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Proximate and Mineral Compositions of *Thaumatococcus Danielli* (Benth) [Sweet Prayer] Plant Leaf Waste Generated from Rice and *Moi-moi* Wrappings in Benin City, Nigeria

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ABSTRACT: Feed scarcity and rising feed costs remain major constraints to livestock production in developing countries, necessitating the exploration of alternative feed resources. *Thaumatococcus daniellii* leaves are widely used as natural food-wrapping materials in southern Nigeria; however, substantial quantities are discarded after use, contributing to environmental waste. Hence, the objective of this paper was to evaluate the proximate and mineral compositions of *Thaumatococcus daniellii* (Benth) [Sweet Prayer] Plant leaf waste (TDLW) generated from rice (RTDLW) and *moi-moi* (MTDLW) wrappings in Benin City, Nigeria using appropriate standard procedures. Proximate analysis revealed substantial nutrient retention in TDLW, with dry matter values of 91.33–92.50%. Crude protein ranged from 18.71% (RTDLW) to 23.62% (MTDLW), while crude fibre was reduced post-use (21.02 – 21.50%) compared with unused leaves (UTDL, 26.18%). Ether extract (10.00–10.67%) and ash (6.67–6.83%) remained stable across treatments. Mineral analysis showed significant ($p < 0.05$) differences in calcium, sodium, and magnesium, with MTDLW exhibiting the highest levels of calcium (4.168 g/kg) and sodium (1.142 g/kg). Trace minerals such as Fe, Zn, Cu, and Mn were present in low concentrations, while cadmium was undetected. The retention of appreciable protein, fibre, and essential minerals indicates that TDLW may serve as a viable supplementary feed ingredient for livestock under appropriate inclusion levels. Feeding trials are recommended to assess the digestibility, anti-nutritional factors, and animal performance responses.

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Livestock production in developing countries faces persistent challenges, particularly feed scarcity and rising feed costs, which limit animal growth and profitability (Isiaka *et al.*, 2023). In Nigeria, the feed industry relies predominantly on conventional

ingredients such as maize, wheat offal, groundnut cake, palm kernel cake, and soybean meal. The high and fluctuating prices of these materials increase production costs and reduce profit margins for farmers (Molina-Flores *et al.*, 2020; Agbonghae and

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Nwokoro, 2023; Obayelu, 2023). Hence, there is a growing interest among livestock nutritionists in identifying alternative feed resources sourced from non-conventional ingredients and agro-industrial by-products. These materials, often considered waste, may provide cost-effective and sustainable substitutes for traditional feedstuffs if their nutritional potentials are properly evaluated. Such utilization aligns with circular bioeconomy principles by promoting waste minimization, nutrient recycling, and sustainable livestock production (McAllister *et al.*, 2025; Shah *et al.*, 2025). *Thaumatococcus daniellii* (Benth), commonly referred to as the sweet prayer plant, represents one of the underutilized agro-resources in Nigeria. This monocotyledonous species of the Marantaceae family is indigenous to the tropical rainforests of West and Central Africa and is abundantly found in the southern regions of Nigeria, such as Benin City (Fadahunsi *et al.*, 2021; Agha *et al.*, 2022). The plant is commercially valued for the extraction of thaumatin, a natural sweet-tasting protein obtained from its aril and widely used as a low-calorie sweetener (Iwueke *et al.*, 2020; Agha *et al.*, 2022). The leaves are traditionally used as natural wrapping materials for rice, *moi-moi*, and *agidi* owing to their aroma, tensile strength, and antimicrobial properties (Ifunanya *et al.*, 2024). However, after usage, large quantities of these leaves are discarded, resulting in environmental littering in Benin City and surrounding areas. Despite their frequent disposal, *T. daniellii* leaves contain appreciable nutrients and minerals that may be harnessed as feed ingredients. Previous studies have reported crude protein values ranging from 10% to 18%, crude fibre from 20% to 30%, and ash from 8% to 12%, along with substantial levels of calcium, potassium, magnesium, iron, and phosphorus (Oforibika *et al.*, 2017; Fadahunsi *et al.*, 2021; Agha *et al.*, 2022). These contents suggest that *T. daniellii* leaf waste (TDLW) could serve as a supplementary or partial replacement for conventional fibre sources in rabbit or ruminant diets. Moreover, the presence of bioactive compounds such as flavonoids, tannins, and phenolics confers antioxidant and antimicrobial properties that may enhance animal health when included at appropriate dietary levels (Igbayilola *et al.*, 2021; Ifunanya *et al.*, 2024). The utilization of any new feed resource requires comprehensive nutritional evaluation to support its inclusion in diet formulations. Proximate composition analysis provides key information on moisture, crude protein, ether extract, ash, crude fibre, and nitrogen-free extract, which serve as indicators of nutrient availability (AOAC, 2016). Mineral analysis further reveals macro- and micro-element profiles essential for growth, metabolism, and overall animal health

(Palai *et al.*, 2025). Although previous research has assessed the nutrient composition of fresh *T. daniellii* leaves, limited information exists on the composition of the leaf waste generated after its use for food wrapping. Post-use factors, such as heat exposure, desiccation, and microbial activity, may alter the nutrient profile, thus necessitating context-specific evaluation before recommending its inclusion in animal diets. Therefore, the objective of this paper is to evaluate the proximate and mineral compositions of *Thaumatococcus daniellii* (Benth) [Sweet Prayer] Plant leaf waste (TDLW) generated from rice (RTDLW) and *moi-moi* (MTDLW) wrappings in Benin City, Nigeria.

MATERIALS AND METHODS

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 distribution and distinct wet (April–October) and dry (November–March) seasons. The mean annual temperature ranges from 24°C to 32°C, while 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.

Sample collection and experimental design: A completely randomized design (CRD) was adopted to assess and compare the proximate and mineral compositions of *Thaumatococcus daniellii* leaf waste (TDLW) with those of fresh leaves used as the control. Fresh leaves were purchased from Oba Market, Benin City, Nigeria, whereas post-use leaf waste was collected from ten restaurants where the leaves are routinely used for food wrapping. Inclusion of fresh leaves as the control enabled comparison of compositional variations caused by exposure to heat, moisture, and food residues during use.

Approximately 500 g of leaf waste was collected from each restaurant, and a similar quantity of fresh leaves was obtained from the market. All the samples were cleaned, oven-dried at 60°C to constant weight, and milled into fine powder. Composite samples were prepared separately for fresh leaves and leaf waste, and representative sub-samples were drawn from each for laboratory analyses.

Proximate composition analysis: The 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).

Moisture content was determined by oven-drying approximately 1 g of powdered sample at $105 \pm 2^\circ\text{C}$ for 4 hours, or until constant weight was attained. Moisture percentage was calculated using the equation 1:

$$\% \text{ Moisture} = \frac{W_i - W_d}{W_i} * 100 \quad (1)$$

Where W_i = Initial weight; W_d = Dry weight)

Crude protein was determined using the Kjeldahl method. The total nitrogen obtained from digestion, distillation, and titration was multiplied by 6.25 to derive crude protein percentage. Ether extract was determined using a Soxhlet extractor with petroleum ether (boiling range: $40\text{--}60^\circ\text{C}$) as solvent. Approximately 2 g of sample was extracted for approximately 6 hours, after which the solvent was evaporated and the extracted fat was weighed and estimated using the equation 2:

$$\% \text{ Fat} = \frac{W_{EF}}{W_s} * 100 \quad (2)$$

Where W_{EF} = Weight of extracted fat; W_s = original sample weight

Crude fiber was analyzed following sequential acid and alkali digestion using standard procedure. The residue obtained after digestion was dried, weighed, and subsequently ashed to determine crude fiber content. Ash content was determined by incinerating approximately 2 g of sample in a pre-weighed crucible using a muffle furnace at $550 \pm 15^\circ\text{C}$ for approximately 4 hours until a light grey ash was obtained. Ash percentage was calculated using the equation 3:

$$\% \text{ Ash} = \frac{W_{ash}}{W_s} * 100 \quad (3)$$

Where W_{ash} = Weight of ash; W_s = original sample weight) $\times 100$.

Nitrogen-free extract was calculated by difference using the equation 4:

$$\% \text{ NFE} = 100 - [\%M + \%CP + \%EE + \%CF + \text{Ash}]$$

Where NFE = Moisture; CP = Crude Protein; EE = Ether Extract; CF = Crude Fibre;

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

Mineral analysis: Mineral composition was determined following wet digestion of 1 g of sample with a mixed acid solution consisting of nitric acid (HNO_3), perchloric acid (HClO_4), and sulphuric acid (H_2SO_4) in a ratio of 5:2:1 (v/v/v). The digested solution was filtered and diluted to 50 mL using deionised water. Concentrations of calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), and cadmium (Cd) were quantified using an Atomic Absorption Spectrophotometer (AAS; Model AA-7000, Shimadzu, Japan). Potassium (K) and sodium (Na) were analyzed using flame photometry, whereas phosphorus (P) was determined calorimetrically using the vanadomolybdate method (AOAC, 2016).

Statistical analysis: All statistical data analyses were performed using SPSS version 25.0.

RESULTS AND DISCUSSION

Proximate composition of Thaumatococcus daniellii leaf waste: The proximate composition of *Thaumatococcus daniellii* leaf waste (TDLW) obtained from rice and moi-moi wrapping is presented in Table 4.1. Dry matter content was consistently high across all samples (91.33–92.50%), confirming adequate drying and preservation of structural integrity after usage. These values are comparable to previously reported values (~90%) for *T. daniellii* leaves (Iwueke *et al.*, 2020; Agha *et al.*, 2022), indicating suitability for storage and potential reuse.

Crude protein content varied significantly ($p < 0.05$), ranging from 18.71% in RTDLW to 23.62% in MTDLW. The higher protein content in MTDLW may be attributed to absorption of soluble proteins from the moi-moi paste during steaming, while the lower value observed in RTDLW likely reflects the lower protein concentration of cooked rice. The protein content of UTDL represents the intrinsic level in fresh leaves and aligns with previously reported ranges (~14–21%: Oforibika *et al.*, 2017; Iwueke *et al.*, 2020). The preservation of protein after usage supports the view that moderate heat exposure does not significantly degrade protein but may enhance surface adsorption and bioavailability (Ayodeji *et al.*, 2016). Crude fibre content was significantly ($p < 0.05$) higher in UTDL (26.18%) and lower in both RTDLW and MTDLW (~21%). This reduction likely results from partial breakdown of cell wall

components due to heat and moisture exposure during wrapping. Similar reductions in fibre content after thermal processing have been reported in banana and plantain leaves (Iwueke *et al.*, 2020). However, the fibre concentration remained sufficient to support digestive functioning in rabbits and ruminants, suggesting that TDLW could serve as a viable dietary fibre source. Ether extract content (10.00–10.67%) did not differ significantly among treatments, indicating stability of lipid components under heat exposure. This observation aligns with Hamid *et al.* (2017), who noted that lipid-based antioxidants such as flavonoids and phenolic compounds in *T. daniellii* remain stable following moderate thermal treatment. Ash content was also

comparable across treatments (6.67–6.83%), although slightly lower than values reported in previous studies, possibly due to variations in leaf maturity, soil mineral uptake, or post-harvest handling processes (Adeogun *et al.*, 2016; Hamid *et al.*, 2017). Nitrogen-free extract (NFE) ranged from 28.11–34.46%, with RTDLW having the highest value, suggesting carbohydrate migration from rice to the leaf surface during wrapping. In contrast, the protein-rich moi-moi paste contributed more to protein enrichment than carbohydrate transfer. Overall, both unused and waste leaves demonstrated appreciable levels of protein, fibre, lipids, minerals, and carbohydrates, reinforcing their potential for feed formulation or recycled agro-material applications.

Table 1: Proximate composition of *Thaumatococcus daniellii* leaf waste obtained from rice and moi-moi wrappings 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

Mineral composition of *Thaumatococcus daniellii* leaf waste: The mineral compositions of the samples are presented in Table 4.2. Significant ($p < 0.05$) differences were observed in calcium, sodium, and magnesium contents among treatments. Calcium concentrations ranged from 3.313 g/kg (UTDL) to 4.168 g/kg (MTDLW), suggesting that steaming and food contact may enhance mineral retention or concentration due to moisture loss. These values were markedly higher than those reported by Osuocha *et al.* (2018a) for fresh leaves (0.0615 g/kg), possibly due to differences in analytical methodology, leaf type, or regional soil composition in Benin City. Phosphorus levels were statistically similar (2.263–2.328 g/kg) across treatments, indicating stability during thermal processing. However, these values were considerably higher than that in a previous report (~0.0575 g/kg; Osuocha *et al.*, 2018a), which may reflect concentration effects induced by drying or methodological variations. Sodium content differed significantly ($p < 0.05$), with the highest value observed in MTDLW (1.142 g/kg), likely due to salt absorption from moi-moi seasoning. Although elevated sodium may be beneficial in specific diets, inclusion levels must be carefully controlled to prevent dietary excess. Magnesium was highest in RTDLW (3.131 g/kg), indicating potential enrichment during steaming or wrapping. This level exceeds the minimum requirement for livestock diets

and highlights the potential of TDLW as a mineral supplement. Potassium and sulphur contents showed no significant differences among treatments, suggesting relative stability under processing conditions. Trace minerals (Fe, Zn, Cu, Mn, Ni, and Pb) were present in low but nutritionally relevant concentrations, with no significant variation among samples. Cadmium was not detected in any sample. Lead concentrations remained low (0.057–0.061 mg/kg) and below established toxicity thresholds, although routine monitoring is recommended. Collectively, the mineral composition demonstrates that TDLW retains appreciable levels of essential macro- and microminerals after use, supporting its potential value as a feed ingredient or soil amendment. The elevated calcium, sodium, and magnesium levels in waste leaves may be linked to moisture loss-induced concentration effects or absorption from food materials. These findings align with those of Wuanor and Ayoade (2020), who reported that post-processing residues often retain or acquire higher mineral concentrations due to structural breakdown and surface deposition during heating. The absence of cadmium and low lead concentrations indicate a favourable safety profile for feed applications, in agreement with Adeogun *et al.* (2016). Overall, the proximate and mineral composition of TDLW satisfies key criteria for alternative feed resource development. The nutrient

stability observed after usage, combined with its safety profile and alignment with circular bioeconomy principles, reinforces its potential as a cost-effective and sustainable ingredient in livestock

nutrition (Adeogun *et al.*, 2016; Ayodeji *et al.*, 2016; Hamid *et al.*, 2017; Osuocha *et al.*, 2018b; Wuanor and Ayoade, 2020).

Table 2: Mineral compositions of *Thaumatococcus daniellii* leaf waste obtained from rice and moi-moi wrappings 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

Conclusion: *Thaumatococcus daniellii* leaf waste generated from rice and moi-moi wrapping retained substantial nutritional quality after usage, demonstrating its potential as a low-cost and sustainable feed resource for livestock. The higher nutrient enrichment in MTDLW suggests that food-contact processing may improve its compositional value, whereas reductions in crude fibre reflect partial structural degradation during heat exposure. The absence of cadmium and low lead concentrations further support its suitability from a feed safety perspective. These findings align with circular bioeconomy principles by promoting waste valorization and nutrient recycling. However, before its incorporation into livestock diets, further investigations on anti-nutritional factors, microbial safety, digestibility, and animal performance are required. Overall, TDLW presents a promising resource that could mitigate feed scarcity, reduce production costs, and contribute to sustainable livestock nutrition in Nigeria.

DECLARATIONS

Ethical Approval: This study did not involve human participants or animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were conducted responsibly and in accordance with standard academic and institutional guidelines.

Disclaimer (Artificial Intelligence): Author(s) hereby declare that no generative Artificial Intelligence (AI) technologies such as Large Language Models (ChatGPT, COPILOT, XLNet, Ernie 3.0 Titan etc)

and text-to-image generators have been used during writing or editing of this manuscript.

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Conflict of Interest: The authors declare that there is no known conflict of interest or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement: Data are available upon request from the corresponding author.

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