

DOCTORAL (Ph.D.) DISSERTATION

**The Composition of African Baobab Leaves and Fruits in Different Regions and Habitats:
Contribution to Food Security and Nutritional Intervention**

Ahmed Abdelhakam Esmail Mohamed

Supervisors:

Prof. Dr. Béla Róbert Kovács, PhD

Associate Professor Dr. Massimo Mozzon, PhD



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Contribution to Food Security and Nutritional Intervention**

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Written by Ahmed Abdelhakam Esmail Mohamed, certified M.Sc. Agricultural Engineering – Food Science.

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Dissertation supervisors:

Professor. Dr. Béla Kovács, PhD, University of Debrecen, Hungary. Associate Professor. Dr. Massimo Mozzon, PhD, Polytechnic University of Marche, Ancona, Italy.

The official opponents of the dissertation:

Name	Scientific degree	Signature
Dr.....
Dr.....

The evaluation committee

Chairperson: Dr.....
Members: Dr.....
Dr.....

The date of dissertation defence2025

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1 List of Abbreviations

Abbreviation	Full Term
GDP	Gross domestic product
OP	Out-of-pocket
TPC	Total phenolic compounds
TFC	Total flavonoid compounds
CCHIP	Community childhood hunger identification project
FCS	Food consumption score
DBFP	Dried baobab fruit pulp
KR	Kordofan
BN	Blue Nile
QGIS	Quantum geographic information system
W	Wetland
P	Plain land
M	Mountain
ICP-OES	Inductively coupled plasma optical emission spectrometry
iCAP	Intelligent coupled plasma
IPE	International plant-analytical exchange
WEPAL	Wageningen evaluating programs for analytical laboratories
DM	Dry matter
ISO	International organization for standardization.
MSZ	Stands for Magyar Szabvány (Translates to Hungarian Standard)
BLs	Baobab leaves samples
BLI	Baobab leaves intake
BFI	Baobab fruit intake
ANB	Average amount of specific nutrients in BLI/BFI
DRV	Dietary reference value
SUD	Sudan
KEN	Kenya
SEN	Senegal

2 Introduction

2.1 Food security and inadequate dietary

Food security is achieved when all people worldwide have access to a necessary, safe, and nutritious diet that meets their nutritional needs for an active and healthy life (Solarin & Gil-Alana, 2025). The most important factor influencing human health is the adequate supply of nutrients in the diet (Singh et al., 2023). Millions of people worldwide, including Africans, are affected by nutritional deficiencies that have led to various public health problems (Jha et al., 2024). In addition, there are widespread diseases in tropical areas, such as anemia, which is positively correlated with inadequate dietary iron intake (Bushra et al., 2010).

The discovery of natural areas completely covered with underutilized and valuable plant species is one of the most important strategies for alleviating food insecurity and poverty problems related to human health. For example, African regions and habitats are rich in novel tree species that are believed to have health benefits, but have not yet been fully explored and utilized by the global community (Lamien-Meda et al., 2008). The baobab (*Adansonia digitata* L.) is a native and iconic tree in Africa with a massive trunk (Hendam et al., 2024; Lamien-Meda et al., 2008), belonging to the Bombacaceae family and Malvaceae subfamily. It is widespread in the Sahel (Baum et al., 2004; De Caluwé et al., 2010), with a stem diameter of up to 10 m and a height of up to 25 m. This tree is well known because of its size (Figure 1) and life expectancy, which can exceed hundreds of years. It is widespread in the warm and dry zones of tropical Africa (Gebauer et al., 2016). The baobab is native to numerous sub-Saharan countries and thrives mainly in dry savannah regions such as South Africa, Mozambique, the Ivory Coast, Malawi, Sudan, Zimbabwe, Kenya, Cameroon, Burkina Faso, Senegal, and Uganda (Sidibe, 2002). A common characteristic of the baobab tree is the possession of very large, spectacular flowers that grow overnight (Baum, 1995). This tree grows in clay or sandy soils and in different ecological areas (El Amin, 1990).

2.2 The baobab tree products as a solution

The baobab tree has many benefits, with most of its parts playing a key role in promoting the livelihoods of poor people, especially in areas characterized by a lack of food sources (De Caluwé et al., 2010). The benefits of the baobab tree are recognized in most African countries. Local

communities in several African societies consume baobab fruits and leaves throughout the year (Christine et al., 2010).



Figure 1. Baobab tree with a stem diameter of up to 10 meters and a height of up to 25 meters

2.3 Food insecurity and human health situation in Africa

Food insecurity and poverty influence people's health in Sudan, Kenya, and Senegal. This is based on information from the DataBank database (World Bank Group), Health Nutrition and Population Statistics (<https://databank.worldbank.org/source/health-nutrition-and-population-statistics>) for the period 2013-2023. The following indicators were used as evidence.

2.3.1 The prevalence of undernourishment and health expenditure

Kenya shows a steady worsening of malnutrition (23%) in the total population. While health expenditure is steadily increasing and remains very low at 4.5 % of GDP, representing a strong negative correlation, where higher spending should contribute to better nutrition and health outcomes. Senegal shows a simultaneous deterioration in undernourishment and health expenditure, suggesting that initial investments in healthcare and current public health and

nutrition intervention strategies have reduced this need. On the other hand, in Sudan, undernourishment levels are unstable, and health expenditure is low, indicating systemic challenges in addressing food insecurity due to inadequate resource allocation Figure 2.

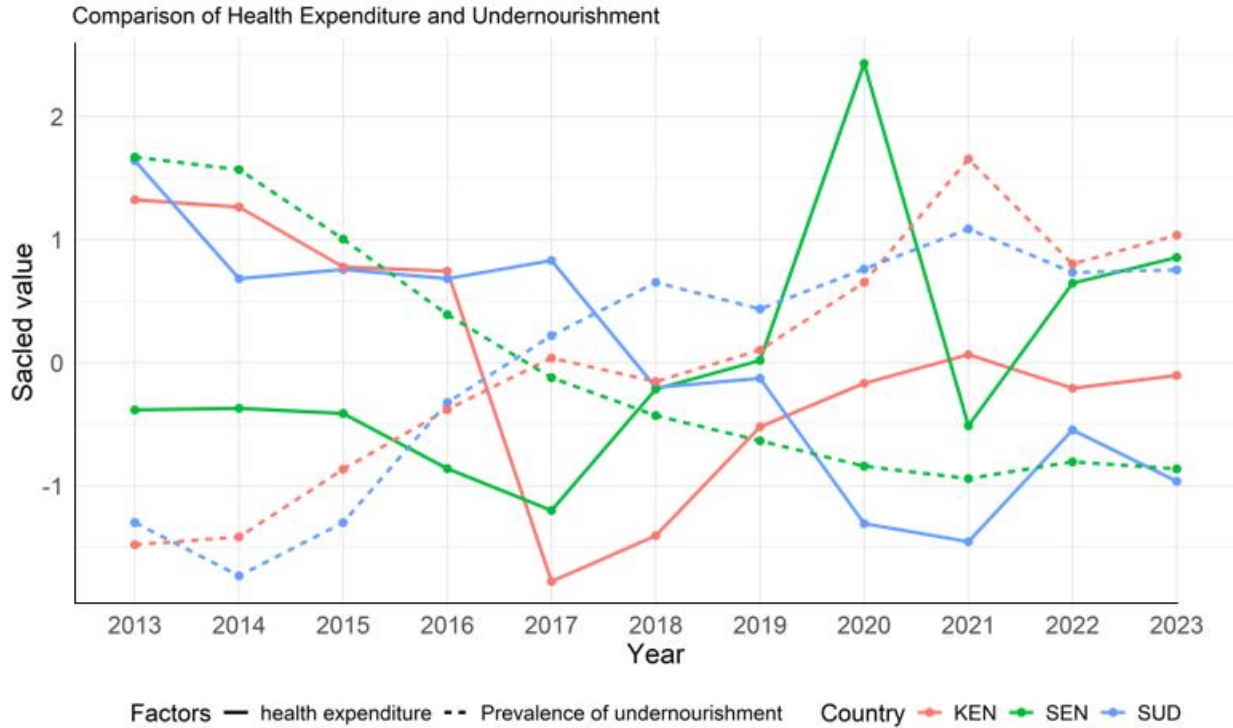


Figure 2. The association between the prevalence of undernourishment and health expenditure in Kenya (red), Senegal (green), and Sudan (blue) throughout the study period

2.3.2 Undernourishment and out-of-pocket (OP) healthcare expenditure

In Kenya, malnutrition is gradually declining but is still high at 23%, while OP expenditure also remains high but shows a slight decrease, indicating a weak negative correspondence where financial barriers still hinder broader development in health and nutrition. In Senegal, there was a strong positive correlation. Both undernourishment and OP expenditure are gradually declining, but are still high at 31 US\$ per capita, suggesting that better public health care and a reduction in the country’s financial problems are needed to support progress in nutrition and the poverty situation. Conversely, Sudan shows inconsistent malnutrition without reliable improvement and resolutely high OP expenditure, indicating systemic challenges in which financial constraints delay effective nutritional and health interventions Figure 3.

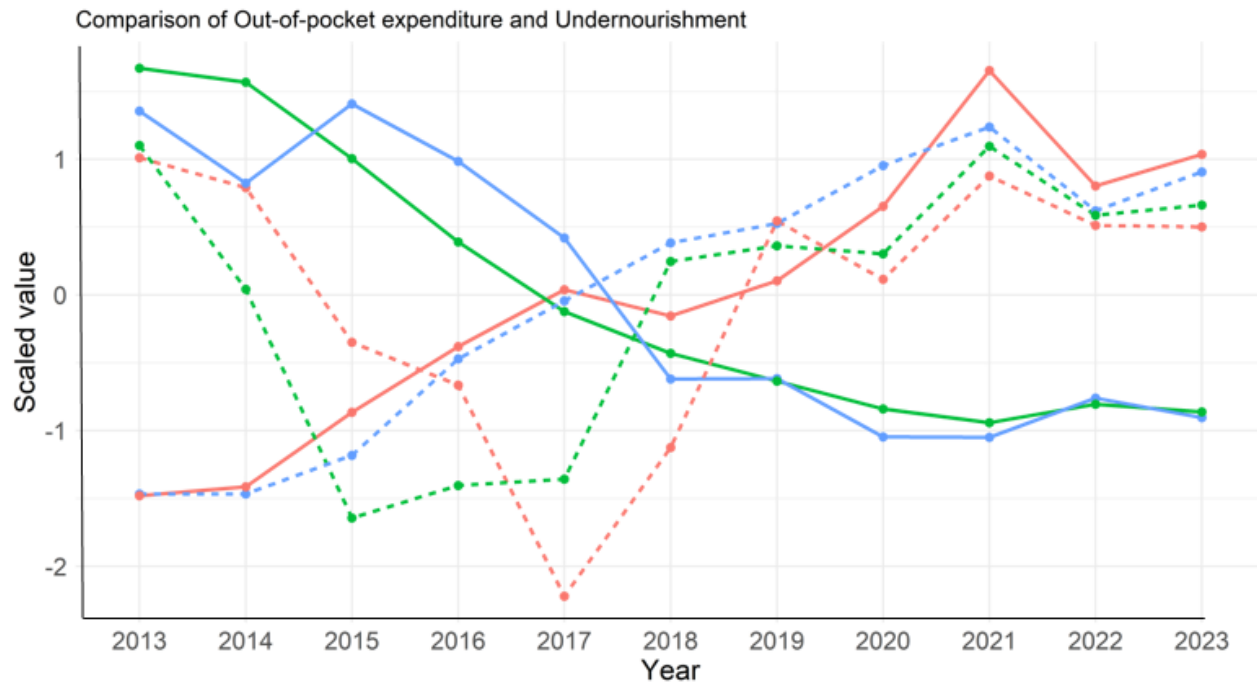


Figure 3. Demonstrates the relationship between undernourishment and out-of-pocket (OP) healthcare expenditure across Kenya (red), Senegal (green), and Sudan (blue) during the study period.

2.3.3 The prevalence of anemia and health expenditure

In Kenya, the prevalence in children (percentage of children aged 6-59 months) shows a regular deterioration but is still very high at 40%, while health expenditure is gradually increasing and is still very low at 4.5% of GDP, suggesting that greater investment in healthcare is needed to protect children from anemia. In Senegal, the prevalence of anemia in children has increased by 70%, and health expenditure has fallen by 4.5% of GDP. This shows that an efficient public health sector has failed to initiate a program that sustains spending while achieving better anemia prevention. The situation is similar in Sudan, where anemia prevalence in children is persistently high and fluctuates at 51%, while health expenditure is low at 4.7% of GDP. This shows that investment in healthcare is low, and the impact on anemia control is limited Figure 4.

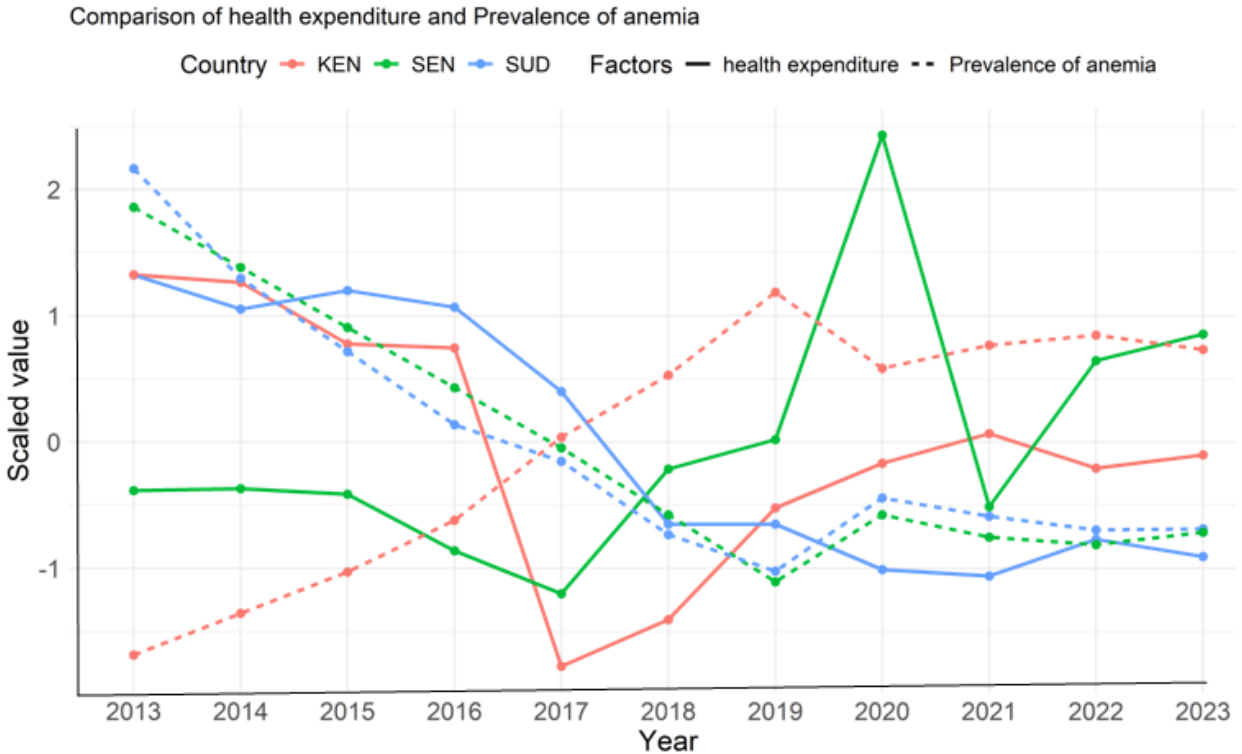


Figure 4. Observe the association between the prevalence of anemia and health expenditure across Kenya (red), Senegal (green), and Sudan (blue) over the study period.

2.3.4 The prevalence of hypertension and health expenditure

In Kenya, the prevalence of hypertension is rising slowly despite increasing health expenditures, suggesting that although investment in health care has increased, it may not be targeted at non-communicable diseases such as hypertension. A similar trend can be observed in Senegal; the prevalence of hypertension is rising slightly, while health expenditure is worsening. This indicates gaps in the reach of health interventions for the treatment of hypertension. In Sudan, the prevalence of hypertension showed considerable variation, with no clear trend, coupled with low health expenditure, reflecting the overall challenges in managing chronic conditions due to inadequate funding of health services and nutritional intervention strategies Figure 5.

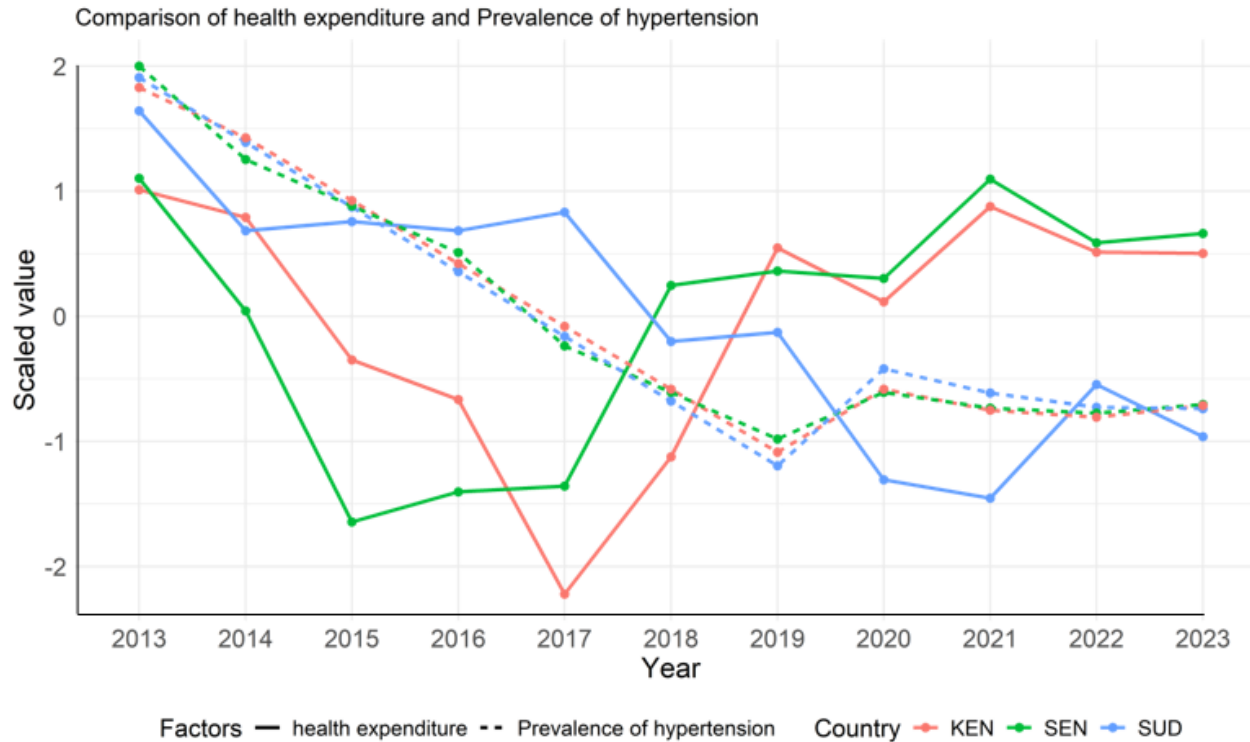


Figure 5. The link between the prevalence of hypertension among adults and hypertension prevalence in Kenya (red), Senegal (green), and Sudan (blue) throughout the study period.

The overview of Figures 2–5 in Kenya, Senegal, and Sudan shows several crucial correlations and emphasizes the need to provide people with essential and adequate food to protect them from non-communicable diseases. The high prevalence of malnutrition and anemia, particularly among vulnerable populations such as children, underscores large gaps in nutrition. These deficits, compounded by high out-of-pocket healthcare expenditures and inadequate public health funding in all the regions analyzed, lead to an urgent need for available and cost-effective nutritional solutions.

2.4 Baobab plant-based foods for prevention

Therefore, a systematic approach is needed to manage people’s lives, especially in Africa (Singh et al., 2023). A diet rich in various fruits and vegetables is one of the best methods for nutritional prevention (Rocha et al., 2024). A study conducted by Amiot et al. (2021) showed that plant-based foods are essential for providing nutritious ingredients for prevention (Amiot et al., 2021). Therefore, the discovery of a new plant-based resource for a healthy diet is necessary for nutritional interventions (Jensen & Orfila, 2021).

Baobab, a natural and available product with a nutrient-dense composition, offers a possible solution. The leaves and fruit pulp, which are rich in calcium and iron, could help combat iron deficiency anemia, whereas the fruit, with its high vitamin C content, improves iron absorption, making it particularly helpful in regions with a high prevalence of anemia.

2.5 Objectives

The main objective of this research was to discover a new plant resource with an adequate and healthy composition, such as the African baobab, to improve food security and contribute to nutritional intervention in rural and urban communities (different age groups in Sudan, Kenya, and Senegal).

We then propose a protocol for nutritional intervention using dried baobab leaves and fruit pulp powder to achieve the daily recommended reference values for proteins and minerals (K, Ca, Mg, Na, Fe, and Mn) for different target groups.

The specific objectives are:

- i. Determination of regional differences in nutrient content, such as protein, fat, ash, dry matter, pH, minerals (Na, Mg, K, Ca, Fe, Mn), total phenolic compounds (TPC), and total flavonoid compounds (TFC)
 - Baobab leaves were collected from two regions of Sudan, with three habitats (wetlands, plains, and mountains) in each region.
 - Dried baobab fruits are available in the rural and urban markets of Sudan, Kenya, and Senegal.
- ii. Estimation of the amount of dried baobab leaves and fruit pulp powder required to meet the daily protein and mineral requirements of different age groups of the target population was based on the daily reference values recommended by the European Food Safety Authority.

2.6 Significance of Study

This study fills critical knowledge gaps by exploring nature as a food source through regional and habitat-specific differences in baobab product composition. By linking these differences to health indicators and poverty that impact people's lives, this study provides evidence for targeted nutrition

interventions. These findings will recommend strategies to improve the contribution of baobabs to public health, food security, and economic development in Sudan, Kenya, and Senegal.

3 Literature Review

3.1 Food insecurity and poverty related to human life

Food insecurity has become a public concern as it affects many people worldwide. This is referred to as food scarcity, lack of essential nutrition, and poor global nutrition. The complexity of food security, hunger, food insecurity, and other indicators related to human needs and health requires a unique coping strategy and advanced management as a resilience system to achieve Sustainable Development Goals related to human food sources Figure 6. Furthermore, food insecurity is related to a nutrient deficiency of 89% (Lopes et al., 2023). As called for by the 2030 Agenda for Sustainable Development, food insecurity, hunger, and malnutrition must be addressed internationally. Health policymakers and nutritionists are in a position to contribute to solving the existing problems (Xie et al., 2021). At the regional level, sub-Saharan African countries have drawn the most attention to food security, including Sudan (Al Sharjabi et al., 2024). According to the Integrated Food Security Phase Classification (IPC), Sudan has a high rate of food insecurity, which is considered critical (Anwar et al., 2023). In addition, low health expenditures and the prevalence of poverty exacerbate nutritional deficiencies, especially among the rural population, both locally and internationally (Giller et al., 2021).

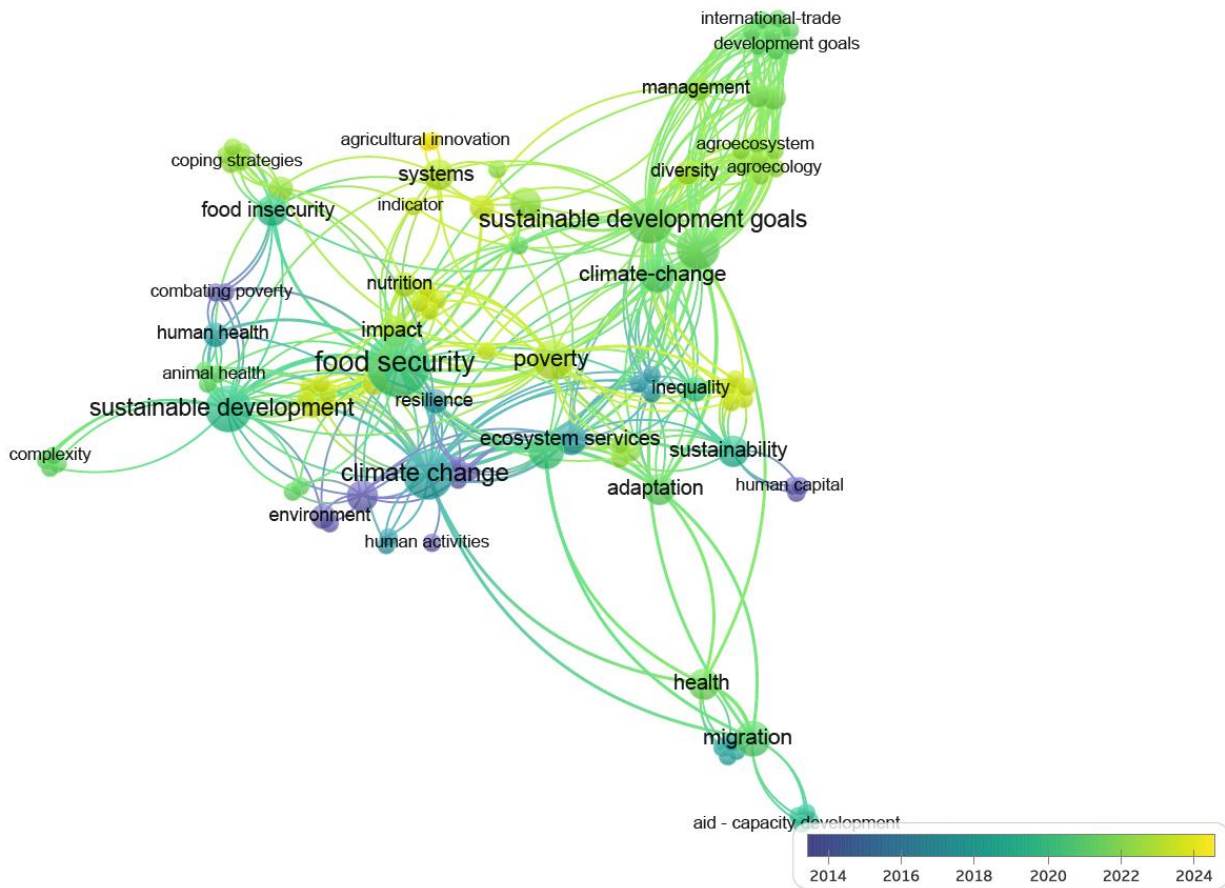


Figure 6. The complexity between food security, hunger, food insecurity, and other human needs and health indicators. Source: Data imported from the Web of Science database and analysed using VOSviewer software.

Poor and starving people are less resilient to stress and disasters and rely on ordinary resources to recover from disasters. Moreover, considering that the health of local individuals is important, policies need to be implemented to improve food accessibility in Kenya (Oluoko-Odingo, 2011).

Food insecurity is a persistent problem in Kenya, affecting many population groups, such as children, the elderly, and the disadvantaged rural and urban population, especially low-income families. Differences in vulnerability are mainly related to sociodemographic characteristics and household income. Current policies aimed at promoting adequate access to food play an important role in addressing food insecurity and reducing its impact on various population groups (Korir et al., 2021). Rural regions in Senegal are highly affected and categorized by poverty and food insecurity due to current environmental problems, such as drought. A cross-sectional study conducted in 2018 analysed food accessibility and security in households and villages. The results

showed that 64% of people were categorized as severely food insecure. Accordingly, immediate food aid can alleviate acute needs; however, long-term strategies are required to sustain food security (Akpaki et al., 2020). Another study conducted in Senegal examined the relationship between childhood food insecurity and non-communicable diseases such as hypertension and diabetes, using the Community Childhood Hunger Identification Project (CCHIP) survey. More than half of the 54 participants reported experiencing food insecurity as a child and were subsequently diagnosed with hypertension or diabetes. These conclusions emphasize the importance of developing food access tracking tools that could be used to update interventions to reduce food insecurity and the prevalence of chronic diseases in Senegalese communities (Walker et al., 2020). Food insecurity remains a major problem for many households in Sudan. (Fadol et al., 2024) reported that based on the analyses of the Food Consumption Score (FCS) used in Red Sea State of Sudan to assess the stockholder situation, 23.8% of households were food secure and 76.2% were considered food insecure. In this context, more than 20.3 million Sudanese, about 42% of the total population, are affected by food insecurity due to the ongoing conflict and suffer from malnutrition, especially among children (Homeida, 2023; Noorallah et al., 2024). Sudanese women often suffer from a lack of essential microelements such as iron during the first trimester of pregnancy (Abbas et al., 2023).

3.2 Nutrient contents of baobab fruits and leaves from different regions

The baobab plant *Adansonia digitata* L. is a remarkable example of enrichment of the human diet with important elements and nutrients (Stadlmayr et al., 2020). Baobab is an underutilized species with important edible parts that play a crucial role in food security and protect people from malnutrition (Wiehle et al., 2014). The fruits and leaves of baobab are known for their nutritional and pharmacological value, and are widely used as food and for medicinal purposes in Africa (Sanchez et al., 2010; Zahrau Bamalli, 2014). Variability in the composition of baobab products is influenced by regional and habitat-related factors. Gebauer et al. (2016) reported that baobab leaves from arid regions tend to have higher mineral content, indicating nutrient-rich but water-scarce soils. Similarly, Jäckering et al. (2019) found significant differences in fruit composition according to habitat type, with coastal regions producing fruit with higher sodium content due to saline soils, whereas fruits from inland regions were richer in K and Mg.

Regional and habitat-specific differences play a decisive role in the nutrient composition of baobab trees. Sudan, Kenya, Senegal, and other African countries represent different ecological zones with unique environmental conditions Figure 7.

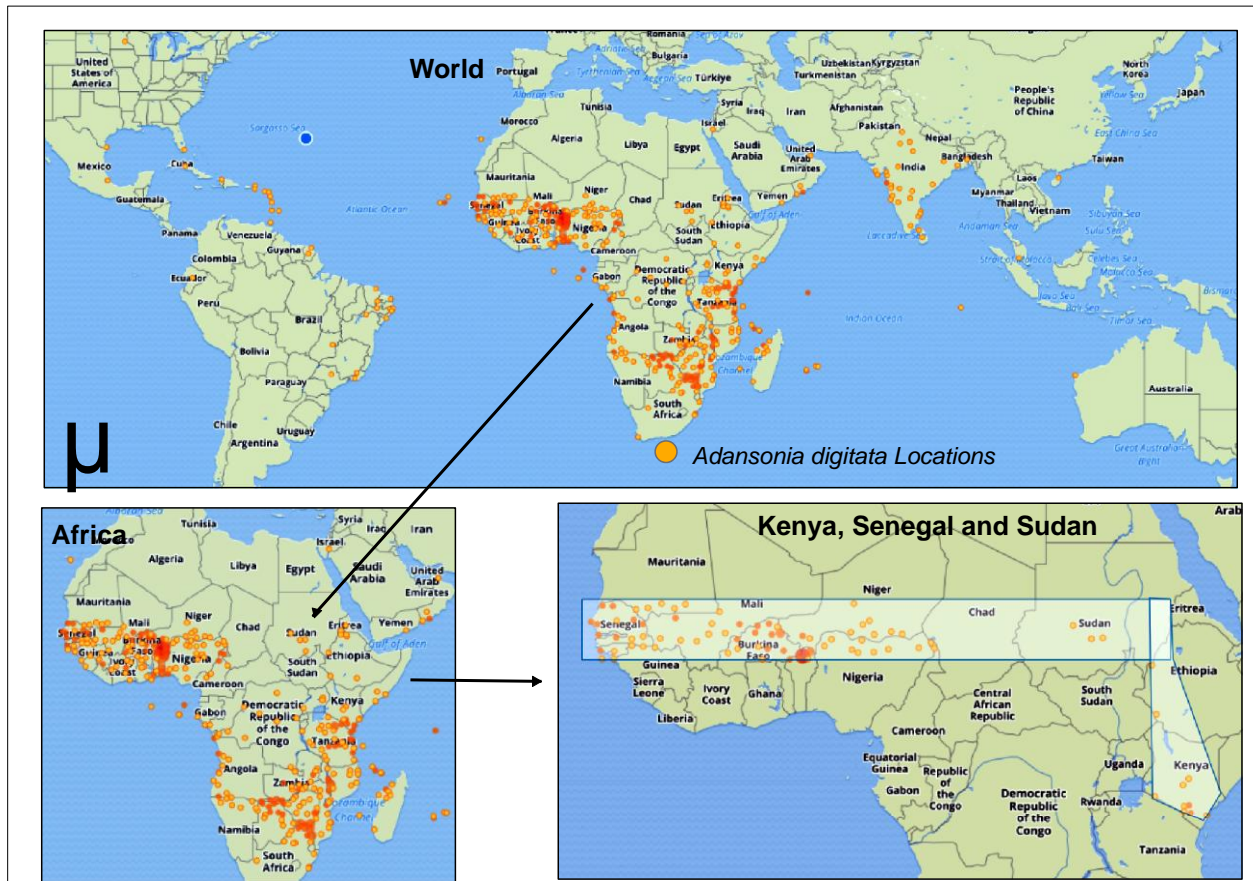


Figure 7. Distribution of *Adansonia digitata* in various regions and habitats in Africa. Source: Adapted from GBIF (Global Biodiversity Information Facility).org (15 November 2024) GBIF Occurrence Download <https://doi.org/10.15468/dl.49aq2t>.

3.2.1 Baobab as a natural food in Sudan

Baobab trees grow in the humid and dry regions of tropical zones (Donatien Kaboré, 2011). In Sudan, baobab trees are mainly distributed in the southeastern region of the country on sandy, loamy, and rocky soils, typically in savannahs with abundant short grasslands and the mountainous landscape of central Sudan (El Amin, 1990; Wiehle et al., 2014). Baobab trees are widespread in the extremely dry regions of Darfur and Kordofan and thrive mainly along

wadis, where water accumulates during the rainy season (El Amin, 1990). Baobab is a multipurpose tree that provides a variety of products with various uses for food and medicinal purposes (Rahul et al., 2015; Wickens, 1982). It also provides numerous products, such as fruit pulp, seeds, and leaves, which are mainly used as natural foods and consumed daily by rural people in Africa when food is scarce (Habte & Krawinkel, 2017; Sidibe, 2002).

3.2.2 Baobab as a natural food in Kenya and Senegal

In Kenya, baobabs grow in six different geographical locations, including inland and coastal areas, and the nutritional composition varies across locations. In addition, fruit pulp is a reputable source of minerals and vitamins, especially vitamin C, K, and calcium, which could play a key role in combating food insecurity (Stadlmayr et al., 2020).

In Senegal, baobab is distributed across three agro-ecological regions, revealing important biochemical differences between morphotypes, nutrient variations, and variations in biochemical compounds, emphasizing the potential of the tree for food security and nutritional challenges (Sanogo et al., 2013). Although the baobab tree is native and widespread on the African continent, its field of research has international significance and is associated with many countries, such as Germany, England, and Denmark Figure 8.

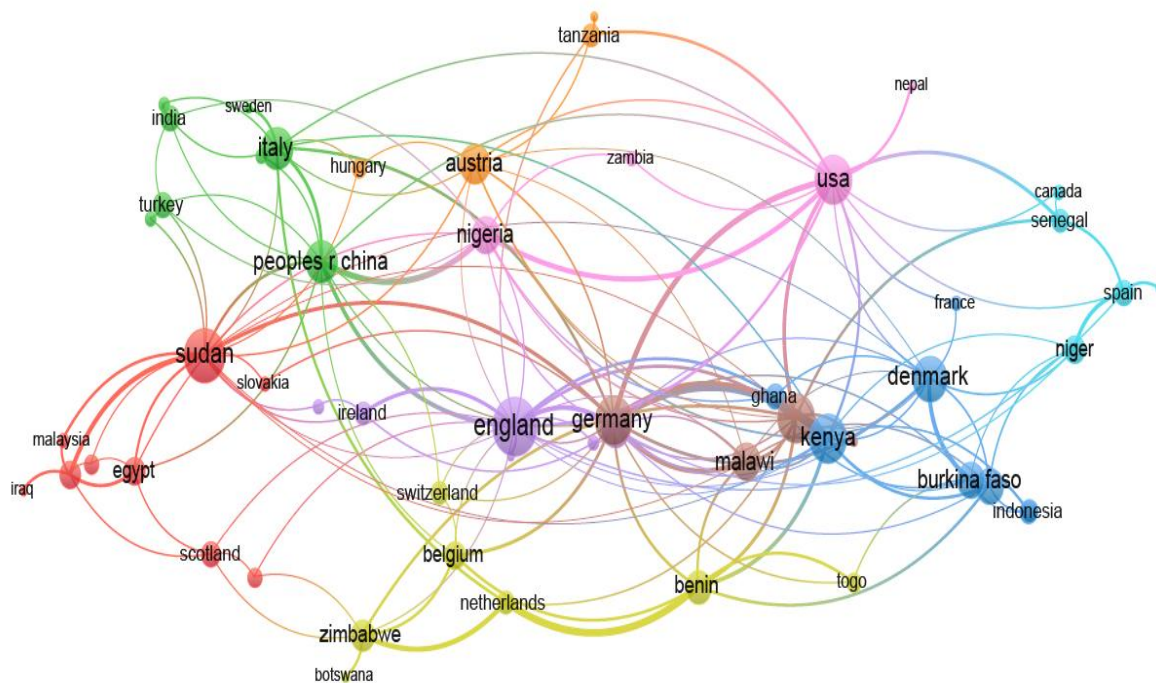


Figure 8. The most important countries contributed to the baobab research field. Source: Data imported from the Web of Science database and analysed using VOSViewer software.

3.3 African baobab products as a healthy diet

A healthy diet that contains all essential nutrients in sufficient quantities is considered one of the most effective ways to meet our energy needs and prevent noncommunicable diseases (Amiot et al., 2021). The most important macroelements for human nutrition are (Ca), potassium (K), sodium (Na) and magnesium (Mg), while iron (Fe), copper (Cu), zinc (Zn) and manganese (Mn) are categorized as trace elements (Dobrowolska-Iwanek et al., 2022). Therefore, an adequate supply of these elements can help maintain human health (Chapple et al., 2007; Enwonwu et al., 2002). Macroelements such as calcium are crucial for the development of the immune system. A drop in Ca ion levels leads to immunodeficiency (Donatien Kaboré, 2011). Additionally, insufficient Ca intake leads to a negative Ca balance in the human body, which can lead to osteoporosis and parathyroid hyperplasia (El Amin, 1990). The metabolic reactions of the human body depend mainly on magnesium levels, and 73.8% of women worldwide are affected by magnesium deficiency, especially at fertile age (Wiehle et al., 2014). There is a significant correlation between Mg deficiency and sleep quality in older adults; therefore, adequate Mg intake in the daily diet can mitigate this problem (Rahul et al., 2015). Connective tissue diseases are also associated with Mg

calcium (Ca), phosphorus (P), potassium (K), and essential chemical components such as proteins, lipids, sugars, and fiber (Chabite et al., 2019) (Table 1). The pulp or powder of the fruits of *Adansonia digitata* can provide 40 g of Vitamin C, which corresponds to 54–100% of the recommended dietary intake and is ten times higher than that of oranges (Namratha & Sahithi, 2015). According to Williamson (2011), the dried fruit pulp of *Adansonia digitata* contains approximately 3–499 mg/100 g of vitamin C. *A. digitata* fruits serve as a source of food and beverages (Caluwé et al., 2010). Baobab fruit pulp powder can be used as a raw material for various types of beverages and other foods, such as juices, jams, and ice cream (Gebauer et al., 2002). Baobab fruit or pulp powder can also be used as a milk-clotting agent. Most commonly, pulp or fruit powder is used for seasoning in traditional dishes (Ajayi, 2003).

The assessment of baobab fruit variance/characteristics and nutritional quality was conducted with the main objective of promoting and providing information on baobab trees that reflect attractive characteristics for different uses. However, some chemical properties, such as total sugar, ash content, and vitamin C content, were also determined. In addition, the protective effect of the African baobab fruit pulp on the oxidative effects induced by a high-fat diet was investigated in rats. Interestingly, the results showed that baobab fruit pulp or powder can be consumed as an efficient food for natural therapy and the inhibition of hyperlipidemia-associated health abnormalities by promoting the activities of antioxidant enzymes (Althwab et al., 2019).

Dried baobab fruit pulp (DBFP) is consumed in several East African countries (Gebauer et al., 2014). Important macroelements, such as potassium (K), magnesium (Mg), calcium (Ca), and high amounts of vitamin C, have been found in the fruit pulp of this tree (Assogbadjo et al., 2021). The crude protein and fat contents are high in baobab seeds and fruits, in addition to a significant amount of antioxidant compounds (Thompson et al., 2024). DBFP is used to produce nutritious beverages, healthy snacks, and sweets (Wiehle et al., 2014). In addition, it has been introduced to improve the nutritional value of various products, such as dark chocolate drinks and ice cream, as well as the quality of baked goods (Dossa et al., 2023; Monteiro et al., 2023; Sakr et al., 2023). BDFP is considered an important nutrient for the human body because of its high carbohydrate, iron, and zinc (Dobrowolska-Iwanek et al., 2022; Namratha & Sahithi, 2015).

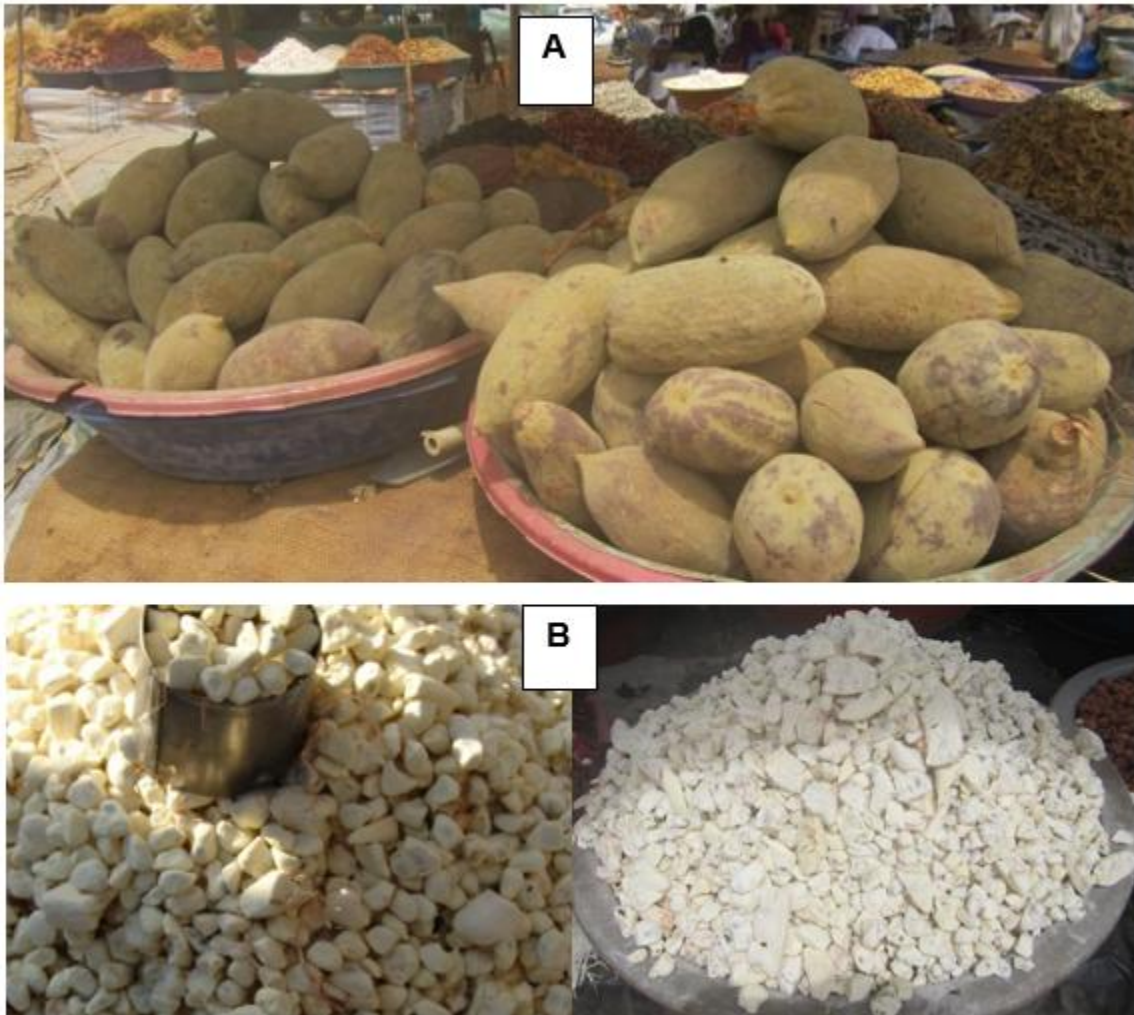


Figure 10. (A) Dried baobab fruits, and (B) Dried baobab fruit pulp from Sudan.

Source: Author (Ahmed, Mozzon, Shaikh, et al., 2024).

Table 1. Mean values of various nutritional components in dried baobab fruit pulp.

Parameters	Mean value	References
Moisture (loss on drying) (g/100 g)	11.5 7.66 10.4 13.5	(Soloviev et al., 2004; Wehmeyer, 1966). (Gurashi et al., 2016). (Osman, 2004). (Ibrahima et al., 2013).
Protein (g/100 g)	5.3 3.2 11.72 2.5	(Murray et al., 2001; Wehmeyer, 1966). (Osman, 2004). (Gurashi et al., 2016). (Ibrahima et al., 2013).
Fat (g/100 g)	1.93 0.3 0.5	(Gurashi et al., 2016) (Osman, 2004) (Ibrahima et al., 2013)
Ash (g/100 g)	4.9 4.73 4.5 5.3	(Kalenga Saka & Msonthi, 1994; Murray et al., 2001; Nour et al., 1980; Obizoba & Amaechi, 1993; Wehmeyer, 1966) (Osman, 2004). (Gurashi et al., 2016) (Ibrahima et al., 2013)
Fiber (g/100 g)	13.7 5.4 4.73 17.2	(Kalenga Saka & Msonthi, 1994). (Osman, 2004). (Gurashi et al., 2016). (Ibrahima et al., 2013)
Total carbohydrate (g/100 g)	74.9 76.2 69.72	Murray et al., (2001); Wehmeyer, (1966). Osman, (2004) Gurashi et al., (2016) Ibrahima et al., (2013)
Sodium (mg/100 g)	23.5 27.9 5.9	Gurashi et al., (2016). Osman, (2004). Ibrahima et al., (2013)
Calcium (mg/100 g)	302 555 295	Nour et al., (1980); Osman, (2004). Osman, (2004) Ibrahima et al., (2013)
Potassium (mg/100g)	1794 1240 608 2728	(Kalenga Saka & Msonthi, 1994; Sena et al., 1998). Osman, (2004) Gurashi et al., (2016) Ibrahima et al., (2013)
Phosphorus (mg/100g)	106 57.5 116	Kalenga Saka and Msonthi, (1994); Nour et al., 1980; Obizoba and Amaechi, (1993). Gurashi et al., (2016)
Magnesium (mg/100g)	543.3 90 224	Gurashi et al., (2016) Osman, (2004) Ibrahima et al., (2013)
Vitamin C	227 138	Gurashi et al., (2016) Ibrahima et al., (2013)

Source: (Ahmed, et al., 2024).

3.3.2 Baobab leaves

The second most important part of the baobab tree is the fresh leaves Figure 11 which are often cooked like spinach but are also processed and dried. Baobab leaves are often pulverized and used as a sauce. In addition, available data and many studies show that baobab leaves can contain 13–15% protein, 6–7% carbohydrate, 4–10% fat, and approximately 11% crude fiber in dry matter, with an ash content of 16%. The energy values are well-known and are between 1180 and 1900 KJ/1 g. Earlier studies have reported that the ascorbic acid content of baobab leaves is as high as this amount 856.8 mg/g. Baobab leaves also have high contents of vitamin A, vitamin B, and amino acids (Sidibe et al., 1998). Nevertheless, the use of baobab leaves remains limited at the international level. Baobab leaves are recognized as a considerable source of proteins and minerals, especially (Mg) magnesium, (Mn) manganese, (Ca) calcium and (Fe) iron (Kayode et al., 2018).

The baobab tree has shown a large amount of antiviral and antimicrobial activity, such as methanolic extracts obtained from the baobab root, bark, and leaves. The alkaloid “adansonin,” which is extracted from the bark, is used to treat malaria and other fevers (Namratha V & Sahithi P, 2015). Adegoke et al. (2017) reported that the medicinal benefits of the baobab tree are experimentally approved; for example, an in vitro test to investigate the effects of methanolic extracts of baobab leaves on the chemical component of sodium arsenate-induced intoxication in rat samples. At administered doses of 250 mg and 500 mg, they concluded that the methanolic extract of baobab leaves has the greatest potential to reduce the effects of sodium arsenate poisoning and provide good preservation in arsenicosis.

Traditionally, baobab leaf powder has been added to sauces made from various ingredients, such as onions, tomatoes, salt, and dried fish, and the pulp of the baobab fruit has been added to a porridge made from maize. Both recipes were developed for consumption by children aged 6-23 months in northern Benin (Malikath Bankole et al., 2024). Baobab fruits and fresh young leaves, and seeds are known for their nutritional and pharmacological value and are widely used in Africa as food and for medicinal purposes, and the powder of baobab leaves is also used as an anti-stress agent. They are mainly used to treat fatigue, insect bites, guinea worm symptoms, external pain, and dysentery. The pulp and seeds of the baobab tree were used to treat stomach diseases. The extracted baobab seed oil is used for inflamed gums and diseased teeth (Gebauer et al., 2002;

Zahrau Bamalli, 2014). According to Sanchez et al. (2010), baobab products have been known for many centuries and are frequently consumed because of poor nutrition and low income in African societies. Baobab leaves are cooked as soup by locals in northern Nigeria (Yazzie et al., 1994). In Malawi, baobab leaves are boiled in potash (Williamson, 2011). In Zimbabwe, the rural population consumes fresh baobab leaves as an alternative to leafy vegetables (Dovie, 2000). In Mali, the leaves are used as a sauce mixed with various local foods such as okra, onions, meat, fish, and other foods (Nordeide, 1996).



Figure 11. Baobab fresh leaves collected from plain land site, and mountain site, Sudan. Source: Author.

4 Materials and Methods

4.1 Sample Site and Collection

4.1.1 Baobab Leaves samples

Baobab trees were mainly distributed in two different regions in Sudan: North Kordofan (KR) and Blue Nile (BN). In addition, *Adansonia digitata* trees are found in different areas, including sloping areas such as mountains (El Amin, 1990). Samples of a mixture of young and old fresh leaves were collected in Sudan Figure 12 between July 15, 2022, and September 15, 2022. Two regions were covered: the Blue Nile in southeastern Sudan (coordinates: 11°15'00" N and 34°10'00" E) and North Kordofan, an arid zone in central Sudan (14°68'33" N and 29°93'33" E), as shown in Figure 13. Three habitats were selected for each region: mountain (M) Figure 14, wetland (W) Figure 15 and plain land (P) Figure 16. QGIS 3.20.1 software was used to create maps showing the areas where the baobab leaf samples were collected. Each area covered approximately 1500 km². Ten trees were selected at each site, and two samples of fresh baobab leaves were collected per tree, totalling 3 kg of leaves per tree, to ensure representative sampling. The collected baobab leaves were dried in a shed at a room temperature of 25°C to preserve their nutritional properties and then packed in transparent, fully closed, and sealed polyethylene bags for analysis. Eighteen samples weighing approximately 500 g each were taken to the laboratory of the Food Science Institute, University of Debrecen, Hungary, for nutritional values analysis.

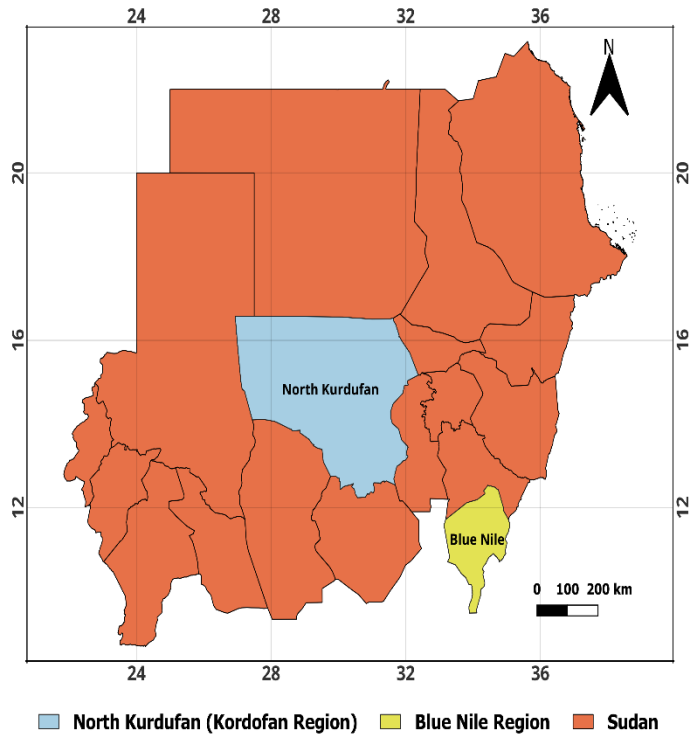


Figure 12. Sudan map: Source, QGIS 3.20.1 software, (Ahmed A.E. M. et al., 2024).

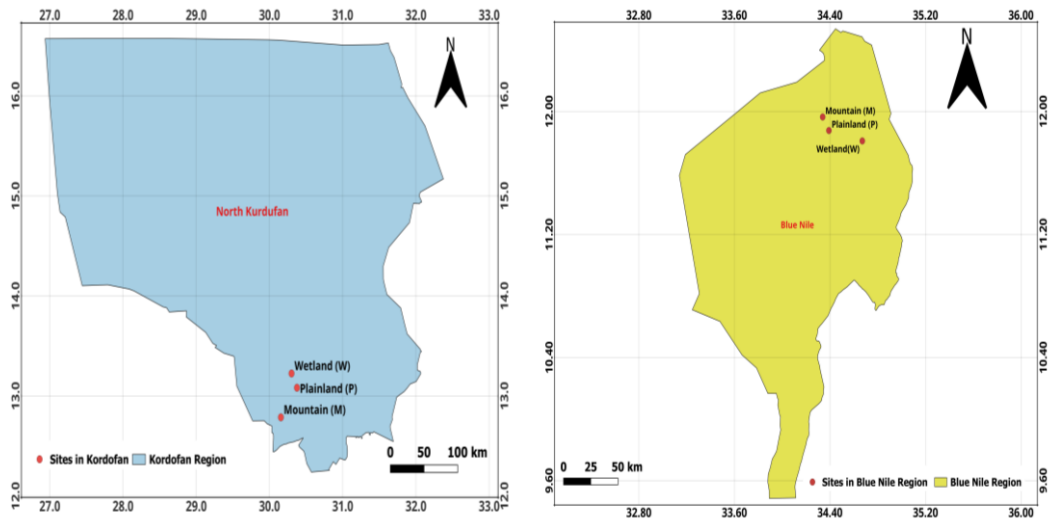


Figure 13. Kordofan and Blue Nile regions. Source: QGIS 3.20.1 software, (Ahmed et al., 2024).



Figure 14. Baobab trees in mountain site (M), North Kordofan, Sudan. Source: Author.



Figure 15. Baobab trees in a wetland site (W), North Kordofan, Blue Nile, Sudan.
Source: Author.



Figure 16. Baobab trees in a plain land site (P), North Kordofan, Blue Nile, Sudan. Source: Author.

4.1.2 Baobab dried fruit source and collection

The samples of dried baobab fruit pulp (DBFP) were collected in three different African countries: Sudan, Kenya, and Senegal. Rural and urban markets were targeted, and the DBFPs were collected (i) from the rural market of El Obeid in North Kordofan in Central Sudan with coordinates 14°68'33" N, 29°93'33" E; (ii) from the rural market of Garissa in the northeastern province of Kenya with coordinates 0° 27' 14.99" " N, 39° 39' 17.99"" E; and (iii) from the urban market of Mombasa in southeastern Kenya with coordinates of -4.04348 N and 39.66821 E. DBFP samples from Senegal were ordered from the Hungarian market using the following data Table 2.

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. Netherlands. 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.	

4.2 Sample Preparation

The dried baobab leaves were manually cleaned of all foreign matter and air-dried. The samples were then ground using an electric mill with a mesh size of 10 µm. The resulting powder was stored in labeled hygienic plastic containers until further use. The dried baobab fruits from Kenya, Sudan, and Senegal were stripped of all plant matter. A Retsch PM100 planetary ball mill was used to separate the pulp and seeds of baobab fruit. The DBFP powder was homogenized and packaged for analysis Figure 17.

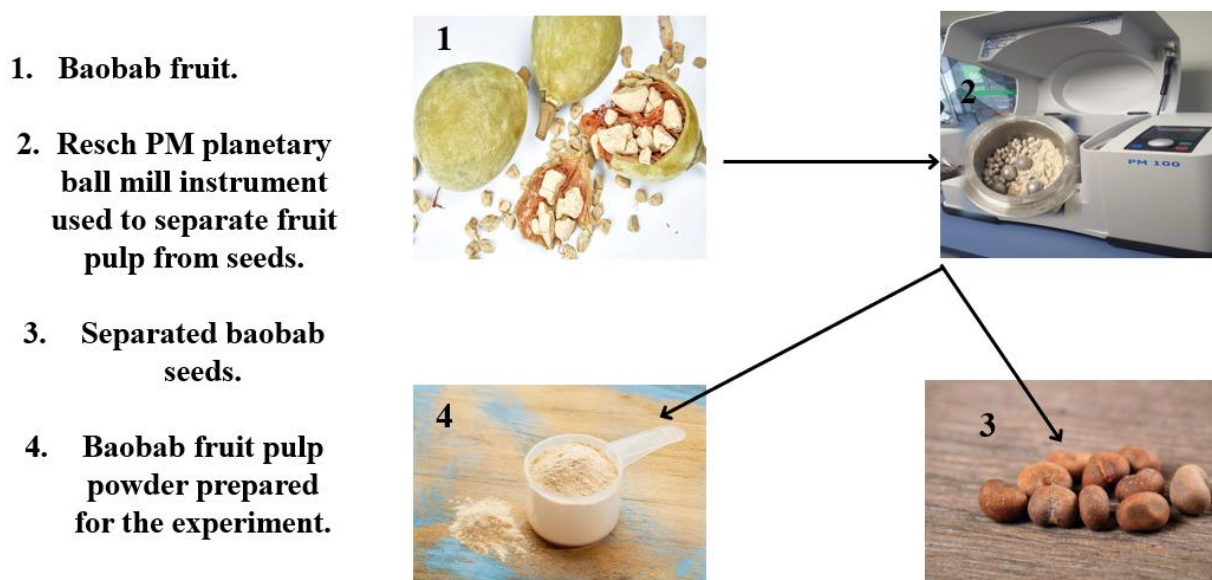


Figure 17. The method used in the sample preparation of dried baobab fruit.

4.3 Mineral Analysis

Mineral analysis of the baobab leaf and dried fruit pulp powder was conducted in the laboratory of the Institute of Food Science at the University of Debrecen using inductively coupled plasma–optical emission spectrometry (ICP-OES). An iCAP 6300 instrument (Thermo Fisher Scientific, Waltham, MA, USA) was employed for elemental analysis. One gram of dried baobab leaf or fruit pulp sample was ashed overnight at 550 °C. The resulting ash was dissolved in 30 mL of 3 M nitric acid and left to stand for 72 hours to ensure complete mineral dissolution. The solution was then thoroughly mixed and filtered to eliminate particulate impurities. For digestion, 10 mL of 65% HNO₃ (Scharlau Chemie, Spain) was added to each sample, followed by overnight pre-digestion at 60 °C. Subsequently, 3 mL of 30% H₂O₂ (Merck, Germany) was introduced, and digestion was carried out at 120 °C for 90 minutes. After digestion, the final volume was adjusted to 50 mL with ultrapure water.

Samples were introduced into the ICP-OES using a peristaltic pump system. The instrument operated in both axial and radial detection modes, ensuring accurate determination of a broad range of elements across multiple wavelengths. The optimized plasma operating conditions were as follows: plasma gas flow rate of 10 L/min, auxiliary gas flow rate of 0.1 L/min, nebulizer gas flow rate of 1.14 L/min, radio frequency power of 1200 W, viewing height of 5 mm, and flushing gas flow rate of 0.13 L/min.

Calibration was performed using mono-element standard solutions (1000 mg/dm³, Merck and BDH) and multi-element standards (100 mg/dm³, Spectrascan, Teknolab, Norway), ensuring precision and reproducibility. The analytical procedure and instrumental parameters applied were in accordance with (Kovács et al., 1996), and are aligned with protocols validated by the International Plant-Analytical Exchange (IPE-245) proficiency testing scheme coordinated by Wageningen Evaluating Programs for Analytical Laboratories (WEPAL). This scheme uses unmodified natural reference materials, such as *Salix alba* (willow wood), to establish consensus values through inter-laboratory comparisons and to benchmark analytical quality.

Quantification of mineral elements, including Ca, Mg, K, Na, Fe, and Mn, was carried out using the acid-digested solution. All results are expressed in mg/100 g DM (milligrams per 100 grams of dry matter), indicating the concentration of each element relative to the sample's dry weight.

Reporting on dry matter eliminates the influence of variable moisture content, thereby ensuring standardized, accurate comparisons across all analyzed samples.

4.4 Proximate composition

4.4.1 Dry matter determination (ISO 6496:2001)

The dry matter content was determined by drying the BLs and DBFP in a drying oven at $103 \pm 2^\circ\text{C}$ to a constant weight and homogenizing them so that the water content was completely removed. The difference in weight before and after drying was used to calculate dry matter as a percentage of the original sample weight. This method ensures accurate quantification of the total solid content of the sample.

4.4.2 Nitrogen and crude protein content (ISO 5983-2:2009)

The nitrogen content in the BLs and DBFP was determined using the Kjeldahl method, in which the sample was digested with strong sulfuric acid and a catalyst copper to convert organic nitrogen into ammonium sulfate. The solution was then alkalized, and ammonia was distilled into a boric acid solution. Ammonia was titrated with standardized acid to determine the nitrogen content. Crude protein content was calculated by multiplying the nitrogen value by a conversion factor of 6.25, which establishes a general nitrogen-to-protein ratio.

4.4.3 Crude fat content (ISO 11085:2015)

The crude fat content in BLs and DBFP was determined using solvent extraction methods, such as Soxhlet extraction. The sample was pre-dried and finely ground to allow for good extraction. An organic solvent (petroleum ether) was used to dissolve fat. The solvent was evaporated, and the residue (crude fat) was weighed. Fat content was expressed as a percentage of the dry weight of the sample.

4.4.4 Crude ash content (ISO 5984:2022)

The crude ash content of BLs and DBFP was determined by heating the sample in an oven at $550 \pm 25^\circ\text{C}$ until all organic matter was completely burned off. Only the minerals (ash) remained and were allowed to cool in a desiccator and weighed. Ash content was expressed as a percentage of the dry weight of the sample, reflecting the total inorganic mineral content.

4.4.5 pH value determination (Hungarian standard MSZ-08-0206-2:1978)

The pH was measured by mixing homogenized BLs and DBFP with distilled water (typically in a mass ratio of 1:10) and allowing the suspension to stabilize. The mixture was allowed to equilibrate to ensure the proper dissolution of the active pH components. A calibrated pH meter was used to measure the pH directly.

4.5 Determination of antioxidant content

Five grams of BL or BF powder were diluted to 50 ml with a mixture of methanol/water 80:20 (v/v) and allowed to stand for 6 h. The samples were then filtered through folded filter paper (grade 292; Sartorius Stedim Biotech GmbH, Göttingen, Germany). The principle of this method is that phosphotungstic and phosphomolybdic acids contained in the Folin-Ciocalteu reagent oxidize phenolic compounds, resulting in a blue-colored solution. The color intensity was proportional to the concentration of phenolic compounds. The absorbance of the mixtures was measured using a spectrophotometer (Evolution 300 LC, Thermo Electron Corporation, England) at a wavelength of 760 nm against a mixture of methanol and distilled water (80:20). A gallic acid stock solution was used to prepare the calibration solutions. The chemicals used were 3,4,5-trihydroxybenzoic acid (Alfa Aesar GmbH & Co. KG, Karlsruhe, Germany), sodium carbonate (Sigma-Aldrich Chemie GmbH, Germany), methanol (Scharlab S.L., Spain), and Folin-Ciocalteu reagent (VWR International S.A.S., France). The results of total phenolic content (TPC) were expressed as mg gallic acid equivalent (GAE)/100 ml (Jiménez et al., 2010; Vida, 2021; Singleton et al., 1999).

A spectrophotometric method was used to determine the flavonoid content. The absorbance of the pink-colored complex formed during the analysis was measured against a blank solution at 510 nm using a spectrophotometer (Evolution 300 LC, Thermo Electron Corporation, England). A catechin stock solution was used to prepare calibration solutions. The chemicals used were catechin (Cayman Chemical Company, USA), aluminum chloride (Scharlab S.L., Spain), sodium nitrite (Scharlau Chemie S.A., Spain), sodium hydroxide (Sigma-Aldrich Chemie GmbH, Germany), and methanol (Scharlab S.L., Spain). The total flavonoid content (TFC) was expressed as mg catechin equivalent (CE)/100 ml (Hong & Kim, 2010; Vida, 2021). Nine replicates were performed for all the above studies.

4.6 Estimation of baobab leaves and fruit intakes (BLI and BFI)

The estimated amount of BLI or BFI to be included in the diet of the target groups (children 1-3 years, C1; children 4-6 years, C2; children 7-10 years, C3; children 10-18 years, C4; adults \geq 25 years, AD; pregnant women, PQ; lactating women, LQ) was calculated as follows:

$$BLI, BFI(g/day) = \left(\frac{DRV}{\alpha \times ANB} \right) \times 1000$$

where DRV is the dietary reference value recommended by the European Food Safety Authority for a specific nutrient (Table 3), ANB is the average amount of a specific nutrient in BLI or BFI, and α is the in vitro bioavailability value. According to (Habte et al., 2021), the values of α for Ca and Mg were 31.5% and 59%, respectively.

Table 3. Dietary reference values recommended by the European Food Safety Authority.

Group/Age	Potassium (mg/day)	Calcium (mg/day)	Magnesium (mg/day)	Sodium (g/day)	Protein (g/kg/day)	Iron (mg/day)	Manganese (mg/day)
Children (1-3 years)	800	450	170	1.1	0.66	7	-
Children (4-6 years)	-	800	230	1.3	0.66	7	-
Children (7-10 years)	-	800	230	1.7	0.66	11	-
Children (10-18 years)	3,500	1,150	B: 300, G: 250	2.0	0.66	B: 11, G: 13	-
Adults (\geq 25 years)	3,500	750	M: 350, W: 300	2.0	0.83	M: 11, W: 16	3
Pregnant Women	3,500	750	300	2.0	1 g (1 st *), 9 g (2 nd *), 28g (3 rd *)	16	3
Lactating Women	4,000	750	300	2.0	19 g (FI), 13 g (AF)	16	3

1st trimester, 2nd trimester, 3rd trimester. “B”: Boys, “G”: Girls, “M”: Men, “W”: Women, “-” value is not available or not applicable. “FI”:(First 6 months), “AF”:(After 6 months). Source: (EFSA, 2017; “Scientific Opinion on Dietary Reference Values for Manganese,” 2013).

4.7 The bibliometric and statistical analysis

VOSviewer software (v 1.6.18), advanced by the Centre for Science and Technology Studies (CWTS) at Leiden University, was used to conduct a bibliometric examination and produce

visualizations of scientific data used in this research. Data analysis was performed using the programming environment R (version 3.6.1, R Core Team). Descriptive statistics (mean and standard deviation) were calculated for all nutrients across different habitats and regions. Analysis of variance (ANOVA) and Tukey Honest Significant Difference (HSD) post hoc tests were performed to test for differences in BL and DBFP nutrients between habitats. A two-sample t-test was performed to test for differences in BL nutrient levels between the Sudanese regions. A reduction of variables was achieved by performing principal component analysis (PCA) on the correlation matrix to describe the relationships between the analytical data and the geographical origin of the samples (regions and habitats). To better understand the basic statistical concepts used in this study, a brief explanation is provided below.

4.7.1 Descriptive analysis

Descriptive analysis is a key statistical method for systematically examining the fundamental characteristics of a dataset in a clear and systematic manner. It provides an overview of the data, which is concluded with numerical summaries and visual representations, helping researchers understand the contours, trends, and variability within the data. Unlike inferential statistics, descriptive analysis does not involve estimates or conclusions beyond the data being analysed. Instead, it focuses on reflecting the dataset as it is (Brill, 2004).

Descriptive analysis is essential for measures of central tendency, such as the mean, median, and mode, which provide information about the typical or fundamental value of the dataset. The mean represents the arithmetic average, the median categorizes the middle value when the data are ranked, and the mode shows the most frequently occurring value. Along with these values, distribution measures such as the range, variance, standard deviation, and interquartile range (IQR) quantify the range or variability of the data. Measures of dispersion are important to understand how data points deviate from the central tendency and emphasize the degree of homogeneity or variability in the dataset (Strough, 2014).

Another important aspect of descriptive analysis is the evaluation of data distribution, shape, and dispersion. This may include estimating skewness, which measures the symmetry of the distribution, and kurtosis, which indicates the "peakedness" or flatness of the data compared with a normal distribution. Visual aids, such as histograms, box plots, scatter plots, and bar charts, are

often used to improve the interpretability of these features and highlight trends, clusters, or outliers within the data (Chapman, 2018).

Descriptive analysis is valuable for discovering and presenting data before resorting to complex statistical analyses. For example, in our study, descriptive statistics were applied to summarize the average of all analysed nutrients, such as mineral content, fat, ash, and protein, to assess the variability of antioxidant properties in different regions and to visualize the frequency of certain nutrient concentrations. Despite their value, their role is to define the data, making it a dynamic preliminary step in research to ensure data quality, identify outliers, and gain initial insights into the structure of the dataset (Field, 2013).

4.7.2 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is a statistical method used to compare the means of three or more groups to determine whether there are statistically significant differences between them. The main aim of the ANOVA is to compare the null hypothesis, which states that all group means are equal, with the alternative hypothesis, which states that at least one group mean differs. By partitioning the total experimental difference in the data into components attributed to "between-group" and "within-group" variability, ANOVA helps identify the sources of variation (Douglas C. Montgomery, 2019).

The "between-group" variability characterizes differences that are due to the circumstances or methods of the study, while the "within-group" variability shows random differences within each group. The ratio of these variances, known as the F-ratio, served as the test statistic for ANOVA. A higher F-ratio indicates that the differences between groups are significantly greater than those within groups, which means that the treatment or group variances are statistically significant. ANOVA is particularly useful for evaluating trial-by-trial treatments or identifying significant factors influencing a trial. Based on our experimental research design, a one-way ANOVA was used to compare a single factor (region or habitat) with multiple levels (e.g., minerals or other proximal parameters). ANOVA provides a basis for further investigation of specific group differences (Lenth & Fleiss, 1999; Montgomery, 2017).

4.7.3 Tukey honest significant difference (HSD)

Tukey's (HSD) test is a post-hoc statistical procedure used after performing analysis of variance (ANOVA) to determine which specific group means differ from each other. Although ANOVA determines whether at least one group mean is significantly different, it does not determine which groups differ. Tukey's HSD fills this gap by performing pairwise comparisons between group means and adjusting the overall Type I error rate (the probability that a true null hypothesis is falsely rejected) (Montgomery, 2017; Wulff, 2003). The test compares the absolute variance between each pair of group means to a critical value that depends on the number of groups, within-group variability (mean square error), and sample size. If the difference exceeds this critical value, then the means of the two groups are significantly different (Lawson, 2014). The formula for Tukey's HSD test is as follows:

$$HSD = q \times \sqrt{\frac{MSE}{n}}$$

where:

q: Critical values from studentized range statistics (based on the number of groups and degrees of freedom for the error).

MSE: Mean squared error from the ANOVA table.

n: Number of observations per group (assuming they are equal; adjustment is made for unequal groups).

4.7.4 Two sample t-test

The t-test is a statistical hypothesis test used to determine whether there is a significant difference between the means of two groups or between a group mean and a known value. It is often used in studies to correlate sample data and draw conclusions about the samples. The t-test assumes that the data are approximately normally distributed and that the variances of the groups are the same, although variations in the test can allow for deviations from these expectations (Montgomery & Runger, 2002).

In the t-test, the observed change between the means was related to the normal variability under the null hypothesis that the means were equal. This assessment is reported in the form of a t-statistic that measures the size of the difference in the disparity of the sample data. A larger t-statistic indicates a greater likelihood that the difference in experience is not due to chance. The p-

value, which is the result of the t-statistic and degrees of freedom, calculates the possibility of detecting the data if the null hypothesis is true. If the p-value falls below a predetermined value (e.g., 0.05), the null hypothesis is rejected and a statistically significant difference is detected (Brill, 2004; Montgomery & Runger, 1994).

In this study, a two-sample t-test (or independent t-test) was used to determine the association between the means of two independent groups, such as the nutrient content of baobab samples from two different regions: the Blue Nile and North Kordofan.

4.7.5 Principal Component Analysis (PCA)

Principal component analysis (PCA) is a statistical method for reducing dimensionality in datasets with multiple interrelated variables. It converts the original variables into a smaller set of uncorrelated variables called principal components (PCs), which capture the most important variations in the data. PCA is particularly valued when analysing complex datasets, as it shortens data structures while preserving as much of the variability as possible. The first principal component explains the largest amount of variance, whereas the subsequent components explain smaller amounts, each being orthogonal to the others (Abdi, 2010).

The PCA process begins with the normalization of the dataset to confirm that the variables measured at different scales are equally subsidized. A covariance matrix was then calculated to analyse the relationships between the variables. From this, eigenvalues and eigenvectors were derived. The eigenvalues measure the variance explained by each principal component, and the eigenvectors indicate the direction of these components in a multidimensional space. The principal components are linear combinations of the original variables ordered by their ability to explain variance. In our research on baobab products, PCA revealed patterns in the nutrient composition of leaf samples from different regions and ecosystems in Sudan, and fruit samples from Sudan, Kenya, and Senegal, providing a deeper understanding of regional differences. *Beyond Food Science* (Abdi & Williams, 2010; Jolliffe & Cadima, 2016).

5 Results

The normality of the data was checked using the Shapiro test, and the results are described as follows:

5.1 Simple variance analysis

5.1.1 The composition of baobab leaves in different regions

Table 4. The concentration (means and SDs; n =9) of nutrients in dried baobab leaves from the North Kordofan and Blue Nile regions of Sudan.

Region key	Blue Nile		North Kordofan	
	Means	SDs	Means	SDs
Ash content g/100 g	11.9 ^a	0.7	9.9 ^b	0.8
Ca concentration (mg/100 g) dw	2689 ^a	305	2354 ^b	293
Cu concentration (mg/100 g) dw	0.801 ^a	0.203	0.806 ^a	0.072
Dry m. (m/m)%	92 ^a	0.4	92 ^a	0.2
Fat content g/100 g	1.8 ^a	0.3	1.9 ^b	0.2
Fe concentration (mg/100 g) dw	13 ^a	1.4	17.0 ^b	2.8
K (mg/100 g) dw	1660 ^a	132	1324 ^b	259
Mg concentration (mg/100 g) dw	444 ^a	14	556 ^b	56
Mn concentration (mg/100 g) dw	2.3 ^a	0.4	5.7 ^b	3.2
Na concentration (mg/100 g) dw	6.9 ^a	0.5	7.8 ^b	0.9
pH	5.9 ^a	0.1	5.8 ^b	0.1
Protein content g/100 g	15.5 ^a	1.2	15.3 ^a	1.5
TFC CE (mg/100 g)	1328 ^a	91	1471 ^b	64
TPC GAE (mg/100 g)	361 ^a	26	361 ^a	9
Zn concentration (mg/100 g) dw	2.5 ^a	0.6	1.8 ^a	0.2

Means followed by different letters are significantly different at the alpha level of 0.05.

The nutritional values of baobab leaves in Table 4 show that the calcium and potassium contents were higher in the Blue Nile region (2689 ± 305 mg/100 g and 1660 ± 132 mg/100 g, respectively). In contrast, the magnesium and sodium values were higher in the Kordofan region (556 ± 55.6 mg/100 g and 7.8 ± 0.9 mg/100 g). In the simple analysis of variance, a two-sample t-test was performed at significance levels of 0.05, 0.01, and 0.001 Figure 18. The mean concentrations of the macroelements (Ca, K, Mg, and Na) differed significantly between the two regions ($p < 0.001$). Analysis of the content of trace elements in the baobab leaves revealed that significantly ($p < 0.001$) higher levels of iron and manganese (17.2 ± 2.8 mg/100 g) and 5.7 ± 3.2 mg/100 g) were found in Kordofan and higher levels of zinc (2.6 ± 0.6 mg/100 g) in the Blue Nile region. However, the actual difference in the mean copper concentration between the two regions was not significantly different.

The results of the proximate analysis of the additional nutritional values also differed. Blue Nile had higher ash (11.9 ± 0.7 g/100 g), protein (15.5 ± 1.2 g/100 g), and pH (5.9 ± 0.1), while Kordofan had higher fat (1.9 g/100 g), TFC (1470 ± 64 mg CE/100 g), and TPC (362 ± 8.7 mg GAE/100 g). Dry matter values were the same in both regions (92 m/m%). A t-test confirmed that there were no significant differences between the mean values of protein, dry matter, and TPC.

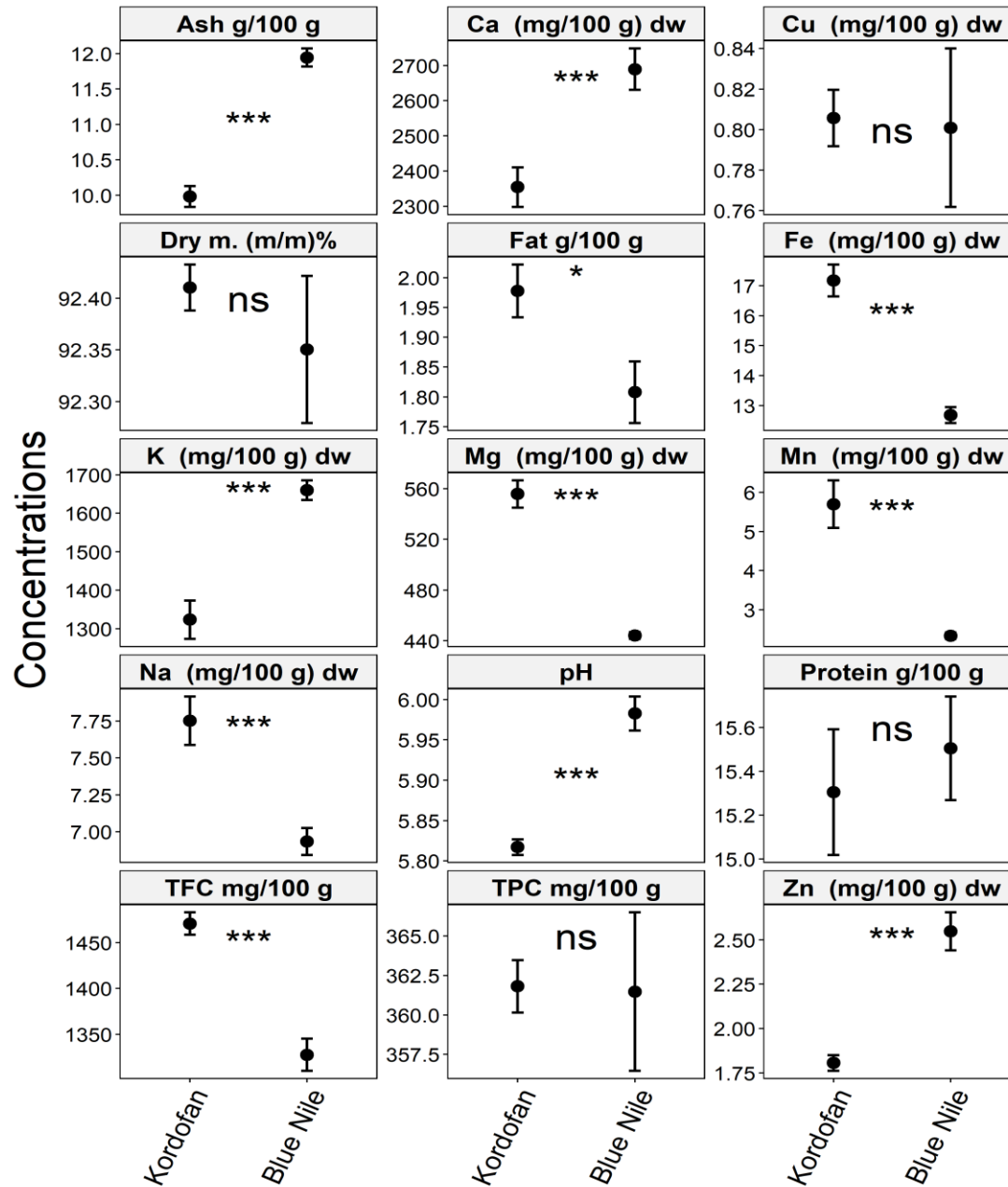


Figure 18. Nutritional concentrations of baobab leaves in two regions (Blue Nile and North Kordofan) of Sudan. Significance codes: at the $p < 0.05$ (*), and $p < 0.001$ (***) levels. ns, not significant.

5.1.2 The composition of baobab leaves in different habitats

Table 5. The concentration (means and SDs; n =9) of nutrients in dried baobab leaves from different habitats in Sudan.

Habitats	Mountains (M)		Plain land (P)		Wetland (W)	
	Means	SDs	Means	SDs	Means	SDs
Ash content g/100 g	11.7 ^a	1.19	10.1 ^b	1.2	11.1 ^c	0.6
Ca concentration (mg/100 g) dw	2903 ^a	187	2236 ^b	169	2426 ^c	222
Cu concentration (mg/100 g) dw	0.67 ^a	0.09	0.83 ^b	0.09	0.92 ^c	0.15
Dry m. (m/m)%	92.0 ^a	0.1	92 ^a	0.3	93.0 ^a	0.1
Fat content g/100 g	1.9 ^a	0.4	2.0 ^b	0.2	1.8 ^c	0.1
Fe concentration (mg/100 g) dw	14.0 ^a	0.6	15.0 ^a	4.2	14.0 ^a	3.3
K (mg/100 g) dw	1477 ^a	365	1345 ^b	185	1654 ^c	34
Mg concentration (mg/100 g) dw	499 ^a	41	529 ^b	101	471 ^c	32
Mn concentration (mg/100 g) dw	3.9 ^a	1.6	5.9 ^b	3.9	2.3 ^c	0.3
Na concentration (mg/100 g) dw	7.4 ^a	0.3	6.9 ^b	0.5	7.7 ^c	1.2
pH	5.9 ^a	0.2	5.8 ^b	0.1	5.9 ^c	0.1
Protein content g/100 g	13.6 ^a	0.5	16.6 ^b	0.3	15.9 ^c	0.3
TFC CE (mg/100 g)	1368 ^a	76	1396 ^a	163	1434 ^a	26
TPC GAE (mg/100 g)	350 ^a	13.9	374 ^b	23	361 ^c	11
Zn concentration (mg/100 g) dw	2.2 ^a	0.1	1.9 ^b	0.3	2.5 ^c	0.8

Means followed by different letters are significantly different at the alpha level of 0.05

The ANOVA test showed that the concentrations of all macro elements in baobab leaves were significantly different in all three habitats at a significance level of 0.05 (Table 5). Calcium was highest (2903 ± 187 mg/100 g) in the M sites, potassium (1654 ± 34 mg/100 g) and Na (7.7 ± 1.2 mg/100 g) in the W sites, and magnesium in the P sites (529 ± 101 mg/100 g) (Table 5). In addition, the Tukey HSD mean comparison test showed significant differences in Ca levels between each pair of study habitats. For Mg and Na, the test also showed a significant difference between the pairs of habitats studied, except between (W-P) for Mg and (M-W) for Na. The K content also differed significantly between the ecological zone pair (W-P). For the trace elements in baobab leaves analysed in different habitats, the highest levels of copper (0.9 ± 0.2) and zinc (2.5 ± 0.8) were found in ecological zone W, and the highest levels of iron (15 ± 4) and manganese ($5.9 \pm$

0.3.9) were found in ecological zone P. ANOVA showed that the mean concentrations of all trace elements, except iron, were significantly different ($p < 0.05$) within the different habitats (W, P, and M). Tukey's HSD multiple comparison test of means showed a significant difference in the values of Cu between all habitat pairs; for Mn in all pairs except (P-M), there were significant differences only between the W-M pair. Proximate analysis of nutrients in baobab leaves showed that the highest values for ash (11.7 ± 1.2 g/100 g) and pH (5.9) were found in the M sites. The highest content of protein (16.6 ± 0.3 g/100 g) and TPC 373.7 mg/100 g was found in P sites. The highest contents of dry matter (93.6 m/m%) and TFC (1433 mg/100 g) were found in the W sites. The ANOVA test showed significant differences for all mean values except TFC and fat content ($p = 0.181$ and 0.062 , respectively).

More details of Tukey's post-hoc results were provided to understand the most substantial differences in the content of Ca, K, Mg, and Na in baobab leaves among the three studied sites (P, W, and M) Figure 19. This statistical test controls family-wise error rates and performs pairwise comparisons of the means across the sites, providing confidence intervals (CIs) and commonly reported p-values. Significance of mean differences (Tukey HSD) at the $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***), and $p < 0.0001$ (****) levels. ns, not significant.

The results of Ca concentration are well-defined when relating the studied sites. A significant p-value of < 0.0001 was shown for the (P-M) association, representing that P has a meaningfully lower Ca amount than M. This is supported by the great negative mean difference (-667.78) and CI of ($-823.96, -511.60$), which eliminates zero and approves the statistical consequence of the result. In addition, the sites (W-M) association exposed a p-value of < 0.0001 , which is very significant, indicating that W has a lower Ca profile compared to M, with a mean difference of (-477.83) and a CI of ($-634.02, -321.65$). While W displayed reduced Ca levels, the decrease was less noticeable than that in the P-M association. Lastly, (W-P) indicated that a p-value of (0.0136) with significant, indicating that W had significantly higher Ca levels than P. The positive mean variance of ($+189.94$) and the CI of ($33.76, 346.13$) indicate that W exceeds P in Ca levels; nevertheless, the difference is smaller compared to the other assessments.

The results for the K concentration are summarized as follows. The lower p-value of (0.2313) for the (P-M) specifies no substantial difference in K levels when comparing P and M. This assumption is supported by the varied CI of ($-322.37, 59.86$), which is zero, signifying no reliable distinction

in K levels across the studied sites. In the (W-M) evaluation, a p-value of (0.0749) shows a slight non-significant alteration, with W displaying greater K levels than M. The mean difference of (+176.91) and the CI of (-14.20, 368.02) are close to zero, suggesting that although W might have advanced K levels, the indication is not sufficient to authorize significance. The (W-P) contrast exposes an extremely substantial p-value of (0.0008), indicating that W has meaningfully difficult K levels compared to P. The considerable optimistic mean difference of (+308.17) and CI of (117.05, 499.28), which dismisses zero, authorizes the statistical meaning of this outcome.

The results of Mg levels are detailed in this manner. The comparison for sites (P-M) indicated a non-significant difference, with a p-value of (0.4052) levels between P and M. The CI of (-24.76, 81.96) was zero, suggesting no reliable disparity between the two studied sites. In addition, (W-M) illustrates no significant difference, supported by (0.4062) as a p-value highlighted with (*), and a CI of (-81.92, 24.80) that embraces zero, indicating that any experiential variances are probably outstanding to accidental variation. However, the (W-P) comparison exposes a significant p-value of (0.0332), showing that W has a lower Mg profile compared to P. This deduction is supported by the mean difference of (-57.16) and the CI of (-110.52, -3.80), which reject zero, approving the statistical significance of the result.

The outcomes of Na levels are described in this term. For the comparison of (W-M) sites, a lower p-value of (0.2701) specifies no significant variation in Na levels between W and M. The CI of (-1.01, 0.22) was zero, confirming the absence of a reliable tendency for Na levels between these sites. The comparison of (P-M) displays substantial differences, with a p-value of (0.04611). However, the comparison of (W-P) shows a significant difference with a p-value of (0.0215), indicating that W has meaningfully greater Na levels compared to P. This result is supported by a mean difference of (+0.70) and a CI of (0.09, 1.31), which rejects zero and authorizes statistical consequence.

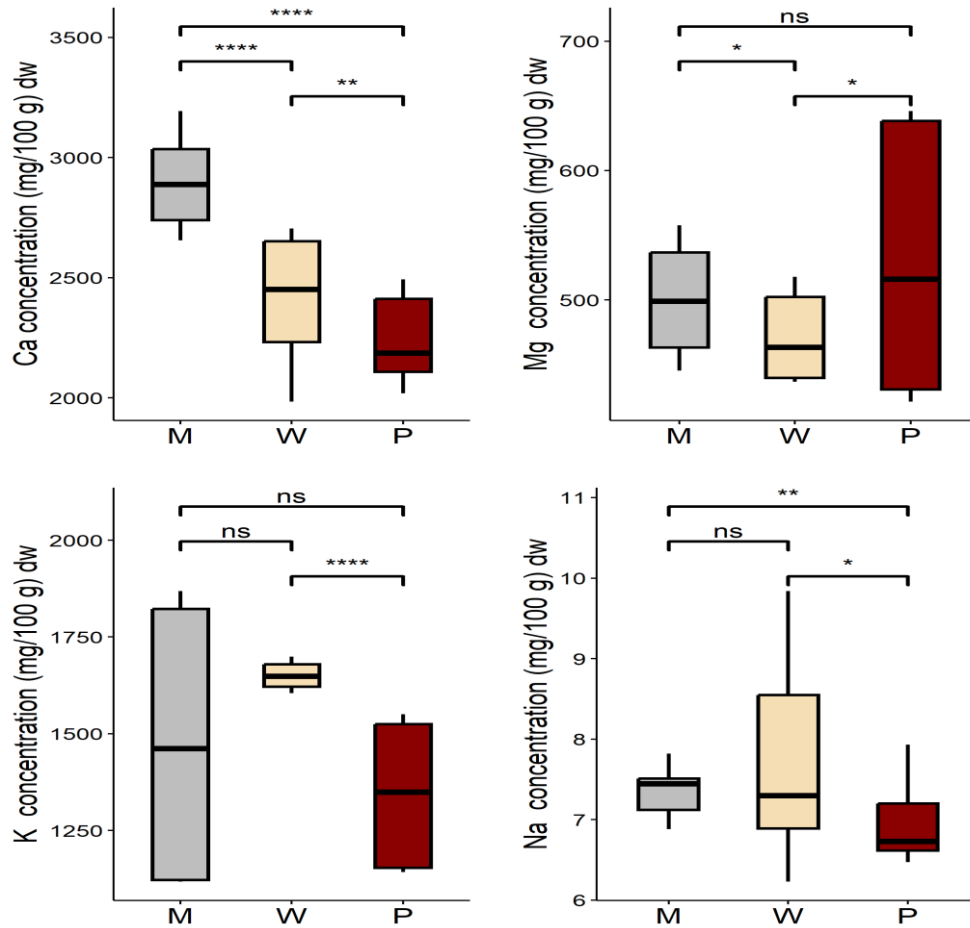


Figure 19. Calcium, magnesium, potassium, and sodium content in baobab leaves from three different habitats (W) wetland (P) plain land, and (M) mountain in Sudan.

Tukey's post-hoc results for trace elements in baobab leaves were shown in Figure 20. The results for the Cu concentration are as follows: For comparison of (P-M) sites, a significant p-value of (0.0003) shows that Cu levels in P are considerably higher than those in M. This is supported by a mean difference of (+0.159) and CI of (0.068, 0.249), which rejects zero, authorizing the statistical impact. In addition, the comparison of (W-M) sites show an extremely substantial p-value of (<0.0001), signifying that the W site has significantly higher Cu levels than the M site, with the largest detected difference. The mean difference of (+0.248) and CI of (0.158, 0.338) confirm this result. However, for the comparison (W-P) sites, a slightly significant p-value of (0.053) indicates that Cu levels at the W site may be slightly greater than those at the P site.

The Fe content was described in this manner. The comparison of (P-M) sites indicates that there is no significant difference with a p-value of (0.207) of Fe levels between P and M. The CI of

(-0.715, 4.281) included zero, confirming the lack of constant variation in the Fe content. In contrast, the comparison (W-M) sites showed no substantial difference, indicated by a p-value of (0.696) and a CI of (-1.655, 3.3). Similarly, the comparison (W-P) showed no significant difference, as specified by a p-value of (0.638). The mean difference of (-0.940) and the CI of (-3.438, 1.558) are zero, indicating that there is no significant variation in the Fe level between W and P.

For the comparison (P-M) sites, the results of Mn content indicated a slightly non-significant difference with a p-value of (0.054) suggesting that Mn levels in P are slightly greater than in site M, as shown. However, the CI of (0.030, 3.896) did not include zero, indicating that this difference was statistically significant. Similarly, the comparison of (W-M) indicates a substantial difference, supported by a p-value of (<0.0002) and a CI of (3.593, 0.332), emphasizing the variability in Mn content between sites. The comparison of (W-P) exposes a p-value of (0.0121), indicating that Mn levels in W are significantly lower than those in P.

Highlighting the comparison of (P-M), which results in the level of Zn in P, is considerably lower than in M, with a mean difference of (+0.667). However, this variance is highly statistically significant, as specified by the p-value of (<0.0001) and the CI of (0.732, 0.074), which do not comprise zero. In contrast, the comparison of (W-M) sites indicates that the Zn level in W is greater than that in M, with a mean difference of (-0.337). This difference is not statistically significant, as indicated by a p-value of (0.118) and a CI of (-0.066 to 0.740), which includes zero. In contrast, the comparison of (W-P) sites revealed a p-value of 0.006, indicating that Zn levels in W were significantly higher than in P. The significant mean difference of (+0.529) and the CI of (0.264, 1.070) prove the statistical consequence of these outcomes.

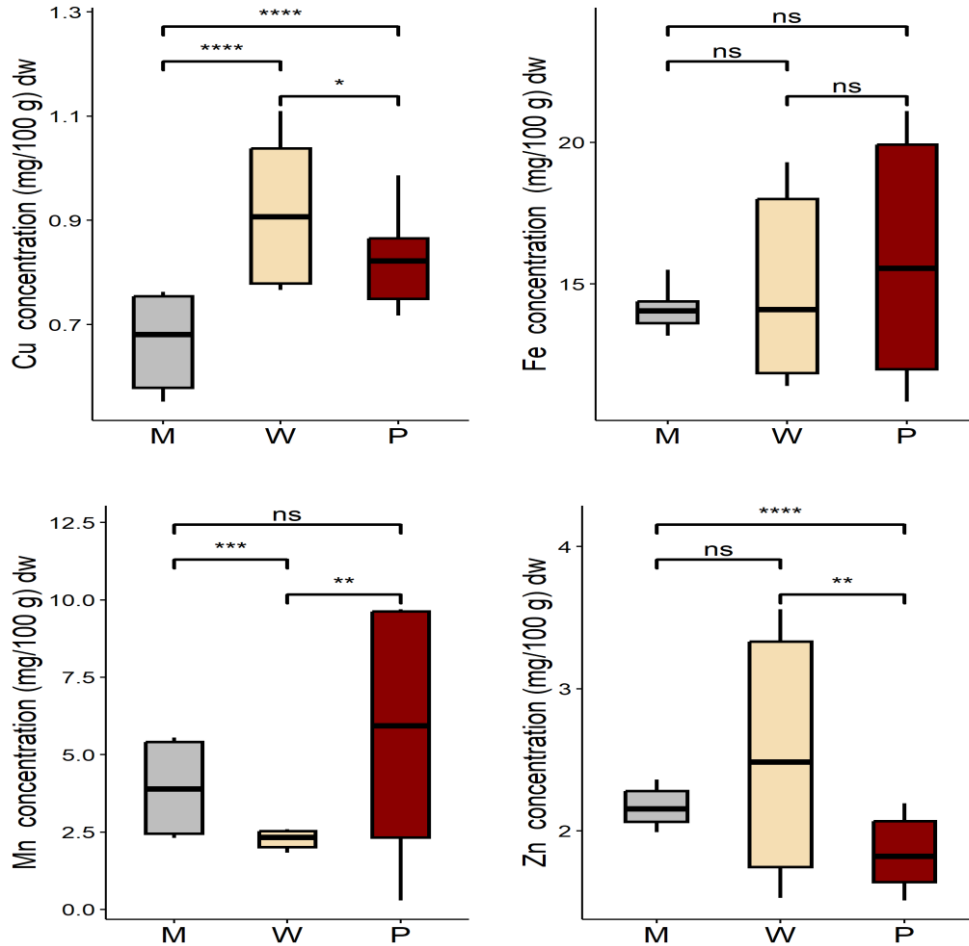


Figure 20. Copper, iron, manganese and zinc content in baobab leaves from three different habitats (W) wetland (P), plain land and (M) mountain in Sudan.

Tukey's post-hoc result for proximate analysis (Ash, protein, fat contents, and dry matter) in baobab leaves was shown in Figure 21. The results of ash content are described as follows: site P versus site M showed a highly significant p-value of 0.0001. Site P had a significantly lower ash content than site M. The large negative mean difference (-1.56) indicates a notable decrease in ash content at P. The confidence interval (CI) of ($-2.41, -0.72$) does not include zero, indicating statistical significance. Site W vs. M resulted in a mean difference of (-0.59) and a p-value of 0.2231, which was not significant. The CI crosses zero (-1.43 to 0.26), signifying that experiential difference may be due to random variation. Sites (W-P) resulted in a mean difference of ($+0.98$), a significant p-value of (0.0196), and a CI of ($0.13, 1.82$) to highlight that site W has a higher ash content when compared to site P. This difference indicates that site-specific factors may have increased the ash level at site W.

The results of dry matter content were defined as follows: sites (P-M) showed a highly significant p-value of (0.0000003), indicating that site P had a notably lower dry matter content compared to site M. The large negative mean difference (-0.33) indicates a substantial decrease in the solid content of P, which may be linked to higher moisture levels or reduced accumulation of structural components. The confidence interval CI of ($-0.46, -0.20$) did not include zero, adding further statistical validity to the result. Sites (W-M) have a significant p-value of 0.0017 and a mean difference of ($+0.20$). However, site W had a higher amount of dry matter than site M. The CI of ($0.07, 0.33$) does not comprise zero, a subsidiary of the detected difference. The evaluation of sites (W-P) revealed a highly important p-value of 0.0000000, with a great confidence mean difference of ($+0.53$). This suggests that W has a significantly higher dry matter level than P.

The fat content results are defined as follows (P-M): a p-value of 0.4243, no significant difference in fat concentration between P and M. The minor optimistic mean difference ($+0.11$) and inclusive confidence interval CI of ($-0.10, 0.31$) propose a nominal site-specific distinction in fat accumulation. Correspondingly, there was no substantial difference in fat level when comparing (W-M), as shown by the p-value of 0.4818. The mean variance of (-0.10) and CI of ($-0.30, 0.11$) crossing zero indicate that fat levels are similar across these sites. Sites (W-P), a slightly significant p-value of 0.0493 was highlighted, and W showed a somewhat lower fat level than P.

The outcomes of protein content are defined as follows when comparing sites (P-M) with an extremely significant p-value of (0.0000) was shown, demonstrating that P has a greater protein concentration than M. There was a significant positive mean difference ($+3.00$) and CI of ($2.70, 3.31$). When comparing (W-M), site W also had a significantly greater protein level than site M, with a very significant p-value of 0.0000. The mean difference of ($+2.35$) and the CI of ($2.04, 2.66$) show that both P and W are greater in protein level compared to M, with W showing a slightly lower protein content than P. Sites (W-P) showed a significant p-value of (0.00001), indicating that W has a significantly lower protein level than P. The mean difference of (-0.66) and the CI of ($-0.96, -0.35$) indicate that P has a higher level of protein.

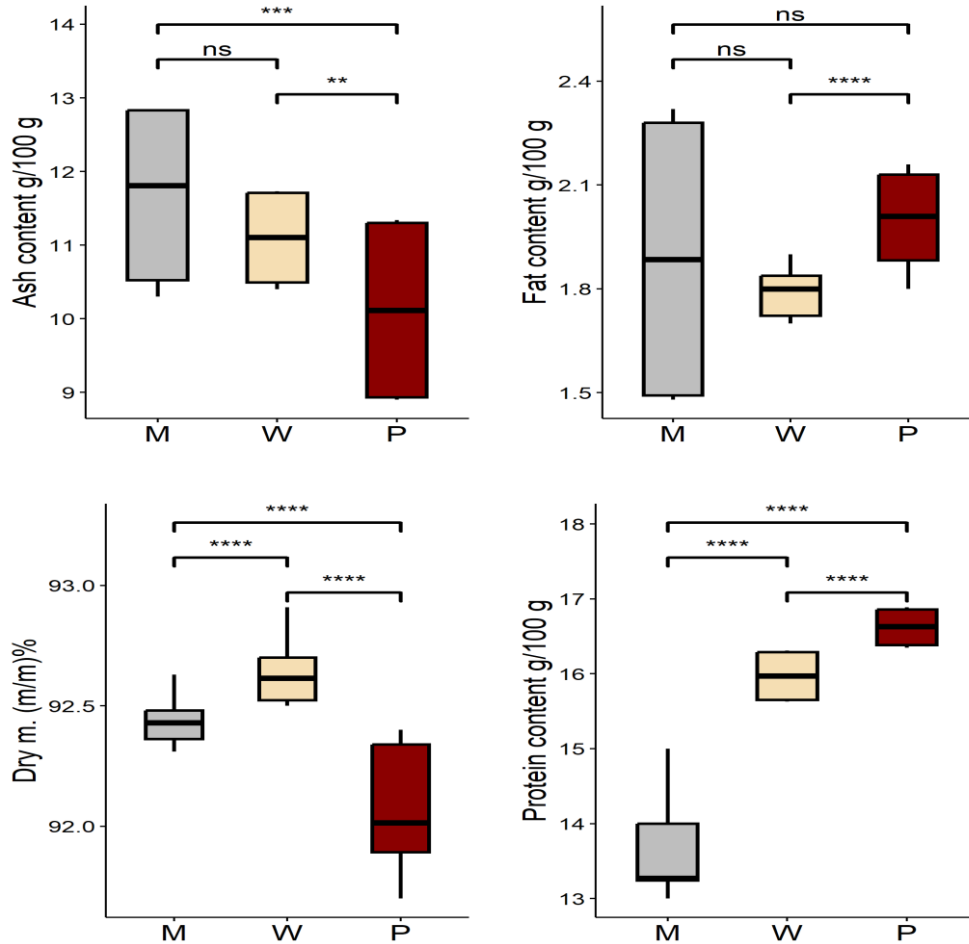


Figure 21. Ash, fat, dry matter, and protein content in baobab leaves from three different habitats (W) wetland (P), plain land, and (M) mountain in Sudan.

Tukey's post-hoc results of (TPC, TFC, and pH) in baobab leaves were indicated in Figure 22. The outcomes for the TPC are summarized as follows. In the comparison of (P-M), P showed significantly greater TPC than M, with a significant mean difference of (+23.39). The significance (p-value of 0.04) and the CI of (5.72, 37.06), which rejects zero, confirm this result. For the comparison of (W-M) sites, a significant difference in TPC was observed, as shown by a p-value of 0.01596 and a CI of (3.11, 24.22), which does not include zero, indicating variability with statistical significance. Lastly, the comparison of (W-P) sites reveals that W has a somewhat lower TPC than P, with a mean difference of 12.83. However, the p-value of 0.0599 indicates a marginally significant difference, and the CI of (-26.50, 0.84) includes zero, signifying insufficient evidence to approve a steady difference in phenolic levels.

In this regard, the TFC results are concise. For the comparison of (P-M), there was no significant variance in TFC between P and M, regardless of the mean difference of (+28.28). The p-value of (0.6996) and the CI of (-56.17, 112.73), which includes zero, indicate no consistent difference between the two compared sites. Similarly, for the comparison of (W-M), the TFC concentration between W and M displays a significant difference, with a mean difference of +65.56 and a p-value of 0.01567. A CI of (18.90, 150.01) indicates the presence of a significant influence. In contrast, in the comparison of (W-P), there was no significant alteration in TFC between W and P, with a mean difference of (-37.28). The p-value of (0.5396) and CI of (-47.17, 121.73) further support the absence of statistical consequences.

The pH concentration at the sites exposes the following variances. When associating site P with site M, P had a meaningfully lower pH, with a mean difference of (-0.148). The p-value of (0.002) approves the statistical consequence of this variance, and the CI of (-0.230 to -0.065), which excludes zero, further supports this assumption. In contrast, no substantial difference in pH was observed between W and M, with a mean difference of (-0.038) and a p-value of (0.5163), representing no consistent difference. The CI of (-0.120, 0.045) was zero, confirming the lack of significance. Finally, Site W had a significantly higher pH than Site P, with a mean difference of (+0.110). The p-value of (0.0063) and the CI of (0.027, 0.193) excluded zero, confirming a statistically substantial difference between these two sites.

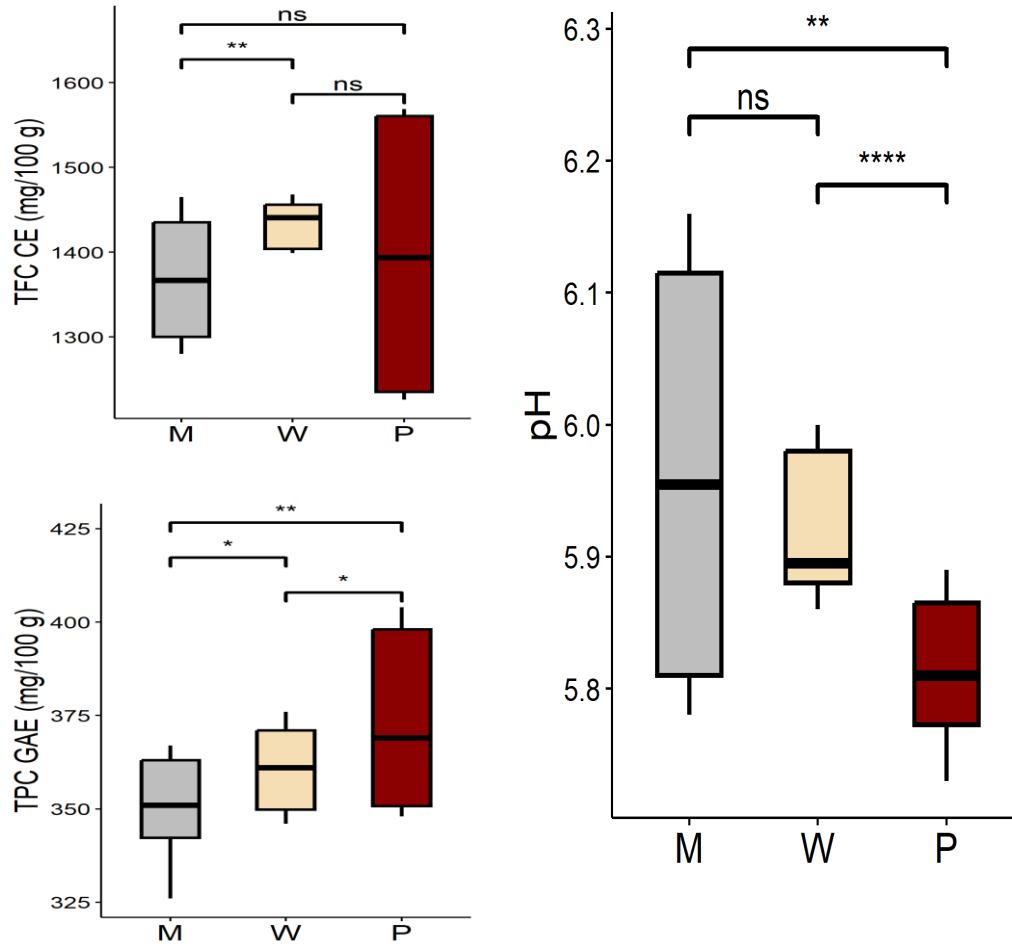


Figure 22. Total flavonoid, total phenolic content, and pH in baobab leaves from three different habitats (W) wetland (P), plain land, and (M) mountain in Sudan.

5.1.3 The composition of dried Baobab fruit pulp in different regions

Table 6. The concentration (means and SDs; n =9) of nutritional values in dried baobab fruit pulp obtained from Kenya, Senegal, and Sudan.

Region	Kenya		Senegal		Sudan	
key	Means	SDs	Means	SDs	Means	SDs
Ash content g/100 g dw	6.9 ^a	1.9	4.8 ^b	0.2	5.4 ^c	0.2
Ca Level (mg/100 g) dw	286 ^a	19	313 ^b	3.0	329 ^c	0.5
Cu Level (mg/100 g) dw	0.759 ^a	0.058	1.131 ^b	0.441	1.160 ^c	0.046
Dry m. (m/m)%	90 ^a	0.7	89 ^b	1.7	88 ^c	0.5
Fat content g/100 g dw	1.6 ^a	0.6	0.94 ^b	0.33	0.69 ^c	0.03
Fe Level (mg/100 g) dw	18 ^a	9.7	4.9 ^b	0.1	6.36 ^c	0.4

K level (mg/100 g) dw	2145 ^a	635	1742 ^a	113	1907 ^a	0.5
Mg Level (mg/100 g) dw	107 ^a	57	191 ^b	10	175 ^c	0.4
Mn Level (mg/100 g) dw	0.9 ^a	0.2	0.9 ^a	0.1	0.91 ^a	0.04
Na Level (mg/100 g) dw	6.6 ^a	4.2	5.4 ^a	1.1	6.4 ^a	0.1
PH	2.9 ^a	0.1	3.3 ^b	0.1	3.2 ^c	0.1
Protein content g/100 g dw	3.9 ^a	0.9	2.9 ^b	0.3	2.9 ^c	0.1
TFC. CE(mg/100 g)	414 ^a	42.0	844 ^b	30.0	734 ^c	24
TPC GAE(mg/100 g)	358 ^a	3.8	367 ^b	10.0	370 ^c	13.9
Zn Level (mg/100 g) dw	1.2 ^a	0.2	0.8 ^b	0.2	1.1 ^c	0.1

Means followed by different letters are significantly different at the alpha level of 0.05.

The result of the analysed nutritional values in DBFP in Table 6 shows that the highest values of dry matter ($90 \pm 0.7\%$), fat content (1.6 ± 0.6 g/100 g dw), protein content (3.9 ± 0.8 g/100 g dw), Fe (18 ± 9.7 mg/100 g), K (2145 ± 635 mg/100 g), Na (6.6 ± 4.2 mg/100 g) and Zn 1.2 ± 0.2 mg/100 g) were reported in Kenya. The highest levels of Mg (191 ± 10 mg/100 g), Mn (0.96 ± 0.11 mg/100 g), pH (3.3 ± 0.1 mg/100 g), and TFC 844 ± 30 mg/100 g) were found in Senegal. In contrast, the highest levels of Ca (329 ± 0.5 mg/100 g), Cu (1.2 ± 0.1 mg/100 g), and TFC (370 ± 14 mg/100 g) were found in Sudan. The ANOVA test showed that all nutrient and mineral contents of all DBFP samples differed significantly ($p < 0.05$), except for K, Na, and Mn.

Tukey's HSD multiple comparison tests of means at a significance level of 0.05 were used to examine the difference between pairs of values for all nutrients, and the results showed that there was a significant difference between all pairs of ash, Ca, fat, Fe, Mg, pH, and other nutrients among different regions Kenya (KEN, Senegal (SEN) and (SUD). Nevertheless, there was no significant difference between the mean values of some pairs; for example, between all pairs of Mn, (KEN-SEN, and KEN-SUD for K and Na, SEN-SUD for protein and Cu, and KEN-SEN for dry matter. This statistical test controls for family-wise error rates and offers pairwise evaluations of the means across the sites, in addition to confidence intervals (CIs) and familiar p-values. Significance of mean differences (Tukey HSD) at the $p < 0.05$ (*), $p < 0.01$ (**), $p < 0.001$ (***), and $p < 0.0001$ (****) levels. ns, not significant. The ash content, dry matter, fat content, and protein content are shown in Figure 23 and described as follows:

For the comparison of (SEN-KEN), SEN has a meaningfully lower ash level than KEN, with a mean difference of (-2.12). The p-value of (0.014) specifies statistical meaning, and the CI of (-3.44, -0.80) eliminates zero, approving the difference. This suggests that the KEN samples had a significantly higher mineral content. For (SUD-KEN), SUD also has a lower ash content compared to KEN, with a mean difference of (-1.50). The p-value of (0.0234) supports this outcome, and the CI of (-2.82, -0.18) excludes zero, demonstrating a statistical consequence; however, the difference is less distinct than that between SEN and KEN. For (SUD-SEN), the substantial difference is experiential in the ash content between them. The mean difference of (+0.62) and p-value of (0.004796) advocate a consistent pattern. The CI of (0.70, 1.94) excluded zero, indicating a significant difference.

In the dry matter content results, the comparison of (SEN-KEN) indicated that there was no significant variance. The mean difference of (-0.74) and p-value of (0.3223) show that the alteration is not statistically significant, and the CI of (-2.00, 0.52) includes zero, indicating that any variation is probably random. For SUD-KEN, SUD had a lower dry matter compared to KEN, with a mean difference of (-2.14). The p-value of (0.0008) and CI of (-3.39, -0.88) exclude zero, confirming that samples from SUD have lower dry matter. For (SUD-SEN), SUD also displayed significantly lower dry matter content compared to SEN, with a mean difference of (-1.40). The p-value of (0.0276) specifies statistical significance, and the CI of (-2.65, -0.14) excludes zero, signifying that SEN samples retain more dry content.

For the comparison of (SEN-KEN), SEN has a significantly lower fat level compared to KEN, with a mean difference of (-0.69). The p-value of (0.0050) and the CI of (-1.18, -0.20) exclude zero, indicating statistical significance and indicating that plants from SEN contain lower fat. For (SUD-KEN), SUD had a significantly lower fat concentration than KEN, with a greater mean difference of (-0.94). The extremely significant p-value of (0.0002) and CI of (-1.43, -0.45) indicate that SUD samples have remarkably less fat. For the comparison of (SUD-SEN), A simple significant difference was observed in the comparison of the SUD-SEN. The mean difference between (0.26) and the p-value of (0.04049) supports this.

The comparison of (SEN-KEN) indicated that SEN has a lower protein level than KEN, supported by a mean difference of (-1.04). The p-value of (0.0008) and the CI of (-1.66, -0.43) confirm this significant variance, signifying that SEN samples have notably lower protein levels. For (SUD-

KEN), SUD also showed a knowingly lower protein level compared to KEN, which was confirmed by the negative mean difference of (-0.95). The p-value of (0.0020) and the CI of (-1.57, -0.34) showed a substantial difference, although the decrease in protein levels was somewhat smaller than that between SEN and KEN. For (SUD-SEN), in terms of protein level, the low mean difference of (+0.09) and the p-value of (0.9287) indicated that no weight difference was observed.

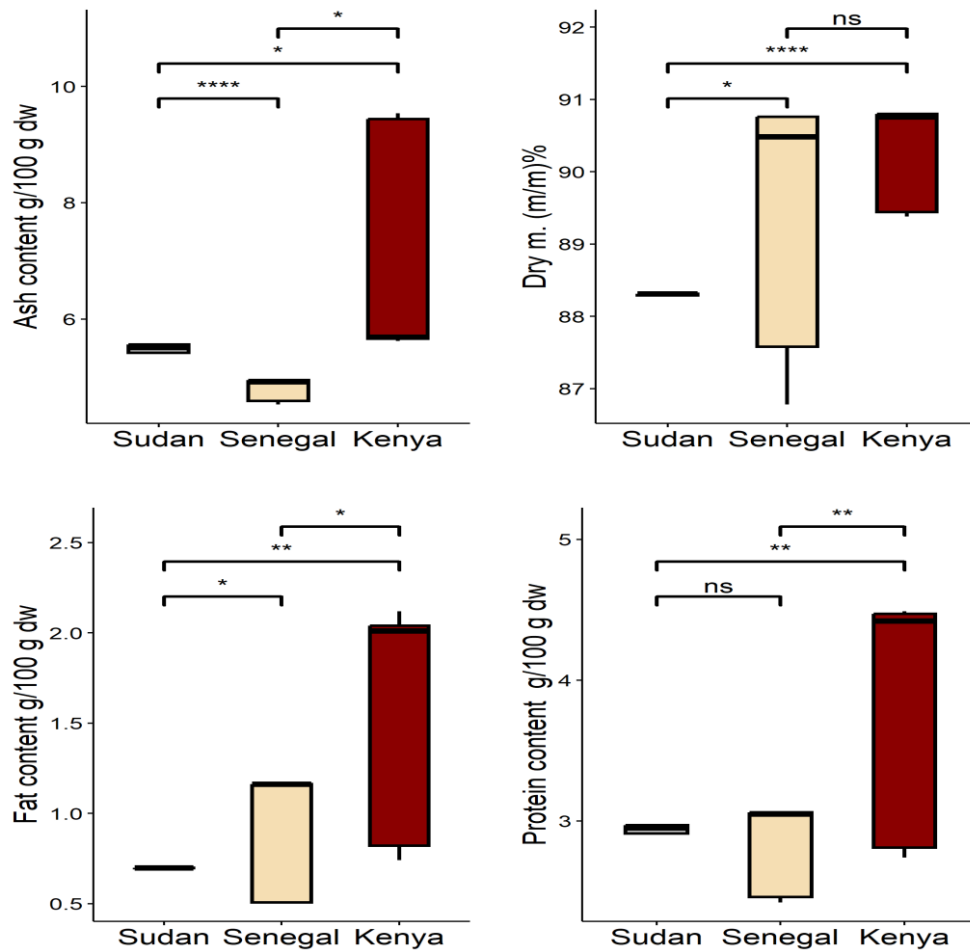


Figure 23. Ash, fat, dry matter, and protein content in baobab fruit pulp from three different countries.

To understand more about Tukey’s HSD results of macro elements in dried baobab fruit pulp explained in Figure 24. For comparison of sites (SEN-KEN), the levels of Ca in SEN are known to be higher than those in KEN, supported by a mean difference of 27.45. The greater p-value of (<0.0001) and the CI of (14.39, 40.50) confirm the meaning of this variance. For (SUD-KEN), SUD shows a significantly greater Ca profile compared to KEN, with a principal perceived mean

difference of 42.82. The higher p-value of (<0.0001) and the CI of (29.77, 55.88) indicate an extremely significant difference in Ca levels. For (SEN-SEN), Ca levels in SUD were higher than in SEN separately, supported by a mean difference of 15.38. The p-value of (0.0189) and the CI of (2.32, 28.43) suggest that SUD samples have more Ca; however, the variation is smaller than that between SUD and KEN.

For the comparison of (SEN-KEN), the levels of K in SEN are lower than in KEN, but the CI of (-841.16, 35.15) includes zero, demonstrating that the difference is not statistically significant. A p-value of 0.0755 more supports this outcome. For (SUD-KEN), there was no significant difference in K levels; the CI was (-676.16, 200.15) and the p-value was (0.379). For (SUD-SEN), the level of K in SUD was slightly higher than that in SEN, and this was supported by the p-value of (0.621) and CI of (-273.16, to 603.15).

The Mg levels in SEN are significantly higher than in KEN in comparison with (SEN-KEN). The mean difference was (84.29), with a highly substantial p-value (<0.0001), and the CI of (44.74, 123.84) excluded zero, confirming the consistency of the results. For SUD-KEN, SUD had significantly higher Mg levels than KEN, supported by the mean difference of (68.20), with a p-value of (0.0007), and the CI of (28.65, 107.75) further confirming the important difference. For (SUD-SEN), the results showed no significant difference in Mg levels between SUD and SEN ($p = 0.5742$). For the comparison of sites regarding the Na level, only (SUD-SEN), suggested no significant difference, supported by the p-value of 0.688.

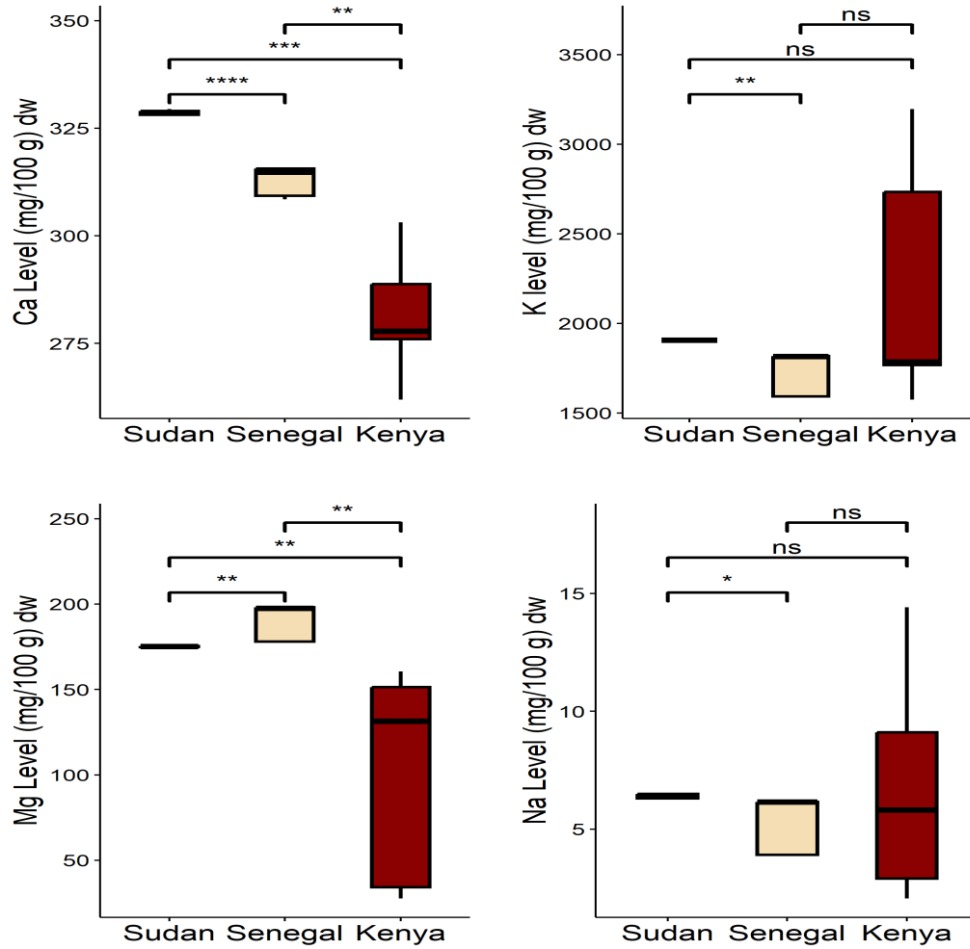


Figure 24. Calcium, magnesium, potassium, and sodium content in dried baobab fruit pulp from three different countries.

To understand more about the Tukey's HSD results of trace elements in dried baobab fruit pulp, as explained in Figure 25. For the comparison of Cu levels among different regions, only (SUD-SEN) suggests no significant difference with a p-value of (0.953), supported by the low mean difference of (0.036), and CI of (0.268, 0.340), which excludes zero. In contrast, (SUD-SEN) indicated a significant difference in Fe levels, supported by a significant p-value of 0.0001. For Zn concentration, the only comparison of (SUD-KEN) was not significantly approved by the low mean difference of (-0.046), a p-value of (0.835), and a CI of (-0.245, 0.153). However, comparison of all pairs showed no significant differences in Mn levels.

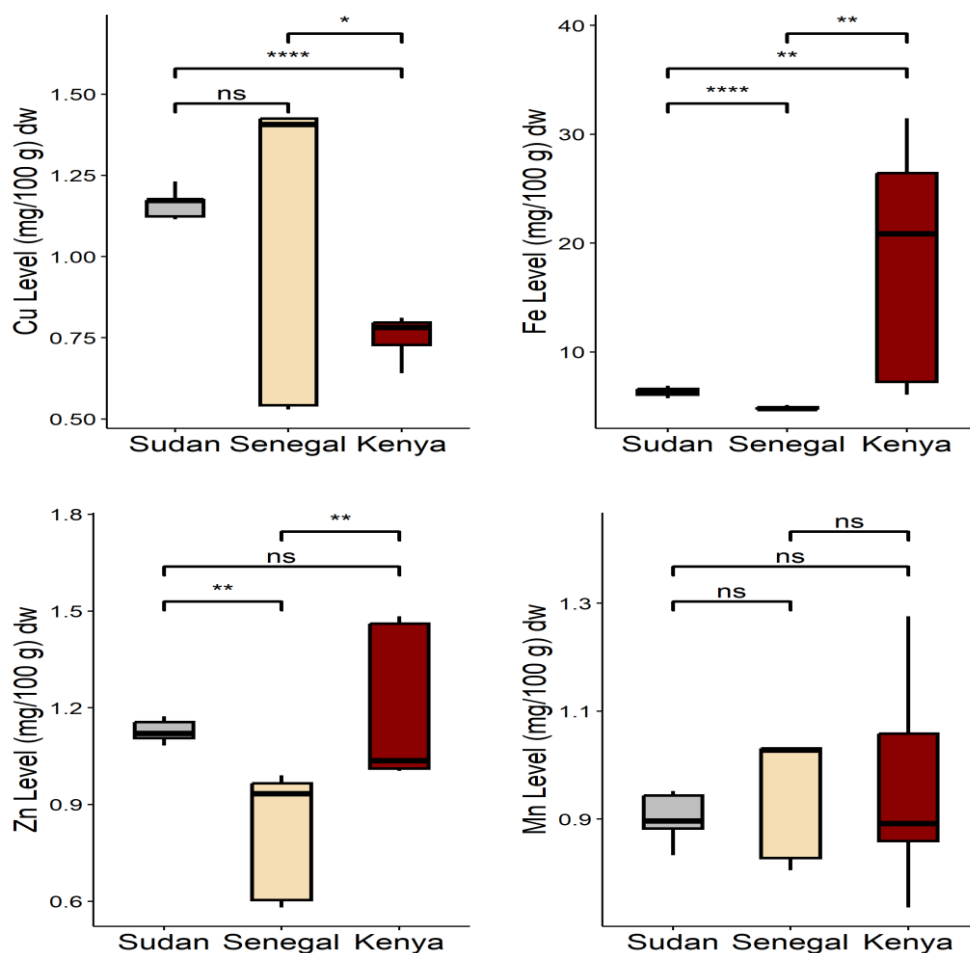


Figure 25. Copper, iron, manganese, and zinc content in baobab fruit pulp from three different countries

To understand more about the Tukey's HSD results of (TPC, TFC, and pH) in dried baobab fruit pulp, as explained in Figure 26. The comparison of (SEN-KEN) for TPC level indicated that the mean difference is 8.78, with a p-value of (0.01849 and CI of (3.27, 20.82)). There was a significant difference in the TPC between the SEN and KEN groups. For (SUD-KEN), the levels of TPC and SUD were slightly higher than those of KEN, but this difference was only slightly significant and was approved by a p-value of (0.0503). For (SUD-SEN), there was no significant difference in TPC level, supported by a p-value of (0.7797). For the TFC level, the comparison of (SEN-KEN), (SUD-KEN) and (SUD-SEN) shows significant differences supported by a p value of (<0.0001) among all regions. For pH level, significant differences were observed among all pairs, with a p-value of (<0.001).

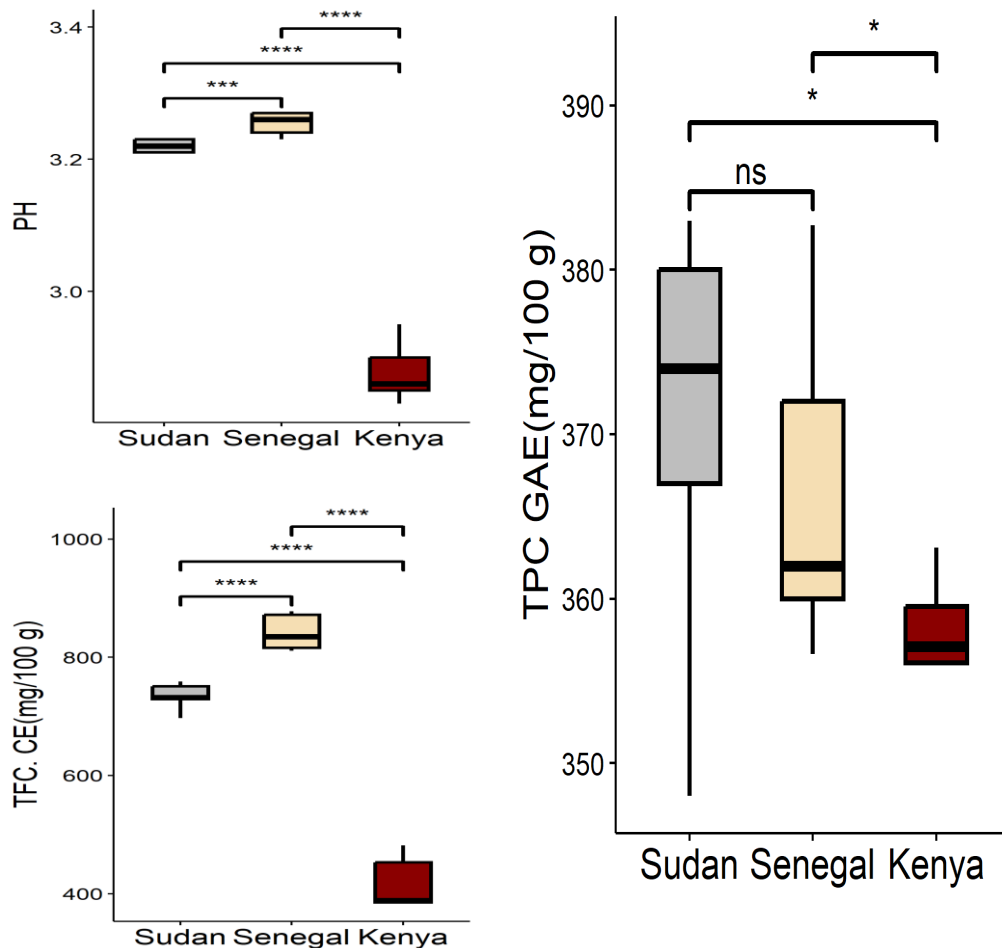


Figure 26. Total flavonoids, total phenolic content, and pH in baobab fruit pulp from three different countries.

5.2 Principal component analysis (PCA)

5.2.1 Analytical characteristics of baobab leaves samples

Principal component analysis (PCA) was used to evaluate the relationships between the analytical characteristics of the leaf samples and their geographical origins (region and sites). The first two PCs explain 63.4% of the variance in the samples. The PC1 component, defined by the x-axis, explained a larger proportion of the variance (41.9%), indicating that it captured the main difference in the data. The PC2, as the y-axis (21.5%) of the variance, is also significant, but it captures less variation than PC1. This could help further refine or separate the samples vertically, but its lower explained variance suggests that it plays a minor role in discriminating between regions.

The loading plot in Figure 27b shows that the concentrations of TFC, Mg, Mn, and Fe had the highest positive loadings on PC1, whereas ash content and pH had negative loadings. PC2 was influenced mainly by dry matter (positive loading) and TPC (negative loading). Positive linear correlations (vectors pointing in the same direction) were found between Mg and TFC ($r = 0.771$), between Mg and Fe ($r = 0.810$), and between TFC and Mn ($r = 0.738$). The strongest inverse correlation (variables arranged in opposite directions with respect to the origin of the axis and far from the origin of the plot) was found between Mg and pH ($r = -0.629$). The scores plotted in Figure 27a show the distribution of the samples on the plane defined by PC1 and PC2. PC1 was effective in discriminating between geographic regions: higher levels of Fe (15.8 – 14.9 vs. 14.1 mg/100 g), TFC (1433-1396 vs. 1368 CE (mg/100 g), Mn (25.9 - 3.9 vs. 2.3 mg/100 g) and Mg (528 – 500 vs. 471 mg/100 g) drew samples collected in the Kordofan region to positive loadings on PC1. The samples from the Blue Nile region showed negative loadings on PC1, mainly due to the higher dry matter (92.6 – 92.4 vs. 92.1 m/m%), ash content (11.7 – 11.1 vs. 10.1 g/100 g), Zn (2.5 – 2.2 vs. 1.8 mg/100 g), Ca (2426- 2236 vs. 2903 mg/100 g) and K (1653–1476 vs. 1345 mg/100 g) than the samples from Kordofan. The range of variables along the x-axis (PC1) suggests that PC1 is the most important factor for discriminating between samples. Therefore, PC1 is likely to be more effective in discriminating between regions as it captures the most variance. PC2 was able to discriminate the samples by zone, but in different ways for samples from different regions. The P and M samples from Kordofan and the P and W samples from the Blue Nile had positive loadings for PC2.

Leaves

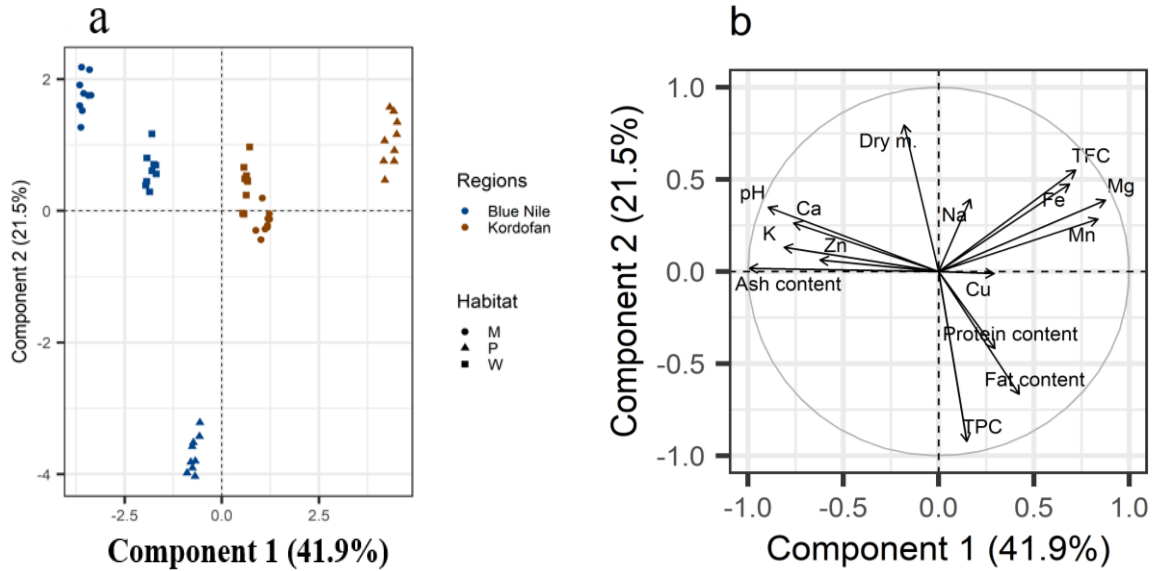


Figure 27. PCA score plots of the Baobab leaves samples (a) and PCA loadings plots of the variables on the first two components (b). The groups are blue (Blue Nile) and red (Kordofan). Zones are in plus signs (M), cross signs (P), and triangles (W).

5.2.2 Analytical characteristics of baobab fruit samples

Principal component analysis (PCA) was performed to visualize the relationships between the variables and the ecological origin of the fruit samples. The x-axis (PCA 1) explains 46.3 % of the variance in the data and is thus the actual axis for distinguishing between the regions. The spread along the x-axis indicates that it played a major role in distinguishing the samples. The y-axis (PCA 2) clarifies 19.0 % of the variance and contributes to further differentiation along the y-axis, but is secondary to PC1 in discriminating between regions. These two components capture 65.3% of the variance and provide an excellent representation of the underlying data structure.

The loading plot in Figure 28b shows that the ash, Fe, K, and protein contents had positive loadings in PCA 1. The strongest positive linear correlations (vectors pointing in the same direction) were found between ash and Fe ($r = 0.853$), and protein and K ($R = 0.641$). The strongest inverse correlation (variables arranged in opposite directions with respect to the origin of the axis and far from the origin of the plot) was found between Fe and Ca ($r = -0.821$), K and Mg ($r = -0.844$), and Fe and pH ($r = -0.712$). Figure 28a shows the score plot used to reduce the multidimensionality of the data and to visualize the relationships between the samples studied on the plane indicated by PC1 and PC2. There is a clear separation between the samples from Kenya (blue), Senegal (brown), and Sudan (green) in PCA 1 and PCA 2, indicating that the samples from the three

countries have different characteristics as captured by PCA. The samples from Sudan and Senegal were similar, indicating less variability. On the other hand, the closed samples from Senegal and Sudan were further away from the Kenyan samples, indicating greater variability. The highest mean contents of ash, Fe, protein, and K were observed in the samples from Kenya. In contrast, the highest mean values for Mg, TFC, and Ca were found in the samples from Senegal and Sudan. This discontinuity helps us to understand which parameters are important in differentiating the samples, which probably reflects the differences between the regions in terms of their nutrient components.

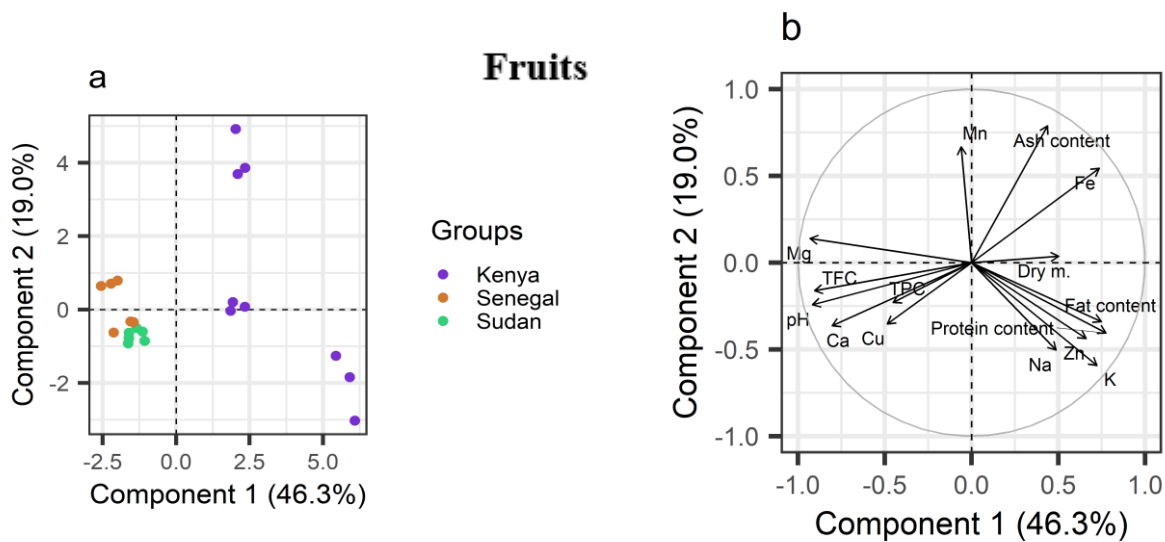


Figure 28. PCA score plots of the Baobab fruit samples (a) and PCA loadings plots of the variables on the first two components (b). The groups are blue (Kenya), brown (Senegal), and green (Sudan).

5.3 The estimated amount of baobab leaves (BLI) as a nutritional intervention

The estimated amount of baobab leaves daily intake (BLI g/day to meet the reference values of nutrients for different age groups are summarized in Tables 7–12. The BLI g/day was calculated based on the nutritional data in Table 5 and the dietary reference values in Table 3. Abbreviations used in all tables explained as follows Age groups: Children (1-3 years) (C1), children (4-6 years) (C2), children (7-10 years) (C3), children (10-18 years) (C4), adults (≥ 25 years) (AD), pregnant women (PQ), and lactating women (LQ). 1st trimester, 2nd trimester, 3rd trimester. “B”: boys, “G”: girls, “M”: men, “Q”: women, “FI” : (first 6 months), “AF”: (after 6 months).

Table 7. The baobab leaves amount (BLI g/day) for the required potassium and manganese per day

Study Area	C1 (K)	C4 (K)	AD (K)	PQ (K)	LW (K)	AD (Mn)	PQ (Mn)	LQ (Mn)
Wetlands (W)	48	212	212	212	212	0.6	0.6	0.6
Plain's land (P)	59	260	260	260	297	0.5	0.5	0.5
Mountains (M)	54	230	237	237	271	0.6	0.6	0.6

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 8. The baobab leaves amount (BLI g/day) for the required calcium per day

Study Area	C1	C2	C3	C4	AD	PQ	LQ
Wetlands (W)	19	33	33	47	31	31	31
Plain land (P)	20	36	36	51	34	34	34
Mountains (M)	16	29	28	40	26	26	26

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 9. The baobab leaves amount (BLI g/day) for the required magnesium per day

Study Area	C1	C2	C3	C4 - B	C4 - G	AD - M	AD - W	PQ	LQ
Wetlands (W)	36	48	49	64	53	74	64	64	64
Plain land (P)	32	44	44	57	47	66	57	57	57
Mountains (M)	34	46	46	60	50	70	60	60	60

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 10. The baobab leaves amount (BLI g/day) for the required sodium per day

Study Area	C1	C2	C3	C4	AD	PQ	LQ
Wetlands (W)	14	17	22	26	26	26	26
Plain land (P)	14	19	24	29	29	29	29
Mountains (M)	15	18	23	27	27	27	27

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 11. The baobab leaves amount (BLI g/day) for the required protein per day

Study Area	C1	C2	C3	C4	AD	PQ (1st)	PQ (2nd)	PQ (3rd)	LQ (FI)	LQ (AF)
Wetlands (W)	4	4	4	4	5	6	56	175	119	81
Plain land (P)	4	4	4	4	5	6	54	168	114	78
Mountains (M)	5	5	5	5	6	7	66	206	140	95

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 12. The baobab leaves amount (BLI g/day) for the required iron per day

Study Area	C1	C2	C3	C4 - B	C4 - G	AD - M	AD - Q	PQ	LQ
Wetlands (W)	47	47	74	74	87	74	107	107	107
Plain land (P)	44	44	69	69	82	69	101	101	101
Mountains (M)	50	50	78	78	93	78	114	114	114

Abbreviations used in this table were explained in sections 3.6 and 4.3.

The amount of BLI required to achieve the recommended daily potassium intake ranged from 48 g/day to 297 g/day in all study areas (W, P, and M). The highest intake across all the above sites was found in W, and the lowest in P. C1 had the lowest intake requirements. Groups C4, AD, PQ, and LQ had a uniform BLI of 212 g/day in site W. On the other hand, the dietary recommendations for manganese were limited to the AD, PQ, and LQ age groups, with no major differences between them in all study sites, the average being between 0.5 and 0.6 g/day (Table 7). The amount of BLI required to achieve the daily calcium reference intake for different age groups ranged from 16 to 51 g/day. The lowest intake was observed in M and the highest in P. Group C1 required a lower amount of BLI per day than groups C2-4, AD, PQ, and LQ (Table 8). The highest and lowest BLI g/day, to cover the daily reference intake of magnesium, were found in the W and P areas, respectively. The AD-M group required the highest BLI value of 74 g/day; in contrast, C1 had the lowest BLI amount at 32 g/day. C4-B required a higher BLI than C4-G in all study areas (57, 60, and 64 g/day compared to 47, 50, and 53 g/day) (Table 9). The lowest BLI for compliance with the recommended daily sodium reference values was found in the C1 group for leaves of W and P, whereas leaves of P had the highest BLI, especially for C4, AD, PQ, and LQ. The BLI increased with the age of the target group from C1 to the LQ. The AD, PQ, and LQ groups required the same

BLI of 29 g/d (Table 10). To achieve the recommended daily iron intake, the lowest BLI value of 44 g/day was reported in the P area for the C1 and C2 age groups, and the highest value of 114 g/day was reported for the AD-Q, PQ, and LQ in the M area (Table 12). The estimated BLI for adequate protein intake ranged from 4 to 7 g/day for the C1, C2, C3, C4, AD, and (PQ 1st) groups and from 54 to 206 g/day for PQ 2nd, PQ 3rd, LQ (FI), and LQ (AF) (Table 11).

5.3.1 The estimated amount of baobab dried fruit pulp (BFI) as a nutritional intervention

The estimated amounts of daily intake of dried baobab fruit pulp (BFI g/day) from different countries, Kenya (KEN), Senegal (SEN), and Sudan (SUD) to meet the reference values of nutrients for different age groups are summarized in Tables 13 to 18.

Table 13. The baobab dried fruit pulp amount (BFI g/day) for the required potassium and manganese per day

Study Area	C1 (K)	C4 (K)	AD (K)	PQ (K)	LQ (K)	AD (Mn)	PQ (Mn)	LQ (Mn)
KEN	37	163	163	163	186	3	3	3
SEN	46	201	201	201	230	2	2	2
SUD	42	184	184	184	210	2	2	2

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 14. The baobab dried fruit pulp amount (BFI g/day) for the required calcium per day

Study Area	C1	C2	C3	C4	AD	PQ	LQ
KEN	157	280	280	402	262	262	262
SEN	144	256	256	367	240	240	240
SUD	137	243	243	350	228	228	228

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 15. The baobab dried fruit pulp amount (BFI g/day) for the required magnesium per day

Study Area	C1	C2	C3	C4 - B	C4 - G	AD - M	AD - Q	PQ	LQ
KEN	159	214	214	280	233	327	280	280	280
SEN	89	120	120	157	130	183	157	157	157
SUD	97	131	131	171	142	200	171	171	171

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 16. The baobab dried fruit pulp amount (BFI g/day) for the required sodium per day

Study Area	C1	C2	C3	C4	AD	PQ	LQ
KEN	17	20	30	31	31	31	30
SEN	20	24	32	37	37	37	37
SUD	17	20	27	31	31	31	31

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 17. The baobab dried fruit pulp amount (BFI g/day) for the required protein per day

Study Area	C1	C2	C3	C4	AD	PQ (1st)	PQ (2nd)	PQ (3rd)	LW (FI)	LQ (AF)
KEN	17	17	17	17	22	26	230	717	487	333
SEN	22	22	23	23	30	34	310	966	655	448
SUD	23	23	23	23	29	34	310	966	655	448

Abbreviations used in this table were explained in sections 3.6 and 4.3.

Table 18. The baobab dried fruit pulp amount (BFI g/day) for the required iron per day

Study Area	C1	C2	C3	C4 - B	C4 - G	AD - M	AD - Q	PQ	LQ
KEN	39	39	61	61	72	61	89	89	89
SEN	144	144	226	226	267	226	329	329	329
SUD	110	110	172	173	204	173	252	252	252

Abbreviations used in this table were explained in sections 3.6 and 4.3.

The amount of BFI required to achieve the recommended daily potassium intake ranged from 37 g/day to 230 g/day in all study areas, KEN and SEN SUD. The highest intake of 230 g/day across all regions was found in SEN, and the lowest intake of 37 g/day was reported in KEN. C1 had the lowest intake requirement. Groups C4, AD, and PQ had a uniform BFI of 201 g/d in the SEN region. On the other hand, dietary recommendations for Mn were limited to the AD, PQ, and LQ age groups, with no major differences between them in all study regions, with BFI ranging from 2 to 3 g/day (Table 13). The amount of BFI g/day required to achieve the daily calcium reference intake for the different groups ranged from 137 g/day to 402 g/day. The lowest intake of BFI g/day was observed in SUD and the highest in KEN. Group C1 required less BFI g/day than groups C2-4, AD, PQ, and LQ (Table 14). The highest and lowest BFI g/day to cover the daily reference intake of magnesium were found in KEN and SUD. The AD-M group required the highest BFI value of 327 g/day, whereas C1 had the lowest value of 97 g/day. C4-B required a higher BFI than

C4-G in all study areas (157, 171, and 280 g/day versus 130, 142, and 233 g/day), and AD-M required a higher amount than AD-Q (183, 200, and 327 g/day versus 157, 171, and 280 g/day) (Table 15). The highest amount of BFI to meet the recommended daily sodium reference value of 37 g/day was found in the SEN region and was required for the age groups C4, AD, PQ, and QL, whereas the lowest amount of 17 g/day was found in KEN and SUD, especially for C1 (Table 16). To achieve the recommended daily iron intake, the lowest BFI value of 39 g/day was given in the KEN region for the C1 and C2 age groups, and the highest amount of 329 g/day for AD-Q, PQ, and LQ in SEN (Table 18). The estimated BFI for adequate protein intake ranged from 17 to 34 g/day for groups C1, C2, C3, C4, AD, and (PQ 1st) and 310 to 966 g/day for PQ 2nd, PQ 3rd, LQ (FI), and LQ (AF) (Table 17).

6 Discussion

6.1 The composition of baobab leaves

The study of baobab leaves (BLs) collected from different locations shows the nutritional potential of this plant as a healthy food suitable for several age groups. Baobab leaves are rich in essential nutrients (Asogwa et al., 2021), and their components meet the nutritional requirements of different population groups (Assogbadjo et al., 2021). The parameters analysed are discussed below, and how these results underline their importance.

Previous research has shown that the baobab tree plays an important role in increasing the income of rural populations in Sudan (Adam et al., 2024), and it is a significant source of nutrients with implications for human health (Ogbaga et al., 2017). Baobab leaf extract effectively reduced the cardiotoxicity of doxorubicin owing to its antioxidant compounds (Uhuo et al., 2022). Previous studies have also shown that the mineral content in baobab leaves varies significantly within and between different areas in African countries (Gabaza et al., 2018; Hyacinthe et al., 2015). Similarly, this study also showed remarkable variations in the contents of various nutrients, such as protein, fat, potassium, sodium, magnesium, calcium, manganese, and zinc, emphasizing the dynamic nature of the chemical composition of baobab leaves. This study adds to existing knowledge by examining the effects of habitat and regional factors on the nutrient composition of baobab leaves and provides a new perspective on the variability of nutrient concentrations.

The levels of the essential microelements Ca, K, Mg, and Na found in the BLs in this study were consistent with previous studies (Boukari et al., 2001; Hyacinthe et al., 2015; Kayode et al., 2018), which are important for bone well-being, electrolyte stability, and muscle function (Bennet et al., 2021; Cruz-Jentoft et al., 2020). In particular, the K content of BLs is high, which can support blood pressure regulation (Fadol et al., 2024). A high magnesium and calcium content supports bone development in children and adolescents and helps prevent bone-related situations (Proia et al., 2021). BLs are also rich in Mn and Fe (Hyacinthe et al., 2015; Ogbaga et al., 2017), which is consistent with the results of the present study. Iron supports the prevention of dangerous diseases, such as anemia, especially in children, pregnant women, and people of reproductive age (Mwangi et al., 2021; Stoltzfus, 2011). Mn content is helpful for metabolism, especially in adults and adolescents who engage in regular physical activity (Banach et al., 2020; Martins et al., 2020). Referring to our results and previous research findings, we found that BLs are reliably emphasised

as a nutrient-rich food source. Nonetheless, this study proves that BLs from different areas can show slight variations in nutrient content due to the adaptability of baobabs to ecological factors such as soil type and macroclimate, which can affect the amount of baobab leaves consumed in different locations (Ahmed et al., 2024).

The protein content found in this context was consistent with the results of previous studies (Alba et al., 2020; Dimopoulou et al., 2021; Habte & Krawinkel, 2017). The BLs have a high protein content and are a reputable plant protein source. Protein content is valuable for children and adolescents as it maintains growth and development (Capra et al., 2024). It supports muscle maintenance in adults and the elderly (Carbone & Pasiakos, 2019). Low fat content was consistent with the fat values of baobab leaves, as reported by Abioye et al. (2014) and Chadare et al. (2008). The presence of fatty acids can help all age groups, mainly adults and the elderly, by supporting cardiovascular health (Hirahatake et al., 2020; Klempel et al., 2013). The dry matter and ash contents were consistent with the results reported by (Gbaguidi et al., 2020; Kayode et al., 2018; Ogbaga et al., 2017). The high dry matter content in BLs indicates nutrient density, while the ash content is rich in minerals. Mineral content provides benefits for all age groups and is important for various bodily functions (Dobrowolska-Iwanek et al., 2022; Quintaes & Diez-Garcia, 2015). The pH of BLs was lower than that reported by Assogbadjo et al. (2012), but within the range of many leafy vegetables (Fimbres-Acedo et al., 2023), showing that it is suitable for general consumption without causing acid-related problems.

The evaluation of the antioxidant perspective was considered in this study to demonstrate the potential of BLs for human well-being. TPC and TFC in the BLs were investigated to evaluate the antioxidant and well-being perspectives. The results showed that BLs contain considerable amounts of both TPC and TFC. The TPC content in the BLs in the present study was significantly lower than the levels reported in previous studies, but the TFC levels were similar and comparable to those reported by (Mohammed et al., 2024). Phenolic compounds and flavonoids are known for their antioxidant activity, which is essential for scavenging free radicals and reducing oxidative stress in the body (Mutha et al., 2021; Parcheta et al., 2021; Rudrapal et al., 2022).

6.2 The composition of baobab fruits

The protein content in the DBFP in our samples ranged from 2.44 ± 0.02 to 3.06 ± 0.01 g/100 g. This amount aligns with the averages reported by (Gebauer et al., 2016; Gurashi et al., 2016; Nour et al., 1980). This protein content, as a source of amino acids in DBFP, contributed significantly to the recommended dietary intake of people in the regions studied.

These amino acids are essential for various functions of the human body (Akhtar et al., 2024; Korhonen et al., 2024; Morishita et al., 2024). The results showed that DBFP is characterized by a low-fat content, typically below 1 g/100 g, which agrees with previous studies (Gurashi et al., 2016; Nour et al., 1980). The fat content in DBFP emphasizes its value as a cardioprotective diet, which is particularly helpful for managing obesity and reducing cardiovascular diseases (Katsi et al., 2022; Patikorn et al., 2021; Rahmawati et al., 2024).

The amount of calcium in DBFP is 3285 ± 4.64 mg/kg, which makes it an important source for a healthy diet as it is important for muscle contraction and bones. It also supports the immune system and nerve functions. In regions where access to food is scarce, DBFP is an important alternative to dietary calcium (Agrawal et al., 2018; Chaudhary et al., 2024; Dobrowolska-Iwanek et al., 2022; Sarhan et al., 2024). The results also show that the DBFP is rich in potassium, containing 19074 ± 7.86 mg/kg, which is higher than the average determined by Bilal et al. (2022) and Rocha et al. (2024). It is important for the regulation of fluid balance, nerve transmission, and muscle function (Asogwa et al., 2021; Assogbadjo et al., 2021; Swareldhab et al., 2021). Potassium controls blood pressure and maintains cardiovascular health in humans (Gan et al., 2024). The high K content in DBFP could reduce the prevalence of common health problems, such as hypertension, in Sudan and Senegal. The average magnesium concentration in DBFP was 1979 ± 3.98 mg/kg, which is consistent with Bilal et al. (2022) and Dimopoulou et al. (2021) but lower than that reported by Kamanula et al. (2018). Mg is a key element in the regulation of the immune system (Weng et al., 2024). The high Mg content of DBFP could contribute to the overall metabolic health of humans and prevent diseases related to Mg deficiency. The low sodium content of the analyzed samples was generally below 10 mg/100 g, which is highlighted in the previously published range (Magaia et al., 2013). This level is useful for maintaining blood health and reducing the risk of cardiovascular diseases (Takano et al., 2024). The low sodium content of DBFP promotes its potential as a preventive healthy diet for heart disease.

The concentrations of Zn, Mn, and Cu are consistent with those reported by Abioye et al. (2014) and Chadare et al. (2008). Mn is crucial for bone formation (Kang et al., 2016), Cu is an essential component of the nervous system (Gale & Aizenman, 2024), and Zn strengthens immune functions (Zahran et al., 2024). The daily requirement of these elements in the diet is relatively important for the growth of children and is useful for pregnant women. Their presence in DBFP can ensure 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 (Kayode et al., 2018; Turck et al., 2019), DBPF remains an important plant source of this essential mineral. Iron is necessary for the production (Alzahrani et al., 2017). This iron content can help prevent iron deficiency and anemia, which are prevalent in many parts of Sudan, Kenya, and Senegal.

6.3 The estimated amount of dried baobab leaves and fruit pulp to be consumed

The nutritional and medicinal properties of baobab leaves, and fruit pulp have been widely recognized in previous studies, highlighting their potential as food ingredients. However, an important gap remains: the lack of studies quantifying the specific amounts of baobab products required to fulfil the recommended daily nutrient intake for different age groups. In addition, previous studies have not sufficiently considered the differences in nutrient composition resulting from the different geographical origins or distributions of baobab trees.

In the current study, the nutritional value of baobabs was thoroughly evaluated, taking these deviations into account. By establishing appropriate consumption levels based on standardized dietary guidelines, our research focused on closing this knowledge gap and providing science-based recommendations for the optimal use of baobab products in the diet. This work not only contributes to a deeper understanding of baobab's potential but also supports its use in addressing nutritional deficiencies and promoting health in diverse populations.

7 Conclusion

This study highlights the essential health policies that will reduce hunger and food insecurity by including certainly available, nutritious substitutes like the baobab dried fruit pulp and leaves. Policymakers internationally must reflect and consider the feedback of this proposed protocol highlighted in this study into public health food programs, precisely in local and rural areas with a lack of foodstuff, to improve the nutrient deficiencies and their significance for health problems, such as undernourishment, anemia, and hypertension. Contribution to food security and rural improvement creativity will diminish gaps due to low health expenditure and economic hurdles. In the context of interventional practice, the study points out the potential for combining nutrient-dense plant-based selections into dietary rules. Showing programs for susceptible populations must be important, and the adoption of nutritional counseling to include locally available food keys.

Further research should be conducted to improve the availability of Fe and to increase its absorption in different age groups. Here, research strategies are suggested: (i) fermentation of BLs and fruits can reduce antinutrients that affect iron absorption (Hendek Ertop & Bektaş, 2018; Jeyakumar & Lawrence, 2021; Mongwaketse et al., 2022); (ii) exploring baobab-based products by adding bioavailable iron constituents such as ferrous gluconate and ferrous sulfate to improve iron content to ensure recommended intake (Hurrell, 2021; Man et al., 2022); (iii) developing concentrated baobab extracts with high iron concentrations, especially for children, to meet their needs; (iv) introducing new processing techniques to improve bioavailability; and (v) investigating different cooking methods for the leaves, such as boiling and steaming, which could influence the anti-nutritional factors. Each of these findings could help improve iron absorption from BLs while managing intake levels. Further studies are needed to confirm their efficacy and practical application.

8 New scientific results

We conducted this research and discovered a significant difference in the nutrient composition of baobab leaves and fruits across different regions and habitats. The findings highlight the importance of geographic factors in determining the nutritional value of baobab products and estimating nutrient reference intakes used for nutritional intervention for various age groups accordingly. The new scientific results have been emphasized as follows:

1. The nutritional profile of baobab leaves has been affected by different regions and habitats:
 - A. The highest calcium (2903 ± 187 mg/100 g) was found in mountains (M), making it an excellent source of this essential mineral.
 - B. Potassium (1654 ± 34 mg/100 g) and sodium (7.7 ± 1.2 mg/100 g) were highest in the wetland (W) site.
 - C. Magnesium (529 ± 101 mg/100 g) was highest in the plain land (P) site, where sodium levels of (6.9 to 7.7 mg/100 g) were comparatively lower.
 - D. The highest iron content (15 ± 4 mg/100 g) and protein content (16.6 ± 0.3 g/100 g) were also found in the plain land (P) site.
 - E. Fat content was low across all study sites (wetland, mountain, and plain land), ranging from 1.9 to 2.0 g/100 g, and sodium values were consistently low (6.9 to 7.7 mg/100 g).
2. The nutritional profile of dried Baobab fruit pulp (DBFP) has been affected by different regions (Kenya, Senegal, and Sudan).
 - A. The highest protein content (3.9 ± 0.8 g/100 g dw), iron (18 ± 9.7 mg/100 g), potassium (2145 ± 635 mg/100 g), and sodium (6.6 ± 4.2 mg/100 g) were reported in Kenya (KEN).
 - B. The highest magnesium content (191 ± 10 mg/100 g) was found in Senegal (SEN).
 - C. The highest calcium content (329 ± 0.5 mg/100 g) was found in Sudan (SEN).

3. The daily estimated amount of baobab leaves to be consumed for nutritional intervention by referring to the recommended daily intake for each age group, and the average nutrient concentration is identified by the habitat of origin as follows: The age group abbreviations used in the following term were explained in sections 3.6 and 4.3 above.
 - a) The estimated daily intake of baobab leaves to meet calcium requirements for different children age groups (C1, C2, C3, C4) is 16 g/day, 29 g/day, 28 g/day, and 40 g/day, respectively, with site mountain (M) being the most suitable source.
 - b) To meet potassium requirements for electrolyte balance, the recommended intake of baobab leaves ranges from 32 g/day to 297 g/day, with the wetland (W) site as the best source.
 - c) For magnesium intake, which supports muscle function, the estimated consumption ranges from 32 g/day to 66 g/day, with the plain land (P) site being the preferred source.
 - d) The estimated amount of baobab leaves that can be added to soups and sauces commonly consumed by local communities as an alternative to other leafy vegetables, according to my new scientific protocol in Figure 29.

4. The estimated amount of baobab fruit pulp to be consumed for nutritional intervention is identified by the region of origin as described below. The target age groups and their abbreviations were explained in sections 3.6, 4.3, and 4.3.1 above.
 - a. The recommended amount of dried baobab fruit pulp powder varies by location:
 - i. The estimated amount of dried baobab fruit pulp obtained from Kenya ranges from 37 g/day to 186 g/day for potassium, 17 g/day to 487 g/day for protein, and 39 g/day to 89 g/day for iron, suitable for different age groups, see section 4.3.1.
 - ii. The estimated amount of dried baobab fruit pulp obtained from Sudan ranges from 137 g/day to 350 g/day for calcium and 97 g/day to 200 g/day for magnesium, suitable for different age groups, see section 4.3.1.

- iii. The estimated amount of dried baobab fruit pulp obtained from all study areas (Kenya, Senegal, and Sudan) ranges from 2 g/day to 3 g/day and is suitable for manganese intake.
- b. The estimated amount of dried baobab fruit pulp can be suspended in water and consumed as a juice or paste, providing a nutrient-rich dietary supplement.

These findings underscore the potential of baobab leaves and fruit pulp as nutrient-dense food sources that vary in composition based on geographic location.

9 Practical utilization of the new scientific results

Baobab products (BP) can be incorporated into daily diets to enhance overall health across different target age groups in this study. Their high mineral content, respectable protein levels, and low fat and sodium content make them ideal for supporting nutritional needs. Based on my new scientific results, the following practical applications are proposed:

1. Geographic considerations for dietary recommendations:

- a) Nutrient composition varies based on region and habitat, and dietary guidelines should consider these differences to address specific deficiencies in different populations.
- b) Incorporating baobab products into daily diets can be an effective solution for combating malnutrition, especially in regions with nutrient deficiencies in countries such as Sudan, Kenya, and Senegal.

2. Public health and policy implications:

- a) Health policies in Sudan, Kenya, and Senegal should integrate naturally available, nutrient-dense foods such as baobab leaves and fruit pulp to combat malnutrition and food insecurity.
- b) Policymakers should consider these findings, especially the new scientific protocol described below, when developing nutrition intervention programs for underserved and rural communities, addressing issues such as anemia, malnutrition, and hypertension.

3. New scientific protocol:

The protocol for implementing nutritional intervention based on baobab products aims to improve nutritional status and combat malnutrition. This protocol applies to rural and urban individuals. The assessment step involves collecting baseline data on dietary needs and health status for target populations. The intervention utilises dried baobab leaves (BLI) and fruit pulp powder (BPI). The BLI powder should be added to the cooked sauce or soup (i.e., onion, tomato, salt, etc.) as an

alternative leafy vegetable, while the BPI should be suspended in water and taken as paste or juice. Distribution networks will be set up using age as a category to ensure that baobab products can be easily introduced to the target age groups. The estimated amount of BLI/BPI (g/day) will be integrated into existing dietary programs for each age group. Expected outcomes include avoiding nutrient deficiency, preventing malnutrition among the population, and enhancing food security.

10 Summary

Baobab (*Adansonia digitata* L.) is an underutilized species, and its edible parts (fruits, leaves, and seeds) contribute to food security and human health in tropical regions. Although the fruits have attracted considerable research interest and have recently been authorized for consumption in EU countries, the leaves are traditionally consumed; however, no study has investigated them from an interventional perspective. The main objective of this research was to discover a new plant resource with an appropriate and healthy composition, such as the African baobab, to improve food security and contribute to nutritional intervention in rural and urban communities (different age groups in Sudan, Kenya, and Senegal). We then propose a protocol for nutritional intervention using dried baobab leaves and fruit pulp powder to achieve the daily recommended reference values for proteins and minerals (K, Ca, Mg, Na, Fe, and Mn) for different target groups. A mixture of young and old fresh leaves was collected in Sudan to cover two regions: the Blue Nile and the North Kordofan. Dried baobab fruits were collected from different markets in Sudan, Kenya, and the Hungarian market for fruits from Senegal. Dry matter, crude fat, protein and ash content, mineral content (Na, Mg, K, Ca, Fe, Mn), and total phenol and flavonoid content were determined in the laboratory of the Food Institute of the University of Debrecen, Hungary. Time series data (2013-2023) from the DataBank Health, Nutrition and Population Statistics database were used to assess the health and nutritional status of these countries. The reference values for nutrients recommended by the European Food Safety Authority were used to estimate the amount of baobab leaf and fruit pulp intake (g/day). For each nutrient, the study area with the lowest number of BLs consumed is recommended. For K and Na, leaves from site W are recommended at 48 and 14 g/day, respectively, which is particularly beneficial for children aged 1–3 years. Leaves from site M were suitable for Ca intake, with approximately 16–40 g/day required for all age groups. Leaves from site P (32–66 g/day, 44–101 g/day, and 4–168 g/day) were optimal for meeting the daily requirements of magnesium, iron, and protein, in that order. The leaves from all locations (0.5-0.6 g/day) were suitable for Mn intake. The amount of baobab pulp powder (BPI) from the study areas KEN, SEN, and SUD (17-37 g/day) is suitable for Na intake. BPI from KEN (37-186 g/day, 17-487 g/day and 39–89 g/day) is recommended for nutrients K, protein, and Fe, respectively. In contrast, the BPI of SUD (137-350 g/day and 97-200 g/day) is recommended for Ca and Mg, respectively. For Mn intake, BPI from all study areas (2-3 g/day) was recommended.

Systematic inclusion of baobab products in the diet can positively support the nutritional status of various population groups. In addition, the results of this study provide a basis for public health and nutrition policymakers on how to combat malnutrition and food insecurity worldwide by incorporating naturally available foods and nutritious alternatives. Further research should focus on assessing the nutritional composition factors that could influence the absorption of nutrients, such as phytates and oxalates, as well as investigating the in vitro bioavailability of these elements.

Keywords: Baobab leaves, baobab fruit, food insecurity, dietary intervention, human health

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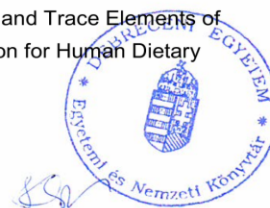
List of publications related to the dissertation

Foreign language scientific articles in Hungarian journals (1)

1. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Kovács, B.: Baobab (*Adansonia digitata* L.) as a remedy to human livelihood challenges: a review.
Acta agrar. Debr. 2, 5-11, 2024. ISSN: 2416-1640.
DOI: <http://dx.doi.org/10.34101/ACTAAGRAR/2/14170>

Foreign language scientific articles in international journals (3)

2. **Ahmed, A. E. M.**, Mozzon, M., Dawod, A. B. A., Awad Mustafa Eltayeb, O., Shaikh, A. M., Kovács, B.: Potential of Baobab (*Adansonia digitata* L.) Dried Fruit Pulp in Contributing to Food and Nutrient Security in Sudan and Senegal.
J. Agric. Food Res. 19, 1-9, 2025. ISSN: 2666-1543.
DOI: <http://dx.doi.org/10.1016/j.jafr.2025.101681>
IF: 4.8 (2023)
3. **Ahmed, A. E. M.**, Mozzon, M., Dawod, A. B. A., Eltayeb, O. A. M., Shaikh, A. M., ElObeid, T., Mohammed, E. A. H., Kovács, B.: Evaluation of the Nutritional Impact of Baobab Leaves (*Adansonia digitata* L.) as a Dietary Intervention to Combat Nutrient Deficiencies and Poverty-Related Health Problems.
Nutrients. 16, 1-21, 2024. EISSN: 2072-6643.
DOI: <https://doi.org/10.3390/nu16244340>
IF: 4.8 (2023)
4. **Ahmed, A. E. M.**, Mozzon, M., Omer, A., Shaikh, A. M., Kovács, B.: Major and Trace Elements of Baobab Leaves in Different Habitats and Regions in Sudan: implication for Human Dietary Needs and Overall Health.
Foods. 13 (12), 1-14, 2024. EISSN: 2304-8158.
DOI: <http://dx.doi.org/10.3390/foods13121938>
IF: 4.7 (2023)





List of other publications

Foreign language scientific articles in Hungarian journals (2)

5. AlNasr, M., Salam, H., Al-Kendi, A., AlAbdi, T., **Ahmed, A. E. M.**, Shaikh, A. M., Kovács, B., ElObeid, T.: Desert Greens: Unveiling the Antioxidant Power and Health Benefits of Qatar's Locally Grown Leafy 1 Vegetables.
Acta agrar. Debr. "Accepted by Publisher", [1-12], 2025. ISSN: 2416-1640.
6. Mohammed, E. A. H., **Ahmed, A. E. M.**, Teye-Gaga, C., Pál, K.: The potential use of *Pediococcus* spp. probiotic in aquaculture: a review.
Acta agrar. Debr. 1, 1-9, 2025. ISSN: 2416-1640.

Foreign language scientific articles in international journals (7)

7. Mohammed, E. A. H., **Ahmed, A. E. M.**, Kovács, B., Pál, K.: The Significance of Probiotics in Aquaculture: A Review of Research Trend and Latest Scientific Findings.
Antibiotics-Basel. 14, 2-26, 2025. EISSN: 2079-6382.
DOI: <https://doi.org/10.3390/antibiotics14030242>
IF: 4.3 (2023)
8. Shaikh, A. M., Wandhekar, S. S., **Ahmed, A. E. M.**, Pandey, V. K., Oláh, C., Daróczy, L., Prokisch, J., Harsányi, E., Kovács, B.: Exploring the Ecological Implications, Gastronomic Applications, and Nutritional and Therapeutic Potential of *Juglans regia* L. (Green Walnut): A Comprehensive Review.
Nutrients. 16 (8), 1-23, 2024. EISSN: 2072-6643.
DOI: <http://dx.doi.org/10.3390/nu16081183>
IF: 4.8 (2023)
9. Divya, S., Pandey, V. K., Dixit, R., Rustagi, S., Suthar, T., Atuahene, D., Nagy, V., Ungai, D., **Ahmed, A. E. M.**, Kovács, B., Shaikh, A. M.: Exploring the Phytochemical, Pharmacological and Nutritional Properties of *Moringa oleifera*: A Comprehensive Review.
Nutrients. 16 (19), 1-22, 2024. EISSN: 2072-6643.
DOI: <http://dx.doi.org/10.3390/nu16193423>
IF: 4.8 (2023)
10. Shaikh, A. M., Wandhekar, S. S., **Ahmed, A. E. M.**, Várallyay, S., Pandey, V. K., Prokisch, J., Kovács, B.: Global Perspectives on the Medicinal Implications of Green Walnut and Its Benefits: a Comprehensive Review.
Horticulturae. 10 (5), 1-24, 2024. EISSN: 2311-7524.
DOI: <http://dx.doi.org/10.3390/horticulturae10050433>
IF: 3.1 (2023)





11. Shams, R., Singh, J., Dash, K. K., Dar, A. H., Nayik, G. A., Ansari, M. J., Hemeg, H. A., **Ahmed, A. E. M.**, Shaikh, A. M., Kovács, B.: Effect of Maltodextrin and Soy Protein Isolate on the Physicochemical and Flow Properties of Button Mushroom Powder.
Front. Nutr. 9, 1-14, 2022. ISSN: 2296-861X.
DOI: <http://dx.doi.org/10.3389/fnut.2022.908570>
IF: 5
12. Yadav, S., Sharma, A., Nayik, G. A., Cooper, R., Bhardwaj, G., Sohal, H. S., Mutreja, V., Kaur, R., Areche, F. O., AlOudat, M., Shaikh, A. M., Kovács, B., **Ahmed, A. E. M.**: Review of Shikonin and Derivatives: Isolation, Chemistry, Biosynthesis, Pharmacology and Toxicology.
Front. Pharmacol. 13, 1-38, 2022. EISSN: 1663-9812.
DOI: <http://dx.doi.org/10.3389/fphar.2022.905755>
IF: 5.6
13. **Ahmed, A. E. M.**, Abdalla, A. M. A., Kovács, B., Yamamoto, F., Foligni, R., Mozzon, M.: Effects of ethephon and methyl jasmonate on physicochemical properties of Acacia seyal var. seyal (L.) gum produced in Sudan.
Food Hydrocolloids. 90, 413-420, 2019. ISSN: 0268-005X.
DOI: <http://dx.doi.org/10.1016/j.foodhyd.2018.12.041>
IF: 7.053

Foreign language conference proceedings (1)

14. Ocwa, A., Acaye, F., Abakeer, R. A., **Ahmed, A. E. M.**, Sidahmed, H. M. I., Harsányi, E.:
Electrical conductivity and germinability of millet seeds from different accessions.
In: Conference Proceedings of the "Challenges of nowadays in the light of sustainability"
8thVUA YOUTH scientific session. Ed.: Róbert Magda, Farheen Naz, Hungarian University of
Agriculture and Life Sciences, Gödöllő, 267-273, 2021. ISBN: 9789632699684

Foreign language abstracts (21)

15. Shaikh, A. M., **Ahmed, A. E. M.**, Kovács, B., Daróczy, L., Oláh, C., Prokisch, J.: "Walnut wonders: a dive into bee product development with green extract".
In: II. Magyar Agrártudományi Doktoranduszok Szimpóziuma : Absztraktkötet. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Budapest, 82, 2024. ISBN: 9786156457431
16. Shaikh, A. M., **Ahmed, A. E. M.**, Prokisch, J., Kovács, B.: Beyond the shell: exploring green walnut's ecological, culinary and health marvels.
In: LXV. Georgikon Napok Tudományos Konferencia = 65th Georgikon Days Scientific Conference /szerk. Pőr Csilla, Szabó-Soós Adrienn, Szabó Péter, Magyar Agrár- és Élettudományi Egyetem Georgikon Campus, Keszthely, 17-18, 2024. ISBN: 9786156338105





17. Shaikh, A. M., **Ahmed, A. E. M.**, Várallyay, S., Baráth, N., Prokisch, J., Kovács, B.: Exploring the Ecological Implications, Gastronomic Applications, and Nutritional and Therapeutic Potential of *Juglans regia* L. (Green Walnut): A Comprehensive Review.
In: XXVII. Tavasz Szél Konferencia 2024 - Absztrakt kötet. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Budapest, 56, 2024. ISBN: 9786156457523
18. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Mohammed, E. A. H., Kovács, B.: Exploring the potential of baobab processed products: a review.
In: II. Magyar Agrártudományi Doktoranduszok Szimpóziuma : Absztraktkötet. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Budapest, 62, 2024. ISBN: 9786156457431
19. Mohammed, E. A. H., Fehér, M., Bársony, P., Csernus, B., Teye-Gaga, C., **Ahmed, A. E. M.**, Pál, K.: Impact of *Pediococcus acidilactici*, *Saccharomyces cerevisiae* and yang on growth, morphometric parameters and intestinal parameters of the common carp (*Cyprinus carpio* L.).
In: 21st Wellmann International Scientific Conference : Book of Abstracts. Ed.: Ingrid Melinda Gyalai; Szilárd Czóbel, University of Szeged Faculty of Agriculture, Hódmezővásárhely, 91, 2024. ISBN: 9789633069806
20. Shaikh, A. M., **Ahmed, A. E. M.**, Várallyay, S., Baráth, N., Prokisch, J., Kovács, B.: Investigating the environmental impact, culinary uses, and health benefits of *Juglans regia* L. (Uripe Walnut): an in-depth examination.
In: XXVII. Tavasz Szél Konferencia 2024 - Absztrakt kötet. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Budapest, 636, 2024. ISBN: 9786156457523
21. Bartolome, D. O., Kovács, B., Shaikh, A. M., **Ahmed, A. E. M.**, Ungai, D., Várallyay, S.: Investigation of sample preparation methods for microelemental analyses of milk powder.
In: 12th Central European Conference on Food : Book of abstracts / Bánáti Diána, CEFood, Szeged, 90, 2024. ISBN: 9786155270826
22. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Mohammed, E. A. H., Kovács, B.: Microelement concentrations in baobab leaves from Sudan: Implications for human nutrition.
In: 15th Egerton University Biennial International Conference : Programme and book of abstracts / M.K. Charimbu, Egerton University, Egerton, Kenya, 90, 2024.
23. Mohammed, E. A. H., **Ahmed, A. E. M.**, Abbo, A. S. H., Ahmed, O. M. M., Siddig, M. E.: Review: Occurrence, Spread, and Management Possibilities of Citrus Bacterial Canker (*Xanthomonas citri* subsp. *citri*) in Sudan.
In: The 3rd International Electronic Conference on Plant Sciences: Program and Abstract Book / Jayanta Kumar Patra, Mauro Comisso, Antonella Vitti et al, MDPI, Belgrade, 78, 2024, (ISSN 2223-7747)
24. **Ahmed, A. E. M.**, Mozzon, M., Eltayeb, O. A. M., Shaikh, A. M., Kovács, B.: The health benefits of baobab fruit pulp *Adansonia digitata* L.: A nutrient-rich resource.
In: 12th Central European Conference on Food : Book of abstracts / Bánáti Diána, CEFood, Szeged, 84, 2024. ISBN: 9786155270826





25. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Kovács, B.: Changes in the nutritional composition of baobab (*Adansonia digitata* L.) leaves as affected by habitat: implications for human dietary needs and health.
In: Nordic Natural Products Conference 2023 : Programme and Abstracts. Eds.: Cristina D. Cruz et al, University of Helsinki, Faculty of Pharmacy, Helsinki, 48, 2023.
26. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Kovács, B.: Determination of the Levels of Potentially Toxic Elements in Baobab Leaves in Sudan.
In: Sustainable and Innovative Solutions in Agriculture and Food Industry (SISAF'23) One Health approach. Ed.: Szilvia Veres, Mariett Kocsisné Papp, University of Debrecen Faculty of Agricultural and Food Sciences and Environmental Management, Debrecen, 31, 2023. ISBN: 9789634905356
27. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Mohammed, E. A. H., Kovács, B.: Dynamics of magnesium concentration in baobab leaves: Site-specific variation in Sudan.
In: Scientific Conference of PhD Students of FAFR, FBFS and FHLE SUA in Nitra with international participation - Proceedings of abstracts on occasion of the Science and Technology Week in the Slovak Republic. Ed.: Monika Tóthová, Judita Lidiková, Kristína Candráková, Dominik Holly, Slovak University of Agriculture in Nitra, Slovakia, Nitra, 64, 2023. ISBN: 9788055226606
28. Mohammed, E. A. H., Fehér, M., Bársony, P., **Ahmed, A. E. M.**, Shaikh, A. M., Pál, K.: Effect of selected feed additives on growth performance and the intestinal microbiota of the Common carp (*Cyprinus carpio*).
In: Scientific Conference of PhD Students of FAFR, FBFS and FHLE SUA in Nitra with international participation - Proceedings of abstracts on occasion of the Science and Technology Week in the Slovak Republic. Ed.: Monika Tóthová, Judita Lidiková, Kristína Candráková, Dominik Holly, Slovak University of Agriculture in Nitra, Slovakia, Nitra, 19, 2023. ISBN: 9788055226606
29. Shaikh, A. M., **Ahmed, A. E. M.**, Prokisch, J., Kovács, B.: Examination of organic and inorganic compounds in enriched honey with spices and herbs.
In: I. Magyar Agrártudományi Doktoranduszok Szimpóziuma.. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Debrecen, 26, 2023. ISBN: 9786156457189
30. Shaikh, A. M., Kovács, B., **Ahmed, A. E. M.**, Oláh, C., Daróczy, L., El-Ramady, H., Prokisch, J.: Green walnut extract: a novel ingredient for enhancing bee products.
In: Proceedings of the 3rd International Conference on Raw Materials to Processed Foods. Ed.: Serkan Selli, Hasim Kelebek, Adana Alparslan Turkes Science and Technology University, Istanbul, 153, 2023. ISBN: 9786250081617





31. Shaikh, A. M., Kovács, B., **Ahmed, A. E. M.**, Oláh, C., Daróczy, L., El-Ramady, H., Prokisch, J.:
Green walnut extract: Innovation for enhancing the Bee feed, Bee conservatin and Bee
Product.
In: 18. Magyar Magnézium szimpózium : Proram és összefoglalók. Szerk.: Takácsné Hájos
Mária, Vojich Viktor József, Magyar Kémikusok Egyesülete, Magyar Magnézium Társaság,
Budapest, 25, 2023. ISBN: 9786156018199
32. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Kovács, B.: Nutritional value assessment of
adansonia digitata leaves in sudan.
In: Proceedings of the 3rd International Conference on Raw Materials to Processed Foods.
Ed.: Serkan Selli, Hasim Kelebek, Adana Alparslan Turkes Science and Technology
University, Istanbul, 154, 2023. ISBN: 9786250081617
33. Shaikh, A. M., **Ahmed, A. E. M.**, Mohammed, E. A. H., Prokisch, J., Kovács, B.: The impact of AI
on food science research: a critical review.
In: Scientific Conference of PhD Students of FAFR, FBFS and FHLE SUA in Nitra with
international participation - Proceedings of abstracts on occasion of the Science and
Technology Week in the Slovak Republic. Ed.: Monika Tóthová, Judita Lidiková, Kristína
Candráková, Dominik Holly, Slovak University of Agriculture in Nitra, Slovakia, Nitra, 69,
2023. ISBN: 9788055226606
34. **Ahmed, A. E. M.**, Mozzon, M., Kovács, B.: Comprehensive uses of African baobab (Adansonia
digitata L.): A review.
In: Leveraging on research and innovation for sustainable development. Proceedings of the
2nd Postgraduate Students Conference (Virtual). / (eds.) Kerich, E., Lutta, S., Alkamoi, B,
University of Eldoret, Kenya, 23, 2022.
35. **Ahmed, A. E. M.**, Mozzon, M., Shaikh, A. M., Gadallah, N. A. H., Mohamed, E. M. A., Kovács, B.:
Nutritional and physical aspects of baobab food products: review.
In: Wellmann International Scientific Conference : Book of Abstracts. Ed.: Orsolya Kiss,
University of Szeged, Hódmezővásárhely, 12, 2022. ISBN: 9789633068601

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12 References

- Abbas, W., Elmugabil, A., Hamdan, H. Z., Rayis, D. A., & Adam, I. (2023). Iron deficiency and thyroid dysfunction among sudanese women in the first trimester of pregnancy: A cross-sectional study. *BMC Endocrine Disorders*, 23(1). <https://doi.org/10.1186/s12902-023-01487-z>
- Abdi, H. (2010). Partial least squares regression and projection on latent structure regression (PLS Regression) (Wiley Interdisciplinary Reviews: Computational Statistics). In *Book* (Vol. 2, Issue 1).
- Abdi, H., & Williams, L. J. (2010). Principal component analysis. Wiley interdisciplinary reviews: Computational statistics. *Wiley Interdisciplinary Reviews: Computational Statistics*.
- Abioye, V. F., Adejuyitan, J. A., & Idowu, C. F. (2014). Effects of different drying methods on the nutritional and quality attributes of baobab leaves (*Adansonia digitata*). *Agriculture and Biology Journal of North America*, 5(3).
- Adam, I. A. A., Adam, Y. O., Olumeh, D. E., & Mithöfer, D. (2024). Livelihood strategies, baobab income and income inequality: Evidence from Kordofan and Blue Nile, Sudan. *Forest Policy and Economics*, 158. <https://doi.org/10.1016/j.forpol.2023.103116>
- Adegoke, A. M., Gbadegesin, M. A., & Odunola, O. A. (2017). Methanol extract of *Adansonia digitata* leaf protects against sodium arsenite-induced toxicities in male wistar rats. *Pharmacognosy Research*, 9(1). <https://doi.org/10.4103/0974-8490.199768>
- Agrawal, S., Bhatt, M., Rai, S. K., Bhatt, A., Dangwal, P., & Agrawal, P. K. (2018). Silver nanoparticles and its potential applications: A review. *Journal of Pharmacognosy and Phytochemistry*, 7(2).
- Ahmed, A. E. M., Mozzon, M., Omer, A., Shaikh, A. M., & Kovács, B. (2024). Major and Trace Elements of Baobab Leaves in Different Habitats and Regions in Sudan: Implication for Human Dietary Needs and Overall Health. *Foods*, 13(12), 1938. <https://doi.org/10.3390/foods13121938>
- Ahmed, A. E. M., Mozzon, M., Shaikh, A. M., & Kovács, B. (2024). Baobab (*Adansonia digitata* L.) as a remedy to human livelihood challenges: A review. *Acta Agraria Debreceniensis*, 2, 5–11. <https://doi.org/10.34101/actaagrar/2/14170>
- Ajayi, I.A., et al. (2003). Fatty acid composition and metal content of *Adansonia digitata* seeds and seed oil. *Revista Italiana Delle Sostanze Grasse*, 80.1(1).

- Akhtar, R., Jilani, S., Yaseen, F., Khan, M. H., Yaqub, A., & Ajab, H. (2024). Overcoming challenges and enhancing Precision: Advancements in optical Bio(sensors) and wearable devices for essential amino acid detection integrated with nanotechnology. *Optics & Laser Technology*, *177*, 111193. <https://doi.org/10.1016/j.optlastec.2024.111193>
- Akpaki, K., Galibois, I., Sall, M., & Blaney, S. (2020). Assessing the Food Availability and Food Insecurity Situation among Communities of Matam Region, Senegal. *Ecology of Food and Nutrition*, *59*(4). <https://doi.org/10.1080/03670244.2020.1733993>
- Al Sharjabi, S. J., Al Jawaldeh, A., Hassan, O. E. H., & Dureab, F. (2024). Understanding the Food and Nutrition Insecurity Drivers in Some Emergency-Affected Countries in the Eastern Mediterranean Region from 2020 to 2024. *Nutrients*, *16*(22), 3853. <https://doi.org/10.3390/nu16223853>
- Alba, K., Offiah, V., Laws, A. P., Falade, K. O., & Kontogiorgos, V. (2020). Baobab polysaccharides from fruits and leaves. *Food Hydrocolloids*, *106*. <https://doi.org/10.1016/j.foodhyd.2020.105874>
- Althwab, S. A., Alsattame, S. M., Al-Mundarij, T. I., Hamad, E. M., & Mousa, H. M. (2019). Protective Effect of Baobab Fruit Pulp (*Adansonia digitata* L.) from Oxidative Stress Induced in Rats by High-Fat Diet. *Life Science Journal*, *16*(1).
- Alzahrani, H. R., Kumakli, H., Ampiah, E., Mehari, T., Thornton, A. J., Babyak, C. M., & Fakayode, S. O. (2017). Determination of macro, essential trace elements, toxic heavy metal concentrations, crude oil extracts and ash composition from Saudi Arabian fruits and vegetables having medicinal values. *Arabian Journal of Chemistry*, *10*(7). <https://doi.org/10.1016/j.arabjc.2016.09.012>
- Amiot, M. J., Latgé, C., Plumey, L., & Raynal, S. (2021). Intake estimation of phytochemicals in a french well-balanced diet. *Nutrients*, *13*(10). <https://doi.org/10.3390/nu13103628>
- Anwar, A., Hyder, S., Mohamed Nor, N., & Younis, M. (2023). Government health expenditures and health outcome nexus: A study on OECD countries. *Frontiers in Public Health*, *11*. <https://doi.org/10.3389/fpubh.2023.1123759>
- Asogwa, I. S., Ibrahim, A. N., & Agbaka, J. I. (2021). African baobab: Its role in enhancing nutrition, health, and the environment. *Trees, Forests and People*, *3*. <https://doi.org/10.1016/j.tfp.2020.100043>

- Assogbadjo, A. E., Chadare, F. J., Kakai, R. G., Fandohan, B., & Baidu-Forson, J. J. (2012). Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. *Agriculture, Ecosystems and Environment*, *157*, 94–99. <https://doi.org/10.1016/j.agee.2012.01.021>
- Assogbadjo, A. E., Chadare, F. J., Manda, L., & Sinsin, B. (2021). A 20-Year Journey Through an Orphan African Baobab (*Adansonia digitata* L.) Towards Improved Food and Nutrition Security in Africa. *Frontiers in Sustainable Food Systems*, *5*. <https://doi.org/10.3389/fsufs.2021.675382>
- Banach, W., Nitschke, K., Krajewska, N., Mongiałło, W., Matuszak, O., Muszyński, J., & Skrypnik, D. (2020). The association between excess body mass and disturbances in somatic mineral levels. *International Journal of Molecular Sciences*, *21*(19). <https://doi.org/10.3390/ijms21197306>
- Baum, D. A. (1995). A Systematic Revision of *Adansonia* (Bombacaceae). *Annals of the Missouri Botanical Garden*, *82*(3). <https://doi.org/10.2307/2399893>
- Baum, D. A., Smith, S. D. W., Yen, A., Alverson, W. S., Nyffeler, R., Whitlock, B. A., & Oldham, R. L. (2004). Phylogenetic relationships of *Malvatheca* (Bombacoideae and Malvoideae; Malvaceae sensu lato) as inferred from plastid DNA sequences. *American Journal of Botany*, *91*(11). <https://doi.org/10.3732/ajb.91.11.1863>
- Bennet, D., Khorsandian, Y., Pelusi, J., Mirabella, A., Pirrotte, P., & Zenhausern, F. (2021). Molecular and physical technologies for monitoring fluid and electrolyte imbalance: A focus on cancer population. *Clinical and Translational Medicine*, *11*(6). <https://doi.org/10.1002/ctm2.461>
- Bilal, J. A., Rayis, D. A., AlEed, A., Al-Nafeesah, A., & Adam, I. (2022). Maternal Undernutrition and Low Birth Weight in a Tertiary Hospital in Sudan: A Cross-Sectional Study. *Frontiers in Pediatrics*, *10*. <https://doi.org/10.3389/fped.2022.927518>
- Boukari, I., Shier, N. W., Fernandez R., X. E., Frisch, J., Watkins, B. A., Pawloski, L., & Fly, A. D. (2001). Calcium Analysis of Selected Western African Foods. *Journal of Food Composition and Analysis*, *14*(1). <https://doi.org/10.1006/jfca.2000.0967>
- Brill, R. V. (2004). Applied Statistics and Probability for Engineers. *Technometrics*, *46*(1). <https://doi.org/10.1198/tech.2004.s743>

- Bushra, M., Elhassan, E. M., Ali, N. I., Osman, E., Bakheit, K. H., & Adam, I. I. (2010). Anaemia, zinc and copper deficiencies among pregnant women in central Sudan. *Biological Trace Element Research*, *137*(3). <https://doi.org/10.1007/s12011-009-8586-4>
- Capra, M. E., Stanyevic, B., Giudice, A., Monopoli, D., Decarolis, N. M., Esposito, S., & Biasucci, G. (2024). Nutrition for Children and Adolescents Who Practice Sport: A Narrative Review. *Nutrients*, *16*(16), 2803. <https://doi.org/10.3390/nu16162803>
- Carbone, J. W., & Pasiakos, S. M. (2019). Dietary protein and muscle mass: Translating science to application and health benefit. *Nutrients*, *11*(5). <https://doi.org/10.3390/nu11051136>
- Chabite, I., Maluleque, I., Cossa, V., Presse, I., Mazuze, I., Abdula, R., & Joaquim, F. (2019). Characterization, Nutritional and Biochemical Properties of Baobab (*Adansonia digitata* L.) Fruit Pulp from Two Districts of Mozambique. *EC Nutrition*, *14*(2).
- Chadare, F. J., Linnemann, A. R., Hounhouigan, J. D., Nout, M. J. R., & Van Boekel, M. A. J. S. (2008). Baobab Food Products: A Review on their Composition and Nutritional Value. *Critical Reviews in Food Science and Nutrition*, *49*(3), 254–274. <https://doi.org/10.1080/10408390701856330>
- Chapman, S. J. (2018). Review of Discovering Statistics Using IBM SPSS Statistics, 4th Edition. *Journal of Political Science Education*, *14*(1). <https://doi.org/10.1080/15512169.2017.1366328>
- Chapple, I. L. C., Brock, G. R., Milward, M. R., Ling, N., & Matthews, J. B. (2007). Compromised GCF total antioxidant capacity in periodontitis: Cause or effect? *Journal of Clinical Periodontology*, *34*(2), 103–110. <https://doi.org/10.1111/j.1600-051X.2006.01029.x>
- Chaudhary, N. K., Sunuwar, D. R., Sapkota, M. R., Pant, S., Pradhan, M., & Bhandari, K. K. (2024). Prevalence of osteoporosis and associated factors among people aged 50 years and older in the Madhesh province of Nepal: A community-based cross-sectional study. *Journal of Health, Population and Nutrition*, *43*(1), 100. <https://doi.org/10.1186/s41043-024-00591-7>
- Christine, B., Prehler, S., Hartl, A., & Vogl, C. R. (2010). The importance of baobab (*Adansonia digitata* L.) in rural west african subsistence-suggestion of a cautionary approach to international market export of baobab fruits. *Ecology of Food and Nutrition*, *49*(3). <https://doi.org/10.1080/03670241003766014>

- Cruz-Jentoft, A. J., Dawson Hughes, B., Scott, D., Sanders, K. M., & Rizzoli, R. (2020). Nutritional strategies for maintaining muscle mass and strength from middle age to later life: A narrative review. *Maturitas*, 132. <https://doi.org/10.1016/j.maturitas.2019.11.007>
- De Caluwé, E., Halamová, K., & Van Damme, P. (2010). *Adansonia digitata* L. – A review of traditional uses, phytochemistry and pharmacology. *Afrika Focus*, 23(1). <https://doi.org/10.21825/af.v23i1.5037>
- Dimopoulou, M., Alba, K., Sims, I. M., & Kontogiorgos, V. (2021). Structure and rheology of pectic polysaccharides from baobab fruit and leaves. *Carbohydrate Polymers*, 273. <https://doi.org/10.1016/j.carbpol.2021.118540>
- Dobrowolska-Iwanek, J., Zagrodzki, P., Galanty, A., Fołta, M., Kryczyk-Kozioł, J., Szłósarczyk, M., Rubio, P. S., de Carvalho, I. S., & Paško, P. (2022). Determination of Essential Minerals and Trace Elements in Edible Sprouts from Different Botanical Families—Application of Chemometric Analysis. *Foods* 2022, Vol. 11, Page 371, 11(3), 371. <https://doi.org/10.3390/FOODS11030371>
- Donatien Kaboré. (2011). A review of baobab (*Adansonia digitata*) products: Effect of processing techniques, medicinal properties and uses. *African Journal of Food Science*, 5(16). <https://doi.org/10.5897/AJFSX11.004>
- Dossa, S., Negrea, M., Cocan, I., Berbecea, A., Obistioiu, D., Dragomir, C., Alexa, E., & Ravis, A. (2023). Nutritional, Physico-Chemical, Phytochemical, and Rheological Characteristics of Composite Flour Substituted by Baobab Pulp Flour (*Adansonia digitata* L.) for Bread Making. *Foods*, 12(14). <https://doi.org/10.3390/foods12142697>
- Douglas C. Montgomery. (2019). Design and Analysis of Experiments, 10th Edition | Wiley. In *Wiley*.
- Dovie, B. D. ; S., C. M. ; Witkowski, E. T. F. (2000). Involving local people: Reviewing participatory approaches for inventorying the resource base, harvesting, and utilization of non-wood forest products. In *Seminar Proceedings for the Joint FAO/ECE/ILO Committee on Forest Technology, Management and Training, Harvesting of Non-Wood Forest Products*, 2–8.
- EFSA. (2017). (European Food Safety Authority) Dietary Reference Values for nutrients: Summary report. *EFSA Supporting Publication*, e15121.

- El Amin, H. M. (1990). *Trees and Shrubs of the Sudan. Extracted from "Trees and Shrubs of the Sudan."* Ph. D thesis, University of Khartoum-Sudan. Ithaca Press Exeter 1990 (50, 163).
- Enwonwu, C. O., Phillips, R. S., & Falkler, W. A. (2002). Nutrition and oral infectious diseases: State of the science. *Compendium of Continuing Education in Dentistry (Jamesburg, N.J. : 1995)*, 23(5), 431–434, 436, 438 passim; quiz 448.
- European Commission. (2016). *EU Register on nutrition and health claims* (pp. 1–856). EFSA.
- Fadol, A. A. A., Tong, G., Raza, A., & Mohamed, W. (2024). Socioeconomic determinants of household food security in the Red Sea state of Sudan: Insights from a cross-sectional survey. *GeoJournal*, 89(2). <https://doi.org/10.1007/s10708-024-11038-1>
- Field, A. (2013). Discovering statistics using IBM SPSS statistics. In *Statistics* (Vol. 58).
- Fimbres-Acedo, Y. E., Traversari, S., Cacini, S., Costamagna, G., Ginepro, M., & Massa, D. (2023). Testing the Effect of High pH and Low Nutrient Concentration on Four Leafy Vegetables in Hydroponics. *Agronomy*, 13(1). <https://doi.org/10.3390/agronomy13010041>
- Gabaza, M., Shumoy, H., Muchuweti, M., Vandamme, P., & Raes, K. (2018). Baobab fruit pulp and mopane worm as potential functional ingredients to improve the iron and zinc content and bioaccessibility of fermented cereals. *Innovative Food Science and Emerging Technologies*, 47. <https://doi.org/10.1016/j.ifset.2018.04.005>
- Gale, J., & Aizenman, E. (2024). The physiological and pathophysiological roles of copper in the nervous system. *European Journal of Neuroscience*, 60(1), 3505–3543. <https://doi.org/10.1111/ejn.16370>
- Gan, L., Zhao, B., Inoue-Choi, M., Liao, L. M., Graubard, B. I., Weinstein, S. J., Albanes, D., & Huang, J. (2024). Sex-specific associations between sodium and potassium intake and overall and cause-specific mortality: A large prospective U.S. cohort study, systematic review, and updated meta-analysis of cohort studies. *BMC Medicine*, 22(1). <https://doi.org/10.1186/s12916-024-03350-x>
- Gbaguidi, A. M., Chadare, F. J., Salako, V. K., Idohou, Y. O. V., & Assogbadjo, A. E. (2020). Optimisation of oven-drying of baobab leaves using a central composite design. *African Crop Science Journal*, 28(s1). <https://doi.org/10.4314/acsj.v28i1.2s>
- Gebauer, J., Adam, Y. O., Sanchez, A. C., Darr, D., Eltahir, M. E. S., Fadl, K. E. M., Fernsebner, G., Frei, M., Habte, T. Y., Hammer, K., Hunsche, M., Johnson, H., Kordofani, M., Krawinkel, M., Kugler, F., Luedeling, E., Mahmoud, T. E., Maina, A., Mithöfer, D., ...

- Kehlenbeck, K. (2016). Africa's wooden elephant: The baobab tree (*Adansonia digitata* L.) in Sudan and Kenya: A review. *Genetic Resources and Crop Evolution*, 63(3). <https://doi.org/10.1007/s10722-015-0360-1>
- Gebauer, J., Assem, A., Busch, E., Hardtmann, S., Möckel, D., Krebs, F., Ziegler, T., Wichern, F., Wiehle, M., & Kehlenbeck, K. (2014). Der Baobab (*Adansonia digitata* L.): Wildobst aus Afrika für Deutschland und Europa?! *Erwerbs-Obstbau*, 56(1), 9–24. <https://doi.org/10.1007/S10341-013-0197-8>
- Gebauer, J., El-Siddig, K., & Ebert, G. (2002). Baobab (*Adansonia digitata* L.): A Review on a multipurpose tree with promising future in the Sudan. *Gartenbauwissenschaft*, 67(4).
- Giller, K. E., Delaune, T., Silva, J. V., van Wijk, M., Hammond, J., Descheemaeker, K., van de Ven, G., Schut, A. G. T., Taulya, G., Chikowo, R., & Andersson, J. A. (2021). Small farms and development in sub-Saharan Africa: Farming for food, for income or for lack of better options? *Food Security*, 13(6). <https://doi.org/10.1007/s12571-021-01209-0>
- Gurashi, N. A., Kordofani, M. A. Y., Abdelgadir, K. A., A.M., A., & Salih. (2016). Variation in Chemical Composition of Baobab (*Adansonia digitata* L.). *International Journal of Scientific Engineering and Applied Science*, 2(11).
- Habte, T. Y., Suleiman, I., Ahmed, A. I., Latif, S., & Krawinkel, M. B. (2021). Nutritional Value of Baobab Leaves (*Adansonia digitata* L.) from North- and West-Kordofan in Sudan: In-Vitro Minerals Bioavailability and Protein Quality. *International Journal of Food Science and Agriculture*, 5(3). <https://doi.org/10.26855/ijfsa.2021.09.019>
- Habte, T.-Y., & Krawinkel, M. (2017). Metaphysical Analysis of the Nutritional and Therapeutic Value of Baobab (*Adansonia Digitata* L.). *Journal of Nutrition and Health Sciences*, 5(1). <https://doi.org/10.15744/2393-9060.5.101>
- Hendam, B. M., Baromh, M. Z., Khafaga, A. F., Shukry, M., El-Son, M. A. M., & Abdel-Latif, H. M. R. (2024). Effects of dietary baobab, *Adansonia digitata* on growth, haemato-immunological status, antioxidant biomarkers, intestinal histomorphometry, gene expression responses, and disease resistance in Nile tilapia, *Oreochromis niloticus*. *Aquaculture*, 581. <https://doi.org/10.1016/j.aquaculture.2023.740473>
- Hendek Ertop, M., & Bektaş, M. (2018). Enhancement of bioavailable micronutrients and reduction of antinutrients in foods through some processes. *Food and Health*. <https://doi.org/10.3153/fh18016>

- Hirahatake, K. M., Astrup, A., Hill, J. O., Slavin, J. L., Allison, D. B., & Maki, K. C. (2020). Potential Cardiometabolic Health Benefits of Full-Fat Dairy: The Evidence Base. *Advances in Nutrition*, 11(3). <https://doi.org/10.1093/advances/nmz132>
- Homeida, A. (2023). The complexities of conflict-induced severe malnutrition in Sudan. *BMJ Global Health*, 8(12). <https://doi.org/10.1136/bmjgh-2023-014152>
- Hong, E., & Kim, G. H. (2010). Comparison of extraction conditions for phenolic, flavonoid content and determination of rosmarinic acid from *Perilla frutescens* var. *Acuta*. *International Journal of Food Science and Technology*, 45(7). <https://doi.org/10.1111/j.1365-2621.2010.02250.x>
- Hurrell, R. F. (2021). Iron Fortification Practices and Implications for Iron Addition to Salt. *Journal of Nutrition*, 151. <https://doi.org/10.1093/jn/nxaa175>
- Hyacinthe, T., Charles, P., Adama, K., Diarra, C. S., Dicko, M. H., Svejgaard, J. J., & Diawara, B. (2015). Variability of vitamins B1, B2 and minerals content in baobab (*Adansonia digitata*) leaves in east and west Africa. *Food Science and Nutrition*, 3(1), 17–24. <https://doi.org/10.1002/FSN3.184>
- Ibrahima, C., Didier, M., Max, R., Pascal, D., Benjamin, Y., & Renaud, B. (2013). Biochemical and nutritional properties of baobab pulp from endemic species of Madagascar and the African mainland. *African Journal of Agricultural Research*, 8(47).
- Jäckering, L., Fischer, S., & Kehlenbeck, K. (2019). *A value chain analysis of baobab (Adansonia digitata L.) products in Eastern and Coastal Kenya*. <https://doi.org/10.17170/KOBRA-20191030732>
- Jensen, P. D., & Orfila, C. (2021). Correction to: Mapping the production-consumption gap of an urban food system: An empirical case study of food security and resilience (Food Security, (2021), 13, 3, (551-570), 10.1007/s12571-021-01142-2). *Food Security*, 13(4). <https://doi.org/10.1007/s12571-021-01170-y>
- Jeyakumar, E., & Lawrence, R. (2021). Microbial fermentation for reduction of antinutritional factors. In *Current Developments in Biotechnology and Bioengineering: Technologies for Production of Nutraceuticals and Functional Food Products*. <https://doi.org/10.1016/B978-0-12-823506-5.00012-6>
- Jha, R., Zhang, K., He, Y., Mendler-Drienyovszki, N., Magyar-Tábori, K., Quinet, M., Germ, M., Kreft, I., Meglič, V., Ikeda, K., Chapman, M. A., Janovská, D., Podolska, G., Woo, S.-H.,

- Bruno, S., Georgiev, M. I., Chrungoo, N., Betekhtin, A., & Zhou, M. (2024). Global nutritional challenges and opportunities: Buckwheat, a potential bridge between nutrient deficiency and food security. *Trends in Food Science & Technology*, *145*, 104365. <https://doi.org/10.1016/j.tifs.2024.104365>
- Jolliffe, I. T., & Cadima, J. (2016). Jolliffe, I.T. and Cadima, J., 2016. Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *374*(2065), p.20150202. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*.
- Kalenga Saka, J. D., & Msonthi, J. D. (1994). Nutritional value of edible fruits of indigenous wild trees in Malawi. *Forest Ecology and Management*, *64*(2–3). [https://doi.org/10.1016/0378-1127\(94\)90298-4](https://doi.org/10.1016/0378-1127(94)90298-4)
- Kamanula, M., Munthali, C. R. Y., Dziwapo, A., & Kamanula, J. F. (2018). Mineral and phytochemical composition of baobab (*Adansonia digitata* L.) root tubers from selected natural populations of Malawi. *Malawi Medical Journal*, *30*(4). <https://doi.org/10.4314/mmj.v30i4.7>
- Kang, J. I., Son, M. K., Choe, H. C., & Brantley, W. A. (2016). Bone-like apatite formation on manganese-hydroxyapatite coating formed on Ti-6Al-4V alloy by plasma electrolytic oxidation. *Thin Solid Films*, *620*. <https://doi.org/10.1016/j.tsf.2016.07.088>
- Katsi, V., Papakonstantinou, I. P., Soulaïdopoulos, S., Katsiki, N., & Tsioufis, K. (2022). Chrononutrition in Cardiometabolic Health. *Journal of Clinical Medicine*, *11*(2). <https://doi.org/10.3390/jcm11020296>
- Kayode, *, Arowora, A., Yakubu, O. E., Shaibu, C., Iornenge, T. J., & Ugwuoke, K. C. (2018). Chemical Composition of Baobab Leaves and Fractionation of its Ethanolic Extract Using Column Chromatography Running title: Baobab Leaves Composition and Ethanolic Extract Fractionation Using Chromatography. *International Journal of Science and Research*, *8*(7). <https://doi.org/10.21275/ART20199083>
- Klempel, M. C., Kroeger, C. M., Norkeviciute, E., Goslawski, M., Phillips, S. A., & Varady, K. A. (2013). Benefit of a low-fat over high-fat diet on vascular health during alternate day fasting. *Nutrition and Diabetes*, *3*(MAY). <https://doi.org/10.1038/nutd.2013.14>

- Korhonen, P. K., Wang, T., Young, N. D., Byrne, J. J., Campos, T. L., Chang, B. C. H., Taki, A. C., & Gasser, R. B. (2024). Analysis of Haemonchus embryos at single cell resolution identifies two eukaryotic elongation factors as intervention target candidates. *Computational and Structural Biotechnology Journal*, 23. <https://doi.org/10.1016/j.csbj.2024.01.008>
- Korir, L., Rizov, M., Ruto, E., & Walsh, P. P. (2021). Household vulnerability to food insecurity and the regional food insecurity gap in Kenya. *Sustainability (Switzerland)*, 13(16). <https://doi.org/10.3390/su13169022>
- Kovács, B.; Gyori, Z.; Prokisch, J.; Loch, J.; Daniel, P. A study of plant sample preparation and inductively coupled plasma emission spectrometry parameters. *Commun. Soil Sci. Plant Anal.* 1996, 27, 1177–1198. <https://doi.org/10.1080/00103629609369625>. 33.
- Lamien-Meda, A., Lamien, C. E., Compaoré, M. M. Y., Meda, R. N. T., Kiendrebeogo, M., Zeba, B., Millogo, J. F., & Nacoulma, O. G. (2008). Polyphenol content and antioxidant activity of fourteen wild edible fruits from Burkina Faso. *Molecules*, 13(3). <https://doi.org/10.3390/molecules13030581>
- Lawson, J. (2014). Design and analysis of experiments with R. In *Design and Analysis of Experiments with R*. <https://doi.org/10.1201/b17883>
- Lenth, R. V., & Fleiss, J. L. (1999). Design and Analysis of Clinical Experiments (Wiley Classics Library). *Journal of the American Statistical Association*, 94(448). <https://doi.org/10.2307/2669953>
- Lopes, S. O., Abrantes, L. C. S., Azevedo, F. M., Morais, N. de S. de, Morais, D. de C., Gonçalves, V. S. S., Fontes, E. A. F., Franceschini, S. do C. C., & Priore, S. E. (2023). Food Insecurity and Micronutrient Deficiency in Adults: A Systematic Review and Meta-Analysis. *Nutrients*, 15(5). <https://doi.org/10.3390/nu15051074>
- Magaia, T., Uamusse, A., Sjöholm, I., & Skog, K. (2013). Dietary fiber, organic acids and minerals in selected wild edible fruits of Mozambique. *SpringerPlus*, 2(1). <https://doi.org/10.1186/2193-1801-2-88>
- Malikath Bankole, B., Bodjrenou, S., Bodecker, J., Noukpoakou, E., Chadare, F. J., Termote, C., & Hounkpatin, W. A. (2024). Formulation of children's nutrient-dense recipes from

- Adansonia digitata* pulp and *Ocimum gratissimum* leaves in North Benin. *NFS Journal*, 35, 2352–3646. <https://doi.org/10.1016/j.nfs.2024.100176>
- Man, Y., Xu, T., Adhikari, B., Zhou, C., Wang, Y., & Wang, B. (2022). Iron supplementation and iron-fortified foods: A review. *Critical Reviews in Food Science and Nutrition*, 62(16). <https://doi.org/10.1080/10408398.2021.1876623>
- Martins, A. C., Krum, B. N., Queirós, L., Tinkov, A. A., Skalny, A. V., Bowman, A. B., & Aschner, M. (2020). Manganese in the Diet: Bioaccessibility, Adequate Intake, and Neurotoxicological Effects. *Journal of Agricultural and Food Chemistry*, 68(46). <https://doi.org/10.1021/acs.jafc.0c00641>
- Mohammed, B. S., Sanadelaslam, E., Salwa, I. A. E., & Ahmed, S. J. (2024). HPLC-PDA-MS Identification of Phenolic Profile and in Vitro Antioxidant Activity of *Adansonia digitata* L. Leaves from Sudan. *Moroccan Journal of Chemistry*, 12(1), 221–232. <https://doi.org/10.48317/IMIST.PRSM/morjchem-v12i1.41327>
- Mongomery, D. C. (2017). Montgomery: Design and Analysis of Experiments. In *John Willy & Sons*.
- Mongwaketse, T., Kruger, J., Lewies, A., Baumgartner, J., & Mattheus Smuts, C. (2022). Minerals, antinutrients content and the bioaccessibility of iron and zinc in cooked, spontaneously fermented-dried, and blanched-dried dark green leafy vegetables commonly consumed in Sub-Saharan Africa. *Food Science and Technology (Brazil)*, 42. <https://doi.org/10.1590/fst.37921>
- Monteiro, S., Dias, J., Lourenço, V., Partidário, A., Lageiro, M., Lampreia, C., Fernandes, J., Lidon, F., Reboredo, F., & Alvarenga, N. (2023). Development of a Functional Dark Chocolate with Baobab Pulp. *Foods*, 12(8). <https://doi.org/10.3390/foods12081711>
- Montgomery, D. C., & Runger, G. C. (1994). Applied Statistics and Probability for Engineers. *European Journal of Engineering Education*, 19(3). <https://doi.org/10.1080/03043799408928333>
- Montgomery, D. C., & Runger, G. C. (2002). Applied Statistics and Probability for Engineers Third Edition. In *Phoenix Usa*.
- Morishita, T., Nishizaki, N., Taniguchi, S., Sakai, S., Kimura, T., Mita, M., Nakagawa, M., Endo, A., Ohtomo, Y., Yasui, M., Shimizu, T., & Sasabe, J. (2024). Plasma d-asparagine and the

- d/l-serine ratio reflect chronic kidney diseases in children regardless of physique. *Amino Acids*, 56(1), 38. <https://doi.org/10.1007/s00726-024-03400-x>
- Murray, S. S., Schoeninger, M. J., Bunn, H. T., Pickering, T. R., & Marlett, J. A. (2001). Nutritional Composition of Some Wild Plant Foods and Honey Used by Hadza Foragers of Tanzania. *Journal of Food Composition and Analysis*, 14(1). <https://doi.org/10.1006/jfca.2000.0960>
- Mutha, R. E., Tatiya, A. U., & Surana, S. J. (2021). Flavonoids as natural phenolic compounds and their role in therapeutics: An overview. *Future Journal of Pharmaceutical Sciences*, 7(1). <https://doi.org/10.1186/s43094-020-00161-8>
- Mwangi, M. N., Mzembe, G., Moya, E., & Verhoef, H. (2021). Iron deficiency anaemia in sub-Saharan Africa: A review of current evidence and primary care recommendations for high-risk groups. *The Lancet Haematology*, 8(10). [https://doi.org/10.1016/S2352-3026\(21\)00193-9](https://doi.org/10.1016/S2352-3026(21)00193-9)
- Namratha V & Sahithi P. (2015). Baobab: A Review about " The Tree of Life ". *Cloud Publications International Journal of Advanced Herbal Science and Technology*, 1(1).
- Noorallah, T., Elgadi, A., & Altayeb, F. (2024). Child malnutrition is a devastating consequence of the conflict in Sudan. *BMJ*. <https://doi.org/10.1136/bmj.q296>
- Nordeide, M. B. ; H., A. ; Følling, M. ; Lied, E. ; Oshaug, A. (1996). Nutrient composition and nutritional importance of green leaves and wild food resources in an agricultural district, Koutiala, in southern Mali. *Food Sci. Nutr.*, 47(6), 455–468.
- Nour, A., Magboul, B., & Kheiri, N. (1980). Chemical composition of baobab fruit (*Adansonia digitata* L.). *Tropical Science*, 22(4).
- Obizoba, I. C., & Amaechi, N. A. (1993). The effect of processing methods on the chemical composition of baobab (*Adansonia digitata*. L) pulp and seed. *Ecology of Food and Nutrition*, 29(3). <https://doi.org/10.1080/03670244.1993.9991305>
- Ogbaga, C. C., Nuruddeen, F. A., Alonge, O. O., & Nwagbara, O. F. (2017). Phytochemical, elemental and proximate analyses of stored, sun-dried and shade-dried baobab (*Adansonia digitata*) leaves. *2017 13th International Conference on Electronics, Computer and Computation, ICECCO 2017, 2018-January*. <https://doi.org/10.1109/ICECCO.2017.8333339>

- Oluoko-Odingo, A. A. (2011). Vulnerability and adaptation to food insecurity and poverty in Kenya. *Annals of the Association of American Geographers*, 101(1). <https://doi.org/10.1080/00045608.2010.532739>
- ORSOLYA VIDA. (2021). *Investigation of the use of glycerol supplementation in the nutrition of lactating sows*. Széchenyi István University.
- Osman, M. A. (2004). Chemical and nutrient analysis of baobab (*Adansonia digitata*) fruit and seed protein solubility. *Plant Foods for Human Nutrition*, 59(1). <https://doi.org/10.1007/s11130-004-0034-1>
- Parcheta, M., Świsłocka, R., Orzechowska, S., Akimowicz, M., Choińska, R., & Lewandowski, W. (2021). Recent developments in effective antioxidants: The structure and antioxidant properties. *Materials*, 14(8). <https://doi.org/10.3390/ma14081984>
- Patikorn, C., Roubal, K., Veettil, S. K., Chandran, V., Pham, T., Yeong, ;, Lee, Y., Giovannucci, E. L., Varady, K. A., & Chaiyakunapruk, N. (2021). Original Investigation | Nutrition, Obesity, and Exercise Intermittent Fasting and Obesity-Related Health Outcomes An Umbrella Review of Meta-analyses of Randomized Clinical Trials Key Points + Supplemental content. *JAMA Network Open*, 4(12).
- Quintaes, K. D., & Diez-Garcia, R. W. (2015). The importance of minerals in the human diet. In *Handbook of Mineral Elements in Food*. <https://doi.org/10.1002/9781118654316.ch1>
- Rahmawati, N. D., Andriani, H., Wirawan, F., Farsia, L., Waits, A., & Karim Taufiqurahman, K. A. (2024). Body mass index as a dominant risk factor for metabolic syndrome among Indonesian adults: A 6-year prospective cohort study of non-communicable diseases. *BMC Nutrition*, 10(1). <https://doi.org/10.1186/s40795-024-00856-8>
- Rahul, J., Jain, M. K., Singh, S. P., Kamal, R. K., Anuradha, Naz, A., Gupta, A. K., & Mrityunjay, S. K. (2015). *Adansonia digitata* L. (baobab): A review of traditional information and taxonomic description. *Asian Pacific Journal of Tropical Biomedicine*, 5(1). [https://doi.org/10.1016/S2221-1691\(15\)30174-X](https://doi.org/10.1016/S2221-1691(15)30174-X)
- Rocha, Dr. I., Pedro, Dr., & . P. (2024). The influence of calcium and phosphorus on immune cell activity. *International Journal of Immunology Research*, 6(1), 31–34. <https://doi.org/10.33545/26648865.2024.v6.i1a.32>
- Rudrapal, M., Khairnar, S. J., Khan, J., Dukhyil, A. B., Ansari, M. A., Alomary, M. N., Alshabrimi, F. M., Palai, S., Deb, P. K., & Devi, R. (2022). Dietary Polyphenols and Their Role in

- Oxidative Stress-Induced Human Diseases: Insights Into Protective Effects, Antioxidant Potentials and Mechanism(s) of Action. *Frontiers in Pharmacology*, 13. <https://doi.org/10.3389/fphar.2022.806470>
- Sakr, S. S., Mohamed, S. H. S., Ali, A. A., Ahmed, W. E., Algheshairy, R. M., Almujaaydil, M. S., Al-Hassan, A. A., Barakat, H., & Hassan, M. F. Y. (2023). Nutritional, Physicochemical, Microstructural, Rheological, and Organoleptical Characteristics of Ice Cream Incorporating *Adansonia digitata* Pulp Flour. *Foods*, 12(3). <https://doi.org/10.3390/foods12030533>
- Sanchez, A. C., Osborne, P. E., & Haq, N. (2010). Identifying the global potential for baobab tree cultivation using ecological niche modelling. *Agroforestry Systems*, 80(2). <https://doi.org/10.1007/s10457-010-9282-2>
- Sanogo, D., Diedhiou, B., Diop, A., Sanou, H., Thiome, M., Gassama, Y. K., & Bassène, E. (2013). Morphologic and biochemical diversity of peasant's baobab tree (*Adansonia digitata* L.) morphotypes in senegal. *ACS Symposium Series*, 1127. <https://doi.org/10.1021/bk-2013-1127.ch016>
- Sarhan, A. A.-M., Mahmoud, W., Aldarah, M. J., & Hashim, N. A. (2024). Serum level of sclerostin and vitamin D in children with epilepsy. *The Egyptian Journal of Neurology, Psychiatry and Neurosurgery*, 60(1), 84. <https://doi.org/10.1186/s41983-024-00857-1>
- Scientific Opinion on Dietary Reference Values for manganese. (2013). *EFSA Journal*, 11(11). <https://doi.org/10.2903/j.efsa.2013.3419>
- Sena, L. P., Vanderjagt, D. J., Rivera, C., Tsin, A. T. C., Muhamadu, I., Mahamadou, O., Millson, M., Pastuszyn, A., & Glew, R. H. (1998). Analysis of nutritional components of eight famine foods of the Republic of Niger. *Plant Foods for Human Nutrition*, 52(1), 17–30. <https://doi.org/10.1023/A:1008010009170/METRICS>
- Sidibe, M., Scheuring, J. F., Kone, M., Schierle, J., Frigg, M., & Hofman, P. (1998). A (and C) for Africa: The baobab tree as a source of vitamins. More on baobab's homegrown vitamin C: some trees have more than others—Consistently. *Agroforestry Today*, 10(4).
- Sidibe M, W. JT. B. (2002). *Adansonia digitata* L. Baobab. In W. JT. B. Sidibe M (Ed.), *Market Brief in the European Union for selected natural ingredients derived from native species* (p. 35).

- https://books.google.com/books/about/Baobab_Adansonia_Digitata_L.html?id=zskefIIIc1IC
- Singh, C., Arti, Yadav, N., Rao, K., Bharti, Bansal, N., & Archana, K. M. (2023). Nutrition Role in Maintaining Health and Preventing Disease. *Current Nutrition & Food Science*, 20(8). <https://doi.org/10.2174/1573401319666230818122640>
- Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Methods in Enzymology*, 299. [https://doi.org/10.1016/S0076-6879\(99\)99017-1](https://doi.org/10.1016/S0076-6879(99)99017-1)
- Solarin, S. A., & Gil-Alana, L. A. (2025). Towards improved food security in 20 OECD countries: Persistence of food imports using a fractional integration approach. *Journal of Rural Studies*, 113, 103491. <https://doi.org/10.1016/j.jrurstud.2024.103491>
- Soloviev, P., Niang, T. D., Gaye, A., & Totte, A. (2004). Variabilité des caractères physico-chimiques des fruits de trois espèces ligneuses de cueillette, récoltés au Sénégal: *Adansonia digitata*, *Balanites aegyptiaca* et *Tamarindus indica*. *Fruits*, 59(2). <https://doi.org/10.1051/fruits:2004011>
- Stadlmayr, B., Wanangwe, J., Waruhiu, C. G., Jamnadass, R., & Kehlenbeck, K. (2020). Nutritional composition of baobab (*Adansonia digitata* L.) fruit pulp sampled at different geographical locations in Kenya. *Journal of Food Composition and Analysis*, 94. <https://doi.org/10.1016/j.jfca.2020.103617>
- Stoltzfus, R. J. (2011). Iron interventions for women and children in low-income countries. *Journal of Nutrition*, 141(4). <https://doi.org/10.3945/jn.110.128793>
- Strough, J. (2014). Review of Discovering statistics using IBM SPSS statistics. *Psychology Learning & Teaching*, 13(2).
- Swareldhab, E. S. E., Al-Jawaldeh, A., Qureshi, A. B., Ali, A. M. E., Abu-Manga, M., Al-Areeqi, M., & Dureab, F. (2021). Assessment of micronutrient situation among reproductive-age women (15–49) and under-five children in sudan. *Nutrients*, 13(8). <https://doi.org/10.3390/nu13082784>
- Takano, K., Monna-Oiwa, M., Isobe, M., Kato, S., Takahashi, S., Nannya, Y., & Konuma, T. (2024). Low urinary sodium-to-potassium ratio in the early phase following single-unit cord blood transplantation is a predictive factor for poor non-relapse mortality in adults. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-51748-7>

- Thompson, P. T., Boamah, V. E., & Badu, M. (2024). In-vitro antioxidant, antimicrobial and phytochemical properties of extracts from the pulp and seeds of the African baobab fruit (*Adansonia digitata* L.). *Heliyon*, *10*(8), e29660. <https://doi.org/10.1016/j.heliyon.2024.e29660>
- Turck, D., Castenmiller, J., de Henauw, S., Hirsch-Ernst, K. I., Kearney, J., Knutsen, H. K., Maciuk, A., Mangelsdorf, I., McArdle, H. J., Pelaez, C., Pentieva, K., Siani, A., Thies, F., Tsabouri, S., Vinceti, M., Aggett, P., Fairweather-Tait, S., Martin, A., Przyrembel, H., ... Naska, A. (2019). Dietary reference values for sodium. *EFSA Journal*, *17*(9). <https://doi.org/10.2903/j.efsa.2019.5778>
- Uhuo, E. N., Egba, S. I., Nwuke, P. C., Obike, C. A., & Kelechi, G. K. (2022). Antioxidative properties of *Adansonia digitata* L. (baobab) leaf extract exert protective effect on doxorubicin-induced cardiac toxicity in Wistar rats. *Clinical Nutrition Open Science*, *45*. <https://doi.org/10.1016/j.nutos.2022.07.004>
- Walker, R. E., NDao, F., & BeLue, R. (2020). Exploring the Concept of Food Insecurity and Family Hunger in Senegal, West Africa. *International Quarterly of Community Health Education*, *40*(2). <https://doi.org/10.1177/0272684X19858015>
- Wehmeyer, A. S. (1966). The nutrient composition of some edible wild fruits found in the Transvaal. *South African Medical Journal*, *40*(45).
- Weng, Z., Ye, J., Cai, C., Liu, Z., Liu, Y., Xu, Y., Yuan, J., Zhang, W., Liu, L., Jiang, J., Cheng, X., & Wang, X. (2024). Inflammatory microenvironment regulation and osteogenesis promotion by bone-targeting calcium and magnesium repletion nanoplatfom for osteoporosis therapy. *Journal of Nanobiotechnology*, *22*(1), 314. <https://doi.org/10.1186/s12951-024-02581-7>
- Wickens, G. E. (1982). The Baobab: Africa's Upside-Down Tree. *Kew Bulletin*, *37*(2), 173. <https://doi.org/10.2307/4109961>
- Wiehle, M., Prinz, K., Kehlenbeck, K., Goenster, S., Mohamed, S. A., Finkeldey, R., Buerkert, A., & Gebauer, J. (2014). The African baobab (*Adansonia digitata*, Malvaceae): Genetic resources in neglected populations of the Nuba Mountains, Sudan. *American Journal of Botany*, *101*(9), 1498–1507. <https://doi.org/10.3732/ajb.1400198>
- Williamson, E. (2011). African Herbal Pharmacopoeia Eds: T. Brendler, J. N. Eloff, A. G. Uribe-Fakim, L. D. Phillips Publisher: Association for African Medicinal Plants Standards (

- AAMPS), 2010 ISBN 978-99903-89-09-8, pp. 289, price US \$125.00. *Phytotherapy Research*, 25(3). <https://doi.org/10.1002/ptr.3429>
- Wulff, S. S. (2003). A First Course in Design and Analysis of Experiments. *The American Statistician*, 57(1). <https://doi.org/10.1198/tas.2003.s210>
- Xie, H., Wen, Y., Choi, Y., & Zhang, X. (2021). Global trends on food security research: A bibliometric analysis. *Land*, 10(2). <https://doi.org/10.3390/land10020119>
- Yazzie, D., VanderJagt, D. J., Pastuszyn, A., Okolo, A., & Glew, R. H. (1994). The Amino Acid and Mineral Content of Baobab (*Adansonia digitata* L.) Leaves. *Journal of Food Composition and Analysis*, 7(3), 189–193. <https://doi.org/10.1006/JFCA.1994.1018>
- Zahran, E., Elbahaswy, S., Mansour, A. I. A., Risha, E., Mustafa, A., Alqahtani, A. sultan, Sebaei, M. G. E., & Ahmed, F. (2024). Dietary algal-sourced zinc nanoparticles promote growth performance, intestinal integrity, and immune response of Nile tilapia (*Oreochromis niloticus*). *BMC Veterinary Research*, 20(1), 276. <https://doi.org/10.1186/s12917-024-04077-w>
- Zahrau Bamalli, A. S. M., Hasanah Mohd Ghazali and Roselina Karim. (2014). Nutrition, Applications in Food and Uses in Ethno. *Annals of Nutritional Disorders & Therapy*, 1(3), 1011.

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14 Declaration

I would like to declare that this dissertation was prepared within the framework of the Nutrition and Food Science Doctoral School of the University of Debrecen, to obtain a doctoral (PhD) degree.

Debrecen, 2025

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The signature of the candidate

We undersigned supervisors, certify that Ahmed Abdelhakam Esmail Mohamed, a doctoral candidate between 2021-2025, and within the framework of the above-mentioned doctoral school, has carried out his work under our guidance/direction. The independent contribution of the candidate to the results comprised in the dissertation; the dissertation is the independent work of the candidate. I suggest/recommend the acceptance of the dissertation.

Debrecen, 2025

Signature of the supervisor(s)

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