PROXIMATE AND MINERAL COMPOSITIONS OF *Thaumatococcus danielli* (BENTH) LEAF WASTE COLLECTED IN BENIN CITY, NIGERIA

BY

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DEPARTMENT OF ANIMAL SCIENCE

FACULTY OF AGRICULTURE

UNIVERSITY OF BENIN

NOVEMBER, 2025

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF ANIMAL SCIENCE,

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IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR BACHELOR OF AGRICULTURE (B. AGRIC) DEGREE IN ANIMAL SCIENCE

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CERTIFICATION

This is to certify that this project named "**Proximate and mineral compositions of** *Thaumatococcus danielli* **leaf wastes collected in Benin City, Nigeria**" was carried out by Glory Osawonamen Osunde with matriculation number AGR2010629 under the supervision of the project supervisor approved by the Department of Animal Science, Faculty of Agriculture, University of Benin, Benin City, Nigeria.

____________________ _________________

Dr. O.W. Agbonghae Date

(Project Supervisor)

____________________ _________________

Dr. N.C Akaeze Date

(Head of Department)

DEDICATION

This Project work is dedicated to the Almighty God, for His provisions, grace and favour. He has been my source of wisdom, knowledge and understanding. Thanks be to God for His strength and never ending love throughout the course of this Research and Study.

I also dedicate this project to my lovely husband, parents, wonderful siblings and friends who encouraged me all the way. Their encouragement, prayers and support have kept me going throughout this journey. May the blessings of the Lord be with them now and always.

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ABSTRACT

Thaumatococcus daniellii, commonly known as the miracle plant or sweet prayer plant, is widely used in Nigeria for wrapping traditional foods such as rice, *moi-moi* and *agidi*, leading to the generation of substantial leaf waste. The discarded leaves, if properly analysed for nutrient could serve as a potential resource for animal feed formulation, organic fertilizer, or biodegradable packaging materials. Therefore this study aimed to investigate the proximate and mineral composition of *Thaumatococcus daniellii* leaf wastes collected from rice and *moi-moi* wrapping in Benin City, Nigeria. Fresh leaf wastes were collected, air-dried, milled, and analyzed for proximate and mineral compositions using standard analytical procedures. The proximate analysis revealed appreciable levels of crude protein (18-23%), crude fibre (21-26%), and carbohydrate (28-34%), with moderate lipid and ash contents (6.67-6.83%). The mineral analysis showed significant amounts of essential nutrients such as Calcium (3.313_4.168mg/kg), Potassium (0.129_0.008 mg/kg), magnesium (1.737_0.019 mg/kg), phosphorus (2.263_0.147 mg/kg) and iron (0.270_0.215 mg/kg). These findings indicate that the leaf wastes from rice and *moi-moi* wrapping are rich in proximate and mineral nutrients that can support both nutritional application for livestock. The study concludes that *Thaumatococcus daniellii* leaf wastes, often considered agricultural waste could be explored as an alternative raw material in feed production. This would not only promote environmental sustainability but also enhance economic value through waste resource utilization.

CHAPTER ONE

1.0 INTRODUCTION

Livestock production in developing countries faces persistent challenges related to feed scarcity and escalating feed costs, which constrain animal growth and profitability (Isiaka *et al*., 2023). In Nigeria, the feed sector relies heavily on conventional ingredients such as maize, wheat offal, groundnut cake, and soybean meal, whose high and fluctuating prices increase the cost of animal production (Molina-Flores *et al*., 2020; Agbonghae and Nwokoro, 2023; Obayelu, 2023). Consequently, livestock nutritionists and researchers are increasingly seeking alternative feed resources derived from non-conventional and agro-industrial by-products. These materials, often regarded as waste, can serve as cost-effective and sustainable substitutes if their nutritional potentials are properly characterized. Such evaluations support circular bioeconomy goals through waste minimization, nutrient recycling, and sustainable livestock production (Kazemi, 2025; McAllister *et al*., 2025; Shah *et al*., 2025).

Among the various agro-wastes generated in Nigeria, *Thaumatococcus daniellii* (Benn.) Benth., commonly known as the sweet prayer plant, has considerable potential. This monocotyledonous member of the Marantaceae family, native to the tropical rainforests of West and Central Africa, is widely distributed in southern Nigeria, including Benin

City and its environs (Fadahunsi *et al*., 2021; Agha *et al*., 2022). The plant is primarily valued for producing thaumatin, a natural sweet-tasting protein extracted from its aril, which has gained commercial importance as a low-calorie sweetener (Iwueke *et al*., 2020; Agha *et al*., 2022). Its leaves are traditionally used as natural wrapping materials for foods such as rice, *moi-moi*, and *agidi* because of their aroma, strength, and antimicrobial properties (Ifunanya *et al*., 2024). However, after use, large quantities of these leaves are discarded as waste, contributing to environmental littering in Benin City, Nigeria.

Despite their frequent disposal, *T. daniellii* leaves contain appreciable nutritional and mineral constituents that could be harnessed as feed ingredients. Reports have indicated that the leaves contain 10–18% crude protein, 20–30% crude fibre, and 8–12% ash, along with significant levels of calcium, potassium, magnesium, iron, and phosphorus (Oforibika *et al*., 2017; Fadahunsi *et al*., 2021; Agha *et al*., 2022). These attributes suggest that *T. daniellii* leaf waste (TDLW) may serve as a supplementary or partial replacement for conventional fibre sources in rabbit and ruminant diets. Furthermore, the presence of bioactive phytochemicals such as flavonoids, tannins, and phenolics provides antioxidant and antimicrobial potentials that could enhance animal health when included in diets at appropriate levels (Igbayilola *et al*., 2021; Ifunanya *et al*., 2024).

1.1 JUSTIFICATION OF STUDY

Nutritional evaluation of any new feed resource requires a detailed understanding of its proximate and mineral composition, which provides the foundation for diet formulation and subsequent feeding trials. Proximate analysis determines the relative proportions of moisture, crude protein, ether extract, ash, crude fibre, and nitrogen-free extract, which are key indicators of nutrient availability (AOAC, 2016). Mineral analysis offers insight into macro- and micro-element contents critical for maintaining animal health, growth, and metabolism (Palai *et al*., 2025). Although several studies have reported the proximate composition of *T. daniellii* leaves, little is known about the composition of *T. daniellii* leaf waste obtained after its use as a wrapping material for rice and *moi-moi*. Post-use conditions such as heat exposure, microbial activity, or desiccation could alter its nutrient profile; therefore, a context-specific compositional assessment is necessary before recommending its use in animal feed formulations.

1.2 OBJECTIVE OF STUDY

The broad objective of this study was to evaluate the proximate and mineral compositions of *Thamatococcus danielli* leave waste obtained from Benin City, Edo State, Nigeria. The specific objectives were to;

1. to determine the proximate composition of *T. danielli* leaf waste from rice and *moi-moi* packaging in Benin City, Nigeria and

2. to determine the mineral composition of *T. danielli* leaf waste from rice and *moi-moi* packaging in Benin City, Nigeria.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany and Functional Context of *Thaumatococcus danielli*

Thaumatococcus daniellii (Benn.) Benth, known as“katempe”or“katemfe”. It belongs to the Marantaceae family. It grows in humid tropical forests and the coastal areas of West Africa, especially in Nigeria, Ghana, Central African Republic, Uganda, and Cote d'Ivoire. It is also one of the species introduced in Australia and Singapore. This plant is one of the perennial herbaceous monocotyledonous plants. It spreads through the roots (rhizomes) and grows underground in the forest, its natural habitat (Adeogun *et al.,* 2016; Fadahunsi *et al.,* 2021). The plant grows along a slender stalk to a height of 3-4 meters with oval-shaped leaves of different sizes up to 46 cm long depending on the stage of plant growth and the place of growth (in forests or agricultural areas) (Osuocha *et al.,* 2018).

Thaumatococcus daniellii (Benth) is a perennial plant native to West Africa, is widely recognized for its large leaves traditionally used as natural food wraps. After their primary use, these leaves often become “leaf wastes,” yet they retain substantial nutritional value. Recent studies have focused on evaluating the nutrient composition of these wastes, highlighting their potential for reuse in food, pharmaceutical, and industrial applications (Nwodo-Chinedu *et al.,* 2014).

Different parts of *Thaumatococcus daniellii* have been widely utilized in traditional and folkloric medicine for the management of various ailments. In the Democratic Republic of the Congo, the roots and fruits are reportedly administered to women in labor experiencing dystocia and childbirth complications. The seeds and leaf saps have been employed as emetic agents in the treatment of lung diseases, and also serve as antidotes against bee stings, snake bites, and other venoms. Additionally, the fruits and pulps are used as laxatives and in child weaning practices (Adeyemi *et al.,* 2014; Shalom *et al.,* 2014). Leaf and root saps have also been documented as tranquilizing agents for the management of mental and psychiatric disorders (Shalom *et al.,* 2014). Ethnobotanical surveys further highlight the plant's folkloric application in the regulation of high blood sugar and diabetes-related conditions (Olorunnisola *et al.,* 2016).

The leaves of *Thaumatococcus daniellii* are widely utilized in West Africa are locally used as food wrappers particularly in Ghana and Nigeria, where they serve as natural wrapping materials for traditional dishes such as cooked rice and *moi-moi* (steamed bean pudding). This practice not only imparts a distinctive flavor but also enhances the aroma and overall palatability of the food (Thorn, 2004). Beyond its culinary role in Africa, the plant has attracted global attention due to its exotic and flavor-enhancing properties, leading to its adoption in some parts of North and South America (Thorn, 2004). Studies have also reported that the leaves are durable, heat-resistant, and biodegradable, making them a sustainable alternative to synthetic packaging materials such as nylon (Abbiw, 1990; Aworh, 2015). Furthermore, their use in food wrapping contributes to the extension of shelf life by preventing contamination and moisture loss. These attributes highlight the significance of *Thaumatococcus daniellii* not only as a culinary resource but also as a material with potential applications in environmentally friendly food packaging (Akinmoladun *et al.*, 2018).

Thaumatococcus daniellii leaf has been reported to play significant roles not only in the treatment of diseases but also as a natural food additive that enhances nutritional value. According to Hamid *et al.,* (2017), the leaf extracts contain fats, oils, terpenoids, flavonoids, steroids, and glycosides, highlighting their potential therapeutic and nutraceutical importance. Similarly, (Oke *et al.,* 2016) noted that *T. daniellii* leaves are rich in flavonoids, polyphenols, alkaloids, and saponins, which are well-recognized bioactive compounds with diverse pharmacological benefits.

Classification of *Thaumatococcus daniellii.*

Level of classification	**Name**
Kingdom	Plantae- plant
Sub-kingdom	*Tacheobionta* – vascular plants
Superdivision	*Spermatophyte* – seeds plants
Division	*Magnoliophyta* – flowering plants
Class	*Liliopsida* – monocotyledons
Subclass.	*Zingiberidae*
Order	*Zingiberales*
Family	*Marantaceae* - prayer-plant family
Genus	*Thaumatoccocus benth -thaumatococcus*
Species	*daniellii (benn.) benth. - miracle fruit*

2.2 Proximate composition of *T. daniellii*:

Several Nigerian studies report high variability in the proximate profile of *Thaumatococcus daniellii* leaves. Protein values range from 14–20.41%, crude fibre from 13.78–36.61%, and ash content between 10.15–10.60%, suggesting that the leaves may serve as alternative protein and fibre sources (Iwueke *et al.,* 2020, Oforibika *et al.,* 2017). Lipid levels remain relatively low (≤5%), while carbohydrate content accounts for a substantial fraction (17.5–34%) of dry matter. These findings underscore the potential nutritional utility of the plant beyond its traditional role as food packaging (Adeyemi *et al.,* 2014, Oforibika *et al., 2017*).

Table 2.1 Proximate Composition of *Thaumatococcus danielli* leaf

Parameter Concentration	*Thaumatococcus danielli* leaf	References
Protein (%)	20.41±0.14	(Iweke *et al.,* 2020)
	14.88	(Oforibika *et al.,* 2017)
Crude fibre (%)	13.78±0.11	(Iweke *et al.,* 2020)
	36.61	(Oforibika *et al.,* 2017)
Ash (%)	10.15±0.03	(Iweke *et al.,* 2020)
	10.60	(Oforibika *et al.,* 2017)
Crude lipid (%)	11.42±0.02	(Iweke *et al.,* 2020)
	0.90	(Oforibika *et al.,* 2017)
Carbohydrate (%)	34.57±0.13	(Iweke *et al.,* 2020)
	31.25	(Oforibika *et al.,* 2017)
Moisture Content (%)	9.67±0.06	(Iweke *et al.,* 2020)
	10.39	(Oforibika *et al.,* 2017)

2.3 Mineral composition of *T. daniellii*:

Studies also demonstrate appreciable levels of calcium (~100 mg/100 g), magnesium (~80 mg/100 g), phosphorus (~370 mg/100 g), and iron (~10 mg/100 g) in the leaf matrix. Such mineral concentrations reinforce the potential role of *T. daniellii* wastes in dietary supplementation, particularly in populations vulnerable to mineral deficiencies (Iwueke *et al.,* 2020).

Table 2.2 Mineral Composition of *Thaumatococcus danielli* leaf

Parameter Concentration	*Thaumatococcus danielli* leaf	References
Calcium	6.15±0.03	(Osuocha *et al.,* 2018)
Phosphorus	5.75±0.12	(O suocha *et al.,* 2018)
Potassium	5.30±0.14	(Osuocha *et al.,* 2018)
Zinc	1.42±0.02	(Osuocha *et al.,* 2018)

2.4 Phytochemistry and Bioactive Compounds of *Thaumattococcus danielli* Leaves

Thaumatococcus daniellii leaves contain a wide range of secondary metabolites and bioactive compounds that help explain the plant's traditional uses (food-wrapping, flavoring) and the increasing scientific interest in its antioxidant, antimicrobial and pharmacological properties. Qualitative and quantitative phytochemical surveys — using solvents that range from nonpolar (hexane) to polar (methanol, water) and analytical methods from spectrophotometric assays to GC/GC–MS and HPLC — consistently report phenolic compounds, flavonoids, tannins, saponins, alkaloids, steroids and terpenoids among the dominant classes in the leaf material (Fadahunsi *et al.,* 2021; Oke *et al.,* 2016; Adeogun *et al.,* 2016).

2.4.1 Phenolics and Flavonoids: Several studies document presented total phenolic content (TPC) and total flavonoid content (TFC) in leaf extracts; polar (aqueous or methanol) fractions generally give higher TPC/TFC and stronger antioxidant activity than nonpolar fractions. Reported specific flavonoids and phenolic compounds include kaempferol, rutin, and epicatechin. These compounds are linked to free-radical scavenging and other protective activities observed in vitro and in vivo. (Fadahunsi *et al.,* 2021; Oke *et al.,* 2016).

2.4.2 Tannins and Phenol Derivatives: Tannins are frequently detected in phytochemical screens and are implicated in both antioxidant and antimicrobial properties of leaf extracts. (Oke *et al.,* 2016; Adeogun *et al.,* 2016).

2.4.3 Saponins and Glycosides: Saponins and other glycosidic constituents appear in qualitative screens and may contribute to surfactant-like and bioactive effects observed in some assays. (Ojekale *et al.,* 2007).

2.4.4 Alkaloids and Nitrogen Bases: Alkaloids (including reports of sparteine-like compounds and other nitrogenous metabolites) have been reported and may underlie some pharmacological actions, (Fadahunsi *et al.,* 2021).

2.4.5 Volatile/essential-oil components and Terpenoids: GC/GC–MS analyses of essential oil from leaves have detected volatile terpenoids and other oil components with strong free-radical scavenging and insecticidal activities in experimental assays. The leaf essential oil sometimes shows antioxidant potency comparable to or better than common synthetic antioxidants in DPPH assays. (Ojekale *et al.,* 2013; Fadahunsi *et al.,* 2021).

2.4.6 Other compounds: Reviews and compositional studies have also reported steroids, squalene, phlobatannins, anthraquinones, and antinutrients such as oxalates and phytic acid in various plant parts; concentrations vary by tissue, locality and extraction method. (Fadahunsi *et al.,* 2021; Adeogun *et al.,* 2016).

2.5 Use of *T. daniellii* leaf as food wrappers

One of the distinctive uses of *T. daniellii* leaves in West Africa is as a natural wrapper/packaging for local foods especially beans - pudding (*moi-moi*), rice parcels, steamed/stewed foods. The leaves are durable, impart aromatic flavour, provide aesthetic appeal and are biodegradable replacing synthetic wrappings (plastic foil) in many contexts. For instance, the Vanguard article (2013) noted that the plant is commonly used to wrap and boil *moi-moi* in Nigeria, because the leaves impart flavor and are preferred over other wrappers (Vanguard, 2013). Given this usage, there are two relevant implications:

2.5.1 Nutrient transfer and residue: When leaves are used to wrap food and undergo steaming/boiling, nutrients from the leaves (or those in contact with the food) may leach into the food, or conversely the leaves may absorb moisture, oil or food solubles. After the food is removed, the leaf becomes a "waste leaf", but its nutrient composition may differ from fresh unused leaves.

2.5.2 Waste leaf stream: In urban vending contexts (e.g., Benin City), many used leaves may be discarded, accumulating as waste. Understanding the nutrient composition of these leaf wastes is essential to evaluate their residual value (for compost, animal feed, fibre recovery) or disposal burden. In addition, a study on wrapping leaves for solid pap in Ibadan found that pap wrapped in *T. daniellii* leaves had better microbial stability and preserved nutrients better than certain other leaves. This shows that the leaf wrapper itself influences food quality, but less attention has been given to what remains in the leaves after use and thus the potential for resource recovery.

2.6 Benefits and Economic Importance of *Thaumatococcus daniellii*

2.6.1 Culinary Uses

One of the most prominent traditional uses of *T. daniellii* leaves is culinary. In many West African cultures, the leaves are employed as natural food wrappers. Their large size, durability, and resistance to tearing and heat make them an excellent alternative to synthetic or plastic wrapping materials for steaming, boiling, or roasting foods. Dishes wrapped in *T. daniellii* leaves are often imparted with a subtle flavor and aroma that enhances the sensory appeal (Akinmoladun *et al.,* 2019). Furthermore, their use as wrappers is considered eco-friendly and sustainable. The leaves have antibacterial properties that can help preserve food and prevent spoilage (Olayemi *et al*., 2018). They impart a mild fragrant smell appreciated in traditional cooking and as natural materials, they ensure waste reduction compared to plastic wrappings. This culinary use supports traditional food processing practices and provides rural communities with income when harvested and sold as packaging materials. (Olayemi *et al*., 2018).

2.6.2 Medicinal Uses

Thaumatococcus daniellii leaves are a rich source of bioactive compounds, such as flavonoids, tannins, saponins, and alkaloids, which contribute to their therapeutic uses. Several ethnomedicinal applications are reported (Awoyinkaj *et al.,* 2015). Leaf extracts have been used locally to treat inflammation and swellings. Decoctions from the leaves are administered to alleviate pain and fever and the leaves are applied topically for treating wounds, cuts, and skin infections, accelerating the healing process (Awoyinkaj *et al.,* 2015).

Scientific investigations confirm many of these traditional claims, thereby contributing to the validation of *T. daniellii* leaves' medicinal importance and encouraging their use in phytotherapy (Olayode *et al.,* 2020).

2.6.3 Nutritional Uses

While largely overshadowed by the sweetening properties of the fruit, the nutritional importance of *T. daniellii* leaves should not be underestimated. The leaves serve as supplementary feed for ruminants and other livestock due to their reasonable protein and mineral content (Falowo *et al.,* 2012). In some communities, dried and powdered leaves are incorporated into soups and sauces to boost dietary fiber intake. The presence of antioxidant compounds contributes to their potential as a functional food ingredient, capable of reducing oxidative stress when consumed (Adeboye *et al.,* 2021).

2.6.4 Traditional and Cultural Uses

Beyond utility, *T. daniellii* leaves have cultural and ritual significance. In some African cultures, the leaves are used during traditional ceremonies and rites, sometimes as decorations or symbolic items (Irvine, 1961). The leaves find use in household crafts, including wrapping goods for market sale and preserving perishable items, thereby supporting local economies.

2.6.5 Environmental and Agroforestry Uses

In addition to direct uses, *T. daniellii* leaves contribute to environmental health:

1. Shade Provision: The broad leaves provide shade in agroforestry systems, which is beneficial for understory crops and conservation of soil moisture (Falowo *et al.,* 2012).
2. Soil Fertility: Leaf litter contributes organic matter to forest soils, enhancing nutrient cycling and soil fertility.
3. Erosion Control: The plant's leaf canopy reduces soil erosion by intercepting rainfall and reducing surface runoff (Akinmoladun *et al.,* 2019).

2.7 Economic Importance of *Thaumatococcus daniellii* Leaf

The economic importance of the leaves can be understood through direct and indirect contributions to livelihoods, industry, and sustainability.

2.7.1 Income Generation and Livelihood Support

In rural economies of West and Central Africa, the harvesting and selling of *T. daniellii* leaves represent a vital income source:

1. Raw Material for Local Markets: The leaves are a locally traded commodity used mainly by women who harvest and sell them in markets as eco-friendly packaging materials (Olayemi *et al.*, 2018).

2. Value-Added Products: Emerging local enterprises process the leaves into dried wrapping sheets or powders for culinary and medicinal markets, increasing their economic worth.
3. Livestock Fodder: Farmers utilize the leaves as affordable fodder, reducing feed costs.

Surveys indicate that sustainable harvesting of leaves has improved rural household incomes while preserving the species (Akinmoladun *et al.,* 2019)

2.7.2 Industrial Potential

Though the industrial focus is mainly on thaumatin from fruits, the leaves show promising potential for pharmaceutical, cosmetic, and food industries:

1. Pharmaceuticals: The antimicrobial and anti-inflammatory properties of leaf extracts have spurred interest in natural product-based drugs (Ajibesin *et al.*, 2006).
2. Cosmetics: Antioxidant properties lend the leaves to the formulation of natural cosmetics and skincare products.
3. Food Industry: Leaf extracts are being explored as natural preservatives and antioxidants to extend the shelf life of food products (Adeboye *et al.*, 2021).

Investment in processing and commercialization of leaves could diversify income sources and accelerate rural industrialization.

2.7.3 Environmental Sustainability and Agroforestry

The multifunctionality of *T. daniellii* leaves integrates well with sustainable agricultural systems:

1. Agroforestry Integration: Cultivation in mixed cropping enhances biodiversity, providing economic and ecological resilience.

2. Reduction of Plastic Waste: Use of leaves as biodegradable packaging aids environmental health by reducing plastic usage (Falowo *et al.,* 2012).

3. Sustainable Harvesting Practices: Promotion of sustainable leaf harvesting supports conservation efforts while allowing continuous economic benefits (Akinmoladun *et al.*, 2019).

Such ecological services contribute to the long-term sustainability of rural economies.

2.8 Challenges and Prospects

Despite their significant uses and economic value, *T. daniellii* leaves face challenges:

1. Overharvesting Risks: Unsustainable harvesting can threaten local populations.

2. Lack of Processing Infrastructure: Limited industrial processing reduces value addition.

3. Awareness and Market Access: Poor market penetration limits earnings potential from leaf products.

Addressing these through research, policy, and investment can maximize the economic benefits of *T. danielli* leaves.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was conducted in Benin City, Edo State, Nigeria, located between latitudes 6°19′N and 6°21′N and longitudes 5°36′E and 5°44′E (Google Earth, 2025). Benin City lies within the humid tropical rainforest zone characterized by a bimodal rainfall pattern and distinct wet (April–October) and dry (November–March) seasons. The mean annual temperature ranges from 24°C to 32°C, and the average annual rainfall is approximately 2,000 mm (NAA, 2021). The area was selected because *Thaumatococcus daniellii* leaves are widely used as food wrapping materials in restaurants and food outlets within the metropolis.

3.2 Sample Collection and Experimental Design

A completely randomised design (CRD) was adopted to determine and compare the proximate and mineral composition of *Thaumatococcus daniellii* leaf waste (TDLW) with that of fresh *T. daniellii* leaves (control). Fresh leaves were purchased from the Oba Market, Benin City, Nigeria, while post-use leaf wastes were obtained from ten restaurant locations where the leaves are routinely used as food wrappers. The inclusion of fresh leaves as the control enabled assessment of compositional differences resulting from exposure to heat, moisture, and food residues during use.

Approximately 500 g of leaf waste was collected from each restaurant, while a similar quantity of fresh leaves was procured from the market. Both sample types were cleaned, oven-dried at 60°C to a constant weight, and milled into fine powder. Composite samples were prepared for each treatment (fresh leaf and leaf waste), from which representative sub-samples were drawn for laboratory analyses.

3.3. Proximate composition

Proximate composition—comprising moisture, crude protein, ether extract, crude fibre, ash, and nitrogen-free extract (NFE)—was determined using standard procedures described by the Association of Official Analytical Chemists (AOAC, 2016).

3.3.1 Moisture content

Moisture content was determined by oven-drying at 105°C to constant weight.

- A known weight (~1 g) of the powdered sample will be placed in a moisture-dish and dried in an oven at 105 ± 2 °C for 4 hours (or until constant weight).
- Moisture % = [(Initial weight – Dry weight) / Initial weight] × 100.

3.3.2 Crude protein

Crude protein was determined using the Kjeldahl method, and total nitrogen was multiplied by 6.25 to obtain crude protein percentage.

- Determined by Kjeldahl method: nitrogen (N) content measured, then converted to protein by factor 6.25 (typical for leafy plants).
- Protein % = N % × 6.25.

3.3.3 Ether extract

Ether extract (crude fat) was determined using a Soxhlet extractor with petroleum ether (boiling point 40–60°C) as solvent.

Determined by Soxhlet extraction: ~2 g sample extracted with petroleum ether (or hexane) for ~6 h. The solvent is evaporated and extracted fat weighed.

- Fat % = Weight of extracted fat / original sample weight × 100.

3.3.4 Crude fibre

Crude fibre was determined by sequential acid and alkali digestion.

- After fat extraction and acid/alkaline digestion (following standard method e.g., AOAC 978.10), the residue is dried, weighed, ashed; fibre % calculated.

3.3.5 Ash content

Ash content was determined by incineration at 550°C in a muffle furnace until a light grey residue was obtained.

- ~2 g of sample will be placed in a pre-weighed crucible and ignited in a muffle furnace at 550 ± 15 °C until white ash (≈4 h).
- Ash % = (Weight of ash / original sample weight) × 100.

3.3.6 Nitrogen-free extract (NFE)

Nitrogen-free extract (NFE) was calculated by difference using the formula:

NFE (%) = 100 − (Moisture + Crude Protein + Ether Extract + Crude Fibre + Ash)

- This assumes that sugars, starch and other non-measured components are captured in carbohydrate fraction.

3.4. Mineral Analysis

Mineral composition was determined following wet digestion of 1 g of the sample using a mixed acid solution of nitric acid (HNO_3), perchloric acid ($HClO_4$), and sulfuric acid (H_2SO_4) in a 5:2:1 ratio (v/v/v). The digested solution was filtered and diluted to 50 mL with deionized water.

Concentrations of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), phosphorus (P), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), and cadmium (Cd) were determined using an Atomic Absorption Spectrophotometer (AAS, Model AA-7000, Shimadzu, Japan). Potassium and sodium were analyzed using flame photometry, while phosphorus was determined colorimetrically using the vanadomolybdate method (AOAC, 2016). Mineral concentrations were expressed as mg/100 g of dry matter.

3.5 Statistical Analysis

All analyses were performed in triplicate, and mean values were used for statistical interpretation. All procedures complied with good laboratory practice (GLP) and AOAC (2016) analytical standards.

CHAPTER FOUR

4.0 RESULTS

4.1 Proximate Composition of *Thaumatococcus daniellii* Leaf Waste

The proximate composition of *Thaumatococcus daniellii* leaf waste obtained from rice and *moi-moi* wrapping in Benin City is presented in Table 4.1. Dry matter content ranged from 91.33% in rice leaf waste (RTDLW) to 92.50% in both unused leaf (UTDL) and *moi-moi* leaf waste (MTDLW). Crude protein content differed significantly ($p < 0.05$) among the treatments, with MTDLW showing the highest value (23.62%), followed by UTDL (20.71%) and RTDLW (18.71%). Crude fibre content was highest in UTDL (26.18%) and was significantly different ($p<0.05$) from that in MTDLW and RTDLW. The lowest was in MTDLW (21.02%), while RTDLW recorded an intermediate value (21.50%) but not significantly different ($p>0.05$) from MTDLW.

Ether extract content ranged between 10.00% and 10.67%, with no significant differences among treatments. Ash content was similar across all samples (6.67–6.83%). Nitrogen-free extract (NFE) ranged from 28.11% in UTDL to 34.46% in RTDLW, though differences were not statistically significant. The corresponding standard error of mean (SEM) for the proximate parameters ranged from 0.17 to 0.86.

Table 4.1: Proximate Composition of *Thaumatococcus daniellii* leaf waste obtained from rice and *moi-moi* wrapping in Benin City

Proximate (%)	UTDL (Control)	RTDLW	MTDLW	SEM
Dry matter	92.50±0.50	91.33±1.26	92.50±0.50	0.48
Crude protein	20.71 ± 1.33^{b}	18.71 ± 0.56^{c}	23.62 ± 0.88^{a}	0.56
Crude fibre	26.18 ± 0.55^{a}	21.50 ± 1.32^{b}	21.02 ± 0.89^{b}	0.56
Ether extract	10.67±1.53	10.00±1.00	10.67±0.58	0.64
Ash	6.83±0.29	6.67±0.29	6.67±0.29	0.17
Nitrogen free extract	28.11±2.15	34.46±0.27	30.52±1.40	0.86

^{a,b,c}: Means with different superscript letters within a row indicate significant difference ($p<0.05$)

UTDL = Unused *Thaumatococcus daniellii* leaf. RTDLW = *Thaumatococcus daniellii* leaf waste from rice wrapping. MTDLW = *Thaumatococcus daniellii* leaf waste from *moi-moi* wrapping.

SEM: Standard error of mean

4.2 Mineral Composition of *Thaumatococcus daniellii* Leaf Waste

The mineral composition of the leaf samples is presented in Table 4.2. Calcium concentration varied significantly ($p < 0.05$) among treatments, ranging from 3.313 g/kg in UTDL to 4.168 g/kg in MTDLW. Phosphorus content was similar across treatments (2.263–2.328 g/kg). Sodium concentration differed significantly ($p < 0.05$), with MTDLW recording the highest value (1.142 g/kg), followed by RTDLW (0.992 g/kg) and UTDL (0.856 g/kg).

Potassium content showed no significant variation, ranging narrowly from 0.129 to 0.132 g/kg. Magnesium concentration differed significantly ($p < 0.05$), being highest in RTDLW (3.131 g/kg) and lowest in UTDL (1.737 g/kg). Sulphur, iron, zinc, copper, manganese, nickel, and lead contents were statistically similar ($p>0.05$) across samples. Cadmium was not detected (ND) in any of the samples. The SEM values for mineral components ranged from 0.002 to 0.110.

Table 4.2: Mineral Compositions of *Thaumatococcus daniellii* leaf waste obtained from rice and *moi-moi* wrapping in Benin City

Minerals	UTDL (Control)	RTDLW	MTDLW	SEM
Calcium (g/kg)	3.313 ± 0.185^{b}	3.847 ± 0.160^{a}	4.168 ± 0.160^{a}	0.098
Phosphorus (g/kg)	2.328±0.147	2.295±0.034	2.263±0.057	0.054
Sodium (g/kg)	0.856 ± 0.011^{c}	0.992 ± 0.015^{b}	1.142 ± 0.051^{a}	0.018
Potassium (g/kg)	0.129±0.002	0.132±0.008	0.130±0.002	0.003
Magnesium (g/kg)	1.737 ± 0.117^{b}	3.131 ± 0.019^{a}	2.963 ± 0.241^{a}	0.090
Sulphur (g/kg)	1.615±0.137	1.832±0.203	1.844±0.220	0.110
Iron (mg/kg)	0.270±0.053	0.411±0.215	0.291±0.097	0.081
Zinc (mg/kg)	0.171±0.002	0.278±0.015	0.174±0.006	0.038
Copper (mg/kg)	0.005±0.002	0.006±0.003	0.005±0.003	0.002
Manganese (mg/kg)	0.144±0.011	0.147±0.015	0.136±0.002	0.006
Nickle (mg/kg)	0.009±0.006	0.008±0.003	0.008±0.007	0.003
Lead (mg/kg)	0.061±0.018	0.057±0.018	0.060±0.014	0.010
Cadmium (mg/kg)	ND	ND	ND	ND

^{a,b,c} - Means with different superscript letters indicate significant difference at $p<0.05$

UTDL = Unused *Thaumatococcus daniellii* leaf. RTDLW = *Thaumatococcus daniellii* leaf waste from rice wrapping. MTDLW = *Thaumatococcus daniellii* leaf waste from *moi-moi* wrapping.
ND = Not detected
SEM: Standard error of mean

CHAPTER FIVE

5.0 DISCUSSION

5.1 Proximate Composition of *Thaumatococcus daniellii* Leaf Waste

The proximate composition of *Thaumatococcus daniellii* leaf waste obtained from rice and *moi-moi* wrapping indicated that the leaves maintained high dry matter content across all treatments. Dry matter was high across treatments (91.33–92.50%), indicating well-dried samples and comparable to literature values (~90%; Iwueke *et al.,* 2020; Agha *et al.,* 2022).This reflects their low moisture level and good storage stability, suggesting that the structural integrity of the leaves was largely retained even after exposure to heat during cooking. Similar high dry matter values have been reported for *T. daniellii* leaves used in traditional food packaging, confirming their resilience and suitability for reuse (Ofori *et al*., 2021).

Crude protein ranged from 18.71% in RTDLW to 23.62% in MTDLW which differed significantly among treatments, with *moi-moi* leaf waste (MTDLW) recording the highest value and rice leaf waste (RTDLW) the lowest. The higher protein content observed in MTDLW may be due to the absorption of soluble proteins from the *moi-moi* paste during steaming, while the lower value in RTDLW could be attributed to the relatively low protein content of cooked rice. The unused leaf (UTDL) had an intermediate value, representing the inherent protein composition of fresh T. daniellii leaves. However these values are within the range (~14–21%; Iwueke *et al.,* 2020; Oforibika *et al.,* 2017).

Crude fibre was highest in unused leaves (26.18%) and significantly lower in *moi-moi* leaf waste (MTDLW) and rice leaf waste (RTDLW) (~21%). The reduction in fibre content in the wastes may be associated with partial degradation of cell wall materials under heat and moisture during the wrapping process. This softening effect could make the leaves more pliable for use but may also reduce the structural fibre fraction. Comparable reductions in fibre content after thermal processing have been reported in other plant wrapping materials such as banana and plantain leaves (Iweke *et al.,* 2020).

Ether extract (fat) content was relatively high (~10%) in all samples, supporting energy value and influencing functional properties such as moisture barrier and flavor transfer in wrapping (Iwueke *et al.,* 2020). This showed no significant differences among treatments, indicating that the lipid and mineral components of the leaves remained stable throughout cooking and wrapping.

Ash content ranged 6.67–6.83%, indicating appreciable mineral content despite being lower than some previous reports, which may reflect differences in leaf age, soil mineral uptake, or post-harvest handling.

The nitrogen-free extract (NFE) was highest in RTDLW and lowest in UTDL, suggesting possible migration of carbohydrates from rice into the leaf surface during wrapping. In contrast, *moi-moi*, being primarily proteinaceous, contributed more to the protein enrichment observed in MTDLW than to carbohydrate transfer.

Nitrogen-free extract (NFE) varied from 28.11% to 34.46%, with RTDLW showing the highest though differences were not statistically significant. The higher NFE in rice wrapping waste may reflect may reflect greater carbohydrate leaching or retention from wrapping process (Iwueke *et al.,* 2020).

This implies that the leaf wastes retain substantial protein, fibre, lipid, mineral, and carbohydrate content, highlighting their nutritional value. From a functional perspective, higher fibre and lipid content support leaf strength and potential barrier properties for wrapping applications. Collectively, these findings indicate that both unused and waste leaves of *T. daniellii* have promising nutritional and functional potential for feed, food wrapping, or other applications.

5.2 Mineral Composition of *Thaumatococcus daniellii* Leaf Waste

The mineral analysis of *Thaumatococcus daniellii* leaf waste revealed significant variations across unused leaves (UTDL) and wastes from rice- (RTDLW) and *moi-moi* (MTDLW) wrapping.

5.2.1 Calcium (Ca)

Calcium concentrations varied significantly ($p < 0.05$) among treatments, from 3.313 g/kg in the unused leaf (UTDL) up to 4.168 g/kg in the *moi-moi* leaf waste (MTDLW). This suggests that processing (wrapping food) may have altered mineral uptake, retention or leaching—MTDLW having the highest value may reflect either concentration due to water loss, or uptake/adsorption of calcium during the food-wrapping or heating/steaming process. Calcium is an important macro-mineral: its presence in appreciable amounts reinforces the potential value of leaf-waste as a mineral resource. Compared with earlier work, one study found calcium ~ 6.15 mg/100 g (i.e., 0.0615 g/kg) in the leaves of *T. daniellii.* (Osuocha *et al*., 2019).

5.2.2 Phosphorus (P)

Phosphorus ranged narrowly (2.263–2.328 g/kg) across treatments, with no significant difference among them. While smaller than the variation seen in Ca and Mg, the fairly constant P suggests stability of that element through the wrapping/processing cycle. Earlier data for *T. daniellii* leaves reported phosphorus ~ 5.75 mg/100 g (0.0575 g/kg) in one study. Again, the values in your study (2.26 g/kg = 2,260 mg/kg) are substantially higher, which may indicate enrichment, concentration via drying, or differences in analytical calibration. (Osuocha *et al*., 2019; Shalom *et al*., 2014).

5.2.3 Sodium (Na)

Sodium also differed significantly ($p < 0.05$), increasing from 0.856 g/kg (UTDL) to 1.142 g/kg (MTDLW). The increase in Na in the waste from moi-moi wrapping might reflect leaching of sodium from the food or cooking process into the leaves or absorption of salt used in food preparation. From a nutritional or feed-value perspective, the elevated sodium would need to be considered (excess sodium may not be desirable for some animals or humans).

5.2.4 Magnesium (Mg)

Magnesium also varied significantly ($p < 0.05$), being highest in rice-wrapping leaf waste (RTDLW, 3.131 g/kg), followed by MTDLW (2.963 g/kg) and lowest in UTDL (1.737 g/kg). Again, the wrapping/use process appears to influence Mg content. Mg is an important co-factor for many enzymes and for bone health; thus its presence at >1 g/kg suggests the leaf waste could be a meaningful contributor of Mg in a feed or compost scenario.

5.2.5 Potassium (K), Sulphur (S), Trace Elements (Fe, Zn, Cu, Mn, Ni, Pb, Cd)

Potassium showed little variation (0.129–0.132 g/kg), indicating stable retention across treatments. Sulphur (1.615–1.844 g/kg) did not differ significantly. Iron (0.270–0.411 mg/kg), Zinc (0.171–0.278 mg/kg), Copper (0.005–0.006 mg/kg), Manganese (0.136–0.147 mg/kg), Nickel (0.008–0.009 mg/kg), Lead (0.057–0.061 mg/kg) were all in relatively low concentrations (mg/kg scale) and did not differ significantly across treatments; cadmium was not detected (ND) in any sample. The detectable lead suggests that although levels are low, there is some heavy-metal presence which may have implications for safe use (feed, compost).

In comparison, other authors (Osuocha *et a*l., 2019) reported for *T. daniellii* leaves Ca $\sim 6.15 \pm 0.03$ mg/100 g (0.0615 g/kg), P $\sim 5.75 \pm 0.12$ mg/100 g (0.0575 g/kg) and Zn $\sim 1.42 \pm 0.02$ mg/100 g (0.00142 g/kg). Your values are orders of magnitude higher—this discrepancy may reflect differences in leaf waste vs fresh leaves, different soil/region (Benin City), or methodological variation.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

This study evaluated the proximate and mineral compositions of *Thaumatococcus daniellii* leaf from comparing unused leaves (UTDL) with leaf wastes obtained from rice wrapping (RTDLW) and *moi-moi* wrapping (MTDLW) in Benin City, Nigeria. The aim was to assess the nutritional potential and possible utilization of these leaf wastes.

Proximate analysis showed that dry matter content was consistently high (91.33–92.50%), indicating properly dried samples. Crude protein ranged from 18.71% in RTDLW to 23.62% in MTDLW, demonstrating that processing and handling affect nutrient retention. Crude fibre was highest in unused leaves (26.18%) and lower in wastes (~21%), suggesting some fibre loss after use. Ether extract (approximately 10%) and ash (6.67–6.83%) reflected appreciable lipid and mineral contents. Nitrogen-free extract (NFE) values ranged from 28.11% to 34.46%, indicating considerable carbohydrate presence and digestibility.

Mineral analysis revealed significant macro- and micro-nutrient contents. Calcium (3.313–4.168 g/kg) and phosphorus (2.263–2.328 g/kg) were dominant, followed by magnesium, sodium, and potassium in varying proportions. Trace elements such as iron, zinc, manganese, and copper were detected in beneficial amounts, while heavy metals such as lead were minimal (0.057–0.061 mg/kg) and cadmium was absent, indicating safety for potential feed or wrapping use. This implies that both unused and waste leaves of *T. daniellii* retained valuable nutrients, suggesting their potential for animal feed, organic fertilizer, and biodegradable packaging applications.

6.1 CONCLUSION

The findings from this study demonstrate that *Thaumatococcus daniellii* leaf wastes contain significant levels of essential nutrients, including proteins, fibres, carbohydrates, and minerals. Despite being considered waste after food wrapping, these leaves maintain a substantial proportion of their nutritional properties. The high dry matter, moderate lipid, and mineral composition further support their value as a possible low-cost, sustainable raw material.

The low heavy-metal content confirms that the leaf wastes are safe for environmental and feed-related applications. Consequently, *T. daniellii* leaf wastes can be effectively utilized to promote environmental sustainability, reduce waste, and support value-added industries in Nigeria.

6.2 RECOMMENDATIONS

1. *Thaumatococcus daniellii* leaf waste can be recommended as a sustainable, nutrient-rich feed supplement for livestock to partially replace conventional fibrous ingredients, supporting both cost-effective production and circular bioeconomy goals and should also be processed and explored as alternative feed ingredients, organic compost, or biodegradable packaging materials to reduce environmental waste and increase the diversity of feed ingredient.
2. Investigations into anti-nutritional factors (e.g., tannins, oxalates, phytates) and microbial contamination should be conducted to ensure safe utilization in feed and food applications.
3. Research should focus on optimizing drying, storage, and processing methods to preserve nutrient quality and prevent degradation during handling.
4. The shelf-life stability of *Thaumatococcus daniellii* leaf should be investigated.

5. Government and research institutions should encourage small- and medium-scale industries to develop sustainable uses for *T. daniellii* wastes through training, policy incentives, and public awareness programs.

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APPENDIX

Plate 1: Unused leaves (UTDL) **Plate 2: Leaf waste from rice wrapping (RTDLW)**

Plate 3: Leaf waste for *moi-moi* wrapping (MTDLW) **Plate 4: Chopped dried leaves**

Plate 5: Milled leaves