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ORIGINAL RESEARCH ARTICLE

Geo-Nutritional Variability of Baobab (Adansonia digitata) Seeds across Diverse Agro-Ecological Zones in Zimbabwe: Insights into Macro-nutrients, Micro-nutrients and Anti nutritional Factors

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ABSTRACT

The baobab tree, *Adansonia digitata*, is a climate-resilient indigenous species native to sub-Saharan Africa that offers significant nutritional and economic potential through its pulp and seeds. This study investigated the proximate composition of baobab seeds collected from three distinct agro-ecological zones: Mashonaland East, Masvingo, and Manicaland, to assess how geographic origin influences nutritional quality. Standard AOAC protocols were used to analyze moisture, ash, crude protein, fat, fiber, and carbohydrate content. Results revealed regional differences**:** Manicaland exhibited the highest mean moisture (6.22 ± 0.02%) and crude protein (20.5 ± 0.01%) levels, while Mashonaland East had the highest crude fat content (23.9 ± 0.03%). Masvingo recorded elevated carbohydrate levels (39.7 ± 0.05%) and antinutrient concentrations, including tannins (10.12 ± 1.02 g/100g), phytates (4.56 ± 0.23 g/100g), and oxalates (2.64 ± 0.02 g/100g). Statistical analysis using a one-way ANOVA test and the Tukey HSD test, revealed that a significant difference ($p < 0.05$) exists between seed composition from differing provinces. This reiterated the effect of genetic or environmental variation of *A. digitata*. It was observed that geographical location plays a significant role in impacting the nutritional composition of *A. digitata*, as different zones possess different compositions of macronutrients, micronutrients, and antinutrients. Such spatial effects are important in determining suitable zones suitable for the utilization of particular varieties of *A. digitata*. This can range from those rich with proteins for particular animal feed compositions or those rich with oil compositions. Consideration should be given to how *A. digitata* seed products should be valorized at national levels.

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1. INTRODUCTION

Achieving global food security is a formidable challenge in the face of population growth, dietary changes, pandemics, conflicts, dwindling supplies of natural resources, land degradation, and changing environmental conditions (Ghosh et al., 2024). In recent years, there has been growing global recognition of underutilized indigenous plant species as potential sources of nutrition, functional food ingredients, and income generation in low-resource settings (Masao et al., 2023; Talucder et al., 2024). This quest has also been driven by the projected population growth which poses a profound challenge to the sustainability of food systems (Constant, 2024). Among these, *Adansonia digitata,* which is commonly known as the baobab tree, stands out for its medicinal, nutritional, economic, and ecological value (Komane et al., 2023; Dogara & Al-Zahrani, 2024).

Native to sub-Saharan Africa and also widespread in southern Zimbabwe, the baobab is referred to as the "tree of life" due to its resilience in arid environments and its multi-purpose utility (Adesina & Zhu, 2022; Mkelemi et al., 2024). However, the Sub-Saharan Africa (SSA) region is facing increasing water scarcity, food and nutrition insecurity, poverty and inequality under climate change (Ndlovu et al., 2024). Although much attention has been given to the nutritional content of the fruit pulp and the leaves, the seeds of the baobab tree have not received enough attention but have a rich nutritional content (Ofori & Addo, 2023; Nyoni et al., 2024). In light of the growing interest in the exploration of alternative foods that are environmentally friendly and have the resilience to withstand the effects of climate change, the seeds of the *Adansonia digitata* tree have the potential to be utilized as a source of alternative food that can be consumed by both humans and animals due to their rich nutritional content (Ogbuewu et al., 2024; Ndiaye et al., 2025).

The seeds of the *Adansonia digitata* tree have a rich nutritional content that includes a high content of crude protein, essential amino acids, and polyunsaturated fatty acids, as well as calcium and magnesium minerals. The nutritional content of the seeds is desirable for the utilization of the seeds as a local indigenous seed for the purpose of addressing the nutritional security of the local populace, especially in a community that is frequently affected by droughts and malnutrition (Owolodun, & Merten, 2023). However spatial variability in the nutritional composition of *A. digitata* seeds can occur due to the intricate interplay of environmental factors, soil characteristics, and geographic locations, collectively shaping the quality and quantity of essential nutrients across diverse ecosystems (Sithara et al., 2024).

Therefore, it is crucial to understand the effect of geographical characteristics on the proximate composition of baobab seeds to ensure the optimal utilization and valorization of the seeds (Monteiro, et al., 2022; Sithara, 2024). Past literature from other African countries indicates that the nutrient content of baobab seeds varies greatly due to environmental and ecological differences (Stadlmayr et al., 2020; Sithara, 2024). However, there is a lack of empirical data to show the variation of the nutrient content of baobab seeds in the various provinces of Zimbabwe, which limits the development of nutritional interventions and the commercialization of *A. digitata* seeds. Without localized, evidence-based insights into nutrient variability, *A. digitata* seeds remain underexploited in both policy and practice.

Proximate analysis is a confirmed technique for evaluating the general composition of nutrients present in biological samples like moisture content, ash content, crude protein, crude fat, fiber content, and carbohydrates (Hart, 1971; Nielsen, 2024). These conditions have direct relation to shelf life, energy content, digestibility, and feasibility of plant substrates for intake by humans and animals. Spatial variation in proximate composition is caused by agroecological factors like climate, altitude, soil nutritional status, and rainfall (Corwin, 2021; Orina et al., 2021; Sithara et al., 2024). For *A. digitata*, such environmental limitations have been found for West and Central Africa but not outcomes specific to Zimbabwe yet.

Studies from Angola, Tanzania, and Kenya for example, have shown regional variability in *A. digitata* nutritional composition due to the differences in geographical location (Muthai et al., 2019; Stadlmayr et al., 2020; Monteiro et al., 2022). This highlights the importance of location-specific studies, especially in countries like Zimbabwe, where agro ecological zones differ widely from the relatively humid plateau of Mashonaland to the semi-arid plains of Manicaland. Such variability necessitates targeted studies to determine the most nutritionally valuable seed sources.

This research endeavored to fill the existing gap in data by presenting the initial systematic assessment of *A. digitata* seed nutritional composition in three ecologically different provinces in Zimbabwe: Mashonaland East, Masvingo, and Manicaland. This study was archived by systematic sample collection of *A. digitata* seeds from three provinces. This was followed by proximate analysis using the AOAC standardised methods. However, the study was limited to three provinces and may not capture micro regional variations within individual provinces. The one-way analysis of variance statistical method was conducted to assess the differences between the regions and correlations between nutritional components and geographic origin.

By establishing the nutritional relationship of *A. digitata* seeds with geographic provenance, this research presents utilitarian benefits for a variety of stakeholders from food scientists through nutritionists, agro-processors, to policy-makers. This will also enable the identification of nutritionally superior samples (Hika et al., 2023). It adds to the overall agenda of promoting diversification of food supplies and native use of resources (Nchanji et al., 2021; Mekonnen, 2024). In addition, the results can now add on to regional agribusiness planning by mapping areas of greatest production of high-protein or high-oil seed yields, enhancing rural livelihood and value chain efficiency.

2. MATERIALS AND METHODS

2.1 Sample Collection

Mature, unblemished *Adansonia digitata* fruits were sourced from three different and ecologically diverse provinces of Zimbabwe, namely Mashonaland East (Mutoko), Masvingo (Chiredzi), and Manicaland (Tanganda), with geographical coordinates of 17°15'58.9"S, 32°14'35.5"E, 21°45'33.8"S, 31°11'21.8"E, and 20°32'26.3"S, 32°24'48.1"E, respectively. These provinces were chosen due to their distinctive agro-ecological characteristics, namely annual rainfall, temperature, and vegetation types, that have been reported to affect the proximate composition of *Adansonia digitata* seeds, thus providing agro-ecological diversity for this exploratory study. From each of these provinces, fruits were collected from 10 different *Adansonia digitata* trees, with a minimum of 500 meters separating each tree to avoid bias arising from proximity effects. A total of 150 fruits, with 50 fruits per province and 5 fruits per tree, were collected during the peak fruiting season, with careful consideration of maturity, lack of mechanical damage, and uniformity of size. From each fruit, seeds were removed, cleaned, and dried under standardized conditions. For each of the provinces, there were 10 different trees, thus providing biological replication, as each of the 10 trees was considered an independent biological unit to ensure biological replication, with seeds from each of the fruits of each tree being pooled together to obtain a single seed sample per tree. To ensure that any observed differences are due to true biological variation and not due to experimental variation, each of the biological replicates was analyzed with high precision, with triplicate analysis being conducted as a measure of analytical replication, where triplicate analysis refers to analytical repeats, not independent biological replicates. Sample A, Sample B, and Sample C refer to the samples collected from Mashonaland East, Masvingo, and Manicaland, respectively.

Fig 1: Map of Zimbabwe showing the three provinces from which *Adansonia digitata* seeds were collected: Masvingo (Chiredzi), Mashonaland East (Mutoko), and Manicaland (Tanganda). These regions were selected to represent contrasting agroecological zones semi-arid Lowveld moderately dry savannah and humid Eastern Highlands.

2.2 Sample Preparation

At the laboratory, the dried baobab fruits were manually cracked open using a wooden mallet to extract the pulp-coated seeds. The pulp-coated seeds were soaked in clean water at a seed-to-water ratio of approximately 1:5 (w/v) for 24 hours at room temperature (≈25 °C) to facilitate removal of the adhering pulp. The selected seed-to-water ratio (≈1:5, w/v) provided sufficient hydration for pulp removal while minimizing excessive dilution that could enhance mineral and anti-nutrient leaching. Following soaking, seeds were gently rubbed and rinsed thoroughly to remove residual pulp. Clean seeds were spread evenly on stainless steel trays and dried in a hot-air oven at 40°C for 12 hours until a constant weight was achieved (Hartmann et al., 2016; Devi & Mani, 2019). This low-temperature drying preserved the nutritional integrity of heat-sensitive compounds. Dried seeds were then cooled to room temperature, packed in airtight polyethylene bags, and stored in a desiccator to prevent moisture reabsorption before analysis. However, soaking may influence measured mineral/antinutrient concentrations. For this study all samples from the different agro-ecological zones were processed uniformly (identical soaking conditions) in order to minimize systematic bias in comparative analysis to ensure consistency across regions.

2.3 Macronutrient Analysis

Proximate composition of the dried Adansonia digitata seeds was analyzed in triplicates according to standard AOAC (Association of Official Analytical Chemists) methods (AOAC, 2019). The parameters analyzed included those in **Table 1.**

Table 1: Summary of the analytical methods that were used for proximate analysis of A. digitata seeds

Parameter	Method Description	AOAC Reference
Moisture Content	Determined by oven drying at 105°C until a constant weight was achieved.	AOAC 934.01
Ash Content	Measured by incinerating 5 g of the sample in a muffle furnace at 550°C for 6 hours to obtain the total mineral residue.	AOAC 942.05
Crude Protein	Quantified using the Kjeldahl method. Total nitrogen was measured and converted to protein using a factor of 6.25.	AOAC 2001.11
Crude Fat	Extracted using a Soxhlet apparatus with petroleum ether as the solvent.	AOAC 920.39
Crude Fiber	Determined via sequential acid and alkaline digestion followed by incineration.	AOAC 962.09
Carbohydrates	Estimated by difference: 100 − (Moisture + Ash + Protein + Fat + Fiber).	FAO (2003)

2.4 Micronutrient Analysis

About 0.5 g of *A. digitata* seed samples from each of the provinces of Mashonaland, Manicaland, and Masvingo were subjected to dry ashing using a muffle furnace at 460 °C for 4.5 hours. After ashing, the samples were allowed to cool before being treated with a mixture of 0.4 mL of 37% hydrochloric acid, 0.4 mL of 69% nitric acid, and 0.6 mL of 30% hydrogen peroxide. Digestion was done using an electric hotplate to near dryness. After that, the samples were allowed to cool before being treated with 25 mL of 0.05 N HCl and stoppered before shaking them thoroughly and leaving them overnight.

For the analysis, 2ml of the digested sample was taken and made up to 25ml in a volumetric flask, followed by the addition of 5ml of distilled water, then 2.5ml of 5% strontium chloride, and the solution was made up to volume by adding distilled water. Calcium, potassium, magnesium, sodium, copper, iron, zinc, and manganese were analyzed by using the ICP-OES technique. Quality control measures were taken by analyzing the reagents to correct the background contaminants and by taking triplicate measurements of the sample to evaluate the precision of the analysis. The calibration curves were prepared by selecting the appropriate range of the concentration of the analyte, and the linearity of the instrument was evaluated before the analysis. The spike recovery tests were carried out by analyzing the selected samples, and the recovery of the spiked sample should be within the acceptable range of the limits of the instrument (90-110%). The elemental content of the sample was evaluated by comparing the intensity of the emitted radiation to the calibration curves prepared by the ICP-OES technique, which uses the multi-element standard solution (Muthai et al., 2017).

2.5 Determination of antinutritional factors

Quantitative determination of tannins and oxalates was performed following the procedures of Oladele & Adebowale (2009) and Ijarotimi et al. (2013), with slight modifications. Briefly, 1 g of powdered sample was extracted with 10 mL of 70% ethanol by shaking at 200 rpm for 0 min at room temperature. The mixture was centrifuged at 5000 × g for 10 min and the supernatant collected for analysis. Tannins were quantified using the Folin–Ciocalteu reagent, and absorbance was measured at 725 nm. Standard curves were prepared using tannic acid in the range 0–200 µg/mL. Oxalate content was determined spectrophotometrically. 1 g of finely ground sample was extracted with 25 mL of 0.2 M HCl for 30 min and filtered. 5 mL of the filtrate was reacted with 2 mL of 0.1% sulfosalicylic acid for 10–15 min at room temperature, and absorbance was measured at 510 nm. Oxalic acid standards (0–50 µg/mL) were used to construct a calibration curve, and sample oxalate concentrations were calculated accordingly. For the determination of phytate (myo-inositol hexakisphosphate), the process applied involved the extraction of 1 g of test substance that was in powder form by mixing it with 20 ml of 0.5MHCl. Then, the mixture was centrifuged using 5000g. After that, the process was subjected to a 0.45µm filter, and iron (III) complexation technique was adopted to enhance the UV-detection of the test substance.

For derivatization, 1 mL of filtered extract was treated with 1 mL of 0.01 M $FeCl_3$ solution and allowed to react at room temperature for 15 min to form an Fe(III) phytate complex. A volume of 20 µL of derivatized extract was injected into an Agilent 1260 HPLC-DAD system equipped with a Zorbax Eclipse XDB-C18 column (4.6 × 250 mm, 5 µm). Isocratic elution was carried out using 0.1 M potassium dihydrogen phosphate (KH_2PO_4) buffer (pH 4.5) as eluent at a flow rate of 1.0 mL/min. The column temperature was set at 30 °C. The total elution time was set at 15 min. The detection wavelength was set at 254 nm, which is characteristic of Fe (III) phytate complexes. Identification of phytate was performed by comparing retention times of phytate in the extract with similarly derivatized phytic acid standards. The phytate content in each extract was determined using an external standard calibration curve constructed from phytic acid standard solutions (0 to 50 µg/mL), which were similarly treated with Fe(III) phytate complexes. The phytate content is expressed in mg/100 g of sample. The concentration of antinutritional factor was determined by converting absorbance values to concentration (µg/mL) using linear regression equations derived from standard calibration curves.

2.6 Statistical Analysis

The experimental data was compiled using Microsoft Excel. The data was then analyzed using SPSS version 25. The statistical analysis (ANOVA) was done using the 10 independent biological replicates from each of the provinces to assess the geographic variability. One-way analysis of variance (ANOVA) was used to determine if there are any statistically significant differences between the three geographical regions at a significance level of ($p \leq 0.05$). In cases where there were differences between the means, mean separation was done using Tukey's honestly significant difference (HSD) post hoc test. Results are shown as mean ± SD.

3. Results and Discussion

3.1 macronutrients

Figure 2 shows **v**ariation in moisture content (%) of *Adansonia digitata* seeds across Masvingo (Chiredzi), Manicaland (Tanganda), and Mashonaland East (Mutoko). The moisture content varied markedly across the three regions with Manicaland (Tanganda) exhibiting the highest moisture content of (6.22+/- 0.02%). This can be attributed to the annual rainfall of the Manicaland regions that is well above 1000mm and is well dominated by cool temperatures. This is likely to enhance the retention of water by seeds, a common attribute of flora from moist climates (Souza et al., 2019). Contrariwise, the seeds from the Masvingo region (Chiredzi) had the lowest content of moisture (4.70 +/- 0.01%). This is consistent with the nature of the climate that is characterized by a semi-arid environment with an annual rainfall of approximately 585mm. The seeds from the Mashonaland East region (Mutoko) with an annual rainfall of approximately 721mm had moderate content of 5.40 +/- 0.02%. Low levels of moisture are advantageous from a post-harvesting perspective as they enhance good storage and stability of the product since they are less vulnerable to microbial spoilage (Awosanmi & Baffoe, 2020; James et al., 2022; Lamidi et al., 2023). Lamayi (2014) reported a moisture content of 5.37%, similar to the values obtained from the Mashonaland East region of this study. Similarly, Odetokun (1996) reported an average seed moisture content of ~6%, similar to the values obtained from the Manicaland region.

In contrast, studies by Abubakar et al. (2015) and Halilu et al. (2023) observed slightly lower moisture contents, 4.41% and 4.0% respectively, which are comparable to the lowest values in the current study from semi-arid Masvingo. This supports the conclusion that environmental dryness and low rainfall limit seed water retention. Interestingly, Babalola et al. (2021) recorded higher moisture levels (8.53–9.03%) depending on the processing method, particularly boiling. This suggests that moisture content can also vary based on post-harvest treatment, a factor not manipulated in the present study.

Manicaland also showed the highest crude protein content (20.5+/- 0.01%), and Mashonaland East showed the lowest, as shown in **Figure 3**. The relatively higher crude protein content observed in Manicaland is consistent with studies reporting associations between seed protein accumulation and environmental nutrient availability (Munyanyiwa, 1999; Wangu et al., 2024). However, as soil nitrogen and mineral composition were not directly measured in this study, these factors are presented here as plausible explanations rather than confirmed causes. Though *A. digitata* tends to have uniform nutrient composition due to being perennial,
localized water availability and soil fertility can enhance amino acid yield in seed tissues (Muthai et al., 2017; Omonhinmin et al., 2023). However, the minimal protein difference between Masvingo and Mashonaland East implies strong genetic and physiological control over this trait across regions. These protein levels are well in line with a study that was conducted by Babaola et al (2021), who concluded that *A. digitata* seeds exhibit a rich nutritional profile, with high protein content. The overall protein content observed in this study was however low as compared to a study that was conducted by Oyesiji et al., where it was 27% in raw seeds.

In **Figure 5**, Mashonaland East (Mutoko) retained the highest crude fat concentration (23.9 ± 0.03%, while Manicaland recorded the lowest (19.63 ± 0.05%). This is ecologically significant, as lipid accumulation in seeds is often optimized by dry or moderately humid zones which cause plants to allocate energy reserves to ensure seed viability during environmental stress (Park et al., 2023). These environmental conditions induce transcriptional regulation of triacylglycerol accumulation in plants as an adaptive strategy (Nam et al., 2022). The observed results were in line with studies conducted by Enocn et al (2020) and Sithara et al (2024) which went on to conclude that geographical location influences lipid composition of *A. digitata* seeds. The high oil content observed in Mashonaland East and Masvingo are indicative of the strong potential of *A. digitata* seeds for commercial oil extraction which will directly contribute to economic valorization through nutritional and cosmetic applications.

Manicaland exhibited the highest ash content of 7.45 %, the higher ash content observed in Manicaland is consistent with regional variation in mineral accumulation reported in previous studies, although direct soil mineral characterization was beyond the scope of this work (**Figure 6**). Ash content is a proxy for total mineral content, and the high levels suggest a great concentration of bioavailable macro and micronutrients (Mammam & Yusuf, 2021). Mashonaland East and Manicaland recorded similar ash contents (6.66% and 6.75% respectively), which may reflect differences in growing conditions that influence mineral deposition in seeds, as reported in comparable agro-ecological studies, which directly impact on poor seed micronutrient retention (Rocha et al., 2020, Suriyagoda et al., 2023). The impact of geographical variation on ash content of *A. digitata* seeds was also proved by Chabite et al (2019) were the ash content ranged from 5.95% to 6.38% from two districts of Mozambique. The overall ash content observed in this study was high for all the geographical locations as compared to 3.15% in a study that was conducted by Mannam et al (2021).

Carbohydrate content (**Figure 7**) was found to oscillate between 37.51 and 39.7% confirming that *A. digitata* seeds are nutritionally rich (Babalola et al., 2021; Mammam et al., 2021). The low carbohydrate content that was found in Mashonaland East can be due to the high lipid accumulation which directly reduces the carbohydrate proportion (Babatunde et al., 2022). At a molecular level these differences can also be attributed to high expression of carbohydrate synthesis genes in Manicaland as compared to Mashonaland East region which have high lipid content as these genes are inversely related (Liu et al., 2022).

Despite regional environmental variability, the similar ranges of macronutrient composition may be attributed to its unique homeostasis capabilities and genetic plasticity of *A. digitata* (Munthali et al., 2013; Ndiaye et al., 2019). According to a study conducted by Kitony et al (2024) it was found that the *A. digitata* genome contains drought resilient genes which are related to circadian rhythms, flowering, and light response which support its longevity and adaptability in different agro ecological regions. *Adansonia digitata* is also characterised by deep taproots and slow growth, thereby allowing it to buffer short term climatic variability, which then promotes stable resource allocation to seeds over multiple years.

3.2 Evaluation of micronutrients

The *A. digitata* seed micronutrient evaluation results are presented in **Table 2** which presents the quantified micronutrient composition across the three provinces. Manicaland exhibited the highest concentrations of calcium (452.86 ± 11.71 mg/100g), magnesium (335.14 ± 7.93mg/100g), and zinc (5.72 ± 0.03 mg/100g), which may be associated with differences in soil mineral availability and organic matter content reported for the region. Masvingo recorded elevated levels of sodium (30.61 ± 0.35 mg/100g), potassium (890.65 ± 0.43 mg/100g), and copper (2.05 ± 0.04 mg/100g), which may reflect the influence of semi-arid conditions that are reported to reduce mineral leaching and enhance retention. Mashonaland East exhibited relatively higher iron (4.09 ± 0.06 mg/100g) and manganese (1.34 ± 0.11 mg/100g) levels, a pattern that is likely to be influenced by soil characteristics such as iron-rich profiles reported for the region.

These findings highlight the subtle yet meaningful influence of agro-ecological variation on micronutrient composition with $p<0.05$, aligning with the significant variation observed in macronutrients. The minerals identified provide an opportunity for focused nutrition planning and local initiatives in agro-processing. These findings are consistent with research conducted in East and West Africa that reported geo-specific differences in minerals of baobab seeds. (Muthai et al., 2017; Stadlmayr et al., 2020).

3.3 Antinutritional factors

The findings on antinutritional factors from this current study, as shown in **Table 3** and **Figure 8**, are very important for an understanding of geo-nutritional diversity for *Adansonia digitata* seeds with $P < 0.05$ from three different agro-ecological zones in Zimbabwe. The zones are: Masvingo Province (Chiredzi District), Manicaland Province (Tanganda District), and Mashonaland East Province (Mutoko District). From this study, it was noted that the content of tannin varies geographically. Higher levels of tannin were recorded for Masvingo Province (10.12 ± 0.03 mg/100g) than for Mashonaland East Province (7.86 ± 0.02 mg/100g). Lower levels of tannin (5.81 ± 0.02 mg/100g) were recorded for Manicaland Province than for Masvingo Province. This could be attributed to agro-ecological stress gradients. In this case, harsh conditions experienced in semi-arid areas such as Chiredzi District in Masvingo Province may trigger higher levels of secondary metabolites for *Adansonia digitata* seeds to adapt to harsh conditions as a means of survival. This assertion is supported by research findings by different scholars that suggested that plants under environmental stress are likely to produce higher levels of phenolic compounds to aid survival (Brito et al., 2020). The same trend was noted for phytate concentration, where seeds from Masvingo Province had a higher concentration (4.56 ± 0.04 mg/100g) than Manicaland Province (2.31 ± 0.03 mg/100g). Phytates, which are known for their chelating properties for essential minerals, are known to be higher in plants grown in nutrient-deficient soils such as phosphorus, which is commonly experienced in semi-arid environments (Sandberg, 2020). Therefore, this high level of phytate for seeds from Masvingo Province could be an adaptation to conditions experienced in this province, while low levels of phytates for Manicaland Province could be an indication of a fertile and well-balanced composition of minerals experienced in this province.

Oxalate content followed the same trend as tannins and phytates: highest in Masvingo at 2.64 ± 0.02 mg/100g, followed by Mashonaland East at 1.94 ± 1 mg/100g, while the lowest among the stations was in Manicaland at 1.19 ± 0.01 mg/100g. Oxalates are known to build up as a mechanism to keep internal ions in check or balance, especially in areas that are dry or high in calcium content (Noonan & Savage, 2022). The lower amounts of antinutrient build-up in the form of oxalates in Manicaland could also be a factor of not only the lower climate condition but also the nutrients in its soils.

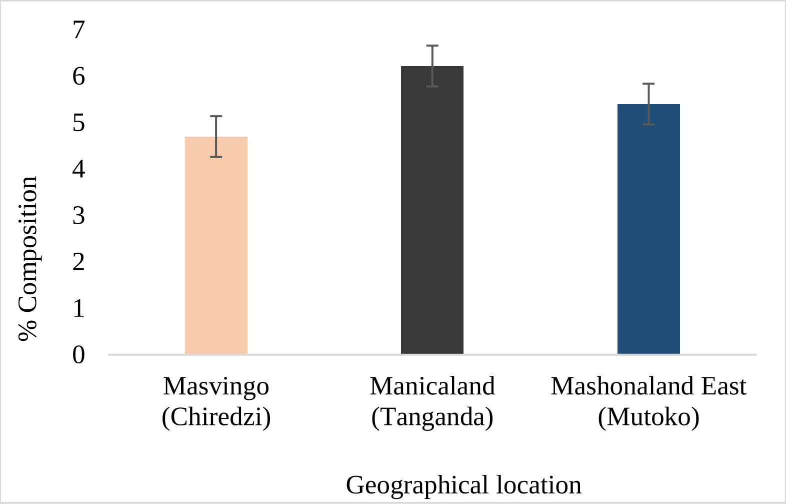

Fig 2. Variation in moisture content (%) of Adansonia digitata seeds.

Figure 2 illustrates that Manicaland exhibited the highest moisture content (6.22 ± 0.02%), followed by Mashonaland East (5.40 ± 0.02%), while Masvingo had the lowest (4.70 ± 0.01%). These differences were statistically significant ($p < 0.05$), reflecting climatic influence on seed water retention.

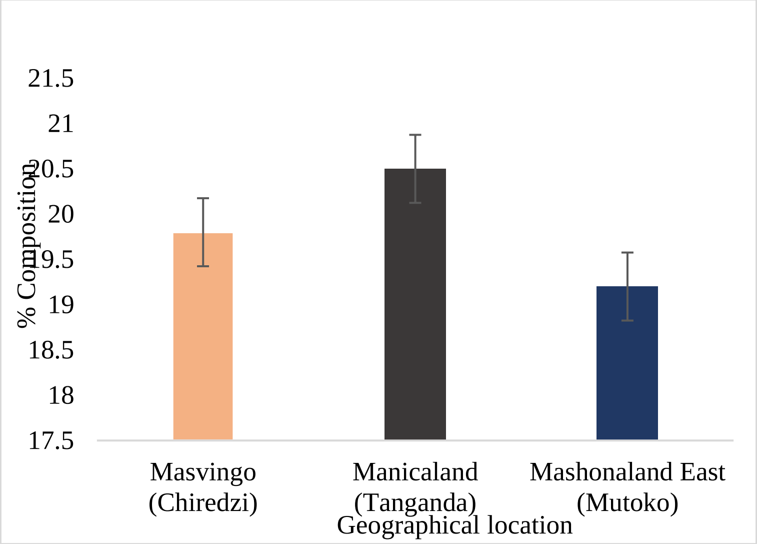

Fig 3. Crude protein content (%) of Adansonia digitata seeds.

Figure 3 shows that Manicaland recorded the highest crude protein content (20.5 ± 0.01%), followed by Masvingo (18.2 ± 0.03%), with Mashonaland East showing the lowest value (16.8 ± 0.04%).

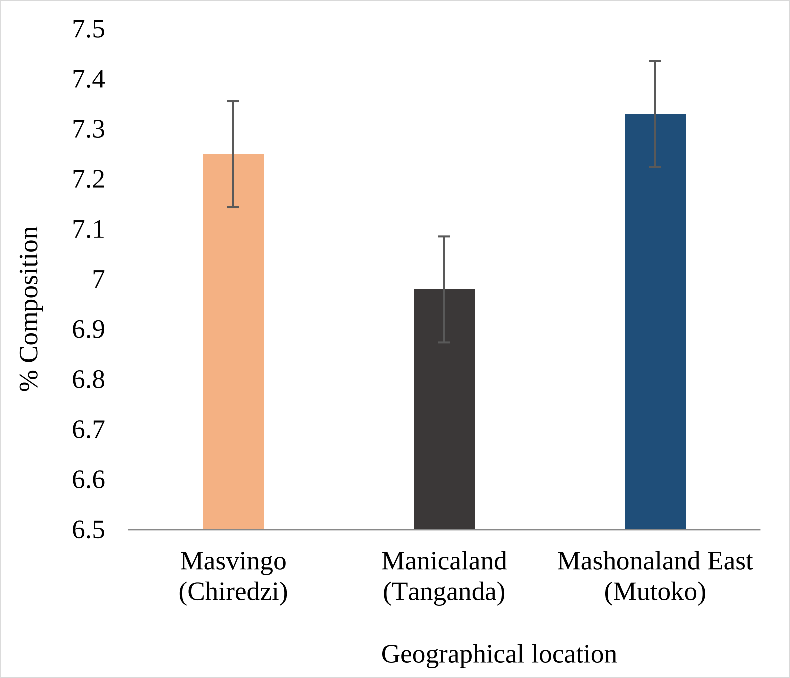

Fig 4. Crude fibre content (%) of *Adansonia digitata* seeds.

Figure 4 shows that Mashonaland East recorded the highest crude fibre content (7.33 ± 0.10%), followed closely by Masvingo (7.25 ± 0.15%), while Manicaland had the lowest value (6.98 ± 0.12). The differences were statistically significant ($p < 0.05$), indicating regional variation in crude fibre content of Adansonia digitata seeds.

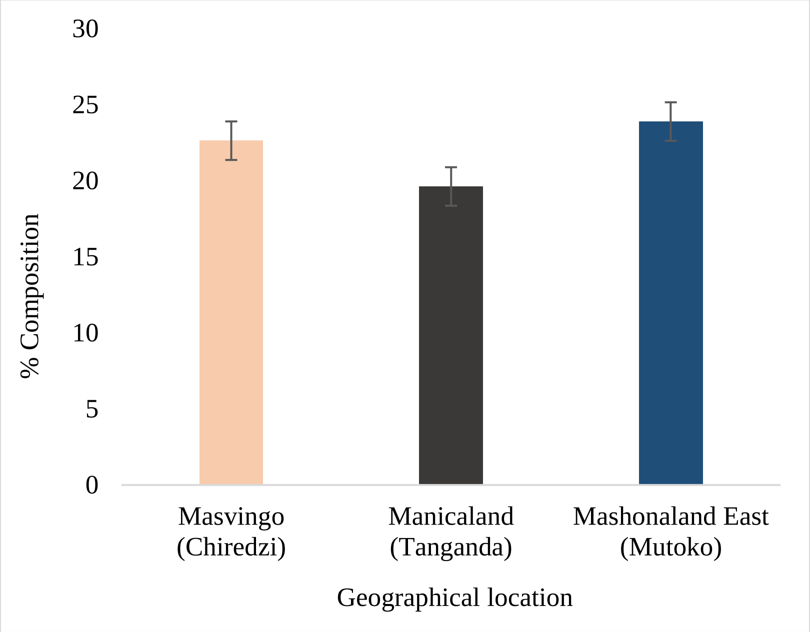

Fig 5. Crude fat content (%) of Adansonia digitata seeds).

Figure 5 demonstrates that Mashonaland East had the highest crude fat content (23.9 ± 0.03%), followed by Masvingo (21.7 ± 0.02%), with Manicaland recording the lowest value (19.63 ± 0.05%). Statistically significant differences ($p < 0.05$) were observed across all regions.

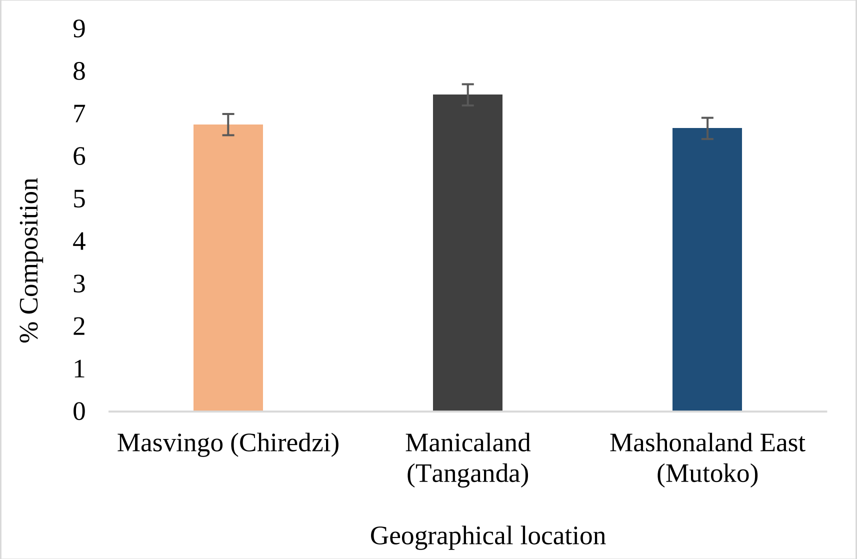

Fig 6. Ash content (%) of Adansonia digitata seeds.

Figure 6 shows that Manicaland had the highest ash content (7.45 ± 0.02%), followed closely by Mashonaland East (6.75 ± 0.02%), while Masvingo recorded the lowest value (6.10 ± 0.03%). The differences were statistically significant ($p < 0.05$), indicating variation in total mineral content across regions.

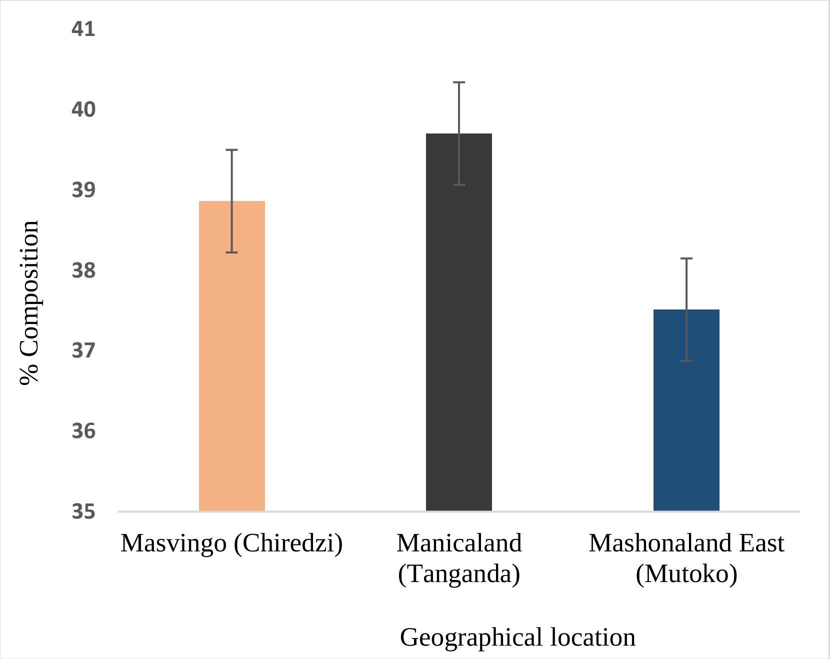

Fig 7. Carbohydrate content (%) of Adansonia digitata seeds. **Figure 7** depicts that Masvingo seeds had the highest carbohydrate content (39.7 ± 0.05%), followed by Manicaland (38.4 ± 0.03%), while Mashonaland East had the lowest (37.51 ± 0.04%). These regional differences were statistically significant ($p < 0.05$).

Table 2 presents the mean concentrations (± SD) of selected micronutrients in Adansonia digitata seeds collected from three geographically and agro-ecologically distinct regions of Zimbabwe. Manicaland samples recorded the highest levels of calcium, magnesium, and zinc, while Masvingo exhibited the highest potassium content. These results suggest a geographic influence on mineral uptake and accumulation in baobab seeds. One-way ANOVA revealed that geographical origin had a significant effect ($p < 0.05$) on all measured micronutrients of *Adansonia digitata* seeds.

Tukey's HSD post-hoc test showed that sodium content was highest in Masvingo (30.61 ± 0.35 mg/100 g), intermediate in Mashonaland East (26.85 ± 0.11 mg/100 g), and lowest in Manicaland (25.13 ± 0.49 mg/100 g). Calcium, magnesium and zinc were significantly higher in Manicaland compared to the other regions, whereas Mashonaland East recorded the highest iron and manganese concentrations. Potassium and copper contents were significantly greater in Masvingo than in Manicaland and Mashonaland East. These findings demonstrate a strong influence of geographical and edaphic factors on mineral accumulation in *A. digitata* seeds.

Table 2. Micronutrient composition (mg/100g dry weight) of Adansonia digitata seeds collected from three agro-ecological zones in Zimbabwe

Micronutrient (mg/100g)	Masvingo (Chiredzi)	Manicaland (Tanganda)	Mashonaland East (Mutoko)
Sodium (Na)	30.61 ± 0.35^a	25.13 ± 0.49^c	26.85 ± 0.11^b
Calcium (Ca)	387.74 ± 8.69^b	452.86 ± 11.71^a	393.03 ± 25.64^b
Magnesium (Mg)	273.38 ± 1.26^c	335.14 ± 7.93^a	292.86 ± 7.18^b
Potassium (K)	890.65 ± 0.43^a	820.75 ± 0.12^b	760.33 ± 0.31^c
Copper (Cu)	2.01 ± 0.04^a	1.87 ± 0.03^b	1.86 ± 0.12^b
Zinc (Zn)	4.92 ± 0.08^c	5.72 ± 0.03^a	5.10 ± 0.07^b
Iron (Fe)	3.49 ± 0.12^b	3.33 ± 0.13^b	4.09 ± 0.06^a
Manganese (Mn)	1.22 ± 0.07^b	1.02 ± 0.02^c	0.11^a

* Values are expressed as mean ± SD (n = 3). Means within the same row followed by different superscript letters are significantly different at $p < 0.05$ according to Tukey's HSD test.

Table 3. Mean Concentration (± SD) of antinutritional factors in baobab seeds by region

Parameter	Masvingo (Chiredzi)	Manicaland (Tanganda)	Mashonaland East (Mutoko)
Tannins (g /100g)	10.12 ± 1.02^a	5.81 ± 0.01^c	7.86 ± 0.02^b
Phytates (g/100g)	4.56 ± 0.23^a	2.31 ± 0.40^c	3.47 ± 0.22^b
Oxalates (g/100g)	2.64 ± 0.02^a	1.19 ± 0.17^c	1.94 ± 0.20^b

* Values are expressed as mean ± standard deviation (n = 3). Means within the same row followed by different superscript letters are significantly different at $p < 0.05$ according to Tukey's HSD multiple comparison test.

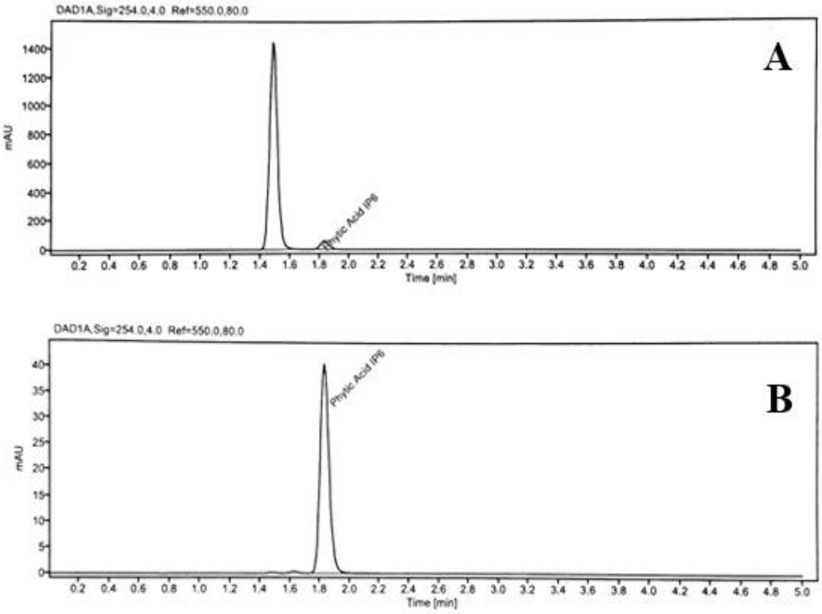

Fig 8. Chromatogram showing (A) the ANF profile for a raw *A. digitata* seed sample (B) Phytic Acid standard

Table 3 presents the mean concentrations (± SD) of selected antinutritional factors tannins, phytates, and oxalates in *Adansonia digitata* seeds collected from three geographically and agro-ecologically distinct regions of Zimbabwe. Manicaland recorded the lowest levels for all parameters, suggesting lower biosynthesis/production of these anti-nutritional compounds in that region, or environmental factors reducing accumulation during seed development.

Table 3 shows that the level of antinutritional compounds in *Adansonia digitata* seeds is affected by the geographical location of the plant. One-way ANOVA results revealed that the geographical location significantly affected the tannin, phytate, and oxalate contents of *Adansonia digitata* seeds. In this experiment, the highest level of tannin, phytate, and oxalate was recorded in the Masvingo sample.

These results showed that the level of tannin was 10.12 ± 1.02 mg TAE/100 g, the level of phytate was 4.56 ± 0.23 mg/100 g, and the level of oxalate was 2.64 ± 0.02 mg/100 g. Mashonaland East had intermediate values for these antinutrient compounds. Manicaland had the lowest concentration of all the antinutrient compounds. According to the results obtained in this experiment, the high level of antinutrient compounds in the Masvingo sample may have been due to environmental stress conditions like higher temperature and lower rainfall, which increase the production of secondary plant compounds.

CONCLUSION

This study assessed the proximate composition of Adansonia digitata seeds collected from three ecologically diverse provinces in Zimbabwe, Mashonaland East, Masvingo, and Manicaland to determine whether geographical origin significantly influences their nutritional quality. The observed differences in individual macronutrient values such as protein (16.8 ± 0.04 % in Mashonaland East, 18.2 ± 0.03 % in Masvingo, and 20.5 ± 0.01 % in Manicaland), fat (23.9 ± 0.03 % in Mashonaland East, 21.07 ± 0.02 % in Masvingo, and 19.63 ± 0.05 % in Manicaland), moisture (5.40 ± 0.02%), in Mashonaland East, 4.7 ± 0.01 % in Masvingo, and 6.22 ± 0.02 % in Manicaland), and ash content (6.75 ± 0.02 % in Mashonaland East, 6.10 ± 0.03 % in Masvingo, and 7.45 ± 0.02 % in Manicaland) were also supported by statistical analysis, which revealed that there is significant variation across the provinces ($P < 0.05$).

These findings indicate that there is significant genetic and physiological diversity among baobab trees. This diversity explains the diversity that exists among their seeds from different agro-ecological zones. They also affirm that *A. digitata*'s seeds are nutrient-dense and offer great potential for application in food and feed systems. However, regional differences in seed composition should inform how these seeds are processed and utilized. On a positive note, these seeds contain substantial macronutrients and micronutrients such as calcium ranging from 387.7 to 452.9 mg/100 g, magnesium ranging from 273.4 to 335.1 mg/100 g, potassium ranging from 760.3 to 890.7 mg/100 g, zinc ranging from 4.9 to 5.7 mg/100 g, and iron ranging from 3.3 to 4.10 mg/100 g. This makes them important for supporting food security and livelihoods under conditions of limited resources (Babalola et al., 2021).Physical, biological, and chemical techniques should also be utilized to ensure that anti-nutritional factors such as tannins (5.81 – 10.12 g /100 g), phytates (2.31 – 4.56 g/100 g), and oxalates (1.19 – 2.64 g/100 g) are reduced, thereby enhancing nutritional bioavailability in A. digitata seeds. Nonetheless, the geographical coverage of the research was restricted to only three provinces. Future research is encouraged to examine the multi-site/multi-year sampling, as well as sampling more agro-ecological zones, the roles of seasonality, as well as molecular mechanisms like gene expressions involved in nutrient biosynthesis. Future research also needs to consider the level of key but unidentified micronutrients like Selenium and Phosphorous. Future research is also encouraged to consider longitudinal research over a period of three or more years to evaluate the potential effect of possibly changing climatic conditions on the composition of the seeds. In recognition of the potential benefits associated with baobab as a source for the development of other products, comprehensive research aimed at enhancing the utilization and valorization may also be encouraged to enable the development of national policy on the utilization of underutilized indigenous resources.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest in this work.

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