OPEN ACCESS

Forest Systems 34 (2)
May-August, 2025, 20945
ISSN-L: 2171-5068, eISSN: 2171-9845
https://doi.org/10.5424/fs/2025342-20945

RESEARCH ARTICLE

Nutritional diversity and economic value of baobab (*Adansonia digitata* L) root tubers and leaf production

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Abstract

Aim of study: Baobab (*Adansonia digitata* L*)* is a deciduous indigenous fruit tree that belongs to the family of Malvaceae. A study was conducted to investigate the nutritional value diversity and economic value for baobab root tubers and leaf production.

Area of study: The study was conducted in Mangochi district, located in the Southern Region of Malawi.

Material and methods: Seeds of baobab were pre-treated and planted in trial plots. The planting was subjected to three treatment factors (season, site, and type of soil). After harvesting, both fresh and dried baobab root tubers and leaves were subjected to nutritional analysis at the Malawi Bureau of Standards (MBS) laboratory in Blantyre, Malawi. Gross profit analysis (GPA) was performed to calculate the following profitability indicators: profit, return on investment (ROI), and net profit margin (NPM).

Main results: The results indicate that there were significant ($p < 0.001$) differences in nutritional values (energy, carbohydrates, protein, magnesium, and potassium) between fresh root tubers and fresh leaves. Fresh root tubers had higher nutritional content in energy and carbohydrates than fresh leaves, while fresh leaves had higher nutritional content in proteins, magnesium, and potassium. On the other hand, there were no significant ($p > 0.05$) differences in iron, lead, and cadmium between fresh root tubers and fresh leaves. The same trend was observed in dried root tubers and dried leaves. However, dried root tubers and dried leaves had higher nutritional values compared to their corresponding fresh nutrients. Furthermore, baobab root tubers and leaf production were viable with an estimated annual profit of about MK1 million (US$1.2 thousand), a positive rate of return on investment (38.5%), and a positive net profit margin (27.8%) per hectare.

Research highlights: The study recommends that baobab root tubers and leaves whether dried or fresh are safe to eat and they are nutritious. Additionally, baobab tubers and leaf vegetables have great potential to be introduced as cash crops among communities in Malawi and the surrounding region.

Keywords: baobab; economic value; leaf vegetables; nutritional value; root tubers.

Diversidad nutricional y valor económico de la producción de tubérculos de raíz y hojas de baobab (*Adansonia digitata L.*)

Resumen

Objetivo del estudio: El baobab (*Adansonia digitata* L.) es un árbol frutal indígena caducifolio que pertenece a la familia Malvaceae. Se llevó a cabo un estudio para investigar la diversidad del valor nutricional y el valor económico de la producción de los tubérculos de raíz y las hojas de baobab.

Área de estudio: El estudio se llevó a cabo en el distrito de Mangochi, ubicado en la Región Sur de Malawi.

Material y métodos: Las semillas de baobab fueron pretratadas y sembradas en parcelas de ensayo. La siembra se sometió a tres factores de tratamiento (estación, sitio y tipo de suelo). Después de la cosecha, tanto los tubérculos de raíz como las hojas de baobab, frescos y secos, fueron sometidos a un análisis nutricional en el laboratorio de la Oficina de Normas de Malawi (MBS) en Blantyre, Malawi. Se realizó un análisis de ganancia bruta (AGB) para calcular los siguientes indicadores de rentabilidad: beneficio, retorno de la inversión (ROI) y margen de beneficio neto (MBN).

Resultados principales: Los resultados indican que hubo diferencias significativas ($p < 0.001$) en los valores nutricionales (energía, carbohidratos, proteínas, magnesio y potasio) entre los tubérculos de raíz frescos y las hojas frescas. Los tubérculos de raíz frescos presentaron un mayor contenido nutricional en energía y carbohidratos que las hojas frescas, mientras que las hojas frescas tuvieron un mayor contenido nutricional en proteínas, magnesio y potasio. Por otro lado, no hubo diferencias significativas ($p > 0.05$) en hierro, plomo y cadmio entre los tubérculos de raíz frescos y las hojas frescas. La misma tendencia se observó en los tubérculos de raíz secos y las hojas secas. Sin embargo, los tubérculos de raíz secos y las hojas secas tuvieron valores nutricionales más altos en comparación con sus nutrientes frescos correspondientes. Además, la producción de tubérculos de raíz y hojas de baobab resultó viable, con una ganancia anual estimada de aproximadamente MK1 millón (US$1.2 mil), una tasa positiva de retorno de la inversión (38.5%) y un margen neto de beneficio positivo (27.8%) por hectárea.

Aspectos destacados de la investigación: El estudio recomienda que los tubérculos de raíz y las hojas de baobab, ya sean secos o frescos, son seguros para el consumo y resultan nutritivos. Además, los tubérculos y las hojas de baobab tienen un gran potencial para ser introducidos como cultivos comerciales entre las comunidades de Malawi y la región circundante.

Palabras clave: baobab; hortalizas de hoja; tubérculos de raíz; valor económico; valor nutricional.

Citation: Mlaviwa, J; Kasulo, V; Mhango, J; Missanjo, E (2025). Nutritional diversity and economic value of baobab (*Adansonia digitata* L) root tubers and leaf production. Forest Systems, Volume 34, Issue 2, 20945. https://doi.org/10.5424/fs/2025342-20945

Received: 27/08/2024. **Accepted:** 28/02/2025. **Published:** 10/03/2026.

Introduction

Agroforestry approaches are designed to improve soil health, increase productivity, and offer environmental benefits among others (Sharma et al., 2022; Kapoor et al., 2023). Diversity International classified some specific Agroforestry tree species to be conserved and domesticated. One of such agroforestry tree species is baobab (*Adansonia digitata* L), known as the "the tree of life." Baobab is highly valued for its nutritional benefits and economic importance (Franzel et al., 2008). Exploring the nutritional and economic value of baobab within agroforestry systems can highlight its role in improving food security, boosting rural economies, and promoting sustainable agricultural practices (Rahul et al., 2015).

Baobab is a deciduous indigenous fruit tree that belongs to the family of Malvaceae and is native to Africa. The tree is found in most of sub-Saharan Africa's semi-arid and sub-humid regions as well as in western Madagascar (Diop et al., 2006; Rahul et al., 2015). In Southern Africa, it is commonly found in Malawi, Mozambique, South Africa, and Zimbabwe (Kamatou et al., 2011).

In Malawi, it is mostly found in dry woodlands and usually grows as a solitary individual though sometimes it can be found in small groups depending on soil type (Munyebvu, 2011; Kapoor et al., 2023). Baobab is regarded as a hot spot for food, nutritional security, and socio-economic marginalization (IFAD, 2011). Baobab is a tree of whose many parts are edible and can be used for food, medicine, and shelter, particularly for marginalized rural communities (Jamnadass et al., 2011). Its leaves are edible, mostly used for making soup, sauce, and vegetables similar to spinach and it has some medicinal purposes (Chadare et al., 2009).

Diversity International classified the baobab tree as one of the top 10 Agroforestry tree species to be conserved and domesticated in West Africa (Franzel et al., 2008). In addition, the baobab tree is among the top 10 priority non-timber forest product species to be valued due to its economic potential and food preservation attributes (Kalaba et al., 2009). The species has great social and economic importance (Amos, 2018). In many African countries, especially in West Africa, rural people rely on the variety of nutritional and medicinal products provided by the baobab tree (Buchmann et al., 2010; Kaboré et al., 2011; Asogwa et al., 2021; Ofori et al., 2023; Silva et al., 2023). Baobab trees are integral to many African communities, providing various edible parts, including leaves and tubers (Kamanula et al., 2018). The leaves are commonly consumed across Africa, particularly in countries like Mali, Nigeria, Sudan, and Kenya. They are often added to soups, stews, sauces, and relishes, enhancing flavour, nutritional value, and acting as a thickening agent. In Mali, for instance, baobab leaves are a staple in many traditional dishes (Nordeide et al., 2006; Rashford, 2019). Furthermore, the tuberous roots of young baobab plants are also edible and are consumed in various regions. In Sudan, for example, the roots are eaten for their nutritional benefits (Kamanula et al., 2018). These practices highlight the baobab tree's role in enhancing food security and nutritional in African communities (Bamalli et al., 2014).

According to Bonneville et al. (2007), nutritional awareness and domesticating the production of baobab leaves and root tubers in Malawi could improve the incomes of rural households and their nutritional status. In Mali and Benin for example, smallholder farmers who cultivate baobab leaves and root tubers have moved up the value chain by adding value and coming up with snacks and leaf powder as value-added products (Dindi, 2018). Regardless of the proven competitiveness of the baobab leaves and root tubers in West Africa, Malawi has not yet discoursed them as high-value products for business opportunities. Therefore, the main objective of the study was to investigate the nutritional values and business opportunities of baobab root tuber and leaf production in Malawi. The specific objectives of the study were to determine: (1) the influence of season, ecological zone, and soil type on the growth and yield of baobab root tuber and leaf; (2) the nutritional value of baobab root tuber and leaf; (3) the profitability of baobab root tuber and leaf production, and (4) the potential demand and valuation of root tubers and leaves. This study contributes to enhancing nutrition and has the potential to create new income streams for rural communities as well as enhancing climate resilience in Malawi and neighbouring regions.

Material and methods

Study area

The study was conducted in Mangochi district (Figure 1), located in the Southern Region of Malawi. Mangochi district has a population of about one million and approximately 252,900 households (GoM, 2018). The ecological characteristics of Mangochi district where baobab grows were identified with respect to silvicultural zones as L and BA (Hardcastle, 1978). According to Hardcastle (1978), zones BA and L have: an altitude range of between 200 m to 700 m above the sea level; a mean annual temperature of 22°C-25 °C; and annual precipitation of at least 700 mm and 840 mm. The study area was selected because of the abundance of baobab trees, which are mostly used for the collection of fruit for pulp production and the remaining seeds are discarded. So, farmers can utilize the seeds for the cultivation of baobab root tubers and leaves, hence improving community nutrition and income levels (Munthali et al., 2012).

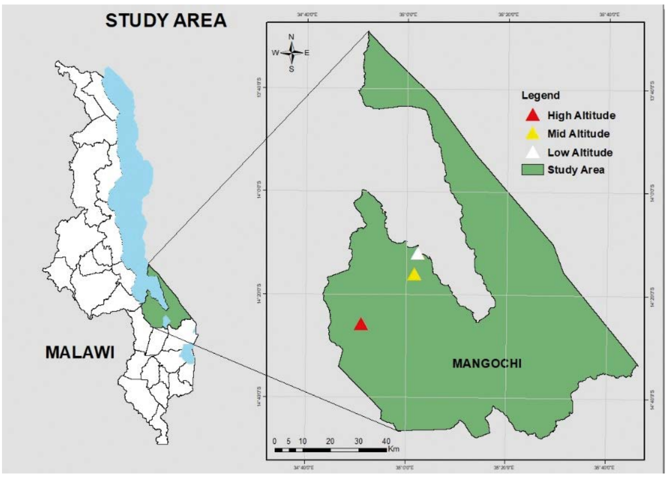

Figure 1. Location of the study site (Mangochi) in Malawi.

Sampling design and treatments

Seeds of baobab were pre-treated and planted in trial plots. The planting was subjected to three treatment factors. These are season, site, and type of soil. A total of sixty (60) farmers (20 farmers in each site) were allocated a trial plot of 100 m^2 each. Zankhalango association farmers were purposively selected to manage trial field plots.

The land was prepared by making 50 cm raised beds and 30 cm apart using holes, rakes, and measuring tapes. Seeds were directly planted into the ridge or the beds at 30 cm apart within rows. During the dry season, seedlings were irrigated once a day with 400 liters per plot. Seedlings were cultivated without any fertilizers and chemicals; insects were killed in natural ways (applying liquid concentration of neem tree (*Azadirachta indica* A. Juss.) or *Aloe vera* [*Aloe vera (L.)* Burm.f.] and by hand picking) and fences were erected to prevent leaves from livestock damage.

Data collection

Growth and yield production of baobab root tuber and leaf

Baobab root tuber and leaf were harvested from farm trials in June 2020 for the rainy season and in November 2020 for the dry season. Harvesting was done after a five-month time period after planting (150 days) for each season. The leaf harvesting technique was by pruning all the leaves from the plant and root tubers were harvested by digging and uprooting the whole plant from the soil. The tubers were cleaned with water to remove soil after which all the parameter measurements were done. A random sampling technique was used in selecting plants for parameter measurement. A total of 50 samples from each farmer were selected and the following parameters were measured: plant length, tuber length, tuber diameter, tuber weight, number of leaves, leaf weight, and length and width of the leaf.

Nutritional value of baobab root tubers and leaf

A total sample of 500 grams of both fresh and dried baobab root tubers and leaves was collected and subjected to nutritional analysis at the Malawi Bureau of Standards (MBS) laboratory in Blantyre, Malawi. The following parameters were tested, energy, carbohydrate, protein, magnesium, iron, potassium, and lead. The testing methods used include an atomic absorption spectrophotometer for magnesium, iron, potassium, and lead; gravimetric for carbohydrates; bomb calorimeter for energy; and AOAC 950.48 Kjeldahl digestion for proteins.

Profitability of baobab root tuber and leaf

The profitability of baobab leaves and root tubers was assessed based on the costs that the farmers from the Zankhalango association incurred from the trials. Data on fixed costs (land, equipment), variable costs (seed, hired labour), and potential revenue were collected. Data for estimating potential revenue were collected from the Baobab value chain actors (agents, sellers, and buyers).

Potential demand for baobab roots tuber and leaf products

The data on the potential demand for baobab root tuber and leaf products were collected through stakeholder interviews. The targeted respondent were Baobab value chain actors (agents, sellers, and buyers). The interview guide was pre-tested on a few selected baobab value chain actors (households). The easiness of completion of the guide and the ambiguity of questions were noted and subsequently revised before a large-scale interview was conducted. Respondents were asked about their willingness to pay, the price of the products, and quantity consumption per week.

Ethical considerations

Informed consent was obtained from all participants involved in the interview and growing of baobab root tubers and leaves. Participants were provided with clear and accessible information about the purpose of the study, the nature of their involvement, the potential risks and benefits, and their right to withdraw at any point without consequences. The study received approval from MZUNIREC (Mzuzu University Research Ethics Committee).

Data analysis

Data on growth and yield production were subjected Shapiro-Wilk and Levene's tests to test for normality and homogeneity of variance in GenStat 18 software, respectively. When the two criterions were met, the data were subjected to a three-factor analysis of variance (ANOVA) model (Equation 1) in GenStat 18 to determine the significant difference on the growth and yield production. Season, ecological zone, and type of soil were considered as fixed effects. Variance components for the sources of variation were also estimated. Furthermore, one-way analysis of variance (ANOVA) was performed to determine the significant difference between root tubers and leaves (both fresh and dried) in nutritional values. Differences between treatment means were separated using Fischer's least significant difference (LSD) at the 0.05 level. According to Daniel Cross (2013), conducting the test analysis at 5% significance level helps to strike a balance between being too conventional (e.g., using a 1% level, which might miss potentially meaningful outcomes) and being too generous (e.g., using a 10% level, which might increase the likelihood of finding spurious outcome). The 5% level allows researchers to conduct the analysis with a reasonable level of confidence while minimizing the risk of both Type I and Type II errors.

$$Y_{ijkl}=\mu+S_i+Z_j+T_k+(SZ)_{ij}+(ST)_{ik}+(ZT)_{jk}+(SZT)_{ijk}+e_{ijkl} \quad (1)$$

where:

- Y_{ijkl} is the response variable (growth and yield production) of jth observation in the ith treatments;
- μ is the overall mean;
- S_i is the fixed effect of season (i = 1, 2);
- Z_j is the fixed effect of ecological zone (j = 1, 2, 3);
- T_k is the fixed effect of type of soil (j = 1, 2, 3);
- $(SZ)_{ij}$ is the effect of the interaction between season and ecological zone;
- $(ST)_{ik}$ is the effect of the interaction between season and type of soil;
- $(ZT)_{jk}$ is the effect of the interaction between ecological zone and type of soil;
- $(SZT)_{ijk}$ is the effect of the interaction between season, ecological zone and type of soil;
- e_{ijkl} is the random residual effect, $e_{ijkl\,0} \sim$ N(0,σe^2).

Gross profit analysis (GPA) was performed to determine the profitability of the baobab root tubers and leaves. The following were the profitability indicators that were calculated: Profit (Equation 2); return on investment (ROI) (Equation 3), and net profit margin (Equation 4).

$$\text{Profit} = \text{Total Revenue} - \text{Total Expenses} \quad (2)$$

Where: Profit is the financial benefit that farmers would realize in baobab root tuber/ leaf trial fields (Mk); Total revenue is total earnings that farmers would realize in baobab root tuber/leaf sale (Mk); Total expenses are total cost incurred by farmers in the trial field (Mk).

$$\text{Return on Investment (ROI) (\%)} = \frac{\text{Annual Revenue} - \text{Annual Expenses}}{\text{Annual Expenses}} \times 100 \quad (3)$$

Where: Annual revenue is the total sales that farmers realized in baobab root tuber/leaf (Mk) annually; Annual expense is all expenses that were incurred during the production of baobab root tuber and leaf minus fixed cost. Return on investment help the study to make future business decision on root tuber and leaf production.

$$\text{Net profit margin (\%)} = \frac{Annual\ Revenue - Annual\ Expenses}{Annual\ Revenue} \times 100 \quad (4)$$

Net profit help to assess whether the baobab root tuber and leaf business is efficient and to forecast profits.

Total annual household consumption of baobab root tubers and leaf products was used as a proxy for potential demand for the baobab products. Total annual household consumption was calculated using estimates of weekly consumption per household and the total number of households willing to purchase baobab root tubers and leaf products. Average weekly consumption per household was computed from data collected during stakeholder interviews. The data on baobab root tuber and leaf consumption were collected in grams per week and were then converted into kilograms per year. The total number of households willing to purchase the products was estimated by adjusting the total number of households in Mangochi district by a percentage that was willing to purchase each of the products. This percentage was also calculated from data collected during stakeholder interviews. In particular, the total number of households in Mangochi district was multiplied by the percentage of households that were willing to purchase a particular product. Total annual consumption was a product of the total number of households willing to purchase a particular product and the total annual household consumption. Finally, the monetary value of the total annual consumption was computed using the average prices of the products estimated from the average amounts that households were willing to pay for the baobab products.

Results

Growth and yield production of baobab root tubers and leaves

A summary of the results on the harvested root tubers and leaves weight are presented in Table 1 and Table 2. Root tubers and leaves weights were on average 6.45 ± 0.39 t/ha and 1.22 ± 0.14 t/ha, respectively. The results indicate that season, site, and type of soil significantly ($p < 0.001$) influenced the amount of root tubers weight harvested. On the other hand, only site and type of soil significantly ($p < 0.001$) influenced the amount of leaves weight harvested. However, ecological zone was highly ($p < 0.001$) significant and contributed the highest (64.31% and 33.15%) of the total variation for leaves and root tubers weights, respectively.

Table 1. Mean values per season, ecological zone and soil type for leaf weight and root tuber weight of baobab.

Category	Leaf weight (t/ha)	Root tuber weight (t/ha)
Season		
1 (Rainy)	1.46 ± 0.22^a	7.00 ± 0.81^a
2 (Dry)	0.91 ± 0.04^b	5.51 ± 0.52^b
Ecological zone		
1 (Hilly)	1.25 ± 0.19^a	6.69 ± 0.42^a
2 (Mid)	1.23 ± 0.11^a	6.54 ± 0.35^a
3 (Low)	1.17 ± 0.13^a	5.84 ± 0.53^b
Soil type		
1 (loamy)	1.18 ± 0.16^a	6.95 ± 0.81^a
2 (sand)	1.04 ± 0.18^c	5.50 ± 0.68^b
3 (sandy loam)	1.39 ± 0.13^a	7.21 ± 0.85^a
Mean	**1.22 ± 0.14**	**6.45 ± 0.39**

Mean values are followed by standard errors. Means with different superscripts within a column and category are significantly different ($p < 0.001$).

Table 2. Baobab tree variance components for leaf and root tuber weights according to season, ecological zone, soil type, interaction between season and ecological zone, and interaction between soil type and ecological zone.

Source of variation	*df*	Root tubers weight		Leaf weight	
		p-value	Var %	*p*-value	Var %
Season (S)	1	< 0.001	29.75	0.129	1.52
Ecological zone (Z)	2	< 0.001	33.15	< 0.001	64.31
Soil type (T)	2	< 0.001	22.07	< 0.001	22.55
S x Z	2	0.009	7.86	0.723	0.42
T x Z	2	0.216	2.50	0.022	5.10

df degrees of freedom*; var* variance (%)

Rainy season had the highest amount of root tubers (7.00 ± 0.81 t/ha) and leaves (1.46 ± 0.22 t/ha). On the other hand, up land area had the highest amount of root tubers (6.69 ± 0.42 t/ha) and leaves (1.25 ± 0.19 t/ha) weights. Conversely, sandy-loam soils had the highest significant amount of root tubers (7.21 ± 0.85 t/ha) and leaves (1.39 ± 0.13 t/ha) weights followed by loam soils with a harvesting of 6.95 ± 0.81 t/ha for root tubers weight and 1.18 ± 0.16 t/ha for leaves weight. Sandy soils produced the lowest insignificant amount of root tubers weight (5.50 ± 0.68 t/ha) and leaves weight (1.04 ± 0.18 t/ha). An example of harvested root tubers and roots are presented in Figure 2 and Figure 3.

Figure 2. Harvested baobab root tubers with leaves and shoots still attached (125 days after sowing). Source: Jansen et al. (2020).

Figure 3. Harvested baobab root tubers with leaves and shoots removed (125 days after sowing). Source: Jansen et al. (2020).

Nutritional value diversity of baobab root tubers and leaves

Nutritional values diversity for fresh and dried root tubers and leaves results are presented in Table 3. The results indicate that there were significant ($p > 0.05$) differences in energy, carbohydrates, protein, magnesium, and potassium between fresh root tubers and fresh leaves. Fresh root tubers had the highest nutritional content in energy and carbohydrates than fresh leaves, while fresh leaves had the highest nutritional content in proteins, magnesium, and potassium. On the other hand, there were no significant ($p > 0.05$) differences in iron, lead, and cadmium between fresh root tubers and fresh leaves.

Table 3. Nutritional values for fresh and dried root tubers and leaves.

Nutrition	Fresh		Dried	
	Root tubers	Leaves	Root tubers	Leaves
Energy (KJ/Kg)	18176.4^{a}	16535.4^{b}	26453.8^{a}	26454.0^{a}
Carbohydrates (% m/m)	43.2^{a}	27.8^{b}	69.2^{a}	37.6^{b}
Protein (% m/m)	3.0^{b}	17.7^{a}	13.4^{b}	26.8^{a}
Magnesium (ppm)	5.8^{b}	6.8^{a}	6.2^{b}	10.8^{a}
Potassium (ppm)	5.5^{b}	6.4^{a}	6.8^{b}	8.0^{a}
Iron (ppm)	0.01^{a}	0.01^{a}	0.01^{a}	0.01^{a}
Lead (ppb)	0.01^{a}	0.01^{a}	0.01^{a}	0.01^{a}
Cadmium (ppb)	0.01^{a}	0.01^{a}	0.01^{a}	0.01^{a}

Means with different superscripts within a row in the same category (Fresh or Dried) are significantly different ($p < 0.05$)

The same trend was observed in dried root tubers and dried leaves. However, dried root tubers and dried leaves had higher nutritional content compared to their corresponding fresh nutrients.

Profitability of baobab root tubers and leaves

A summary of the results on the profitability of baobab root tubers and leaves is presented in Table 4. The results show baobab root tuber and leaf production were viable with an estimated annual profit of about MK 1.0 million (US$ 1.2 thousand), a positive rate of return on investment (38.5%), and a positive net profit margin (27.8%) per hectare.

Table 4. Profitability of baobab root tubers and leaves.

Variable	Dry Season	Rainy Season	Annual
Net profit per hectare (Mk)	1,480,800	519,500	1,000,150
Net profit per hectare (U$)	1,821.85	639.15	1,230.50
Return on Investment (%)	57.0	20.0	38.5
Net profit margin (%)	36.3	16.7	27.8

Note: Selling price; Mk 400/kg for leaf and Mk 500/kg for tuber; Exchange: 1 U$ = Mk 812.80 as of August 2021.

Potential demand and valuation of baobab root tubers and leaves

A summary of the results on the potential demand and valuation of baobab root tubers and leaves is presented in Table 5. The results indicate that respondents were willing to pay an average price of MK 500 per kilogram for baobab root tubers and MK 400 per kilogram for baobab leaves. From the baobab root tuber price, and with a potential demand of 1457.82 metric tons per year, the estimated monetary value of baobab root tubers trade in Mangochi district is around MK 728,910,000 (US$ 896,788.88). Similarly, with a potential demand of 778.71 tons per year, the estimated monetary value of baobab leaves trade is around MK 311,484,000 (US$ 383,223.43). This implies that in total, trade-in baobab leaves and tubers have a potential value of Mk1 billion (1.3 million US$) in Mangochi district, Malawi.

Table 5. Potential demand (consumption) and valuation of baobab root tubers and leaves in Mangochi.

Parameter	Annual consumption (Metric tons)	Annual Monetary Value	
		(Mk)	(U$)
Baobab root tubers	1,457.82	728,910,000	896,788.88
Baobab leafs	778.71	311,484,000	383,223.43
Total	**2,236.53**	**1,040,394,000**	**1,280,012.31**

Note: Selling price; Mk 400/kg for leaves and Mk 500/kg for root tubers; Exchange: 1 U$=Mk 812.80 as of August 2021.

Discussion

Growth and yield production of baobab root tubers and leaves

The achievement of producing the increased tuber and leaf yields in dry season could be attributed to the availability of water from irrigation during the dry season. Crop production is a function of water, nutrient, climate and soil environment. According to Dindi (2018), baobab root tubers and leaves need more water in early stages of the planting. Hordofa et al. (2022) reported that, rainfall is unreliable and erratic in nature thus, rainfall rarely meets the time with required amount of application for plant growth. As a result, average yield of agricultural crops under rain-fed agriculture is low compared to irrigation. The present findings agree with those reported in literature. Dhehibi & Aymen (2016) emphasized that, farmers could increase the production of field crops by applying water more efficiently (irrigation). Thus, it is advisable to grow baobab root tubers and leaves during the dry season under a good irrigation system.

In addition, the findings of this study align with previous research indicating that environmental factors, such as season, site, and soil type, significantly influence the growth and yield of baobab. For instance, Sithara et al. (2024) reported that variations in soil properties, such as nutrient availability and pH, impact the productivity of baobab trees. Additionally, seasonality has been shown to influence root tuber formation, as moisture availability and temperature fluctuations play a critical role in plant growth and resource allocation (Madzhi & Akhsan, 2021). The present study also highlights that ecological zones contribute the most to variation in yields, supporting findings by Assogbadjo et al. (2012), who emphasized the importance of climatic and ecological conditions in determining baobab productivity. These results underscore the importance of site-specific management strategies to optimize baobab cultivation and yield outcomes.

However, the lack of significant seasonal influence on leaves yield production diverges from prior studies, which often emphasize seasonality as a critical determinant of leaf biomass in tree species (Jagodzinski, 2016). This discrepancy could be attributed to differences in microclimatic conditions or the phenological plasticity of baobab leaves, which may enable consistent leaf production across seasons in specific ecological zones (Martinez & Fridley, 2018). The dominant role of ecological zones in explaining variations in both root tuber and leaf yields suggests that broader climatic and environmental gradients may overshadow localized seasonal effects in certain contexts (Jansen et al., 2020). This finding highlights the complex interplay of environmental factors and supports the growing body of literature advocating for regionally tailored approaches to maximize the agricultural potential of baobab.

Nutritional value diversity of baobab root tubers and leaves

Leafy vegetables in Africa play an important role in people's lives (Munyebvu, 2011). They provide essential nutrients such as vitamins, macronutrients, and minerals and provide income for rural populations which often lack staple-based meals (Komane et al., 2017). In the current study, results showed that, from the nutritional analysis of the baobab root tubers and leaves, nutrients of proteins, magnesium, potassium, iron, lead, and cadmium were observed. These nutrients are key in tissue and somatic development in infants, tissue repair in the elderly, and preventing diet-related illnesses, such as some cancers (Boukari, 2001; Joyanes & Lema, 2006).

Iron is a major component of hemoglobin and has been reported to be very important in the oxidation of carbohydrate, proteins and fats (Kamanula et al., 2018). Results on iron concentration value in baobab root tubers and leaves generated from this study (0.01 mg / 100 g) are in contradiction to those generated by Kamanula et al. (2018) of (8.89 mg / 100 g) and 3.95 mg / 100 g from Monteiro et al. (2022). This further indicates the essential need of using baobab products to enhance human nutrition. Carbohydrates such as sugars, starches and fibers found in fruits, grains, vegetables and tubers, are the body main source of energy and they contain carbon, hydrogen and oxygen. The high carbohydrate concentration (69.2% m/m) in baobab root tubers signifies the importance of baobab root tuber in African diets this shows the potential of baobab root tuber as a source of carbohydrates. These levels are like those found in raw cassava (72.1% m/m) (Promthong et al., 2005; Onyango et al., 2006).

Magnesium as an element is essential in protein synthesis, the release of energy from muscles, and storage and is important in regulating body temperature (Florkowski et al., 2009). The high presence of magnesium in dried baobab leaves (10.8 ppm) compared to baobab root tubers (6.8 ppm) signify its importance as a major source of magnesium and thus explains the relevance of having baobab leaves in human diets. The present study agrees with Kamanula et al. (2018) who also recorded magnesium levels in baobab root tubers to be higher than reported values in raw sweet potatoes, cassava, and yams. One of the most significant elements is potassium. This element plays a distinguished role in impulse movement across joints most especially for transduction purposes and plays a significant role in lowering blood pressure and release of energy from fats, proteins, and carbohydrates.

Protein helps make antibodies that fight off infections and illness and help keep cells healthy and create new ones (Sankila, 2019). Women and children need 4 to 46 grams/day of protein, and baobab leaf vegetables contain 26.8% m/m of proteins (Moore et al., 2014). It is therefore advisable for women and children to eat more baobab dried leaf vegetables for improved health and immunity.

Cadmium is an inorganic metal that causes heart diseases and anaemia if ingested in high concentrations (Hutton & Kingdom, 1987). However, the study has found very low cadmium (0.01 ppm) levels in both baobab root tuber and leaf. Lead is an element that is not needed in the body (Hutton & Kingdom, 1987) the study recorded low lead (0.01 ppm) levels of leaf in both baobab root tuber and leaf. The recommended maximum lead level to be consumed by children is 0.1 ppm (National Institute of Safety and Health, 2018). This indicates that lead and cadmium that is present in baobab root tuber and leaf vegetable is not harmful to human health. The levels of lead and cadmium reported in this study could be due to soil contamination from human activities such as technological waste. A study in Nigeria failed to detect lead but found cadmium levels (0.85mg / 100g) in baobab leaves and reported that lead and cadmium are naturally present in the environment (Orisakwe et al., 2013).

The present study has revealed that fresh root tubers had the highest nutritional content in energy and carbohydrates than fresh leaves, while fresh leaves had the highest nutritional content in proteins, magnesium, and potassium. The same trend was observed in dried root tubers and dried leaves. However, dried root tubers and dried leaves had higher nutritional content compared to their corresponding fresh nutrients. The phenomenon is well supported by Sadler et al. (2019) and Banerjee (2020) who reported higher nutritional content in dried root tubers and leaves than in fresh root tubers and leaves. Dried fruits vegetables and tubers contain less water therefore a more concentrated source of nutrients. According to Belice et al. (2020) & Rahaman et al. (2023), dried vegetables and fruits tends to be higher in vitamins and minerals per 100g when compared to their fresh counterpart. However, it depends on the drying process. Oven and solar seem to be better compared with other drying methods (Kiremire, 2010).

In the present study, the lack of significant differences in micronutrients such as iron, lead, and cadmium between baobab leaves and root tubers introduces a new dimension to the conversation. While previous research often highlights the iron content of baobab products as a key nutritional advantage (Bamalli et al., 2014; Belice et al., 2020), this study suggests a more uniform distribution of these elements between the two products. Additionally, the negligible levels of lead and cadmium support earlier studies (Kamanula et al., 2018; Monteiro et al., 2022) that baobab products are safe for human consumption, an important finding for promoting these products in local and international markets. Therefore, baobab root tubers and leaves whether dried or fresh are safe to eat and they are nutritious. However, further research is needed to determine the phytochemicals and nutrient content in processed baobab root tubers and leaves.

Profitability of baobab root tubers and leaves

The profit for baobab root tubers and leaves in the present study is higher compared to US$ 233.99 and US$ 147.78 for growing tomatoes and green vegetables, respectively in Malawi as reported by Mango et al. (2015) and Nyalugwe et al. (2022). This implies that growing baobab root tubers and leaves are much more profitable compared to similar products like carrot, tomatoes, and green vegetables. The results presented in this study imply that baobab cultivation is economically viable and would be attractive to smallholder farmers because of its potential to improve the livelihoods of participating farmers.

The economic analysis of baobab production in the present study provides a fresh perspective on the profitability of this indigenous fruit tree. The positive indicators: annual profit, return on investment (ROI), and net profit margin (NPM); align with broader economic research that positions baobab cultivation as a viable livelihood option for smallholder farmers in sub-Saharan Africa. While previous studies have highlighted the potential for baobab fruit commercialization (Bamalli et al., 2014; Rashford, 2019), this research expands the focus to include root tubers and leaves as additional cash crops, demonstrating their profitability under varying conditions of season, site, and soil type.

Contribution of the present study to social, economic and environmental fields

The present study makes a significant contribution to the field by exploring the nutritional diversity and economic value of baobab root tubers and leaf production in Malawi and the surrounding region. As baobab is a highly resilient and nutrient-rich tree (Ofori et al., 2023), the study highlights its potential to address nutritional deficiencies, particularly in rural areas where malnutrition is prevalent (Rahaman et al., 2023). By analysing the nutritional composition of baobab products, the research underscores their role as an affordable and accessible source of essential nutrients, such as vitamins, minerals, and proteins, for vulnerable populations, including women and children (Kamanula et al., 2018). This work provides evidence that baobab can support food security efforts while promoting dietary diversification, an essential factor in combating malnutrition in resource-limited settings (Sadler et al., 2019).

From an economic perspective, the study demonstrates the potential of baobab cultivation as a viable livelihood option for commercial and smallholder farmers in Malawi and the region. By evaluating the market demand, production costs, and profitability of baobab root tubers and leaves, it establishes their value as high-demand products with untapped market potential (Asogwa et al., 2021). This research not only emphasizes the role of baobab in enhancing household incomes (Kapoor et al., 2023) but also suggests opportunities for integrating it into local and regional value chains. Furthermore, it contributes to broader discussions on sustainable agriculture by presenting baobab as a climate-resilient crop that supports both environmental conservation and socio-economic development (Belice et al., 2020). These findings lay a strong foundation for policymakers, development agencies, and researchers to promote baobab cultivation and commercialization as part of sustainable agricultural and nutritional interventions.

The impact of the present study on practical application

The findings of this research have the potential to drive practical applications by informing strategies to improve food security, nutrition, and economic empowerment in Malawi and the surrounding region. By demonstrating the nutritional diversity of baobab root tubers and leaves, the study highlights their value as affordable and locally available sources of essential nutrients, which could be incorporated into community nutrition programs, school feeding initiatives, and dietary guidelines to combat malnutrition (Mango et al., 2015). Additionally, the economic analysis provides critical insights into the profitability of cultivating and commercializing baobab products, paving the way for commercial and smallholder farmers to diversify their income streams through sustainable agricultural practices. This knowledge could encourage policymakers and development agencies to invest in training, market development, and infrastructure to support baobab value chains (Silva et al., 2023). Furthermore, the study's findings on the crop's adaptability to climate variability could inspire its promotion as a climate-resilient agricultural resource, contributing to environmental sustainability and long-term food security in the region (Jansen et al., 2020).

Limitations and recommendations

It should be noted that this study acknowledges the limitation of using a smaller sample size, which may impact the generalizability of the findings regarding the nutritional diversity and economic value of baobab root tubers and leaf production in Malawi and within the region. While the data collected provides meaningful insights, a larger and more representative sample would enhance the reliability and applicability of the results. Future studies should focus on increasing the sample size (Spangl et al., 2021) to validate these findings further and to capture the variability in production, nutritional content, and economic potential across different regions and farming practices.

However, it should also be noted that to address this potential limitation, the study employed rigorous statistical method, three factor ANOVA with balanced design, which is appropriate for smaller samples and ensure the reliability of the results (Spangl et al., 2021). Therefore, the results from the present study are robust, reliable, and provide a valuable foundation for future research. They offer critical insights into the potential of baobab cultivation as a sustainable and economically viable agricultural product. The study's findings serve as an important starting point for more comprehensive investigations, guiding efforts to optimize cultivation practices, enhance market integration, and support policy development aimed at promoting baobab production in Malawi and within the region.

Conclusion

The study has revealed that the weight of root tubers and leaves was significantly influenced by season and soil type. There were significant differences in energy, carbohydrates, protein, magnesium, and potassium between fresh root tubers and fresh leaves. Overall, baobab root tuber and leaf production were viable with an estimated annual profit of about MK 1 million (US$ 1.2 thousand), a positive rate of return on investment (38.5%), and a positive net profit margin (27.8%). Baobab root tubers had a potential demand of 1457.82 metric tons per year with an estimated monetary value of MK 728,910,000 (US$ 896,788.88). Baobab leaves had a potential demand of 778.71 metric tons per year, with an estimated monetary value of MK 311,484,000 (US$ 383,223.43). Therefore, baobab root tuber and leaf vegetables have the potential to be introduced as cash crops among communities in Mangochi district, as vegetables for daily consumption, and to assist food security strategies. The study recommends future studies with larger sample size to validate and extend the present findings. The insights from this study provide a valuable foundation for such future work.

Data availability: The data that support the findings of this study can be obtained from the corresponding author upon request.

Acknowledgements: This study was conducted as a Master's programme for the first author from Rhine-Waal University of Applied Sciences, Kleve, Germany through the Baoquality project funded by the Germany Federal Ministry of Food and Agriculture (BMEL).

Competing interests: The authors have declared that no competing interests exist.

Statement about use of generative AI: Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

Authors' contributions: Jacinta Mlaviwa: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Victor Kasulo:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jarret Mhango:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Edward Missanjo:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding:

Funding agencies/institutions	Project / Grant
Germany Federal Ministry of Food and Agriculture (BMEL)	Baoquality Project Number 2816PROC17

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