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Comparative Evaluation of Nutritional and Phytochemical Profiling of Seeds and Leaves of *Dennettia tripetala* for Pharmacological Applications

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Abstract
Medicinal herbs and plant foods have long been recognized as major sources of nutrients and bioactive constituents that fight disease and promote good health. This study assesses and compares the nutritional and phytochemical profiles of pepper fruit (*Dennettia tripetala*) seeds and leaves using standard analytical procedures. The results of the proximate analysis show that the leaves contain 11.13% moisture,5.17% ash, 7.65% fat, 9.18% crude fiber, 15.21% protein, and 51.66% carbohydrate, while the seeds contain 10.77% moisture, 4.84% ash, 4.52% fat, 8.31% crude fiber, 12.85% protein, and 58.71% carbohydrate. Mineral analysis shows that the seeds contain potassium (362.40 ppm), calcium (116.65 ppm), sodium (102.55 ppm), magnesium (28.29 ppm), zinc (1.25 ppm), iron (0.55 ppm), and copper (0.51 ppm), while the leaves contain potassium (415.60 ppm), calcium (190.65 ppm), sodium (81.65 ppm), magnesium (33.53 ppm), zinc (1.78 ppm), iron (0.88 ppm), and copper (0.33 ppm). Phytochemical screening showed that the seeds and leaves contain alkaloids, tannins, flavonoids, terpenoids, and cardiac glycosides. However, saponins, steroids, and anthraquinones were present in the seeds but absent in the leaves, while reducing sugars were present only in the leaves. In addition, phlobotannins were absent in both the seeds and leaves. The findings revealed that both the seeds and leaves of *D. tripetala* are vital sources of phytochemicals and nutrients. The seeds contain distinct bioactive constituents that support their therapeutic uses, while the leaves show stronger nutraceutical properties that contribute to their nutritional value. This work supports and provides information on the use of *Dennettia tripetala* in nutritional, pharmacological, and health applications.

Keywords:
medicinal herbs; *Dennettia tripetala*; bioactive components; qualitative phytochemicals; proximate analysis; mineral composition

1. Introduction

Plant foods and medicinal herbs have long been recognized as important sources of nutrients and bioactive compounds that promote health and prevent disease, particularly in developing countries where traditional medicine remains an integral component of primary healthcare [1,2].

Plants contain essential minerals required for a balanced diet, as well as a wide range of primary and secondary metabolites that influence human health and nutrition [3,4]. They provide important macronutrients, micronutrients, and bioactive compounds that contribute to health maintenance and disease prevention [5,6]. In addition, plants are rich sources of essential fatty acids, vitamins, flavonoids, phenolic compounds, proteins, and

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carbohydrates, all of which contribute to their nutritional and therapeutic value. The prevention and management of chronic diseases such as cancer, diabetes, inflammatory and cardiovascular diseases have been linked to these bioactive constituents [7,8]. Therefore, interest in studying plant species as functional foods and sources of bioactive compounds to improve human health and nutrition is increasing.

Dennettia tripetala Baker f., a native spice plant from West Africa commonly known as pepper fruit, is primarily distributed in Nigeria. Local communities widely value it for its unique pungent flavor and medicinal properties, and the Yoruba ethnic group in southwestern Nigeria calls it Ata Igbere [9]. According to ethnobotanical surveys, its fruits, seeds, bark, leaves, and roots can be used to treat a variety of conditions, such as microbial infections, hyperglycemia, toothache, nausea, fever, cough, and inflammation [9–12]. The leaves of this plant are added to herbal preparations for their medicinal properties, while its seeds are widely consumed for their unique flavor and are often dried and stored to extend their shelf life [13]. The plant has been reported to be nutritionally important, with significant levels of protein, dietary fiber, carbohydrates, lipids, and minerals [14]. Its edible parts contain antioxidant vitamins such as A, C, and E [9,15,16]. Bioactive constituents such as alkaloids, saponins, tannins, flavonoids, terpenoids, steroids, phenolic compounds, and cardiac glycosides have been identified as active phytochemicals. These components are associated with several pharmacological activities, such as antimicrobial, antidiabetic, antioxidant, antihypertensive, anti-inflammatory, and analgesic effects [9–12,15].

Considerable research has been conducted on the fruits and seeds of this species, but studies on its leaves remain limited. Reports show that the chemical composition of the leaves is comparable to that of the other parts of the species, and the leaves have prominent antioxidant and antimicrobial activities [17]. This suggests that the leaves may be an underappreciated source of pharmacologically and nutritionally important compounds.

According to the literature on *D. tripetala*, studies deal with specific plant parts, especially the fruits and seeds due to their economic significance and general consumption, while little or no attention is given to comparing the seeds and leaves. Moreover, there is inadequate information on the bioactive compounds and nutrient distribution between these plant organs, which are ethnomedicinally important. The accumulation of nutrients and secondary metabolites is likely to differ, since different plant tissues perform unique physiological processes. This may influence their nutraceutical potential. Therefore, comparative evaluation of leaves and seeds is important for identifying the plant part with the greatest potential for specific food, phytopharmaceutical, and nutraceutical applications. This information will promote sustainable use of the plant resource and may encourage the use of leaves, which are underutilized despite their reported medicinal value.

The novelty of this study is the adoption of a unified analytical framework to simultaneously assess the nutritional composition and phytochemical characteristics of the seeds and leaves of *D. tripetala.* This method can clarify the abundance and distribution patterns of the components found in this species, and the data generated from this work can support the screening of the optimal plant part for use in the nutritional, pharmaceutical, and industrial sectors. Therefore, this study aimed to comparatively evaluate the nutritional composition and phytochemical profiles of the seeds and leaves of *D. tripetala* in order to support their potential applications in food science, pharmacology, and herbal medicine.

2. Materials and Methods

2.1. Materials/Apparatus

The laboratory apparatus/glassware used were a conical flask, magnetic stirrer, measuring cylinders, beakers, ceramic crucibles, analytical balance, Whatman No. 1 filter paper, hot air oven, and electric furnace. Deionized water was used throughout the experiment. All chemicals were obtained from Sigma-Aldrich (USA), while sodium hydroxide (NaOH, $\geq$97% purity) was purchased from Merck (Germany). All chemicals were of analytical grade and used without further purification.

2.1.1. Sample Collection and Preparation

Dennettia tripetala leaves and fruits (Figure 1) were collected from farmland in Ondo town, Ondo State, Nigeria.

Permission was obtained from the farm owner before sample collection. The collection and use of the plant material were conducted in accordance with local regulations and institutional guidelines. Mr. Komolafe O.D. (Organic and Natural Product Chemist) of the Federal Polytechnic, Ado-Ekiti, taxonomically identified and authenticated the plant material. Voucher specimens were prepared and deposited in the Department of Agricultural Technology, School of Agriculture and Agricultural Technology, The Federal Polytechnic, Ado-Ekiti, for future reference. The seeds were manually separated from the fruits. The leaves and seeds were washed thoroughly with

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clean water, sun-dried, and subsequently air-dried at room temperature until a constant weight was obtained. The dried samples were milled separately into a fine powder using an electric blender and stored in airtight containers until required for analysis. For all analyses, sufficient quantities of the powdered samples were prepared. One hundred grams each of dried leaf and seed powders were obtained and used for the various nutritional, mineral, and phytochemical analyses (Figure 2).

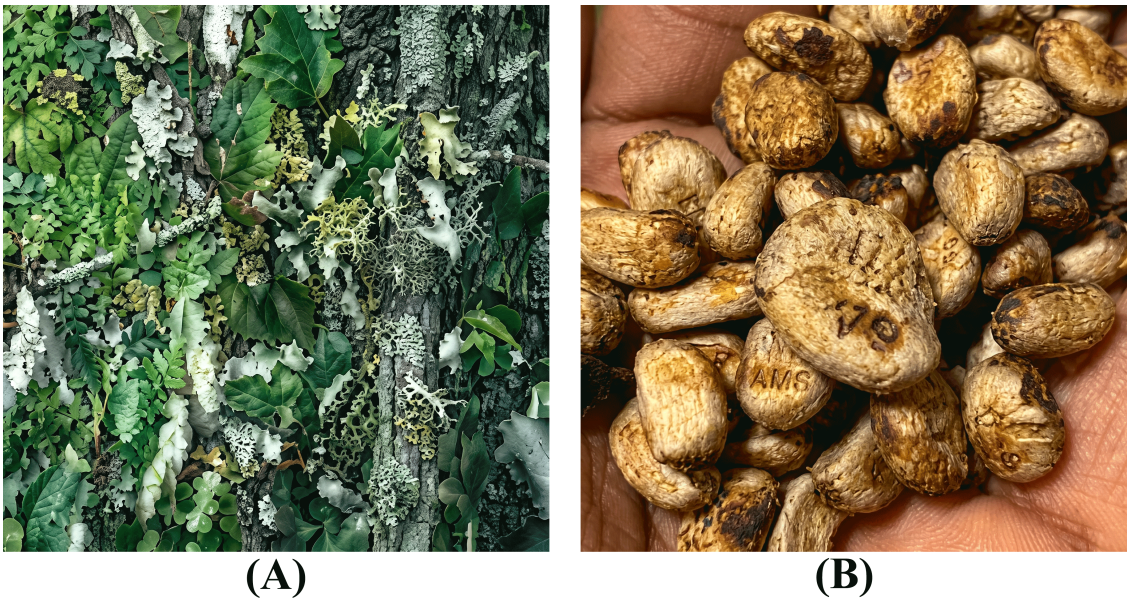

Figure 1: Image of *Dennettia tripetala* (**A**) plant showing the leaves, and (**B**) seeds.

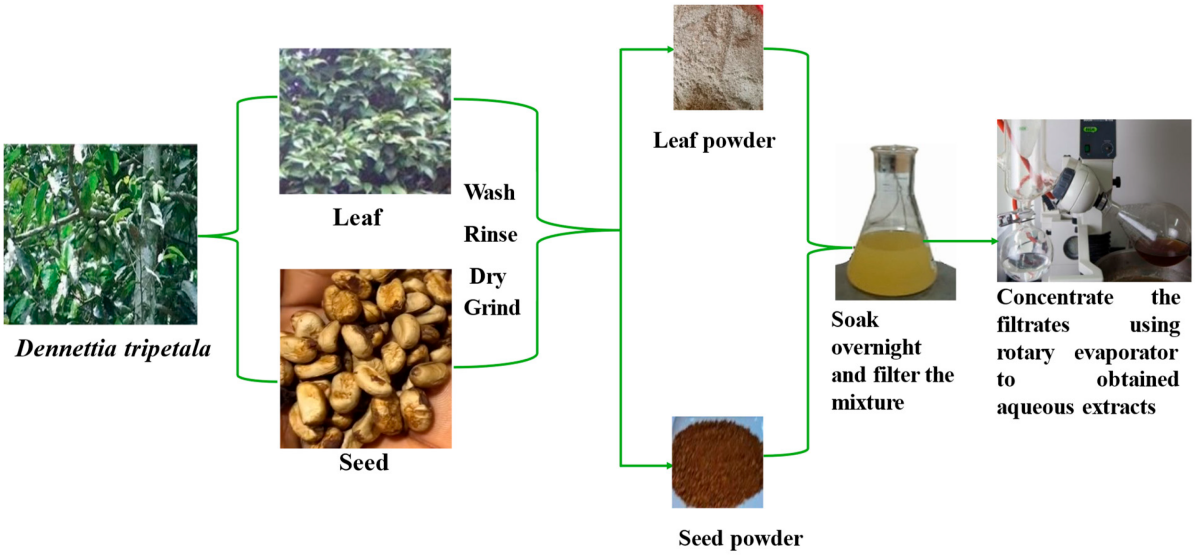

Figure 2: Flow chart for the preparation of the samples for proximate, mineral, and phytochemical analysis.

2.1.2. Determination of Proximate Composition

The proximate parameters, such as ash, moisture, fiber, fat, and protein, of the samples were evaluated following the procedure described by AOAC [18]. Carbohydrate was calculated by difference. All determinations were carried out in triplicate, and results were expressed as mean values.

Determination of Moisture Content: **2 g** of each powdered sample was weighed into a previously dried and weighed moisture dish (W1). The dish containing the sample was weighed (W2) and dried in a thermostatically controlled oven at 105 °C for 3 h. The dish was cooled in a desiccator and reweighed (W3). Drying, cooling, and weighing were repeated until a constant weight was obtained. Moisture content was calculated as:

$$\%\ Moisture = \frac{W2 - W3}{W2 - W1} \times 100 \quad (1)$$

w1 = weight of empty dish
w2 = weight of empty dish + sample
w3 = weight of empty dish + sample after drying

Determination of Ash content: A silica crucible was heated to 350 °C in a muffle furnace for approximately fifteen minutes. After being taken out and allowed to cool for approximately an hour in a desiccator, the crucible was weighed (W1). 2 g of each powdered sample was weighed into a pre-weighed silica crucible (W2). After the crucible was placed in the muffle furnace, the temperature was gradually increased from 200 to 450 °C. After being removed from the furnace and placed in a desiccator, the crucible was left to cool. The crucible and its contents were reweighed (W3) [19]. The ash content was calculated as:

$$\%\ Ash = \frac{W3 - W1}{W2 - W1} \times 100 \quad (2)$$

w1 = weight of empty crucible
w2 = weight of empty crucible + sample
w3 = weight of empty crucible + sample after ashing

Determination of Protein content: Kjeldahl flasks were filled with 1 g of powdered sample each. As a standard blank, tyrosine was weighed into a different Kjeldahl flask. As a catalyst, a mixture of potassium sulfate and copper sulfate (K_2SO_4 and $CuSO_4{\cdot}5H_2O$, 10:150) was added to the samples. A few anti-bumping granules were added to the solutions to prevent bumping of the flask by the acid. The samples were digested by adding 10 mL of concentrated H_2SO_4. The digestion flasks were kept in the digester at 400 °C until the samples became clear.

In order to capture the ammonia vapor from the digest, 15 mL of boric acid (H_3BO_3) was placed in a 200 mL conical flask, which served as the receiving flask. Two drops of a mixed indicator (methylene + methyl red) were added to the boric acid, and 10 mL of digested sample was combined with 10 mL of distilled water in a digestion flask. The conical flask and the Kjeldahl flask were then placed in the nitrogen/protein determinator, and the Kjeldahl flask was filled with NaOH until the color changed. The sample was then steamed and distilled into the conical flask. The distillate was titrated with 0.05 M HCl. The nitrogen content was calculated as follows:

$$\%\ Nitrogen = \frac{(V2-V1)\times C\ \times 0.0140\ \times V}{W \times Vo} \times 100 \quad (3)$$

V1—blank volume
V2—sample volume
C—molarity of acid
V—digested solution volume (mL)
W—sample weight
Vo—volume of distillate (mL)

$$\text{Crude protein} = \%\text{Nitrogen} \times \text{Conversion factor}\ (6.25) \quad (4)$$

Determination of Crude fiber: 2 g of the dried sample was digested with 200 mL of 1.25% sulfuric acid solution under reflux for 30 min. The mixture was filtered and washed thoroughly with distilled water. The residue was then digested with 200 mL of 1.25% sodium hydroxide solution under reflux for 30 min, filtered, and washed repeatedly with distilled water until neutral. The resulting residue was transferred into a pre-weighed crucible (W1), dried in an oven at 105 °C to constant weight, and weighed (W2). The crucible was subsequently ashed in a muffle furnace at 500 °C for 30 min, cooled in a desiccator, and reweighed (W3). The crude fiber content was calculated as:

$$\%\ Crude\ fiber = \frac{W2 - W3}{W2 - W1} \times 100 \quad (5)$$

w1 = weight of empty crucible
w2 = weight of empty crucible + sample after drying
w3 = weight of empty crucible + sample after ashing

Determination of Crude fat: 2 g of the sample was weighed and wrapped in a weighed filter paper. A round-bottom flask was filled to 2/3 of its mark with n-hexane. The Soxhlet extractor was fitted with a reflux condenser. It was heated using a heating mantle at a temperature of 40–60 °C for 6 h and removed. The residue was transferred to the oven and dried for 1 h. It was then transferred to a desiccator and allowed to cool. The residue was weighed, and the fat content was calculated as follows:

$$\%\ Crude\ fat = \frac{Weight\ of\ residue}{Weight\ of\ sample} \times 100 \quad (6)$$

Determination of Carbohydrate content: It was calculated as:

$$\%\ carbohydrate = 100 - (\%\ moisture + \%\ protein + \%\ fat + \%\ fiber + \%\ ash) \quad (7)$$

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2.2. Mineral Analysis

Five grams of each sample were weighed into separate crucibles and heated to 550 °C for six hours in a muffle furnace until completely ashed. The ashing temperature of 550 °C was selected in accordance with standard procedures for plant mineral analysis to ensure complete oxidation of organic matter while minimizing volatilization losses of major mineral elements. The ash was dissolved in 15 mL of aqua regia (a mixture of nitric acid and hydrochloric acid in a ratio of 1:3) in a 100 mL conical flask and allowed to stand for 30 min. The solutions were later heated vigorously for 30 min, cooled, filtered, and made up to 50 mL with distilled water in a volumetric flask, poured into sample bottles, and labeled. Atomic absorption spectrophotometers (AAS) (Buck Scientific, East Norwalk, Connecticut (CT), USA; AAS Model 211 VGP) and Jenway Digital Flame Photometers (PFP7 Model; Bibby Scientific Ltd., Stone, Staffordshire, United Kingdom) were used to measure the mineral concentrations of the digested samples. All experimental analyses were conducted in triplicate, and the mean values were calculated.

2.3. Determination of Phytochemicals

A conical flask was filled with 100 mL of distilled water, 10 g of each powder, and cotton wool plugs. The samples were shaken periodically while being allowed to stand at room temperature overnight. Whatman No. 1 filter paper was used to filter each sample, and a rotary evaporator (Model: RE2000B) was used to concentrate the filtrates (Figure 3). This flowchart illustrates the procedure used for the preparation of the extracts.

Phytochemical screening of the extracts was performed using the procedure adopted by Olorunoje et al. [20], with slight modifications. Three independent samples of each extract (leaves and seeds) were tested under identical conditions.

Test for Alkaloids: 3 drops of Wagner's reagent were added to a portion of the extract. The appearance of a reddish-brown precipitate indicated the presence of alkaloids.

Test for Saponin: 2 mL of the extract was mixed with 6 mL of distilled water in a test tube and shaken vigorously. The formation of a stable, tenacious froth indicates the presence of saponins.

Tannin: A 10% alcoholic FeCl3 solution was treated with 2 mL of extract. The development of a greenish or blue coloration indicated the presence of tannins.

Phlobatannin: The existence of phlobatannins was demonstrated by the red precipitate that formed when 5 mL of extract was heated with 5 mL of 1% hydrochloric acid.

Anthraquinone: 5 mL of benzene was used to dissolve 1 mL of extract, which was then filtered. The filtrate was mixed with 5 mL of a 10% ammonium solution. A pink or red color in the lower ammonia phase indicates the presence of free hydroxyl anthraquinones.

Flavonoid: To 1 mL of the filtrate, a few drops of 20% NaOH solution were added. The suspension was observed for yellow coloration that turned colorless upon the addition of excess dilute HCl, indicating the presence of flavonoids.

Steroid: Acetic acid (2 mL) was added to 0.5 mL of extract, after which 2 mL of concentrated H_2SO_4 was added. A color change from violet to blue indicates the presence of steroids.

Cardiac Glycosides: 0.5 g of extract was dissolved in 2 mL of glacial acetic acid, and 1 mL of ferric chloride was added. Formation of a reddish-brown coloration at the interface was taken as evidence for the presence of cardenolides.

Terpenoid: After mixing about 4 mL of extract with 2 mL of chloroform, 3 mL of concentrated H_2SO_4 was carefully added to the mixture to create a thin layer. Terpenoids are indicated by a reddish-brown color at the interface.

Reducing Sugar: 5 drops of Fehling's solution and 1 mL of water were added to 0.5 mL of extract. The mixture was boiled for five minutes and observed for the formation of a brick-red precipitate indicating the presence of reducing sugar.

3. Results and Discussion

The proximate analysis results (Table 1) indicate differences in macronutrient composition between the seeds and leaves. As seen in Figure 4, the leaves are numerically higher than protein (15.21%), ash (5.17%), fat (7.65%), and crude fiber (9.18%) than the seeds (protein: 12.85%; ash: 4.84%; fat: 4.52%; crude fiber: 8.31%). In contrast, compared with the leaves (51.66%), the seeds have a numerically higher carbohydrate content (58.71%). This pattern is consistent with the widespread knowledge that seeds are frequently used as reproductive structures that are carbohydrate-rich and energy-dense [21,22]. The moisture content of both seeds and leaves was low at 10.77% and 11.13%, respectively. These values suggest storage stability and are similar to those reported in some tropical medicinal plants such as *Aframomum melegueta* (10.30%), *Monodora myristica* (12.6%), *Piper guineense* (10.9%), *Syzygium aromaticum* (8.61%), and *Xylopia aethiopica* (9.54%), which similarly exhibited relatively low moisture contents that favor prolonged storage [12,23].

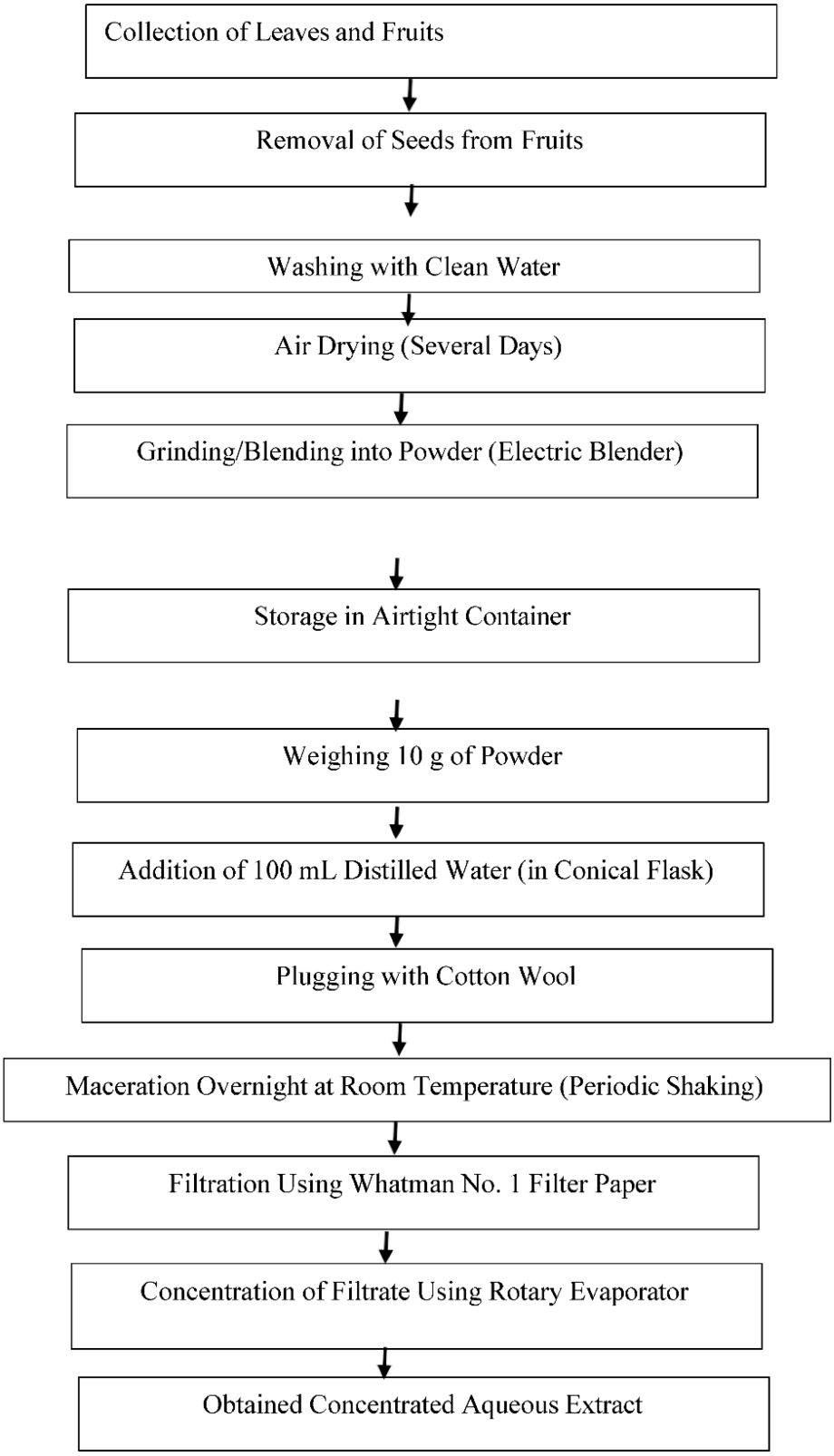

Figure 3: Flow chart for the preparation of the extracts.

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Table 1: Results of proximate analysis of the seeds and leaves of *D. tripetala*.

Sample	Moisture (%)	Ash (%)	Fat (%)	Crude Fiber (%)	Protein (%)	Carbohydrate (%)
Seed	10.77 ± 0.12	4.84 ± 0.05	4.52 ± 0.07	8.31 ± 0.08	12.85 ± 0.09	58.71 ± 0.15
Leaf	11.13 ± 0.10	5.17 ± 0.06	7.65 ± 0.08	9.18 ± 0.07	15.21 ± 0.10	51.66 ± 0.12

Values are presented as mean ± standard deviation (SD) of three replicates.

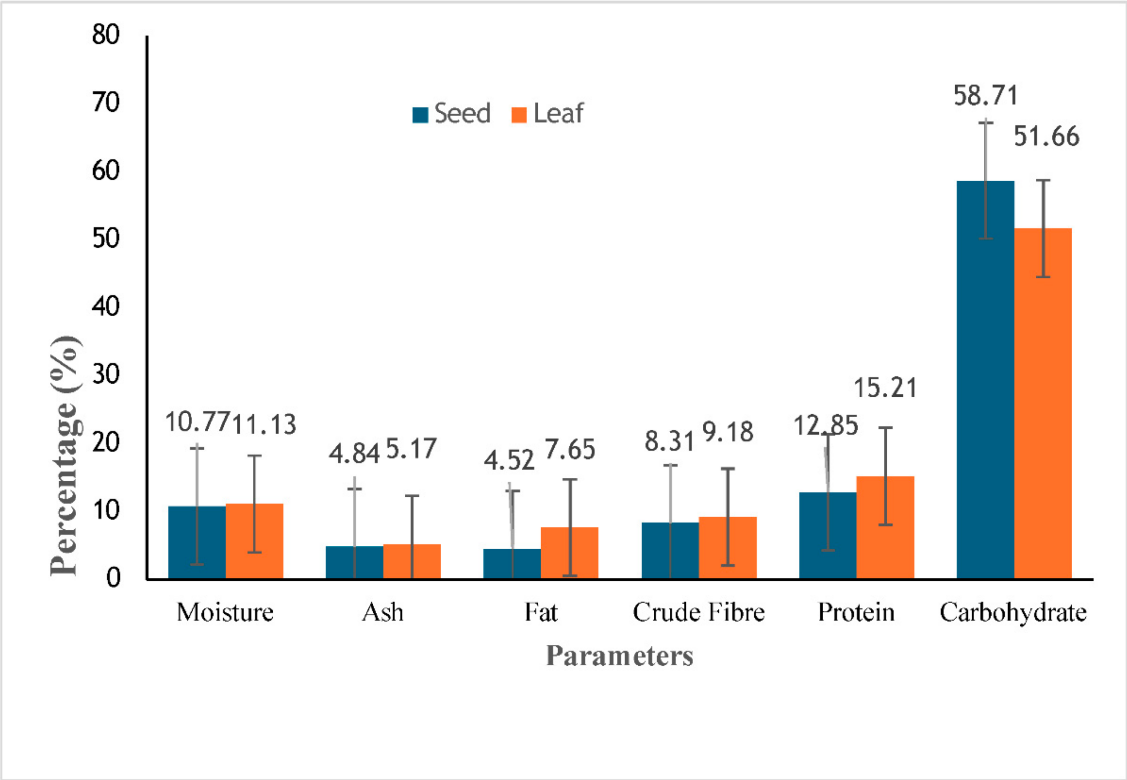

Figure 4: Results of proximate analysis of the seeds and leaves of *D. tripetala*.

D. tripetala leaves had a higher protein content of 15.21% compared with 12.85% in seeds. The leaves contain dietary proteins required for cellular processes, including tissue repair and growth. However, some green vegetables and spices in Nigeria have higher protein values [24,25]. A higher crude protein content of 17.55% has been reported for the leaves of *Piper guineense*; however, lower protein contents of 11.70% and 8.73% have been reported for the leaves of *Manihot esculenta* and *Piper nigrum*, respectively [24,25], indicating that the protein content of *D. tripetala* leaves compares favorably with many tropical medicinal plants. Protein content is also related to antioxidant activity in medicinal plants according to previous literature [26].

The significant fat content of the leaves (7.65%) may add to their energy content and provide vital fatty acids [12]. Table 1 and Figure 4 show that the crude fiber contents of the seeds (8.31%) and leaves (9.18%) suggest their potential contribution to digestive health. Dietary fiber has been associated with improved bowel function, glycemic control, and the prevention of colorectal diseases [27,28]. The proven nutritional value of agricultural products high in fiber further supports the functional dietary potential of plant materials [20,29].

Given their biological significance in plant reproduction and early seedling growth, the seeds' high carbohydrate content suggests they are a significant energy source [12,30]. Ash concentration, which indicates total mineral content, is higher in leaves (5.17%) than in seeds (4.84%), suggesting a richer mineral profile in the foliage [12]. Mineral-rich plant components are often prioritized in nutraceutical development because of their micronutrient density [12]. This result aligns with more thorough phytochemical screening studies showing the range of minerals and secondary metabolites present in parts of medicinal plants [26].

Table 2 shows the elemental composition of *D. tripetala* seeds and leaves. Such an elemental profile is required to understand the quality and potential health benefits of plant-based foods [31,32].

Table 2: Results of mineral composition of the seeds and leaves of *D. tripetala*.

Sample	Na (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)
Leaf	81.65 ± 1.25	190.65 ± 2.10	415.60 ± 3.00	33.53 ± 0.80	0.88 ± 0.02	0.33 ± 0.01	1.78 ± 0.05
Seed	102.55 ± 1.50	116.65 ± 1.80	362.40 ± 2.50	28.29 ± 0.70	0.55 ± 0.01	0.51 ± 0.02	1.25 ± 0.04

Values are presented as mean ± standard deviation (SD) of three replicates. Na = sodium; Ca = calcium; K = potassium; Mg = magnesium; Fe = iron; Cu = copper; Zn = zinc.

Compared with the seeds, the leaves have higher concentrations of calcium (Ca), potassium (K), and magnesium (Mg). In particular, seeds have 116.65 ppm Ca, 362.40 ppm K, and 28.29 ppm Mg, while leaves have 190.65 ppm Ca, 415.60 ppm K, and 33.53 ppm Mg (Figure 5). Since calcium is essential for bone health and other metabolic processes, the higher calcium concentration in the leaves is especially noteworthy [33,34]. Numerous underused leafy greens are acknowledged as essential providers of mineral nutrients that address dietary inadequacies, particularly in areas with limited access to a variety of food sources [35]. High potassium is beneficial in maintaining electrolyte balance and blood pressure homeostasis [12]. As seen in Table 2, the potassium level in the leaves (415.60 ppm) is higher than that in the seeds (362.40 ppm). Phytochemical and antioxidant studies of medicinal plants also show the synergistic effect of bioactive compounds and trace minerals in therapeutic efficacy [26].

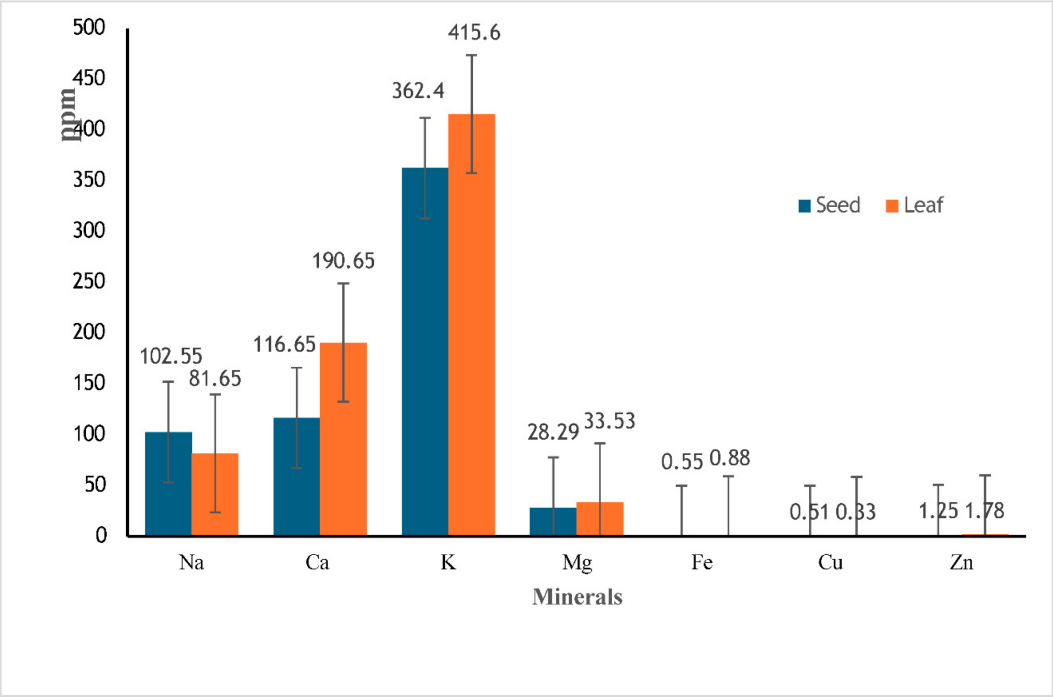

Figure 5: Results of the mineral analysis of the seeds and leaves of *D. tripetala*.

Moreover, the concentrations of sodium (Na) and copper (Cu) are higher in the seeds (102.55 ppm and 0.51 ppm) than in the leaves (81.65 ppm and 0.33 ppm), respectively. However, zinc (Zn) and iron (Fe) are slightly higher in the leaves than in the seeds (Table 2). Iron, zinc, and copper are important trace minerals that enhance immunological function, enzyme activity, and oxygen transport apart from their nutritional value [32]. Olorunoje et al. [29] stated that plant materials rich in minerals may be strategically investigated for the development of func-

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tional foods and nutraceutical applications. Therefore, *D. tripetala* is a potential source of micronutrients due to the appreciable minerals present. Calcium, potassium, magnesium, iron, zinc, and copper are present, which suggests that they could be used in phytopharmaceutical preparations, mineral fortification formulations, and dietary supplements to address micronutrient deficiencies and improve general metabolic health.

Table 3 shows the bioactive components present in *D. tripetala* seeds and leaves. Alkaloids, tannins, cardiac glycosides, flavonoids, and terpenoids are present in both seeds and leaves (Table 3). However, reducing sugars are found only in the leaves, while saponins, steroids, and anthraquinones are found only in the seeds. Interestingly, neither the seeds nor the leaves contain phlobotannins.

Table 3: Results of phytochemical screening of the seeds and leaves of *D. tripetala*.

Parameters	Seed	Leaf
Alkaloid	Present	Present
Saponins	Present	Absent
Tannins	Present	Present
Phlobotannins	Absent	Absent
Anthraquinones	Present	Absent
Cardiac glycosides	Present	Present
Flavonoids	Present	Present
Terpenoids	Present	Present
Reducing sugar	Absent	Present
Steroid	Present	Absent

The shared presence of flavonoids, terpenoids and alkaloids in both leaves and seeds points to their potential broad pharmacological activities, including anti-inflammatory, antimicrobial and antioxidant properties [11,36,37]. For instance, flavonoids are widely known for their potent antioxidant capacity, which helps fight oxidative stress linked to a number of chronic illnesses [10, 38]. Flavonoid-rich extracts frequently show substantial free-radical-scavenging capacity, according to recent antioxidant screening of medicinal plants [26]. Additionally, terpenoids have a variety of biological activities, such as anti-malarial and anti-cancer effects [39]. *D. tripetala* seeds contain saponins, which are absent in the leaves. In addition to their well-known detergent-like properties, saponins have been associated with immune-modulating and cholesterol-lowering actions [40,41].

Also, anthraquinones are only present in the seeds. Anthraquinones are well known for their laxative and antibacterial qualities [42]. On the other hand, the discovery of steroids in the seeds and reducing sugars in the leaves suggests distinct metabolic pathways and potential applications. Steroids have been reported to have anti-inflammatory or hormonal effects [43]. The disparity in the phytochemicals and nutritional values in the various plant parts observed in this study suggests that *D. tripetala* seeds can serve as a source of therapeutic agents and as ingredients in functional foods, while the leaves can be used as nutraceutical supplements and phytomedicines.

4. Conclusions

This study showed that plant organs have unique nutrient and bioactive profiles, indicating the potential value of the seeds and leaves. Higher levels of protein and some mineral elements, such as K, Ca, Mg, and Fe, in the leaves indicate their greater potential as dietary nutrient sources. In contrast, carbohydrate content is higher in the seeds, alongside the presence of various bioactive constituents. The phytochemicals and nutrients in these plant organs may be useful in food, nutraceutical, and phytopharmaceutical applications. Therefore, strategic utilization of plant parts for specific health interventions should be explored. Further investigation into quantifying and characterizing the bioactive compounds for specific therapeutic applications is required.

List of Abbreviations

AAS	Atomic Absorption Spectrophotometer
AOAC	Association of Official Analytical Chemists
ppm	parts per million
W1, W2, W3	Weight measurements at different stages
°C	Degrees Celsius

Author Contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing—

original draft preparation, writing—review & editing, visualization, project administration, supervision: J.G.; Investigation, resources, data curation, writing—review & editing, visualization, supervision: M.K and H.A. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

The datasets generated or analyzed during this study are available from the corresponding author upon reasonable request.

Ethics Committee Approval

This study did not involve human participants or animal subjects. Plant material was collected with the permission of the farm owner, in accordance with local regulations and institutional guidelines.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

The study did not receive any external funding and was conducted using only institutional resources.

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AI Declaration

Bohrium AI-based tool (version not specified by the provider) was used solely for language editing and formatting. No AI tool was used to generate or paraphrase the scientific content of the manuscript. The authors take full responsibility for the accuracy, originality, and integrity of the work.

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