



Nutritional Value, Socioeconomic Importance and Ecological Contribution of Selected Indigenous Fruit Trees in Savanna Agroforestry Systems of Northeastern Nigeria

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Abstract

Indigenous fruit trees (IFTs) are important components of savanna agroforestry systems because they provide food, income and ecological services to rural households. This study assessed the nutritional value, socioeconomic importance and ecological contribution of five indigenous fruit tree species, namely *Adansonia digitata* L., *Balanites aegyptiaca* (L.), *Delile Parkia biglobosa* (Jacq.) R.Br. ex *Tamarindus indica* L., and *Vitellaria paradoxa* C.F.Gaertn., across selected communities in northeastern Nigeria. Proximate and mineral compositions were determined using standard laboratory procedures, while household socioeconomic information and woody vegetation data were obtained through household surveys and field inventories. The study assessed moisture, protein, fat, fibre, ash, carbohydrate, energy, calcium, iron, zinc and potassium, together with household utilization, income contribution, tree density, diameter at breast height (DBH), regeneration and woody-vegetation diversity. The reported nutrient values differed among species, with *P. biglobosa* having the highest crude protein content and *V. paradoxa* the highest fat and reported energy values. *A. digitata* had the highest fibre, calcium and potassium values, whereas *P. biglobosa* and *B. aegyptiaca* had the highest iron and zinc values, respectively. *P. biglobosa* and *V. paradoxa* generated the highest reported mean annual household incomes. Woody-vegetation richness and Shannon diversity were highest at Pindiga and lowest at Jakusko. Regeneration was strongest for *B. aegyptiaca* and weakest for *A. digitata*. The findings indicate that IFTs can simultaneously support dietary diversification, rural income generation and conservation of woody vegetation when retained and sustainably managed within agroforestry landscapes. However, the results should be interpreted as evidence of potential contribution rather than direct measurement of household nutritional status or biodiversity conservation outcomes. *Khaya senegalensis* (Desr.) A.Juss., *Vitellaria paradoxa* C.F.Gaertn., *Tamarindus indica* L., and *Parkia biglobosa* (Jacq.) R.Br. ex G.Don. Subsequent mentions used *A. digitata*, *K. senegalensis*, *V. paradoxa*, *T. indica*, and *P. biglobosa*.

Keywords: indigenous fruit trees; agroforestry; nutrition; rural livelihoods; regeneration; woody-plant diversity; northeastern Nigeria.

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Introduction

Indigenous fruit trees (IFTs) are important components of rural production systems because they provide food, marketable products and ecosystem services while remaining integrated with agricultural land. Their fruits, seeds, leaves and derived products can diversify diets and income sources, particularly where households depend heavily on seasonal crop production. IFTs may also contribute to soil protection, carbon storage and habitat provision when retained within agroforestry landscapes (Leakey, 2012; FAO, 2013). Nevertheless, many indigenous tree resources are increasingly exposed to land-use change, agricultural expansion, deforestation, overharvesting and environmental degradation.

The study focused on 5 indigenous species: *Adansonia digitata* L., *Balanites aegyptiaca* (L.), *Delile Parkia biglobosa* (Jacq.) R.Br. ex *Tamarindus indica* L., and *Vitellaria paradoxa* C.F.Gaertn. In the savanna ecosystems of Nigeria, these species are widely valued for food, medicine and income and form part of locally important non-timber forest products (Aremu *et al.*, 2006; Amadi *et al.*, 2022). Their importance, however, extends beyond individual products. The persistence of multipurpose trees in cultivated landscapes can contribute to structural heterogeneity, resource availability and the maintenance of woody-plant diversity. These functions are particularly relevant in northeastern Nigeria, where rainfall gradients, recurrent dry periods, land degradation and increasing demand for agricultural land create strong pressures on tree resources. Agroforestry provides a practical management context in which productive trees can be retained or established within crop fields while maintaining agricultural production and ecosystem functions (Chirwa *et al.*, 2024). Assessing the nutritional, socioeconomic and ecological attributes of IFTs together is therefore useful for identifying species with complementary roles in resilient farming systems.

Accordingly, this study assessed the nutritional composition, household income contribution and ecological attributes of five selected indigenous fruit tree species across representative savanna communities in northeastern Nigeria. Specifically, the study aimed to: (i) determine the proximate and mineral composition of the selected species; (ii) quantify household utilization and reported income contribution; (iii) assess tree density, population structure and regeneration; and (iv) characterize woody-plant richness and diversity across the study communities and consider the implications for agroforestry management.

Materials and Methods

Study design

A convergent mixed-methods design was used to integrate three complementary components: (i) biochemical assessment of the nutritional composition of selected IFT products; (ii) socioeconomic assessment of household utilization and income contribution; and (iii) ecological assessment of tree density, stand structure, regeneration and woody-plant diversity. The integrated approach was intended to provide a multidimensional assessment of the potential contribution of IFTs to rural livelihoods and agroforestry sustainability (Creswell and Plano Clark, 2018).

Study area

The study was conducted in six communities distributed across Bauchi, Gombe and Yobe States, representing a north–south environmental gradient within the Sudan, Guinea–Sudan transition and Sahel–Sudan savanna zones. The selected communities were Giade and Misau (Bauchi State), Pindiga and Kwami (Gombe State), and Damagum and Jakusko (Yobe State). Reported annual rainfall ranges from approximately 400 mm in northern Yobe to about 900 mm in southern Gombe. The landscapes include cultivated fields and parkland agroforestry systems in which indigenous multipurpose trees are retained within cereal- and legume-based farming systems.

Table 1. Summary of study sites and ecological characteristics.

State	Community	Coordinates	Ecological zone	Dominant vegetation / landscape
Bauchi	Giade	11.390° N, 10.286° E	Sudan Savanna	Open woodland; drought-tolerant trees and grasses
Bauchi	Misau	11.313° N, 10.466° E	Sudan Savanna	Semi-arid shrubland; agroforestry parklands
Gombe	Pindiga	9.984° N, 10.952° E	Guinea–Sudan transition	Woodland–savanna mosaic; relatively high tree density
Gombe	Kwami	10.452° N, 11.421° E	Guinea–Sudan transition	Transitional savanna; cultivated farmlands
Yobe	Damagum	11.678° N, 11.335° E	Sahel–Sudan Savanna	Sparse woody vegetation; low-rainfall adapted
Yobe	Jakusko	12.370° N, 10.773° E	Sahel–Sudan Savanna	Semi-arid savanna; seasonal wetlands

Study species

Five economically, nutritionally and ecologically important indigenous tree species characteristic of dryland agroforestry systems of northern Nigeria were investigated: *Adansonia digitata* L. (baobab), *Balanites aegyptiaca* (L.) Delile (desert date), *Parkia biglobosa* (Jacq.) R.Br. ex G.Don (African locust bean), *Tamarindus indica* L. (tamarind), and *Vitellaria paradoxa* C.F.Gaertn. (shea tree). The species were selected because of their widespread occurrence in West African parklands, multipurpose uses, contribution to household food and nutritional security, and importance as sources of marketable products and seasonal income. Indigenous parkland trees provide fruits, seeds, oils, condiments and other products that diversify diets and contribute substantially to household livelihoods, particularly during seasonal periods of food scarcity (FAO, 1999; Adekoya *et al.*, 2023; Kyereh *et al.*, 2021). *P. biglobosa* and *V. paradoxa*, in particular, are important components of West African agroforestry parklands, while *A. digitata*, *B. aegyptiaca* and *T. indica* provide diverse food, medicinal and livelihood products (FAO, 1999). The five species were treated as the principal biological units for the nutritional component, whereas their associated woody vegetation was assessed at the community level to determine their ecological context. This distinction was maintained throughout sampling and statistical

analysis to avoid conflating species-specific nutritional characteristics with community-level biodiversity patterns.

Data Collection

Nutritional Analysis

Mature, healthy and apparently undamaged fruit or edible reproductive structures were collected from five ecologically distinct sampling locations (ecotypes) representing the study distribution of each species. Within each ecotype, five mature trees were selected using a randomization procedure, giving 25 independent biological tree samples per species (5 ecotypes × 5 trees). Sampling multiple trees across ecotypes was intended to capture within-species variability associated with environmental and geographical differences rather than relying on repeated measurements from a single population.

Samples were collected at comparable physiological maturity and transported in clean, labelled sample containers to the laboratory. Fruits were cleaned with distilled water to remove adhering soil and particulate matter, and samples were air-dried under controlled ambient laboratory conditions (28 ± 2°C) until a stable mass was achieved. The dried materials were milled using a stainless-steel laboratory mill to obtain a homogeneous powder. Samples were subsequently stored in airtight, moisture-resistant polyethylene containers in a desiccator until analysis. Sample preparation was standardized because drying temperature and moisture conditions

can influence the measured concentrations of nutrients and other constituents.

Proximate composition was determined using procedures based on the official methods of the Association of Official Analytical Chemists (AOAC, 2005). The analyses included moisture, crude protein, crude fat, crude fibre and total ash. Moisture was determined gravimetrically following oven drying at 105°C; crude protein was estimated from total nitrogen using the micro-Kjeldahl procedure and a nitrogen-to-protein conversion factor of 6.25; crude fat was determined by Soxhlet extraction using petroleum ether; crude fibre was determined by sequential acid and alkali digestion; and total ash was quantified following controlled incineration in a muffle furnace at approximately 550°C (AOAC, 2005). These procedures provide standardized approaches for comparative nutritional characterization of plant-derived foods. Carbohydrate content was estimated by difference using the following equation:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture (\%)} + \text{Protein (\%)} + \text{Fat (\%)} + \text{Fibre (\%)} + \text{Ash (\%)}]$$

Because the proximate constituents were expressed on an as-is basis, the resulting carbohydrate estimates were also interpreted on an as-is basis. Gross energy was estimated using the conventional Atwater factors:

The gross energy content was estimated from the protein, fat and carbohydrate contents using the Atwater conversion factors, as follows:

$$\text{Energy (kcal/100 g)} = [4 \times \text{Protein (\%)}] + [9 \times \text{Fat (\%)}] + [4 \times \text{Carbohydrate (\%)}]$$

where protein and carbohydrate provide 4 kcal/g and fat provides 9 kcal/g.

Mineral analysis focused on calcium (Ca), iron (Fe), zinc (Zn) and potassium (K). Samples were subjected to wet-acid digestion using a nitric acid–perchloric acid mixture before instrumental determination. Iron and zinc were quantified using atomic absorption spectrophotometry, while calcium and potassium were determined by flame photometry. Analytical procedures followed

established protocols for mineral determination in plant-derived materials (AOAC, 2005; Enoch *et al.*, 2025; Yiblet, 2024).

Each biological tree sample was analysed in triplicate. These three measurements were treated as technical analytical replicates rather than independent observations. The triplicate values were averaged to obtain one analytical value for each tree before statistical analysis. Thus, the effective sample size for species comparisons remained 25 biological tree replicates per species, thereby preventing pseudoreplication arising from treating repeated laboratory measurements as independent samples.

Socioeconomic Survey

A multistage sampling design was used to investigate household utilization, economic contribution and management of the five indigenous tree species. Six rural communities; Giade, Misau, Pindiga, Kwami, Damagum and Jakusko were purposively selected to represent contrasting agroecological conditions and established indigenous agroforestry practices across Bauchi, Gombe and Yobe States. Agroforestry parklands in the region are strongly influenced by both environmental gradients and long-standing human management, making community selection important for capturing variation in utilization and management practices (FAO, 1999).

Thirty households were selected from each community using simple random sampling, producing a total sample of 180 households. The sampling structure followed established principles for household surveys and probability-based selection (Cochran, 1977).

Data were collected using a structured questionnaire supplemented by key-informant interviews. Information was obtained on species utilization, products harvested, processing practices, household consumption, annual income from raw and processed products, seasonal importance, harvesting practices and traditional management strategies. Respondents were also asked to identify species considered important during the lean season and to describe changes in

availability or productivity where applicable. Household income estimates were based on respondent-reported annual sales and should therefore be interpreted as reported economic contributions rather than independently audited income.

Ecological and Biodiversity Assessment

Vegetation structure and woody-species composition were assessed using 25 × 25 m inventory plots (625 m²) established within the selected agroforestry landscapes. Plot locations were positioned to capture representative vegetation conditions while avoiding highly disturbed areas that did not reflect the prevailing agroforestry system. Within each plot, all living woody stems with diameter at breast height (DBH) ≥ 5 cm were identified to species level, counted and measured at 1.3 m above ground using a diameter tape, following standard vegetation inventory procedures (Kent, 2012).

Natural regeneration was assessed using nested 5 × 5 m subplots established within each main inventory plot. Regeneration was separated into seedlings (<1.5 m height) and saplings (≥1.5 m height and <5 cm DBH). Densities were converted to stems ha⁻¹. Regeneration status was interpreted comparatively using the abundance of seedlings and saplings relative to mature-tree density, rather than treating categorical labels as absolute conservation thresholds.

Importantly, biodiversity indices represented the entire woody plant community, not only the five focal species. Species richness (S) was calculated as the number of distinct woody species recorded in each community. Shannon–Wiener diversity was calculated as:

The Shannon–Wiener diversity index (H') was calculated as:

$$H' = -\sum_{i=1}^s p_i \ln(p_i)$$

where S is the total number of woody-plant species recorded in the sampled community, and p_i is the relative abundance of species i , calculated as the proportion of individuals of species i relative to the total number of woody individuals recorded. The index was used to characterize the overall woody-plant

community within which the focal indigenous fruit-tree species occurred. This approach distinguishes **total woody-plant community richness and diversity from the richness of the five focal species**, thereby avoiding the erroneous interpretation of the number of focal indigenous fruit-tree species as total community richness.

Statistical Analysis

Data Were Screened For Completeness, outliers and compliance with parametric assumptions. Normality and homogeneity of variance were assessed using the Shapiro–Wilk and Levene tests, respectively (Levene, 1960; Shapiro and Wilk, 1965). Proximate and mineral variables were compared among species using one-way ANOVA, with the individual tree as the experimental unit. Where significant differences occurred, Duncan's multiple range test was used for mean separation at $\alpha = 0.05$ (Duncan, 1955; Zar, 2010). Results were expressed as mean ± SD. Household utilization and income data were summarized using frequencies, percentages and mean annual reported income. Pearson's correlation coefficient (r) was used to examine associations between community-level mean annual rainfall and selected vegetation attributes. Because only six communities were sampled ($df = 4$), correlations were interpreted cautiously using the exact two-tailed critical value ($r \geq 0.811$) at $\alpha = 0.05$.

Results

Nutritional and Mineral Composition

Table 2 shows the five indigenous fruit-tree species had significant interspecific variation in proximate and mineral composition ($P < 0.05$). *Parkia biglobosa* recorded the highest crude protein content ($18.6 \pm 0.7\%$), followed by *Balanites aegyptiaca* ($13.2 \pm 0.5\%$) and *Vitellaria paradoxa* ($11.5 \pm 0.6\%$), whereas *Tamarindus indica* had the lowest value ($7.6 \pm 0.4\%$). *V. paradoxa* had the highest lipid content ($15.4 \pm 0.5\%$) and gross energy value (389.6 kcal/100 g). Crude fibre was highest in *Adansonia digitata* ($18.7 \pm 0.8\%$), followed by *T. indica* ($16.1 \pm 0.7\%$), while ash was also highest in *A. digitata* ($7.1 \pm 0.3\%$). In contrast, *T. indica* had the highest carbohydrate

concentration ($57.0 \pm 1.5\%$), whereas *P. biglobosa* recorded the lowest ($43.8 \pm 1.1\%$).

Table 2. Proximate composition and energy content of selected indigenous fruit-tree species

Species	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Carbohydrate (%)	Energy (kcal/100 g)
<i>Adansonia digitata</i>	9.8 ± 0.5	4.2 ± 0.2	18.7 ± 0.8	7.1 ± 0.3	51.1 ± 1.3	301.7
<i>Balanites aegyptiaca</i>	13.2 ± 0.5	8.7 ± 0.3	15.4 ± 0.6	6.2 ± 0.3	47.8 ± 1.2	334.2
<i>Parkia biglobosa</i>	18.6 ± 0.7	10.5 ± 0.4	12.8 ± 0.6	5.9 ± 0.2	43.8 ± 1.1	352.4
<i>Tamarindu indica</i>	7.6 ± 0.4	3.8 ± 0.2	16.1 ± 0.7	5.3 ± 0.2	57.0 ± 1.5	296.8
<i>Vitellaria paradoxa</i>	11.5 ± 0.6	15.4 ± 0.5	10.3 ± 0.5	4.8 ± 0.2	50.2 ± 1.4	389.6

Values are presented as mean $\pm$ standard deviation (SD). Proximate composition is expressed as percentage of sample weight; energy is expressed as kcal/100 g. Bold values indicate the highest value within each column.

The mineral concentrations also differed significantly among species ($P < 0.05$). *A. digitata* recorded the highest calcium (212.7 ± 6.3 mg/100 g) and potassium (921.6 ± 21.5 mg/100 g), while *P. biglobosa*

had the highest iron (8.6 ± 0.4 mg/100 g) and zinc (3.8 ± 0.2 mg/100 g). *B. aegyptiaca* also showed relatively high Fe (8.2 ± 0.4 mg/100 g) and Zn (3.5 ± 0.2 mg/100 g). *V. paradoxa* consistently recorded the lowest concentrations of the four measured minerals (Table 3).

Table 3. Mineral composition of selected indigenous fruit tree species.

Species	Ca (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	K (mg/100 g)
<i>Adansonia digitata</i>	212.7 ± 6.3	6.5 ± 0.3	2.9 ± 0.1	921.6 ± 21.5
<i>Balanites aegyptiaca</i>	176.9 ± 5.4	8.2 ± 0.4	3.5 ± 0.2	874.1 ± 19.2
<i>Parkia biglobosa</i>	138.4 ± 4.8	8.6 ± 0.4	3.8 ± 0.2	845.3 ± 18.4
<i>Tamarindus indica</i>	164.3 ± 5.0	7.1 ± 0.3	3.2 ± 0.1	802.2 ± 17.7
<i>Vitellaria paradoxa</i>	124.6 ± 4.1	5.8 ± 0.2	2.5 ± 0.1	710.4 ± 16.8

Values are reported as mean $\pm$ SD.

Household Utilization and Income Contribution

Household utilization of the five species was substantial but varied among species (Table 4). *P. biglobosa* had the highest utilization frequency (92.8%), principally through fermented seed condiment production, and generated a mean annual household income of ₦78,500. *V. paradoxa* generated the highest reported annual income (₦96,800), largely

through shea-butter processing and marketing. *A. digitata* was utilized by 84.6% of households and contributed approximately ₦52,300 annually, while *T. indica* and *B. aegyptiaca* were used by 68.2% and 61.5% of households and generated approximately ₦44,600 and ₦39,400, respectively. *P. biglobosa* and *V. paradoxa* were particularly important during the lean season, reflecting their combined food and income functions.

Table 4. Household utilization and reported income contribution of selected indigenous fruit tree species.

Species	Households utilizing (%)	Mean annual income (₦/household)	Major product sold	Lean-season importance
<i>Adansonia digitata</i>	84.6	52,300	Fruit pulp/leaves	High

<i>Balanites aegyptiaca</i>	61.5	39,400	Fruits/oil	Moderate
<i>Parkia biglobosa</i>	92.8	78,500	Fermented seeds	Very high
<i>Tamarindus indica</i>	68.2	44,600	Fruit pulp	Moderate
<i>Vitellaria paradoxa</i>	76.4	96,800	Shea butter	Very high

Tree Population Structure and Regeneration

Substantial interspecific differences occurred in adult-tree density, diameter at breast height (DBH) and natural regeneration (Table 5). *B. aegyptiaca* had the highest adult density (22.6 ± 2.4 trees ha^{-1}), seedling density (16.5 ± 1.8 stems ha^{-1}) and sapling density (10.2 ± 1.3 stems ha^{-1}), indicating good regeneration. Conversely, *A. digitata* had the

lowest adult density (9.6 ± 1.3 trees ha^{-1}), seedling density (4.8 ± 0.8 stems ha^{-1}) and sapling density (3.2 ± 0.6 stems ha^{-1}), but the highest mean DBH (58.2 ± 4.1 cm). *P. biglobosa* recorded 18.4 ± 2.1 trees ha^{-1} , with 11.2 ± 1.4 seedlings ha^{-1} and 7.4 ± 1.0 saplings ha^{-1} . *V. paradoxa* and *T. indica* had intermediate adult densities of 14.8 ± 1.9 and 11.2 ± 1.5 trees ha^{-1} , respectively.

Table 5. Structural characteristics and regeneration of selected indigenous fruit tree species.

Species	Mean density (trees/ha)	Mean DBH (cm)	Seedlings/ha	Saplings/ha	Regeneration status
<i>Adansonia digitata</i>	9.6 ± 1.3	58.2 ± 4.1	4.8 ± 0.8	3.2 ± 0.6	Poor
<i>Balanites aegyptiaca</i>	22.6 ± 2.4	31.8 ± 2.2	16.5 ± 1.8	10.2 ± 1.3	Good
<i>Parkia biglobosa</i>	18.4 ± 2.1	42.7 ± 3.4	11.2 ± 1.4	7.4 ± 1.0	Moderate
<i>Tamarindus indica</i>	11.2 ± 1.5	36.4 ± 2.5	8.1 ± 1.1	5.6 ± 0.8	Fair
<i>Vitellaria paradoxa</i>	14.8 ± 1.9	39.5 ± 2.8	9.7 ± 1.2	6.8 ± 0.9	Moderate

Values are reported as mean $\pm$ SE in the source table

Woody-Plant Diversity and Environmental Relationships

Woody-plant richness and community diversity varied markedly among the six sampled communities (Table 6). Species richness ranged from nine species in Jakusko to 18 in Pindiga, while Shannon–Wiener diversity ranged from $H' = 1.82$ to 2.88 . Pindiga and Kwami had the highest richness (18 and 17 species) and diversity ($H' = 2.88$ and 2.73), whereas Jakusko and Damagum had the lowest values. Rainfall showed positive associations with adult-tree density ($r = 0.76$), mean DBH ($r = 0.61$) and regeneration density

($r = 0.82$) (Table 7). However, with only six community-level observations ($n = 6$), statistical inference was constrained. Using the prespecified critical value of $|r| = 0.811$ at $\alpha = 0.05$, only the rainfall–regeneration relationship exceeded the significance threshold ($r = 0.82$; $P \approx 0.05$). Correlations between rainfall and tree density or DBH, and among the three vegetation attributes, were not statistically significant. Thus, the results provide an exploratory indication that moisture availability may be associated particularly with regeneration, but do not establish causality.

Table 6. Woody-plant richness and diversity across study communities.

Community	Woody species richness (S)	Shannon–Wiener H'	Dominant focal IFT	Recorded ecological condition
Giade	14	2.46	<i>Parkia biglobosa</i>	Moderate
Misau	12	2.21	<i>Balanites aegyptiaca</i>	Moderate
Pindiga	18	2.88	<i>Vitellaria paradoxa</i>	High
Kwami	17	2.73	<i>Parkia biglobosa</i>	High
Damagum	10	1.94	<i>Balanites aegyptiaca</i>	Low
Jakusko	9	1.82	<i>Balanites aegyptiaca</i>	Low

H' values were calculated for the woody vegetation assemblage recorded in the inventory plots.

Correlation between rainfall and tree structure

Rainfall was positively correlated with tree density ($r = 0.76$), mean DBH ($r = 0.61$) and regeneration ($r = 0.82$). Tree density was also positively correlated with DBH ($r = 0.58$) and

regeneration ($r = 0.69$), while DBH and regeneration were moderately correlated ($r = 0.44$). Given the six community-level observations, only the rainfall–regeneration correlation ($r = 0.82$) meets the conventional two-tailed $P < 0.05$ threshold (Table 7).

Table 7. Pearson correlation matrix for rainfall and tree structural variables.

Variable	Rainfall	Tree density	DBH	Regeneration
Rainfall	1.00	0.76	0.61	0.82*
Tree density	0.76	1.00	0.58	0.69
DBH	0.61	0.58	1.00	0.44
Regeneration	0.82*	0.69	0.44	1.00

* $P < 0.05$, two-tailed; $n = 6$ community-level observations. DBH = diameter at breast height.

Discussion

Nutritional implications

The nutrient profiles indicate complementary nutritional characteristics among the focal species. *P. biglobosa* had the highest reported protein concentration, supporting its importance as a nutrient-dense indigenous food resource and as the raw material for fermented locust-bean condiment. *A. digitata* had the highest fibre and calcium concentrations, while *T. indica* had the highest carbohydrate value. *V. paradoxa* had the highest fat and reported energy values. Collectively, these differences support dietary diversification, but the present study did not measure household dietary intake, nutrient bioavailability or prevalence of micronutrient deficiency. The findings should therefore be presented as evidence of nutritional potential rather than proof that the species directly reduce malnutrition.

Socioeconomic importance

The household data show that *P. biglobosa* and *V. paradoxa* were particularly important

economically, with reported mean annual incomes of ₦78,500 and ₦96,800 per household, respectively. The importance of fermented *Parkia* products and shea butter is consistent with their established roles in rural value chains. The results also suggest that IFT products can provide seasonal income and food resources. However, income estimates are descriptive in the current dataset; the absence of measures of variance, product volumes, production costs and profitability prevents a stronger claim about economic superiority among species.

Regeneration and population sustainability

The ecological results identify a clear management contrast among the focal species. *B. aegyptiaca* showed the highest density and regeneration, whereas *A. digitata* showed the lowest recruitment and the largest mean DBH. A population dominated by mature trees with relatively few seedlings and saplings may indicate weak recruitment, although recruitment alone cannot establish a

demographic bottleneck without age- or size-class distributions, mortality data and repeated observations. The low regeneration of *A. digitata* nevertheless warrants conservation attention because continued removal of mature individuals without adequate recruitment could reduce future population continuity.

Woody-plant diversity across the environmental gradient

Pindiga and Kwami had the highest woody-species richness and Shannon diversity, whereas Damagum and Jakusko had the lowest values. The spatial pattern is consistent with an environmental gradient in which greater moisture availability and less severe aridity can support more complex woody vegetation. However, the present study is observational and cannot separate rainfall effects from differences in land use, grazing pressure, tenure, management intensity or disturbance history. The diversity results should therefore be interpreted as associations rather than causal evidence of climatic control.

Rainfall, tree structure and regeneration

Rainfall showed a strong positive association with regeneration at the community level ($r = 0.82$), while correlations with density and DBH were positive but not statistically significant with only six observations. This small sample size substantially limits inferential power. The positive direction of the associations is ecologically plausible, but additional plots and replicated measurements within communities would be required to establish robust relationships between climatic gradients and tree population dynamics.

Implications for agroforestry and conservation

The combined findings support the retention and sustainable management of indigenous fruit trees within savanna agroforestry systems. *Parkia biglobosa* and *Vitellariaparadoxa* have strong livelihood value; *Adansoniadigitata* has notable fibre and mineral attributes but weak observed regeneration; and *Balanitesaegyptiaca* combines relatively high abundance with strong regeneration. A species-specific management strategy is therefore preferable to

a uniform approach. Such a strategy should combine assisted natural regeneration, protection of mature seed trees, enrichment planting where recruitment is inadequate, sustainable harvesting and stronger local value chains. These recommendations are management implications derived from the study rather than directly tested interventions.

Conclusion

The study demonstrates that the selected indigenous fruit trees have complementary nutritional, socioeconomic and ecological attributes within savanna agroforestry landscapes of northeastern Nigeria. *Parkia biglobosa* had the highest reported protein concentration and was among the most important species for household income, while *Vitellariaparadoxa* had the highest reported fat and energy values and the greatest mean annual household income. *Adansoniadigitata* showed high fibre and mineral values but poor observed regeneration, whereas *Balanitesaegyptiaca* showed the strongest regeneration and highest tree density. Woody-plant richness and diversity were greater in the Guinea–Sudan transition communities than in the drier Yobe communities. Overall, the evidence supports the strategic retention, sustainable management and enrichment of indigenous fruit trees in agroforestry systems as part of integrated approaches to food diversification, rural livelihood support and landscape-level biodiversity conservation. Further work should quantify nutrient bioavailability, profitability, demographic recruitment and the effects of management interventions before stronger causal or nutritional-security claims are made.

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