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Nutritional importance and functional properties of baobab leaves

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Abstract

Dietary fiber has important health benefits, such as lowering blood cholesterol levels by lowering low-density lipoprotein or "bad" cholesterol. It functions as an anti-obesity and anti-diabetic agent, lowering the likelihood of hemorrhoids development. Additionally, increasing face bulk and short-chain fatty acid synthesis improves gastrointestinal health and overall wellness. The potential of Baobab leaves is understudied and not yet fully documented. The purpose of this work is to highlight the important nutritional value and practical qualities of baobab leaves. In this research, proximate analysis was used to determine the macronutrient quantitative analysis in baobab leaves. Moisture content, which is significant to the food business since it affects food quality, preservation, and resistance to deterioration was also investigated. Baobab leaves had a moisture content of 6.4%, fat 16.1%, ash 3.2%, fiber 4.1%, protein 18.7%, carbohydrate 57.2% and crude fibre 4.1%. The functional properties studied include pH, gelation temperature, bulk density, water absorption capacity, oil absorption capacity foaming property, emulsifying property, and stability and swelling capacity which are 8.72, 29, 0.39, 138, 98.20, 0.80, 72.80, and 73.50 for the leaves. FTIR spectra of Baobab leaf powder were recorded, and the frequency range and intensities were obtained from the absorption spectra. The analysis revealed the presence of different types of biomolecules in the sample. Baobab leaves are edible and nutritious and the mineral contents are within the required range.

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Introduction

The baobab plant (*Adansonia digitata)* is a known giant tree with every of its parts valuable and has multiple uses (Asogwa *et al.* 2021). This indigenous fruit tree species holds significant importance in ensuring food security, promoting nutrition, and generating revenue for the rural population in Africa. According to previous studies, the leaves can be roasted and consumed as snacks (Aminat *et al.* 2021, Kaimba *et al.,* 2021). They are also used as a thickening ingredient in soups and can be fermented to provide a flavour. The bark can be used to make ropes, while the pulp can be consumed raw or cooked (Adegoke *et al*. 2017; Patrut *et al.* 2018). Baobab fruit pulp contains characteristics that are comparable to those of phenylbutazone, a common anti-inflammatory drug used in rats, according to research by Ramadan *et al*. (1993). The analgesic benefits of fruit pulp are attributed to its sterols, saponins, and triterpene concentrations, as highlighted by Masola *et al*. (2009). Baobab when extracted with ethanol, petroleum ether and aqueous exhibited antibacterial efficacy against Escherichia coli (Yagoub, 2008). According to Chadare *et al*. (2009), dried leaf powder can be used to make sauces in addition to dry leaves. According to Sibibe and Williams' 2002 research, young leaves can be cooked like spinach or dried and powdered to make sauces for boiled rice or thick gruels of grains.

The physical and chemical characteristics of food ingredients are evaluated regarding the surroundings and circumstances in which they are found (Suresh and Samsher, 2013; Kaur and Singh, 2006; Siddiq *et al.,* 2009). Functional features are necessary tools to accurately predict and assess hw proteins, fats, carbohydrates (starch and sugars), and fiber may behave in particular dietary systems (Suresh and Samsher, 2013; Siddiq *et al.,* 2009). Crosbie (1991)

asserts that swelling power—a measure of a starch's ability to hold water—is a useful tool for comparing different kinds of starches. This work is aimed at defining the nutritional quality and functional properties of baobab leaves. The study of the fibre content can be used as a yardstick to measure the anti-obesity and anti-diabetic potency of baobab leaves. The findings of this study will provide valuable insights for the implementation of policies aimed at mitigating hunger, enhancing nutrition, facilitating the value addition of baobab products, and promoting economic well-being among rural communities in Africa. Furthermore, the presence of diverse nutritional characteristics throughout nations is a potential avenue for the identification and cultivation of high-quality maternal trees within current agroforestry systems, to facilitate their domestication, breeding, and conservation efforts.

Materials and Methods

Proximate analysis

To carry out the proximate analysis, the dried Adansonia digitata leaves powder were evaluated for moisture, crude protein, fat, crude fibre and ash using the standard procedures presented by the Association of Official Analytical Chemists - AOAC (2015) methods.

2.1.1 Determination of moisture content

The moisture content was assessed using the hot air oven method. A 5 g of the powdered Adansonia digitata leaves were weighed in a crucible and put into a hot air oven for 1 hour at a temperature of 105°C. The crucible and the sample were then cooled and placed into an air-tight desiccator for 10 minutes. The procedures were then repeated until the weight is constant (Ogbuagu *et al.,* 2021). The percentage moisture content was calculated from:

$$\frac{W_1 - W_2}{W_3} \times 100 \quad (1)$$

Where; W_1 = weight of crucible + sample before drying
W_2 = weight of crucible and sample after drying
W_3 = weight of sample.

Determination of crude protein

After carefully weighing 0.5g of the sample into a 30ml Kjehdal flask, the flasks were sealed and shaken. 0.5g of the Kjedahl catalyst combination was added, and a heating mantle was used to break down the mixture. Until a transparent solution emerged, digestion was maintained. After standing for 30 minutes, the clear solution was allowed to cool. To prevent caking, the digested sample was diluted to a volume of 100 millilitres using distilled water, and then 50 millilitres were added to the Kjadahl distillation unit. The digested sample condenser in the apparatus and distillation was placed beneath a 100 ml receiver flask with 5 ml of 2% boric acid and an indicator combination containing 5 drops of bromocresol blue and 1 drop of methylene blue, such that the tap was about 20 cm inside the solution. After adding 5 ml of 40% sodium hydroxide to the apparatus's digested sample, distillation started right away and continued for 50 drops before being titrated with 0.01 N hydrochloric acid to get a pink colour (Ogbuagu *et al.,* 2021)

Nitrogen = titre value x 0.01 x 14 x 4 (2)
Protein = Nitrogen x 6.25 (3)

Calculating the ash content

A clean empty silica crucible was placed in a muffle furnace at a temperature of 600°C for an hour to measure ash content. After cooling, the crucible was weighed. A 2 g of the powdered sample was then placed in the crucible, and incinerated by slowly raising the temperature in the muffle furnace at 450ºC for 4 hours. The samples were made carbon-free. It was then cooled in a desiccator and weighed. The procedures were repeated until a constant weight was obtained. The percentages of total ash were calculated.

$$\% \text{ Ash content} = \frac{W_3 - W_1 \times 100}{W_2 - W_1} \quad (4)$$

Where; W_1= weight of empty crucible
W_2 = weight of crucible + sample before burning
W_3 = weight of crucible + ash

Estimation of crude fat

After being cleaned and dried for 30 minutes at 110°C in the oven, a 250 ml boiling flask was allowed to cool before being weighed. 300 milliliters of anhydrous diethyl ether with a 40–60 degree Celsius boiling point is added to the flask. A thimble was filled to the brim with cotton wool after 2.002g of the sample was weighed. The extractor is filled with the thimble containing the substance. After that, the ether in the flask is heated. The ether vapor travels via the extractor's side arm to the condenser, where it condenses to liquid and returns in a thimble to the sample. Meanwhile, the ether-soluble compounds dissolve and are transported into the solution by the siphon tube, returning the mixture to the flask. The extraction takes a minimum of four hours to complete. The majority of the solvent is then distilled into the extractor from the flask after the thimble has been

removed. After that, the flask is disconnected, weighed, and baked at 105 degrees Celsius for an hour. It is then chilled in a desiccator.

$$\%Fat = \frac{\text{weight of fat}}{\text{weight of sample}} \times 100 \quad (5)$$

Determination of crude fibre

A 2.014g amount of the sample was weighed and defatted with 1.26g of NaOH that was dissolved in 100 ml of distilled water. The solution was boiled for 30 minutes and was filtered through linen on a fluted funnel. The residue was transferred to a beaker containing 1.26g of sulphuric acid and was made up to 100ml with distilled water and boiled again for 30 minutes. The solution was then filtered again and the residue was transferred into a crucible which was then dried in an oven for 1hr at 100°C after which it was cooled and weighed.

$$\%\ \text{Crude fiber} = \frac{\text{Loss of weight on ignition}}{\text{Weight of the sample}} \times 100 \quad (6)$$

Calculation of total carbohydrates

For each sample, the percentage of moisture content, total ash content, crude protein, crude fiber, and crude fat were subtracted from 100 to find the percentage of carbs.

$$\text{Percentage of carbohydrates} + (\%\ \text{crude protein} + \%\ \text{crude fat} + \%\ \text{crude fiber} + \%\ \text{total ash} + \%\ \text{moisture content}) - 100\% \quad (7)$$

Determining functional properties

We employed the conventional food analysis analytical techniques, which are outlined below.

2.2.1 pH measurement

A pH meter (model PHSJ-4A pH METER) was used to measure the pH. The electrode of the pH meter was placed into the beaker holding the sample solution, and the pH was recorded
straight from the pH meter's screen.

$$\text{Foam capacity} = \frac{V_1 - V_2}{V_2} \times 100 \quad (8)$$

Gelation temperature

Five per cent of the sample was placed in test tubes and heated in a boiling water bath for thirty seconds while being constantly stirred. This process was done in triplicate, and the sample's temperature was recorded as the gelatinous temperature. (Mathew *et al.,* 2015).

Bulk density

A 250 ml measuring cylinder containing 100 g of the leaf powder was filled with the powder and tapped on a wooden board until the volume did not drop. The apparent (bulk) density was then computed using the volume and weight (Suresh and Samsher, 2015).

Water absorption capacity (WAC) and oil absorption capacity (OAC)

WAC and OAC were calculated using a slightly modified version of the Michael *et al.,* 2021 technique. Ten milliliters of water or oil were added to a centrifuge tube containing one gram of the material. After shaking the material for five minutes at room temperature, it was centrifuged for fifteen minutes at 5,000 rpm. To determine the volume of free water/oil, the combined sample was then moved from the centrifuge tube into a 10 cm3 measurement cylinder. The amount of oil or water absorbed per gram of sample was the absorption capacity, represented in grams.

$$\text{The } \frac{\text{water}}{\text{oil}} \text{ absorption capacity of the sample was calculated as: } \left(\text{Total } \frac{\text{water}}{\text{oil}} \text{ absorbed} - \text{free } \frac{\text{water}}{\text{oil}}\right) \text{x Density of } \frac{\text{water}}{\text{oil}}. \quad (9)$$

Foaming properties

After dissolving 2g of powdered baobab leaves in 100 ml of distilled water, the mixture was mixed at a high speed for a minute. The mixture's volume was calculated. The volume of the mixture after mixing with its initial volume was used to determine the foaming capacity (Santana *et al.,* 2012). The calculation formula that was employed was:

$$\text{Foam capacity} = \frac{V_1 - V_2}{V_2} \times 100 \quad (10)$$

V_1 = Initial volume, V_2 = Final volume.

Emulsion capacity

With certain adjustments, the emulsion or emulsifying qualities were ascertained using the proposal from Michael *et al.,* 2021. In a Vortex, 2 g of powdered Adansonia digitata leaves were homogenized for 30 seconds using 5 mL of water. After adding 25 cm3 of vegetable oil, the mixture was homogenized once again for 30 seconds. After adding 2.5 mL of vegetable

oil, the mixture was homogenized for 90 seconds and centrifuged for 5 minutes at 1600 rpm. After centrifuging, the volume of oil that was separated from the sample was collected straight out of the tube. The emulsifying capacities were calculated thus:

$$\text{Emulsification capacity} = \frac{\text{Volume after homogenization} - \text{Volume after centrifugation}}{\text{Volume after homogenization}} \text{ X } 100 \quad (10)$$

The same method used to evaluate the emulsifying capacity was used to determine the emulsion stability. However, instead of centrifuging the samples, they were heated to 85 °C for 15 minutes and cooled before being cooled. The percentage of the emulsifying activity that remained after heating was used to express the stability of the emulsion.

Swelling capacity

This swelling capacity was calculated using the Okaka and Potter (1977) approach. Each graded 100 ml cylinder was filled with samples up to the 10 ml mark. 50 milliliters was the final capacity after adding distilled water. After securely covering the graduated cylinder's top, the cylinder was inverted and combined. Eight minutes later, the suspensions were let to stand after being flipped once again after two minutes. Following the eight minutes, the volumes occupied by the sample were measured.

Fourier transform infrared spectroscopy (FTIR) analysis of baobab leaves powder

100 mg of potassium bromide and 1 milliliter were combined. After that, a tablet was formed by pressing it under a mechanical pressure of 10 psi and storing it in a Petri dish with desiccants (silica gel). The tablet was placed in the transmission sample holder of an FTIR device (Shimadu, 8400S) with a wavelength range of 500–4000 cm–1 and a resolution of 4 cm–1. Only after achieving at least 60% transmission were the obtained spectra deemed usable.

Mineral analysis

The material was dried at 550 degrees Celsius and then dissolved in distilled water containing 10 milliliters of strong hydrochloric acid in a volumetric flask to provide solutions that were used to identify the minerals. The Varian AA240 Atomic Absorption Spectrometer was used to determine the concentrations of Ca, Fe, Mg, K, Na, P, and Zn using the Ogbuagu *et al.,* 2021 technique.

Results and Discussion

Nutritive Properties Analysis

Baobab leaves have high values of Moisture, Ash, and Fibre (6.4, 10.4, and 4.1 percent respectively) with protein, carbohydrate, and fat content of 18.7, 57.2 and 3.2 percent respectively (Table 1).

Table 1: Proximate composition of dried powdered baobab leaves.

Sample	Protein %	Carbohydrate %	Fat %	Moisture %	Ash %	Fibre %
Leaves	18.7	57.2	3.2	6.4	10.4	4.1

The figures represent the triplicate determination means plus or minus standard deviation.

The proximate compositions of Baobab leaves compared to previously studied generally accepted sources of carbohydrates and protein that is, Rice and Beans respectively (Olopade *et al.,* 2017 and Aminu *et al.,* 2021) are shown in Figure 1. Baobab leaf has a comparable value of protein with beans but remarkably higher than rice (18.7% for baobab leaves, 23.48% for beans and 1.21% for rice respectively) which indicates that Baobab leaves can serve as a source of protein. Baobab leaves also compare relatively in carbohydrates with Rice and Beans (57.2%, 65.74% and 62.48% respectively) which is an indication that Baobab leaves are good source of carbohydrate.

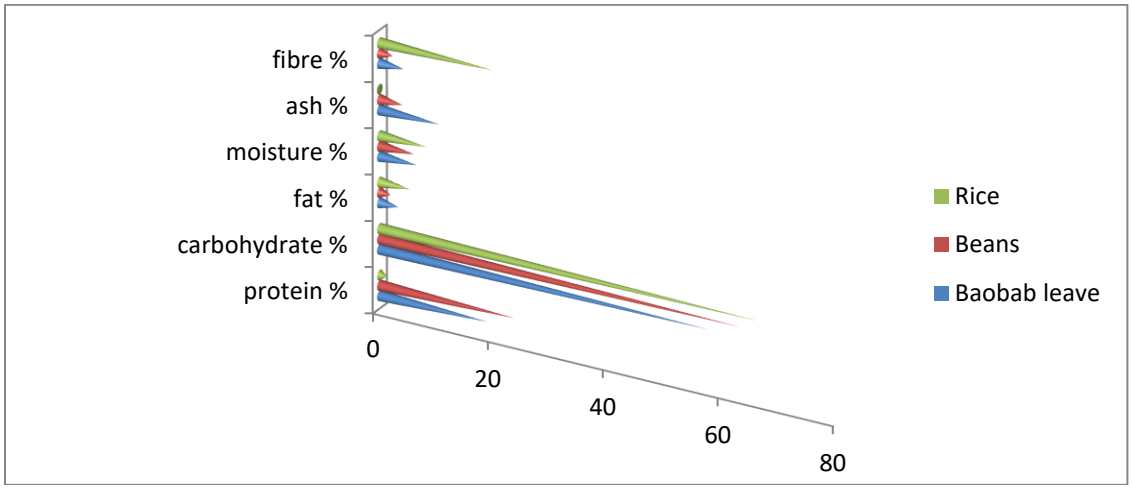

Figure 1: Comparison of proximate values of Baobab leaves with Beans and Rice (Olopade *et al.,* 2017 and Aminu *et al.,* 2021 respectively).

Adansonia digitata leaves (Fig. 3.2) shows the lowest moisture content of 6.4% compared *to C. halicacabum*, *D. elata*, *P. latifolia*, *M. pentaphylla* and *A. pomacea* leaves (Arasaretnam *et al.,* 2017) that have been studied which shows that the shelf life of Baobab leaves is higher than others under comparison and that baobab leaves can be stored for long period without degradation Agomuo *et al.,* (2011). The fat content of *Adansonia digitata* leaves (3.2%) was compared to previously studied fat content of *D. elata, P. latifolia*, *M. pentaphylla* and *A. pomacea* leaves (Arasaretnam *et al.,* 2017) and *Erythina edulis* leaves (Adelmo *et al.,* 2021) shows that fat content of baobab leaves is higher than *Erythina edulis* and *M. pentaphylla,* but similar result was gotten for *P. latifolia* and *A. pomacea* leaves. This indicates the present of oil but in a low amount in the baobab leaves (Mady Cissé *et al.,* 2018). Comparing the ash content value of Baobab leaves (10.4%) with previous work of Sensei *et al.,* (2021) on *M. pentaphylla*, *C. halicacabum* and *P. grandis*, Adelmo *et al.,* (2021) on *Erythrina edulis* leaves, Amaranthus viridis and *Alternanthera sessilis* shows that similar values were recorded for *Erythrina edulis* leaves and *M. pentaphylla* while *C. halicacabum*, *P. grandis*, *Amaranthus viridis* and *Alternanthera sessilis* show a lower value. The value obtained for Baobab leaves was higher than the recommended 1.5-2.5 % for suitability as animal feed. This indicates that Baobab leaves can be used in the production of animal feed. The crude fibre content of baobab leaves was 4.1%. These values were lower compared to the work of S. Arasaretnam *et al.,* (2017) on all the leaves studied. The carbohydrate content in baobab leaves was 57.2%. These values are significantly higher than Pumpkin leaves (1.77) and Mustard leaves (2.58), but a little higher than *Erythrina edulis,* Adelmo *et al.,* (2021), Moringa leaves (40.4%) (Martin, (2016) and (41.2%) reported by Sensei *et al.,* (2021). This indicates that Baobab leaves can be used in carbohydrate-deficient diets.

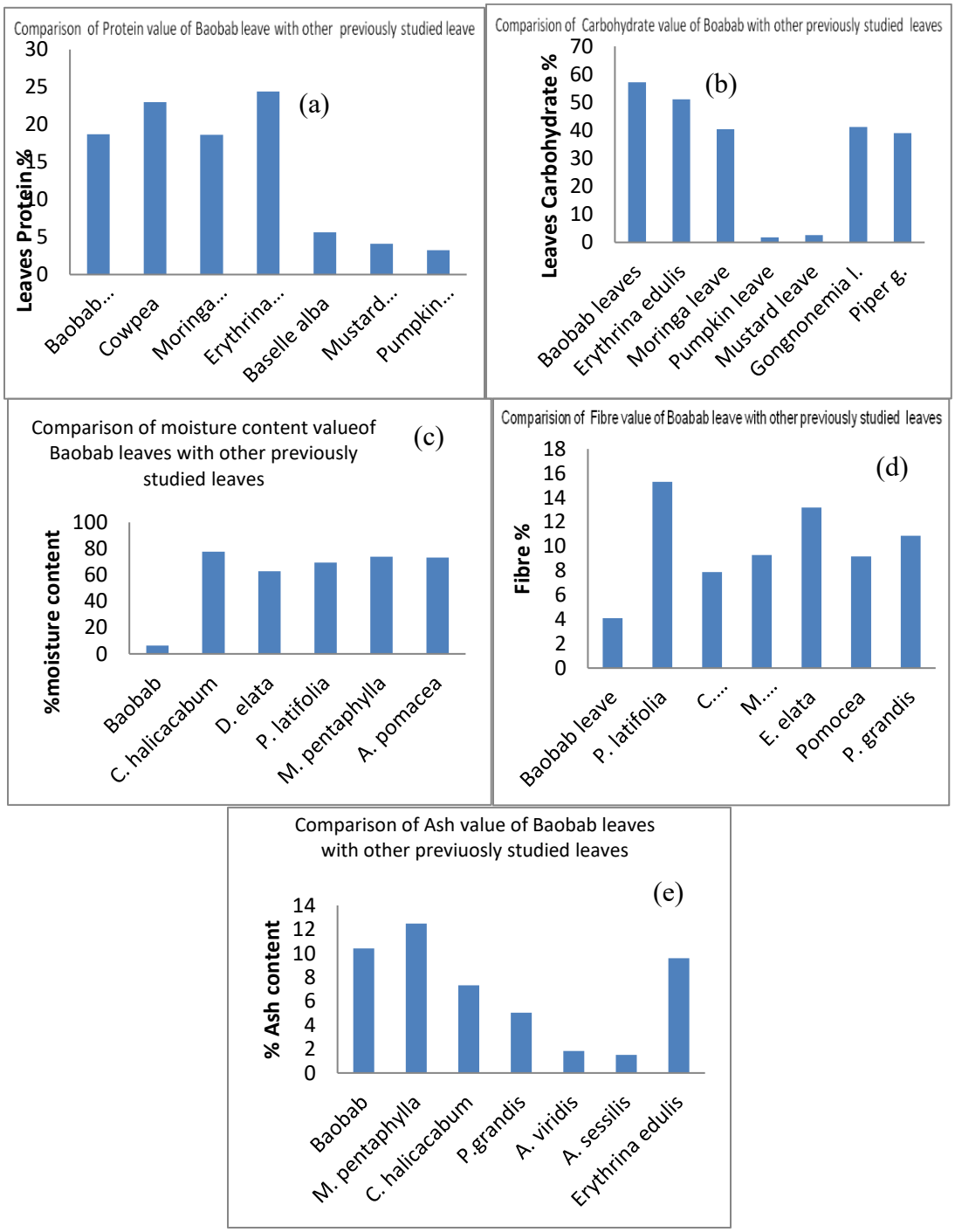

Figure 2 Comparison of proximate composition values of Baobab leaves with other previously studied leaves.

Baobab leaves and its functional properties

The basic pH of baobab leaves is 8.72. Table 2 displays the outcome of the baobab leaves' functional characteristics. Proteins may become permanently denaturized when exposed to pH extremes (Awuchi *et al.,* 2019). Therefore, to preserve their protein content, baobab leaves shouldn't be exposed to extremely high pH levels. According to Kaushal *et al*. (2012), one element influencing flour's ability to gel is the physical struggle between starch gelatinization and protein gelation for water. The temperature at which this starch gelatinization occurs is known as its

gelatinization temperature, and baobab leaves gelled rapidly at the very lowest concentration (6 g/100 ml) (Suresh *et al.,* 2013). The gelatinization temperature observed for baobab leaves is 26°C. The bulk density that was observed for Baobab leaf flour is 0.39±0.0026. The water absorption capacity of baobab leaves was 138%. But for cashew nut protein concentrate, Emmanuel *et al*. (2020) reported 610.20 perc ent. Additionally, according to Aminu *et al*. (2021), water absorption capacity (WAC) is deemed important in viscous media if it falls between 149 and 472.5. As a result, baobab leaves with WAC in the range of (138) can be useful for food products that need to retain a lot of water (Awuchi *et al.,* 2019). The oil absorption capacity obtained for the baobab leaves was 98.2%. Addy *et al.,* (2007) stated that high protein content is an indication of high oil absorption capacity. These high oil absorption capacity values of baobab seed and leaves make it suitable for use in doughnuts and sausage production and also in soup making (Awuchi *et al.,* 2019). The foaming capacity of baobab leaves is 50.8% and this is an indication that the protein structure of baobab leaves in aqueous solutions is more flexible and forms more stable foams for it interacted strongly with the air-water interface (Awuchi *et al.,* 2019).

The amount of oil, non-polar amino acid residues on the surface of proteins, water, and other ingredients in food are all related to its emulsion capacity (EC), which is 72.80% and 73.50% for baobab leaves, respectively

Table 2: Functional properties of baobab leaves

Functional properties	leaves
pH	8.72
Gelation Temp. ^{0}C	29
Bulk Density	0.39
WAC	138
OAC	98.2
Forming Property	50.8
Emulsifying Property	72.8
Emulsifying Stability	73.5
Swelling Capacity	8.6

Mineral analysis

The minerals determined in the sample of baobab leaves are Ca, Fe, Mg, K, Na, P, and Zn and the results are presented in Table 3. In Baobab leaves, Potassium (347.6±0.70) was the most abundant mineral while Zn (9.31±0.60) is the least abundant mineral as depicted in Fig. 3. Calcium is to build and maintain the bones and teeth; essential for blood clotting; required in nerve transmission. The amount of calcium content present in Baobab leaves is 416.34±0.50. This value is higher than what was obtained in cassava-potato flour (2.02g/100g) and wheat flour reported by Michael *et al.,* (2021) and (1.86 ± 0.003) obtained by Ngozi *et al.,* (2017) in Ficus capensis leaves. But it is still within the range specified by WHO. Potassium is utilized to control the osmotic pressure and acid-base balance of bodily fluids. The amount of potassium content in Baobab leaf flour is 347.6±0.0.70 and is within the WHO range. The amount of iron content found in Baobab leaf flour is 11.21±0.03 which is higher than 1.89±0.04 obtained by Ngozi *et al.,* 2017. The magnesium content of Baobab leaves flour is 130.7±0.40 zinc content is 9.31±0.60 and sodium content is 27.93±0.16. All these values are within the WHO range implying that consumption of baobab leaves is not toxic.

Table 3: Mineral composition of *Adansonia digitata* leaves in comparison with WHO standard.

Mineral	Baobab leaves	WHO Standard
Calcium	416.34	≤ 2500
Iron	11.21	≤ 1000
Magnesium	130.7	≤ 224
Potassium	347.6	≤ 2600
Sodium	27.93	≤ 3400
Phosphorus	191.12	≤ 1250
Zinc	9.31	≤ 37

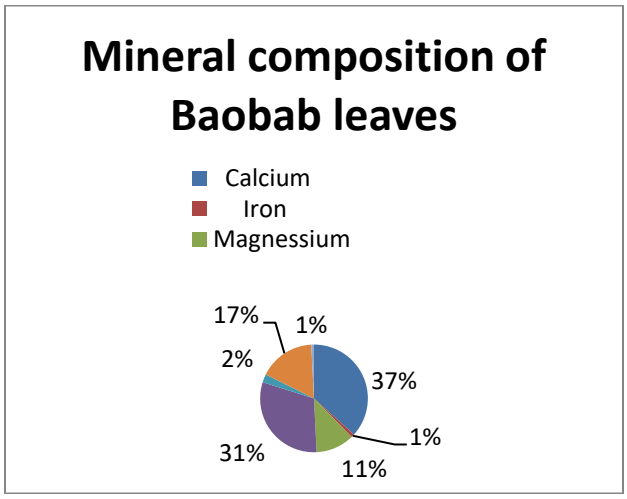

Figure 3: Mineral composition of *Adansonia digitata* leaves.

FTIR analysis of baobab leaves

To find functional groups in sample extracts, researchers are now using supplementary methods like FTIR in addition to mineral analysis (Khyade *et al.,* 2015). In Fig 4, the FTIR spectrum of powdered Baobab leaves is presented. The compound classes corresponding to the observed peaks are presented in Table 4. The functional groups identified in Baobab leaves were halo compound, alkene, sulfoxide, carbonyl, amine, aromatic amine, phenol, nitro compound, alkane, primary amine, aldehyde and isothiocyanate. As stated by Qaiser *et al.,* (2011), The presence of the -OH group connected to the carbonyl group in the samples confirms the presence of carboxylic acid groups. Comparable FTIR findings were published for metal ion biosorption investigations conducted by Onundi, 2010 (using palm nut shells as an adsorbent) and Tangjuank, 2009 (using cashew nut shells).

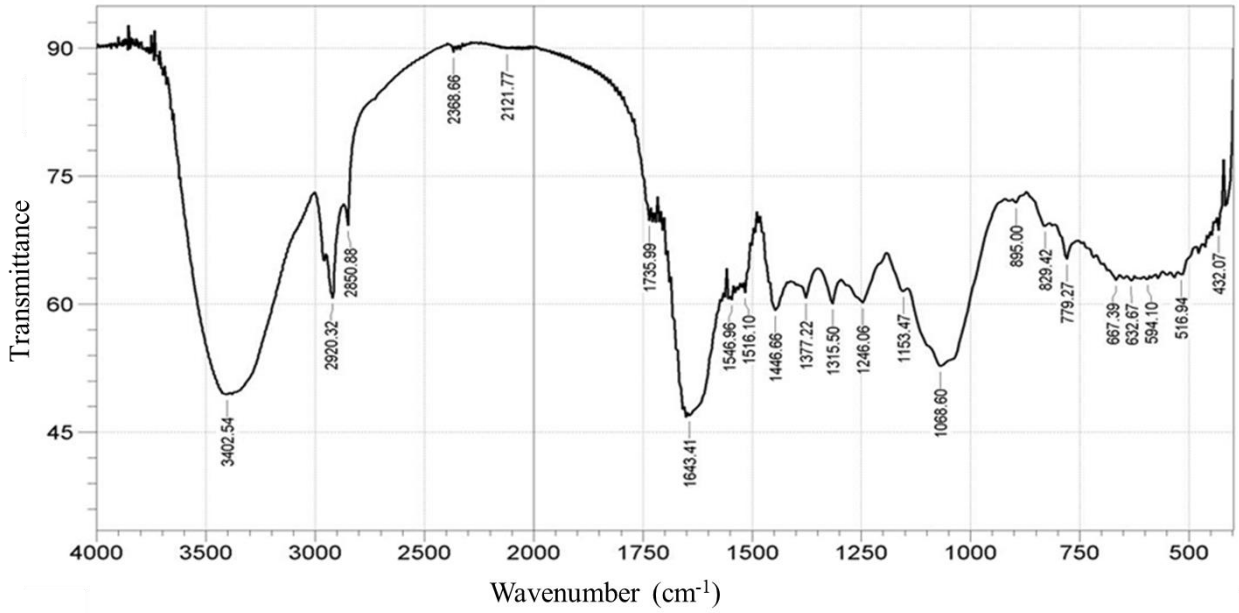

Figure 4: FTIR analysis of powdered leaves of *Adansonia digitata.*

Table 4: The functional groups in powdered *Adansonia digitata* leaves

Standard Peak Position	Sample Peak	Compound Class	Functional Group	Peak Detail	Sharpness
500-600	516.94	Halo compound	C-Br	Stretching	S
515-690	594.1	Halo compound	C-Cl	Stretching	S
566-730	667.39	Alkene	C=C	Bending	S, Disubstituted(cis)
790-840	829.42	Alkene	C=C	Bending	M, Trisubstituted

550-850	779.27	Halo compound	C-Cl	Stretching	S
885-895	895	Alkene	C=C	Bending	S, Vinylidene
1030-1070	1068.6	Sulfoxide	S=O	Stretching	S
1050-1085	1153.47	Carbonyl compound	C-O	Stretching	S
1020-1250	1246.06	Amine	C-N	Stretching	M
1266-1342	1315.5	Aromatic amine	C-N	Stretching	S
1310-1390	1377.66	Phenol	O-H	Bending	M
1500-1550	1516.11	Nitro compound	N-O	Stretching	S
1500-1550	1546.96	Nitro compound	N-O	Stretching	S
1638-1648	1643.41	Alkene	C=C	Stretching	S, Monosubtituted
1720-1740	1735.99	Aldehyde	C=O	Stretching	S
1990-2140	2121.77	Isothiocyanate	N=C=S	Stretching	S
2840-3000	2850.88	Alkane	C-hunorH	Stretching	M
2840-3000	2920.32	Alkane	C-H	Stretching	M
3400-3500	3402.54	Primary amine	N-H	Stretching	M

Key: M = medium, S= strong

Conclusion

This study has revealed the presence of different types of biomolecules in the Baobab leaf sample which are both edible and nutritious and the mineral contents are within the required range. Baobab leaves had a moisture content of 6.4%, fat 16.1%, ash 3.2%, fibre 4.1%, protein 18.7%, carbohydrate 57.2% and crude fibre 4.1%. The leaf's pH, gelation temperature, bulk density, water and oil absorption capacities, foaming and emulsifying capabilities, stability, and swelling capacity were among the functional features. These values were 8.72, 29, 0.39, 138, 98.20, 0.80, 72.80, and 73.50. FTIR spectra of Baobab leaf powder were recorded and the frequency range and intensities were obtained from the absorption spectra. The analysis revealed the presence of different types of biomolecules in the sample. Consumption of Baobab leaves is not toxic because their nutrients are within the range recommended by WHO. The high fiber content of Baobab leaves makes them a good aid for the human digestive system.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

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Ethics Statement:

Not applicable

Funding: Not applicable.
Conflict of Interest: Not applicable.
Ethical approval: Not applicable.

Informed consent: Not applicable.

Authors' contribution

Khadijat Ayanpeju Abdulsalam designed the research, carried out mineral analysis, collated all data and wrote the manuscript.

Abdullahi Akanmu Tiamiyu, Monsurat Olajide and Bolanle Mary Olawoye carried out the proximate analysis that is, the determination of: moisture content; crude protein; ash content; crude fat; crude fibre and carbohydrate.

Paul Babatunde Ayoola and Geshin John Ibikunle carried out the determination of functional properties such as pH; gelation temperature, bulk density, emulsifying stability and swelling capacity.

Kayode Adesina Adegoke carried out FTIR analysis and co-wrote the manuscript.

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