Nutrition	Ad / No / FN
	Sautéed as a stew	Nutrition	No / FN
	Steamed fresh pods	Nutrition	Ad / No / FN
	Bambara groundnuts purée with groundnuts or sesame	Nutrition	No / FN
	Mixture of Bambara groundnuts and millet flour for making couscous	Nutrition	No / FN
	Bambara groundnuts flour for making couscous or fritters	Nutrition	Ad / No / FN
Medicinal	Bambara groundnuts porridge	Healing of fractures	No / FN
	Food based on Bambara groundnuts products	Regulation of blood sugar levels	No / FN
	Eating steamed seeds	Regulation of digestive disorders	No / FN
	Eat the large raw seeds of certain varieties	Reducing dementia attacks	No / FN
	Boil Bambara groundnuts seeds and drink the cooking juice	Reducing aches and pains in the joints	No / FN

* Regions: Ad = Adamawa; FN = Far North; No = North.

is vortexed for 1 minute using a vortex (Assistent Karl Heicht KG type VM 4, Germany) then centrifuged at 4000 $trnsm^{-1}$ for 20 minutes at 25 °C in a centrifuge (Eppendorf AG, 22331 Hamburg, Germany).

2.3.2. Determination of the oil absorption capacity (OAC) of 20 morphotypes of Bambara groundnuts

According to Beuchat [38], a quantity of 0.5g flour (Mo) is mixed with 4 ml oil (Soya). The mixture is vigorously stirred and centrifuged at 4000 $trnsm^{-1}$ for 20 min using a centrifuge.

2.3.3. Determination of the solubility index (SI)

The water solubility index is calculated according to [40]. It is deduced from the water absorption capacity and is expressed in g of soluble /100 g of dry matter.

2.3.4. Determination of physical properties of Bambara groundnuts

Colour was measured using a colorimeter. In relation to the parameter linked to the colour of the seed coats of Bambara groundnuts, the three CIE coordinates L*a*b* correspond to the luminance (L*), the red-green balance (a*) and the yellow-blue balance (b*).

3. Results and discussion

3.1. Uses of Bambara groundnuts seeds in the study area

Surveys of growers in the field reveal that Bambara groundnuts seeds are used both as food and in the treatment of certain human diseases (Table 1). As food, they are consumed in several forms. The seeds are eaten raw or cooked, fresh, or dried. Raw dried seeds are also roasted, steamed or stewed (Fig.2). Sometimes the seeds are ground into flour and used singly or in combination in meals or fritters. As a medicine, the seeds are reputed to remedy digestive and nervous disorders, as well as aches and pains. In Burkina Faso, the use of composite flours in the preparation of traditional dishes is a way of improving people's nutritional status. Three flour formulations were chosen, with the Sorghum-Bambara groundnuts formulation receiving the highest ratings for colour, aroma and texture from 54.1%, 47.5% and 44.3% of the panel respectively [41].

Figure 2. Two ways of preparing Bambara groundnuts in the septentrional area of Cameroon (A: roasted seed; B: boiled seed).

3.2 Characterisation of the seed coat of different morphotypes of Bambara groundnuts

Table 2 of the results of the colour analysis by the colorimeter shows that L* varies from 12.55 to 54.55; a* from 2.67 to 20.62 and b* from 8.97 to 16.25. This suggests that Bambara groundnuts seeds are predominantly lighter, redder and yellower in colour. The whiteness index (IB) values ranged from 71.45±1.18 to 78.37±1.11 recorded on morphotypes CM/EN/DW/20 and CM/EN/DW/01. A highly significant difference ($P \leq 0.0001$) between the

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Table 2: Characterisation of the colour of the integuments of 40 morphotypes of Bambara groundnuts

Code	L	a	B	IB
CM/AD/MC/32	43.5±0.84 ^{ijklm}	7.25±1.19 ^{abc}	12.87±3.09 ^{ab}	76.21±0.32 ^{abcd}
CM/EN/DW/12	33.7±2.04^{cdefghijk}	9.65±0.82 ^{abcdef}	15.37±2.70 ^{b}	74.02±0.31 ^{abcd}
CM/EN/DW/08	42.07±2.79^{hijklm}	8.95±1.27 ^{abcdef}	11.84±0.84 ^{ab}	75.89±0.51 ^{abcd}
CM/EN/MC/39	24.15±1.77 ^{abcdef}	4.57±1.02 ^{ab}	0.67±2.16 ^{ab}	75.54±0.67 ^{abcd}
CM/EN/DW/09	34.12±2.39^{defghijkl}	8.6±1.01 ^{abcdef}	-0.85±5.05 ^{ab}	76.73±0.95 ^{cd}
CM/EN/DW/24	26.95±3.41^{abcdefghi}	7.8±2.80 ^{abcd}	11.27±7.57 ^{ab}	74.00±1.29 ^{abcd}
CM/EN/MC/13	28.35±2.30^{abcdefghi}	11±0.97 ^{abcdefg}	6.7±1.48 ^{ab}	74.30±0.26 ^{abcd}
CM/EN/MC/30	27.1±3.04 ^{abcdefghi}	10.77±1.90 ^{abcdef}	12.72±5.91 ^{ab}	73.39±1.21 ^{abc}
CM/EN/DW/19	13.9±2.30^{ab}	12.45±2.98 ^{abcdefg}	-4.3±4.07 ^{ab}	73.65±0.88 ^{abcd}
CM/EN/DW/03	48.4±4.28 ^{klm}	9.52±0.36	12.35±7.34 ^{ab}	76.93±1.92 ^{cd}
CM/NO/MC/43	23.77±4.09 ^{abcde}	4.47±0.57 ^{ab}	12.2±2.39 ^{ab}	73.81±0.50 ^{abcd}
CM/EN/MC/45	29.62±1.38 ^{bcdefghi}	6.42±0.64 ^{abc}	7.15±2.14 ^{ab}	75.11±0.52 ^{abcd}
CM/AD/CM/25	28.25±3.81^{abcdefghi}	6.42±1.75 ^{abc}	-8.97±4.75 ^{a}	77.43±0.85 ^{cd}
CM/EN/DW/27	19.55±1.77 ^{abcd}	5.92±1.65 ^{abc}	-2.37±3.70 ^{ab}	75.12±0.81 ^{abcd}
CM/EN/MC/33	19.72±2.68 ^{abcd}	17.42±1.62 ^{defg}	10.67±2.48 ^{ab}	71.73±0.83 ^{ab}
CM/EN/DW/20	17.3±3.02^{abc}	17.92±5.92 ^{efg}	10.2±4.78 ^{ab}	71.45±1.18 ^{a}
CM/EN/MC/36	37.1±2.39 ^{efghijkl}	2.82±0.50 ^{a}	4.97±1.96 ^{ab}	77.17±0.69 ^{cd}
CM/EN/DW14	25.45±1.44^{abcdefgh}	14.9±1.11 ^{cdefg}	8.4±1.98 ^{ab}	73.12±0.53 ^{abc}
CM/EN/MC/38	29.3±2.74 ^{bcdefghi}	9.05±1.73 ^{abcdef}	7.9±2.80 ^{ab}	74.56±0.49 ^{abcd}
P value	0.00*	0.00***	0.00***	0.00***

* : p<0.05 ; *** : p<0.0001. NB: Values bearing the same letters in a column are not significantly different at the 5% threshold.

morphotypes of Bambara groundnuts collected was observed. The ~~difference in colour~~ colour difference was shown to be related to internal (genetic) factors. The expression of these characteristics indicates the existence of high genetic variability between Bambara groundnuts accessions in the far north of Cameroon [42-43]. Within this diversity, there is an overlap in colour between individuals from the two agro-ecological zones.

3.2. Chemical characterization of the flours of 20 morphotypes of Bambara groundnuts

The analysis of the biochemical composition of the 20 different Bambara groundnuts flours is presented in Table 3. From this table, it can be seen that the moisture content of the flour of the different Bambara groundnuts morphotypes varies between 6.69±0.32 and 9.12±0.23% fresh matter for the morphotypes CM/EN/DW/27 and CM/EN/DW14, this reveals a significant difference (p<0.05). Morphotypes of Bambara groundnuts have ash contents between (1.08±0.13%) for CM/AD/CM/25 and (3.35±0.26%) for CM/EN/DW/08. The results of the morphotypes (CM/AD/CM/25) and (CM/AD/MC/29) are identical with 1% ash. Thus, the analysis reveals a significant difference between these parameters. Lipid contents vary between (7.8±0.01 and 9.05±0.69%) respectively for morphotypes CM/EN/MC/36 and CM/EN/DW14. Energy values vary from (393.46±1.11 to 408.42±3.79%) for CM/EN/MC/43 and CM/AD/CM/25 respectively. On the other hand, lipid content and energy value do not vary significantly for the different morphotypes. Concerning the protein content, the minimum value is (16.93 ± 0.06%) while the maximum is (27.14 ± 0.15%) for CM/AD/MC/32 and CM/EN/DW/12 respectively. The powders of the different Bambara groundnuts flours show a significant difference in protein content (p<0.05). The available sugar contents vary from (64.71 ± 0.26 to 48.39 ± 0.19%) respectively for CM/EN/MC/43 and CM/EN/DW/27. A highly significant difference (P < 0.05) is observed between the different cultivars.

The biochemical analyses of our 20 Bambara groundnuts morphotypes reveal that the water content of the seeds varies between 6.69 and 9.12%. These results are lower than those mentioned by [25] which vary between (8.54 and 10.14%) on ten Bambara groundnuts morphotypes collected in the Far North Region of Cameroon. These values indicate a higher

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Table 3. Chemical composition of 20 morphotypes of Bambara groundnuts

Ecotypes	H2O (%)	Ash (%)	Protein (%)	Carbohydrate (%)	Fat (%)	Energy value (Kcal/100g)
CM/AD/MC/32	7.44±0.22^{ab}	3.26±0.19^{ab}	16.93 ± 0.06^{ab}	64.42 ± 0.29^{g}	7.92±0.19^{a}	396.78±2.64^{a}
CM/EN/DW/12	7.75±0.45^{ab}	3.20±0.59^{ab}	27.14 ± 0.15^{m}	53.65 ± 0.78^{a}	8.23±0.11^{a}	397.34±4.77^{a}
CM/EN/DW/08	8.48±0.58^{ab}	3.35±0.26^{ab}	17.32 ± 0,06^{b}	62.69 ± 0.78^{efg}	8.13±0.13^{a}	397.06±4.10^{a}
CM/EN/MC/39	7.49±0.15^{ab}	2.16±0.13^{ab}	18 ± 0.06^{c}	63.43 ± 0.11^{fg}	7.90±0.66^{a}	405.90±2.84^{a}
CM/EN/DW/09	7.38±0.16^{ab}	2.48±0.02^{ab}	19.47 ± 0.15^{d}	62.14 ± 0.12^{defg}	8.51±0.10^{a}	403.08±1.08^{a}
CM/EN/DW/24	7.00±0.30^{a}	2.06±0.01^{ab}	22.55 ± 0.03^{ij}	60.17 ± 0.05^{cdef}	8.20±0.29^{a}	404.73±2.78^{a}
CM/EN/MC/13	7.43±0.15^{ab}	3.07±0.21^{ab}	22.72 ± 0.06^{a}	64.03 ± 0.29^{g}	8.72±0.13^{a}	401.57±2.11^{a}
CM/EN/MC/30	7.70±0.33^{ab}	3.12±0.44^{ab}	24.88 ± 0.09^{l}	55.63 ± 0.57^{ab}	7.6±0.69^{a}	399.95±4.66^{a}
CM/EN/DW/19	7.47±0.25^{ab}	2.77±0.45^{ab}	19.11 ± 0.03^{i}	59.61 ± 0.60^{cde}	8.02±0.07^{a}	399.10±3.26^{a}
CM/EN/DW/03	7.72±0.06^{ab}	2.87±0.67^{ab}	22.9 ± 0.09^{jk}	58.23 ± 0.69^{bc}	8.26±0.05^{a}	398.93±2.71^{a}
CM/NO/MC/43	9.10±0.61^{b}	3.06±0.41^{ab}	21 ± 0.06^{h}	48.39 ± 0.19^{bc}	7.92±0.43^{a}	393.46±1.11^{a}
CM/EN/MC/45	8.24±0.06^{ab}	3.64±0.68^{b}	20.06 ± 0e^{f}	59.20 ± 0.66^{cd}	8.83±0.03^{a}	396.64±1.11^{a}
CM/AD/CM/25	7.85±0.01^{ab}	1.08±0.13^{a}	23.17 ± 0.09^{k}	59.06 ± 0.43^{cd}	8.82±0.65^{a}	408.42±3.79^{a}
CM/EN/DW/27	6.69±0.32 ^{a}	2.66±0.46^{ab}	18.04 ± 0.06^{c}	64.71 ± 0.26^{g}	7.88±0.19^{a}	401.99±0.40^{a}
CM/EN/MC/33	7.54±0.32^{ab}	2.70±0.98^{ab}	20.33 ± 0.03^{fg}	60.60 ± 1^{cdef}	8.81±0.26^{a}	403.08±6.57^{a}
CM/EN/DW/20	7.37±0.76^{ab}	2.56±0.00^{ab}	22.72 ± 0.09^{jk}	58.67 ± 1.17^{bc}	8.65±0.50^{a}	403.51±0.52^{a}
CM/EN/MC/36	7.48±0.27^{ab}	2.77±0.04^{ab}	19.62 ± 0.03 ^{of}	62.22 ± 0.36^{defg}	7.8±0.01^{a}	403.29±1.17^{a}
CM/AD/MC/29	8.39±0.19^{ab}	1.10±0.03^{a}	20.75 ± 0.05^{gh}	62.20 ± 0.36^{defg}	7.53±0.57^{a}	399.65±3.49^{a}
CM/EN/DW14	9.12±0.23^{b}	2.20±0.12^{ab}	19.78 ± 0.03 ^{of}	59.83 ± 0.62^{cde}	9.05±0.69^{a}	399.94±3.91^{a}
CM/EN/MC/38	7.65±0.34^{ab}	2.37±0.07^{ab}	20.94 ± 0.09^{h}	60.44 ± 0.46^{cdef}	8.57±0.09^{a}	402.76±0.62^{a}
P	0.006*	0.014*	0.00*	0.000***	0.119ns	0.180ns

ns : $p>0.05$; *: $p<0.05$; ***: $p<0.0001$. NB: Values with the same letters in a column are not significantly different at the 5% threshold.

water content in the seeds compared to our studied samples. A high moisture content reduces storage time and impacts seed quality [44]. The ash contents range between (1.08%) and (3.35%). Our values are much lower than those reported by [45] who obtained contents of between 4% and 7% with Bambara groundnuts seeds originating from Nigeria. According to [46], this difference in ash content could be explained by soil texture and composition which would affect plant mineral uptake and varietal differences.

The lipid contents of the different morphotypes of Bambara groundnuts obtained varied between 7.06 and 9.05%. Statistical analysis did not reveal any significant difference. The results obtained are not similar to those obtained by [13] which is (4 –12%). The lipid contents of seeds of the Bambara groundnuts morphotype are relatively low compared to those of soybean (22%) and groundnut (46%) [47]. Given the low lipid content of these seeds of Bambara groundnuts cultivars, they can be recommended for a low-fat diet [48]. The majority of fatty acids in Bambara groundnut are unsaturated, predominated by oleic and linoleic acids (omega-6) [49]. In addition, the total carbohydrate content of the cultivars ranged from 53.05 to 64.03% dry matter. The majority of the carbohydrate fraction is complex oligosaccharides and polysaccharides, of which starch accounts for up to 49.5% of the total carbohydrates [18]. In relation to proteins, the 20 morphotypes of Bambara groundnuts have average protein contents ranging between 16. 72 and 27.14%. Statistical analysis revealed a highly significant difference between the protein contents of the flours of the different Bambara groundnuts morphotypes collected. This difference could be due to the genotypes and environmental conditions under which these seeds were [50]. In general, most studies report glutamic acid to be the most abundant amino acid in Bambara groundnut, suggesting its potential to be isolated for use as a flavoring agent. Out of the essential amino acids, leucine and lysine are present at a higher concentration while methionine is the lowest [51-52]. Nutritionally, Bambara groundnut represents a cheap protein-rich source that can improve the food and nutrition security status of rural households [50]. Biochemical analysis of the

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Table 4. Functional properties of 20 Bambara groundnuts morphotypes analyzed

Morphotypes	Water absorption capacity (ml/g)	Oil Absorption capacity (ml/g)	Solubility index
CM/AD/MC/32	224.67±17.62^{a}	4.33±0.05^{a}	0.21±0.04^{ab}
CM/EN/DW/12	246.05±18.97 ^{a}	4.24±0.46^{a}	0.23±0.00^{ab}
CM/EN/DW/08	192.35±3.41 ^{a}	3.64±0.04^{a}	0.25±0.00^{ab}
CM/EN/MC/39	233.41±18.16 ^{a}	3.90±0.01^{a}	0.23±0.01^{ab}
CM/EN/DW/09	196.79±13.68 ^{a}	4.06±0.06^{a}	0.28±0.03^{ab}
CM/EN/DW/24	211.14±8.69 ^{a}	3.80±0.61^{a}	0.22±0.00^{ab}
CM/EN/MC/13	249.92±2.82 ^{a}	3.25±0.18^{a}	0.22±0.00^{ab}
CM/EN/MC/30	228.2±5.29 ^{a}	3.76±0.11^{a}	0,32±0,03^{b}
CM/EN/DW/19	210.97±9.42 ^{a}	4.22±0.02^{a}	0.23±0.01^{ab}
CM/EN/DW/03	213.19±39.3 ^{a}	3.89±0.06^{a}	0.23±0.00^{ab}
CM/EN/MC/43	235.56±8.05 ^{a}	3.55±0.24^{a}	0.23±0.00^{ab}
CM/NO/MC/45	203.96±11.68a	4.12±0.12^{a}	0.21±0.00^{ab}
CM/AD/CM/25	208.08±2.18 ^{a}	4.09±0.03^{a}	0.20±0.00^{ab}
CM/EN/DW/27	232.48±4,33 ^{a}	4.45±0.08^{a}	0.18±0.00^{a}
CM/EN/MC/33	219.99±36.13 ^{a}	3.92±0.04^{a}	0.28±0.06^{ab}
CM/EN/DW/20	237.64±4.42 ^{a}	3.48±0.24^{a}	0.23±0.00^{ab}
CM/EN/MC/36	195.74±18.67 ^{a}	3.79±1.08^{a}	0.20±0,00^{a}
CM/AD/MC/29	183.21±35.5 ^{a}	3.90±0.12^{a}	0.25±0.00^{ab}
CM/EN/DW14	224.88±12.21 ^{a}	3.80±0.08^{a}	0.21±0.00^{ab}
CM/EN/MC/38	231±10.43	3.32±0.13^{a}	0.20±0.00^{a}
P	0.04*	0.47ns	0.03*

ns: $p>0.05$; *: $p<0.05$. NB: Values with the same letters in a column are not significantly different at the 5% threshold. Abs: absorption.

carbohydrate, fat, protein and mineral content reveals that Bambara groundnut produces an almost balanced diet and can solve the problem of malnutrition very often observed in children and adults in these precarious areas. The energy content in our work is between 393.46 and 403.51(Kcal/100g). Statistical analysis does not reveal any significant difference. The energy value of most legumes per 100g is between 300 and 540 Kcal. This energy is necessary for all metabolic processes. The energy of legumes comes from the intake of proteins, lipids and carbohydrates [53]. In Cameroon, Bambara groundnuts are used both as food and for the treatment of certain human diseases. As food, they are consumed in several forms, raw or cooked, fresh or dried. The dried raw seeds are also roasted, or steamed or stewed. Sometimes they are ground into flour and used singly or in combination in meals or ~~in~~ the preparation of fritters. Likewise, in Benin [8] research indicates that whole or broken dry seeds are prepared seasoned and consumed with *gari* and oil or prepared with corn flour. The grilled form is also eaten by the *Lokpa* people. The same source indicates that researchers from the BIORAVE laboratory's local product development unit have developed five food products based on Bambara groundnuts: precooked Bambara groundnuts, biscuit, *aklui* cake, amaranth baobab. As a medicine, the seeds are said to remedy digestive and nervous disorders and aches; their seeds consumption also contributes to maintaining the body in good health because Bambara groundnuts contain~~s~~ antioxidants [54].

3.3. Functional characterization of flours of 20 Bambara groundnuts morphotypes

The values of the functional properties of the flours of 20 Bambara groundnuts morphotypes are recorded in Table 4. The values of the water absorption capacity for the flours of the morphotypes range from 183.21±35.5 to 249.92±2.82 mL/100g flour for morphotypes CM/AD/MC/29 and CM/EN/MC/13, showing a significant difference ($P<0.05$). Concerning the Oil Absorption Capacity (OAC) of the flours of the Bambara groundnuts morphotypes, they range between 3.32 ± 0.13 and 4.45 ± 0.08 mL g-1 of flour. The

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results show that there is no significant difference between the different flours. The solubility indices of the flours from the Bambara groundnuts morphotypes ranged from 0.18±0.00 to 0.28±0.03. The morphotypes CM/EN/DW/19, CM/EN/DW/03, CM/EN/DW/20 and CM/EN/MC/43 have similar solubility indices. All values are below 0.5. This index gives the affinity for ~~a~~ flour to disperse in water and give a homogeneous solution.

The water absorption capacity of flour~~s~~ plays an important role in the food preparation process because it affects certain functional and sensory properties. Statistical analysis of the water absorption capacity (WAC) of Bambara groundnuts flours showed a significant difference. Flours with high water absorption capacity could be good bakery ingredients for the manufacture of products such as bread [48]. Water Absorption Capacity (WAC) is a useful indicator to determine whether flour~~s~~ can be incorporated into aqueous food formulations [54]. The Oil Absorption Capacity (OAC) of Bambara groundnuts morphotypes flours ranges from 3.25 mL/g to 4.45 mL/g flour. Statistical analysis of the results does not show a significant difference. This difference could be explained by the particle size of the flours. The Oil Absorption Capacity is of paramount importance as it allows the retention of food flavor [55]. The solubility indices of flours from Bambara groundnuts cultivars are all lower than 0.5, i.e. between 0.20±0.00 and 0.32±0.03. In addition to providing essential nutrients, both the starch and protein of Bambara groundnut have functional properties, which may find wide application for food and non-food uses [18-56]. Evaluating the potential of underutilized and neglected crops such as Bambara groundnut can help transform African agriculture and reduce its dependencies on food imports while improving land quality and diets.

4. Conclusions

The chemical parameters such as the water, ash, lipid, sugar, and protein contents studied vary considerably. In general, the analysis of Bambara groundnuts flour shows that this legume is a nutrient-rich food for humans. In other words, the high protein content was observed in morphotypes CM/EN/DW/12 (27.14%), CM/EN/MC/30 (24.88%) and CM/AD/CM/25 (23.17%). Similarly, high sugar levels were also observed in CM/AD/MC/32, CM/EN/MC/13 and CM/EN/DW/27 with contents varying between 64.03 and 64.74%. Bambara groundnuts contain an important source of energy. However, the nutritional potential observed through the local morphotypes of Bambara groundnuts can allow an improvement in breeding programs for agronomic, nutritional, and processing needs. It would also be interesting that the research should include this legume as a crop priority in the program of national agricultural diversification and national strategies to ~~ensuring~~ ensure food security and adapting to change climate.

Authors' contributions

The conceptualization, methodology, and analysis, C.M., P.A.E. and C.B.B.B.; Writing and original draft preparation, C.M. and N.B.M.W., Data analysis, N.B.M.W. and P.A.E.,

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Availability of data and materials

All data will be made available on request according to the journal policy

Conflicts of interest

The authors declare no conflict of interest.

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