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"Potential of baobab (*Adansonia digitata* L.) dried fruit pulp in contributing to food and nutrient security in Sudan and Senegal"

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ABSTRACT

Food insecurity and nutritional deficiency have become a common problem in Sudan, leading to significant public health problems such as malnutrition. In Senegal, a strong link has been established between the low income of the population and poor nutrition, followed by a high intake of unhealthy foods. Therefore, plant-based products are commonly considered to play a key role as a natural healthy food source that improves the human body's nutritional stability by providing essential nutrients and promoting proper growth and development. This study aimed to investigate the nutritional values of dried baobab fruit pulp (DBFP) and to show how it contributes to food security and provides healthy nutrients to people. The baobab dried fruit pulp (DBFP) was obtained from Sudan (Eastern Africa), and Senegal (West Africa). Experiments were conducted in the laboratory of the Food Institute, University of Debrecen, Hungary. The results showed significant differences in nutritional value at the 5 % level. The protein and ash content were higher in Sudan (2.943 g/100 g, and 5.39 g/100 g), while the dry matter (89.45 %) fat content (0.834 g/100 g) and pH (3.25) were higher in Senegal samples. The high concentration of crucial components such as Ca (3286 mg/kg) and K (19072 mg/kg) combined with the low fat (0.681 g/100 g) and sodium content (50.17 mg/kg) gives this DBFP an excellent chance of being consumed as a healthy food. The integration of this ingredient into the daily diet can greatly contribute to the mitigation of nutritional deficiencies and overall health. Further research is needed to investigate the bioavailability of nutrients in the human body as a cofactor for nutritional therapy and intervention.

1. Introduction

1.1. Food and nutritional challenges

Due to climatic conditions and conflicts in different parts of Sudan, most of the population suffers from food insecurity and nutritional deficiencies [1]. In addition, many Sudanese, especially children, are affected by major public health problems, such as malnutrition [2]. In Senegal, a strong link has been found between the low income of the population, poor nutrition, and malnutrition, leading to a high intake of unhealthy foods and beverages, especially among children [3]. Therefore, plant-based products are commonly recognised as playing a key role as a natural healthy food source that improves the human body's nutritional stability by providing essential nutrients and promoting proper growth and development [4].

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1.2. African baobab tree as a dietary solution recourse

Africa is rich in novel tree species that are considered to have health benefits but are not fully explored and utilised by the global community [5]. The African baobab tree (*Adansonia digitata* L., Malvaceae) Fig. 1a) is a widespread indigenous plant that can be utilised for food [6,7]. Baobab trees are commonly distributed in sub-Saharan Africa's semi-arid areas [8]. In many African countries such as Sudan, Senegal, Benin, and Mali, the traditional use of the baobab tree is already known [9]. The wild dried and fresh baobab fruit pulp is a commercial product for most rural people in different regions of Senegal and is used as food for poverty [10]. In addition, DBFP has been recognised and consumed in several Eastern African countries (EA), such as Sudan [11]. Important macro elements such as potassium (ranging from 2010 to 2390 mg/100 g), calcium (ranging from 257 to 370 mg/100 g), and high amounts of vitamin C (ranging from 74 to 163 mg/100 g) were found in the fruit of this tree Fig. 1b) [12,48]. The level of total phenolics (ranging from 4.1 to 5.5 mg GAE/g), and total flavonoids (ranging from 10.1 to 16.5 mg QE/g) is high in baobab seeds and fruits, in addition to a significant amount of antioxidant compounds [13]. The DBFP is used to make nutritious drinks, healthy snacks, and sweets [14]. In addition, it has been introduced to improve the nutritional value of various products, such as dark coca drinks [15] and ice cream [16], and the quality of baked goods [17]. The DBFP is considered an important nutrient to the human body due to its high level of carbohydrates, iron, and zinc [18, 19].

1.3. Research objectives

Despite the widely known uses and nutritious profile of DBFP, few scientific studies have highlighted the health benefits associated with its existing nutrient quantification. To address this knowledge gap, this study primarily aimed to conduct a proximate analysis of baobab fruit pulp from Sudan and Senegal, highlighting its valuable nutrient profile. The findings emphasise the potential of baobab fruit pulp to contribute to food security and offer a nutritious dietary option for individuals suffering from nutritional deficiencies and malnutrition.

2. Materials and methods

2.1. Source of baobab dried fruit pulp

The largest rural market for wild products, including DBFP, found in El Obeid town, North Kordofan state, Sudan [20]. To achieve the aim of this study, Two DBFP samples (EA1 and EA2) were randomly collected from the specified market, based on their differing places of origin at the time of purchase.

Each sample weighed approximately 5 kg, was packaged in polyethylene bags, labeled, and directly sent to the laboratory for experiment.

Africa is a producer of many plant products, especially fruits [21] which are consumed and listed as an ingredient in the EU Novel Food catalogue [22,23] (Table 1). Accordingly, Hungary has adopted a favorable trade policy to accept many food ingredients such as DBFP and other products from their domestic producers or the European Union market. Therefore, two samples of DBFP were ordered from the Hungarian market for the trial (WA1 and WA2) with the following details provided in (Table 2) below.

2.2. Baobab dried fruit powder preparation

Dried baobab fruit obtained from Sudan and Senegal were cleaned from any plant object. The Ritsch PM100 planetary ball mill instrument is used to separate the baobab fruit pulp and seeds. The DBFP powder was homogenised and packed for analysis.

Table 1
Specifications of nutritional components of dried Baobab fruit pulp.

Component	The Commission of the EU Communities (2008/575/EC)	Phyto Trade Africa Organizations
Moisture (g/100 g)	11.1–12.0	11.1–13.7
Protein (g/100 g)	2.3–3.24	2.3–3.24
Fat (g/100 g)	0.4–0.7	0.4–0.7
Ash (g/100 g)	5.5–6.6	5.5–6.6
Sodium (mg/100 g)	7.42–12.2	7.42–12.2

a *b*

Fig. 1. (a) Baobab tree, (b) Baobab fresh fruit, Sudan.

Table 2
Information on collected dried Baobab samples from the Hungarian market.

Sample code	Sample brand	Sample type	Producer	Distributor	Sealer in the Hungarian market	Source
WA1	Zena	Baobab Fruit	Manufactured by Zena exotic fruits Dakar-Senegal www.zenaexoticfruits.com	Imported and distributed by Unidex B. V. Netherland. www.unidexholland.com	Kohinoor Bazar Kft. Budapest	Samples were ordered by the author
WA2	Karam Aliment	Baobab fruits	Produced in Senegal Exported by MSN Sarl Senegal.	Distributed by Touba Palene SAS Italy.	Kohinoor Bazar Kft. Budapest.	

2.3. Sample preparation for mineral analyses

Sample preparation for laboratory analysis was performed using the methods described by Ref. [24]. The baobab dried fruit pulp (1 g) was added to digestion tubes, and 10 ml of nitric acid (69%v/v) (VWR International Ltd, Radnor USA) was added to these samples and incubated overnight for further reaction. The Baobab dried fruit pulp samples were heated in a digestion unit at 60 °C for 30 min during the pre-digestion phase. After the Baobab dried fruit pulp samples were cooled, 3 ml of hydrogen peroxide (30 % v/v) (VWR International Ltd., Radnor, USA) was added. The samples were heated to 120 °C for 90 min during the primary digestion phase. After chilling, ultrapure water (Millipore S.A.S Molshein France; Millipore Q water purification system) was added to obtain a final volume of 50 ml. Following this, the materials were homogenised and filtered into sterile centrifuge tubes using a subjective filter paper (Sartorius Stedim Biotech S.A., Gottingen, Germany). The tubes held the samples until they were analysed. Inductively coupled plasma optical emission spectroscopy (ICP-OES) was used for macro elements, and inductively coupled plasma mass spectrometry (ICP-MS) was used for microelements. Six replicates were used to ensure maximum reliability and repeatability.

2.4. Proximate analysis

The proximate analysis of the DBFP was investigated as follows: for the dry matter, crude ash, protein content, fat, and pH, the following methods were applied: MSZ ISO 6496:2001, MSZ ISO 5984:1992, MSZ EN ISO 5983–2:2009, MSZ EN ISO 11085:2015 8.3, and MSZ-08-0206-2:1978 2.1 [25].

2.5. Statistical analysis

The data analysis was carried out using the programme R (version 4.2.2, R Core Team). Descriptive statistics (means and standard deviations) were calculated for all nutritional values. And an analysis of variance (ANOVA) was performed to test for differences. The Tukey Honest Significant Difference (HSD) post-hoc test was used to distinguish between different groups. A two-sample *t*-test was conducted to test the differences in DBFP between the two countries. Full factorial analysis was performed using the same software to test and assess the effect of independent factors (countries and samples from different markets) on the tested variables (nutritional values). The significance level was set at $p < 0.05$. A reduction of variables was achieved by performing a principal component analysis (PCA) on the correlation matrix to explain the relationships between the analytical data and their locations.

3. Result

3.1. Regional variations (countries)

The proximate analysis results of the dried baobab fruit pulp showed that ash content was higher in Sudan (5.39 ± 0.25 g/100 g), while Senegal samples had a higher pH (3.25 ± 0.017). The results of macroelements showed that Ca, K, and Na had higher values in Sudan samples (3286 ± 5.49 g/kg dw), 19072 ± 5.97 g/kg dw, and 63.89 ± 0.9 g/kg dw), while Mg had a higher level in Senegal (1879 ± 110 g/kg dw). In addition, the highest levels of the analysed microelements Fe (62.72 ± 4.21 g/kg dw) and Zn (11.33 ± 0.35 g/kg dw) were found in Sudan samples, see Table 3.

3.2. Nutritional variation of dried baobab fruit pulp from different markets

The highest values for dry matter (89.61 ± 1.77 %), fat content (89.61 ± 1.77 g/100 g dw), protein content (3.06 ± 0.01 g/100 g dw), pH (3.26 ± 0.02), Mg (1979 ± 3.98 mg/kg dw), Mn (10.3 ± 0.02 mg/kg dw) and Cu (14.193 ± 0.11 mg/kg dw) were found in WA1. The highest value of Ca (3287 ± 7.22 mg/kg) dw), K (19074 ± 7.86 mg/kg) dw), Na (63.96 ± 1.03 mg/kg) dw) and Zn (11.55 ± 0.27 mg/kg) dw), on the other hand, was found in EA2. The highest concentration of Fe (65.22 ± 4.14 mg/kg) and the highest ash content (5.50 ± 0.08 mg/100 g dw) were found in EA1. However, the lowest nutritional value of DBFP was found in sample WA2 (Table 4). The ANOVA test revealed that all nutrient and elemental values of all DBFP samples differed significantly at $p < 0.05$, except for the dry matter. Tukey's HSD multiple comparison tests of means at significant differences ($p < 0.05$) were used to investigate the variation among pair values for all nutrients, and the results showed that there was no significant difference between all dry matter means (Fig. 2). For protein and fat content, the results showed that there were significant differences between each pair, except (EA1-EA2). For ash content, there were significant differences between the pairs (EA1-EA2), (WA1-EA2), and (WA2-EA2). The only significant difference in pH was also found in the pair (WA1-EA2) (Fig. 3). For Ca, K, and Mg contents between each pair of the DBFP samples analysed, the results

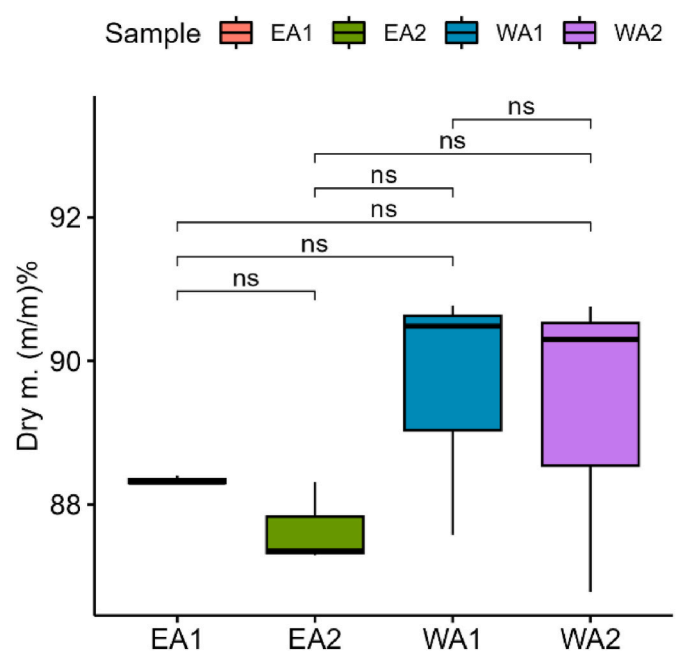

Fig. 2. Dry matter (%) value of dried Baobab fruit pulp samples collected from different markets. Significant codes: ns, not significant.

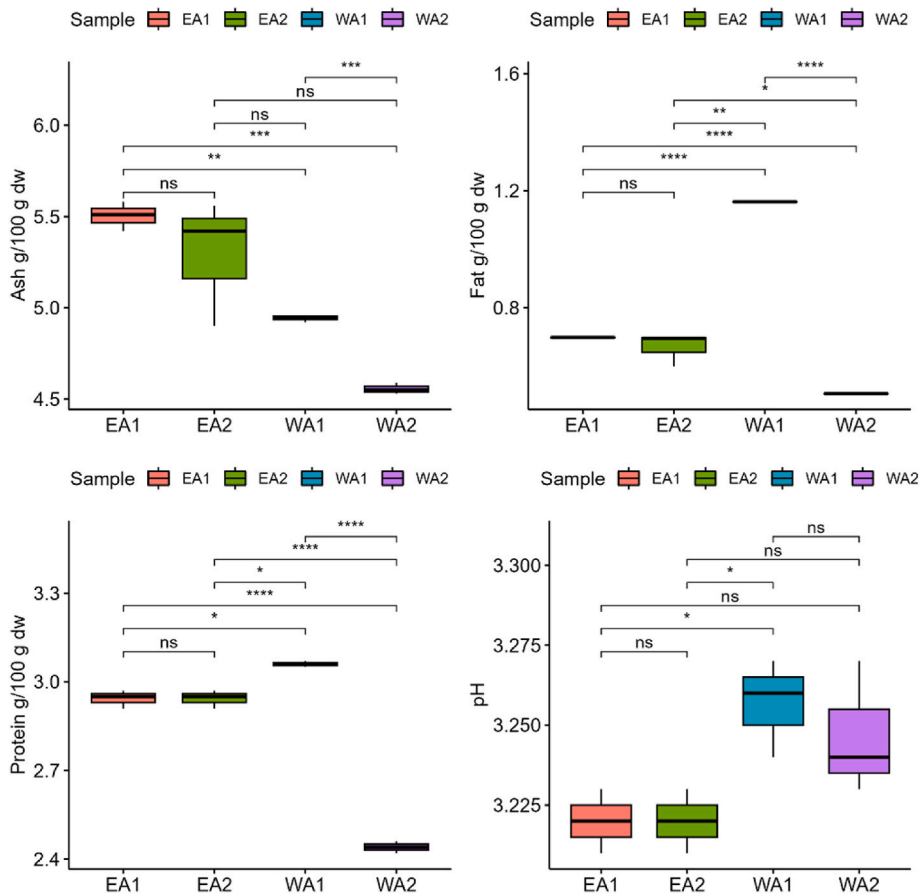

Fig. 3. Protein, fat, ash content (g/100 g), and pH value of dried Baobab fruit pulp samples collected from different markets. Significant codes: '****' 0.0001, '***' 0.001 '**' 0.01 '*' 0.05, ns, not significant.

showed significant differences only between the pair (EA1-EA2). Significant differences were found between the pairs (EA1-WA2), (EA2-WA2), and (WAI-WA2) for Na. For the micronutrients Fe and Zn, the results showed that there were no significant differences only between the pairs (WA1-WA2) and Mn (EA2-WA2) pairs (Fig. 5) (see Fig. 4).

3.3. Multivariate analysis

Principal component analysis (PCA) was conducted to visualise the relationships between the variables and the geographical origin of the samples. The x-axis (PCA 1) explains 55.8 % of the total variance of the data. The y-axis (PCA 2) explains 33.9 % of the total variance in the data. The two components capture 89.7 % of the variance, providing an excellent representation of the underlying data structure. The loading plot in Fig. 6b indicates that the levels of Fe, Ca, K, Ash, Zn, Na, protein, and Cu have positive loadings on PCA 1. The strongest positive linear correlations (vectors pointing in the same direction) were found between Zn and K ($r = 0.992$). Variables such as pH and dry matter have arrows pointing in directions that are less aligned with the cluster of Fe, Ca, and ash, suggesting that these variables contribute differently and may capture other aspects of the variance in the data. The strongest inverse correlation (variables arranged in opposite directions concerning the origin of the axis and far from the origin of the plot) was revealed between dry matter and Ca ($r = -0.454$), and between pH and Fe (=-0.732). Fig. 6a represents the score plot, used to reduce the multidimensionality of the data and visualise the relationships between the studied samples on the plane indicated by PC1 and PC2. There is a clear separation between the samples from Senegal (red points) and Sudan (green points) in PCA 1 and PCA 2, indicating that the samples from the two countries have different characteristics captured by PCA. The samples from Sudan (green) cluster closely together, indicating less variability between these samples. The samples from Senegal (red) are more spread, indicating greater variability within these samples. The higher average content of ash (5.39 vs. 2.75 g/100 g), protein (2.943 vs. 2.06 g/100 g), Ca (3286 vs. 3121 mg/kg), K (19072 vs.17046 mg/kg), Na (63.89 vs. 50.17 mg/kg), Fe (62.72 vs. 49.07 mg/kg), Zn (11.33 vs. 49.07 mg/kg), and Cu (11.74 vs. 9.78 mg/kg) differentiates the samples collected in Sudan (EA1 and EA2). In contrast to WA1 samples obtained from Senegal.

4. Discussion

Our findings of protein content in the DBFP samples ranged from 2.44 ± 0.02 to 3.06 ± 0.01 g/100 g. This amount aligns with the average reported by Refs. [26–28]. This protein content as a source of amino acids found in DBFP contributes significantly to the recommended dietary intake of people in Sudan and Senegal.

These amino acids are essential for various functions in the human body [29–31]. The results revealed that DBFP is characterized by a low-fat content, typically below 1 g/100 g, which is in the range of previous studies [26,27]. The fat content in DBFP underscores its value as a cardioprotective diet which is particularly helpful for obesity management and reducing cardiovascular diseases [32–34]. The amount of calcium in the DBFP is 3285 ± 4.64 mg/kg, making it an important source of a healthy diet, as it is vital for muscle contraction, and bone. In addition, it supports the immune system and nerve functions. In regions where access to food is scarce, DBFP can serve as an important alternative to dietary calcium [19,35–37]. Also, the results show that the DBFP is rich in potassium, containing 19074 ± 7.86 mg/kg, which is higher than the average found by Refs. [7,38].

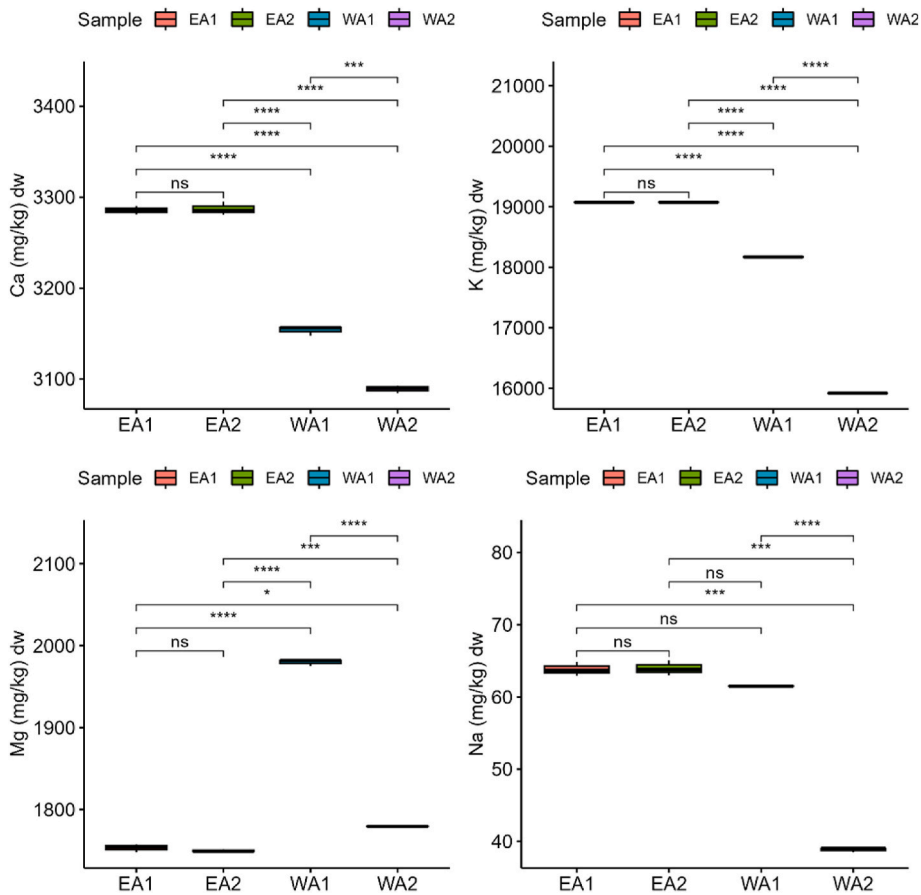

Fig. 4. Macro elements concentration (mg/Kg) of dried Baobab fruit pulp samples collected from different markets. Significant codes: '****' 0.0001, '***' 0.001'*' 0.05, ns, not significant.

Potassium is important for regulating fluid balance, nerve transmission, and muscle function [39–41]. Potassium controls blood pressure and maintains human cardiovascular health [42]. The high K content in DBFP could decrease the prevalence of common health issues such as hypertension in Sudan and Senegal. The average magnesium concentration in DBFP was 1979 ± 3.98 mg/kg, which is consistent with [38,43], but lower than the amount detected by Ref. [44]. Mg is a key element in regulating the body's immune system [45]. The high Mg content in DBFP could contribute to the overall metabolic health of humans and prevent diseases related to Mg deficiency. The low sodium level of the analysed samples was generally less than 10 mg/100 g, which is emphasised in the previously published range [46]. This level is useful for maintaining blood health and reducing the risk of cardiovascular disease [47]. The low sodium in DBFP promotes its potential to be a preventive healthy diet for heart diseases. The findings of Zn, Mn, and Cu showed that their concentration is consistent with those [6,23,46,48]. Mn is crucial for bone formation [49]. Copper is an essential component of the nervous system [50]. Zinc boosts the immune functions [51]. The daily dietary needs of the mentioned elements are relatively important for the children's growth and useful for pregnant women. Their presence in DBFP can provide and contribute to the overall necessary mineral intake for the maintenance of various physiological processes. Even though the average iron content of 65.22 ± 4.14 mg/10 g determined in this study is lower than the average reported by Refs. [27,52]. DBPF remains an important plant-based source of this essential mineral. Iron is necessary for hemoglobin production [53]. This iron content can help in preventing iron deficiency and anemia, which are prevalent in many parts of Sudan and Senegal.

5. Conclusion

In summary, the broad spectrum of nutrient profiles of DBFP (*Adansonia digitata* L.) demonstrates its significant potential as a superfood and recommended dietary supplement, especially in Sudan and Senegal. The high concentration of important elements, such as Ca, K, Mg, Fe, and other microelements, combined with the low fat and sodium content, gives this DBFP an excellent chance to be consumed as a healthy food, as reported by the European Food Safety Authority, especially in countries and regions where nutrient deficiencies and malnutrition are widespread. Overall, DBFP offers a wide range of health benefits, emphasising its importance as a healthy food source in both modern and traditional diets. Incorporating this ingredient into the daily diet can significantly help to reduce nutritional deficiencies and promote overall health. Further research is recommended to investigate the bioavailability of DBFP nutrients in the human body as a cofactor for nutritional therapy and intervention.

CRediT authorship contribution statement

Abdelhakam Esmaeil Mohamed Ahmed: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Massimo Mozzon:** Writing – review & editing, Visualization, Validation, Supervision, Investigation. **Abdaljbbar B.A. Dawod:** Writing – review & editing, Software, Resources, Methodology, Formal analysis, Data curation. **Eltayeb Omaima Awad Mustafa:** Writing – review & editing, Visualization, Investigation. **Shaikh Ayaz Mukarram:** Writing – review & editing, Visualization, Software, Resources, Formal analysis. **Béla Kovács:** Writing – review & editing, Visualization, Validation, Supervision,

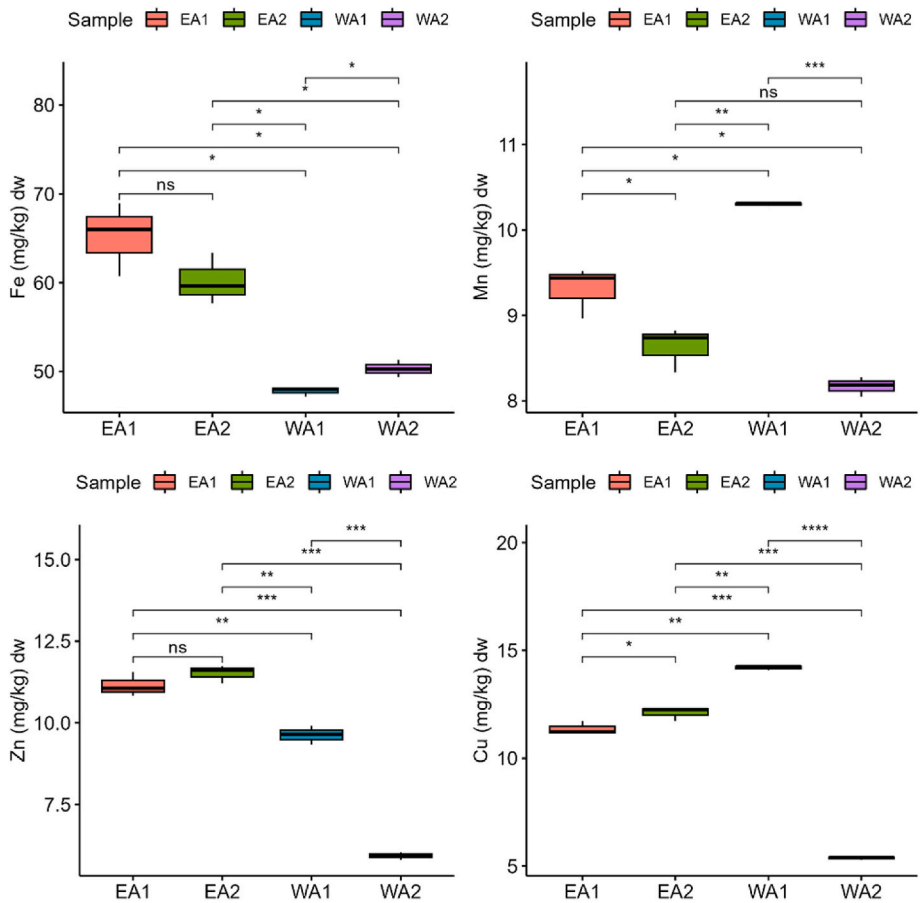

Fig. 5. Microelements concentration (mg/Kg) of dried Baobab fruit pulp samples collected from different markets. Significant codes: '****' 0.0001, '***' 0.001 '**' 0.01 '*' 0.05, ns, not significant.

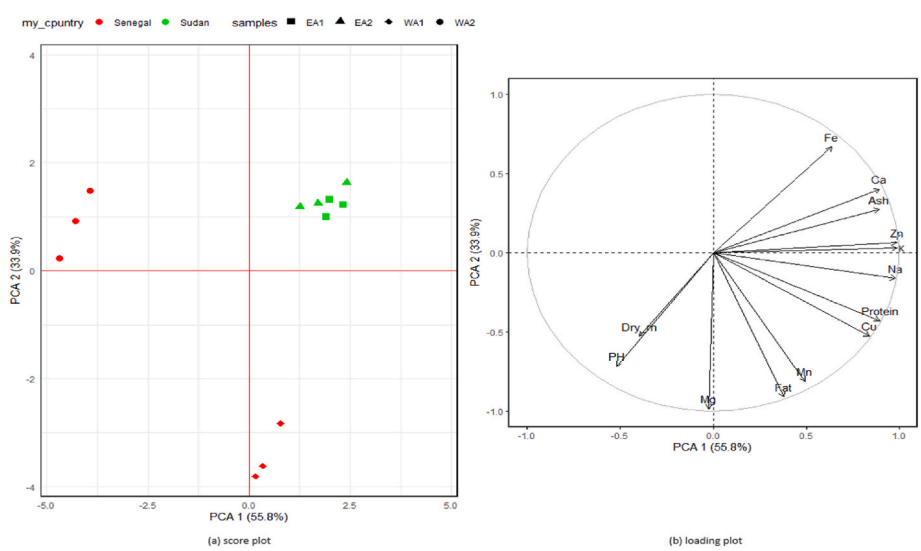

Fig. 6. PCA score plots of the dried Baobab fruit pulp samples (a) and PCA loadings plot of the variables on the first two components (b). The countries are Sudan (Green) and Senegal (Red). Samples are in circles (WA2), squares (EA1), triangles (EA2), and diamonds (EA2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Software, Resources, Project administration.

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Declaration of competing interest

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If any conflicts of interest do arise during the review or publication process, they will be disclosed to the journal promptly.

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Appendix

Table 3
Nutritional properties (mean ± SD; n = 6) of dried Baobab fruit pulp samples collected from Sudan and Senegal

Parameters	Sudan	Senegal
Dry matter %	87.99 [a] ± 0.52	89.45 [a] ± 1.78
Ash content g/100 g dw	5.39 [a] ± 0.25	4.75 [b] ± 0.21
Fat content g/100 g dw	0.681[a] ± 0.04	0.834 [a] ± 0.359
Protein content g/100 g dw	2.943 [a] ± 0.027	2.75 [a] ± 0.34
PH	3.22 [b] ± 0.009	3.25 [a] ± 0.017
Ca (mg/kg) dw	3286 [a] ± 5.49	3121 [b] ± 35.708
K (mg/kg) dw	19072 [a] ± 5.97	17046 [b] ± 1232
Mg (mg/kg) dw	1751 [b] ± 3.84	1879 [a] ± 110
Na (mg/kg) dw	63.89 [a] ± 0.9	50.17 [b] ± 12.41
Fe (mg/kg) dw	62.72 [a] ± 4.21	49.07 [b] ± 1.55
Mn (mg/kg) dw	8.97 [a] ± 0.45	9.24 [a] ± 1.17
Zn (mg/kg) dw	11.33 [a] ± 0.35	7.78 [b] ± 2.04
Cu (mg/kg) dw	11.74 [a] ± 0.49	9.78 [a] ± 4.83

Different letters above values indicate the significant differences ($P < 0.05$).

Table 4
Nutritional properties (mean ± SD; n = 6) of dried Baobab fruit pulp samples collected from different markets

Parameters	EA1	EA2	WA1	WA2
Dry matter %	88.33 [a] ±0.059	87.65 [a] ±0.57	89.61 [a] ±1.77	89.28 [a] ±2.18
Ash content g/100 g dw	5.50 [a] ±0.08	5.30 [b] ± 0.39	4.94 [c]±0.02	4.557 [d] ± 0.031
Fat content g/100 g dw	0.69 [a]±0.001	0.66 [b] ± 0.06	1.16 [c]±01	0.506 [d] ± 01
Protein content g/100 g dw	2.93 [a]±0.031	2.94 [b] ± 0.03	3.06 [a]±0.01	2.44 [d] ± 0.02
pH	3.22 [a]±0.01	3.22 [b] ± 0.01	3.26 [c]±0.02	3.25 [d] ± 0.02
Ca (mg/kg) dw	3285 [a]±4.64	3287 [b] ± 7.22	3154 [c]±5.23	3089 [d] ± 4.21
K (mg/kg) dw	19069 [a]±3.56	19074 [b] ± 7.86	18171 [c]±12.79	15921[d] ± 2.001
Mg (mg/kg) dw	1753 [a]±4.88	1749 [b] ± 1.75	1979 [c]±3.98	1779 [d] ± 0.62
Na (mg/kg) dw	63.84 [a]±0.97	63.96 [b] ± 1.03	61.50 [c]±0.04	38.84 [d] ± 0.30
Fe (mg/kg) dw	65.22 [a]±4.14	60.23 [b] ± 2.92	47.80 [c]±0.55	50.33 [d] ± 0.98
Mn (mg/kg) dw	9.31 [a]±0.30	8.62 [b] ± 0.26	10.30 [c]±0.02	8.17 [d] ± 0.11
Zn (mg/kg) dw	11.15 [a]±0.37	11.55 [b] ± 0.27	9.63 [c]±0.29	5.93 [d] ± 0.12
Cu (mg/kg) dw	11.37 [a]±0.31	12.10 [b] ± 0.32	14.19 [c]±0.11	5.37 [d] ± 0.10

Different letters above values indicate the significant differences ($P < 0.05$).

Data availability

The data presented in this article are available upon reasonable request from the corresponding author.

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