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Revaluing Underutilized Agrobiodiversity Through a Biocultural Indigenomics Framework

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Indigenomics is proposed as an integrative analytical framework for examining relationships between Indigenous Peoples and Local Communities (IPLCs) and ethnobotanical resources through interconnected ecological, cultural, and socioeconomic dimensions. The framework emphasizes four key components of biocultural value: ecological integration, collective well-being, cultural sovereignty, and monetary valuation. To operationalize this approach, we developed four participatory indices: the Ecological Integration Score (EIS), the Collective Well-being Index (CWI), the Cultural Sovereignty Index (CSI), and the Monetary Value Score (MVS). These indices were combined to generate a composite Indigenomics Index (II) and an Indigenomics Value Rating (IVR), enabling comparative assessment of plant species across multiple value domains. The framework was applied to underutilized palm species in northwest Nigeria using a mixed-methods design involving 86 participants from local communities. Results indicate variation in biocultural and socioeconomic valuation across species. Native palms generally exhibited higher composite scores across ecological, cultural, and well-being dimensions. In particular, *Phoenix dactylifera* L. showed the highest collective well-being (CWI = 9.0) and monetary value (MVS = ₦20,578,000; USD 13,645.19), as well as full recognition of cultural sovereignty (CSI = 100%). *Borassus aethiopum* Mart. and *Hyphaene thebaica* (L.) Mart. also demonstrated strong biocultural integration, as evidenced by high II values. In contrast, introduced species (*Caryota mitis* Lour. and *Roystonea regia* O.F. Cook) consistently recorded lower scores across all indices. These findings suggest that the Indigenomics framework can support the comparative assessment

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of biocultural values in agrobiodiversity systems, particularly in highlighting the interconnected ecological and cultural significance of native species. Further refinement and cross-regional validation are required to assess its broader applicability in sustainable agrobiodiversity governance.

Keywords: agrobiodiversity, biocultural valuation, ethnobotany, Indigenous knowledge systems, participatory indices, sustainability, underutilized species

Introduction

Indigenous and Local Knowledge (ILK) systems have been pivotal in driving economic innovation across diverse sectors, including agriculture, health, biotechnology, and tourism (Bridgewater and Rotherham, 2019; Poyser and Daugaard, 2023). In ethnobotany, quantitative indices developed since the 1980s have provided foundational tools for assessing the cultural and utilitarian significance of plant species based on ILK (Hoffman and Gallaher, 2007; Gaoue et al., 2017). However, many of these indices remain reductionist in nature, often emphasizing narrowly descriptive metrics such as Use Value (UV) and Informant Consensus Factor (ICF) (Hoffman and Gallaher, 2007), while failing to capture the multidimensional and relational character of ILK systems.

This limitation is particularly evident in the assessment of Neglected and Underutilized Species (NUS), which constitute an important component of agrobiodiversity and have historically supported livelihood resilience across ecological, cultural, spiritual, and commercial dimensions (Salako et al., 2018; Igwe, 2021; Skroblin et al., 2021; Obadiah et al., 2025; Ariyo, 2023; Beehner, 2024). Despite their importance, existing ethnobotanical frameworks often fail to integrate these multiple dimensions into a unified evaluative structure that reflects both ecological function and socio-cultural embeddedness.

To address these limitations, this study adopts the concept of "Indigenomics," a biocultural economic epistemology articulated by Hilton (2021) and further developed by Obadiah et al. (2025). This framework seeks to translate the roles of species in ecological integration, relational well-being, biocultural sovereignty, and market valuation into quantifiable metrics grounded in the socioeconomic knowledge systems of Indigenous Peoples and Local Communities (IPLCs). Specifically, the framework operationalizes four indices: the Ecological Integration Score (EIS), the Collective Well-being Index (CWI), the Cultural Sovereignty Index (CSI), and the Monetary Value Score (MVS), which are synthesized into an overarching Indigenomics Index (II) and Indigenomics Value Rating (IVR).

This conceptual expansion moves beyond traditional ethnobotanical approaches by explicitly integrating ecological, cultural, and economic dimensions of neglected and underutilized species into a single analytical structure. Indigenomics repositions IPLCs as dynamic socio-economic systems with distinct and sustainable development logics (Hilton, 2021), thereby offering a potential tool for optimizing the valuation of underutilized agrobiodiversity (Obadiah et al., 2025). It emphasizes reciprocity, collective well-being, intergenerational sustainability, and cultural continuity rather than individual profit maximization in the market (Hilton, 2021; Obadiah et al., 2025).

The aim of this research is to optimize underutilized plant agrobiodiversity through the application of the Indigenomics framework, evaluating species contributions to ecological integration, relational well-being, biocultural sovereignty, and commercial value. The specific objectives are to develop and operationalize Indigenomics indices, validate them using community-informed data, and assess their relevance for biocultural economic analysis and traditional biodiversity conservation, using neglected and underutilized tropical palm species as a case study.

We hypothesize that native species will achieve higher levels of ecological integration, cultural sovereignty, and socioeconomic value than introduced species, reflecting their long-term embeddedness within local socio-ecological systems. First, the study examines whether the proposed indices effectively capture differences in ecological integration, cultural sovereignty, collective well-being, and market value across species. Second, it assesses how these measures reflect broader biocultural significance. Finally, it explores the potential of the Indigenomics framework to inform policy and strengthen ethnobotanical research.

Material and Methodology

Study design

This study employed a transdisciplinary mixed-methods approach integrating biodiversity assessment protocols with participatory ethnobotanical surveys. The design aimed to operationalize the Indigenomics framework by capturing ecological, cultural, and socioeconomic dimensions of plant–community relationships, while centering the perspectives of Indigenous Peoples and Local Communities (IPLCs) in resource valuation.

Study area

The research was conducted in Northwest Nigeria, characterized by a tropical continental climate and Sudan Savannah vegetation. Fieldwork took place between November 2024 and May 2025 across 22 Local Government Areas and 65 districts in Kebbi, Jigawa, and Sokoto states.

The study area covers approximately 131,600 km^2 (latitudes 11°–13° 30′ N; longitudes 4°–9° 30′ E), with annual rainfall of 600–700 mm and high temperature variability. The vegetation supports drought-tolerant species such as *Adansonia digitata*, *Balanites aegyptiaca*, and *Acacia* spp. (Abubakar et al., 2023). The region is inhabited by Hausa, Fulani, Kabbawa, and C'lella communities whose livelihoods are based on farming, livestock production, and seasonal fishing.

Species selection

The study focused on three underutilized native palm species (Arecaceae): *Borassus aethiopum* (African fan palm), *Phoenix dactylifera* (date palm), and *Hyphaene thebaica* (doum palm).

Native species were defined as those that naturally occur in the region and co-evolve with IPLCs. These species contribute to food systems, fiber production, oil extraction, and cultural practices (Daudu et al., 2022).

Two introduced species were included for comparison: *Roystonea regia* (royal palm) and *Caryota mitis* (fishtail palm).

This comparison enabled assessment of differences in ecological integration and biocultural value between native and introduced taxa. The spatial distribution of the selected palm species across the study area is presented in Figure 1.

Sampling and participants

Sampling followed a stratified design based on species and demographic characteristics, combining

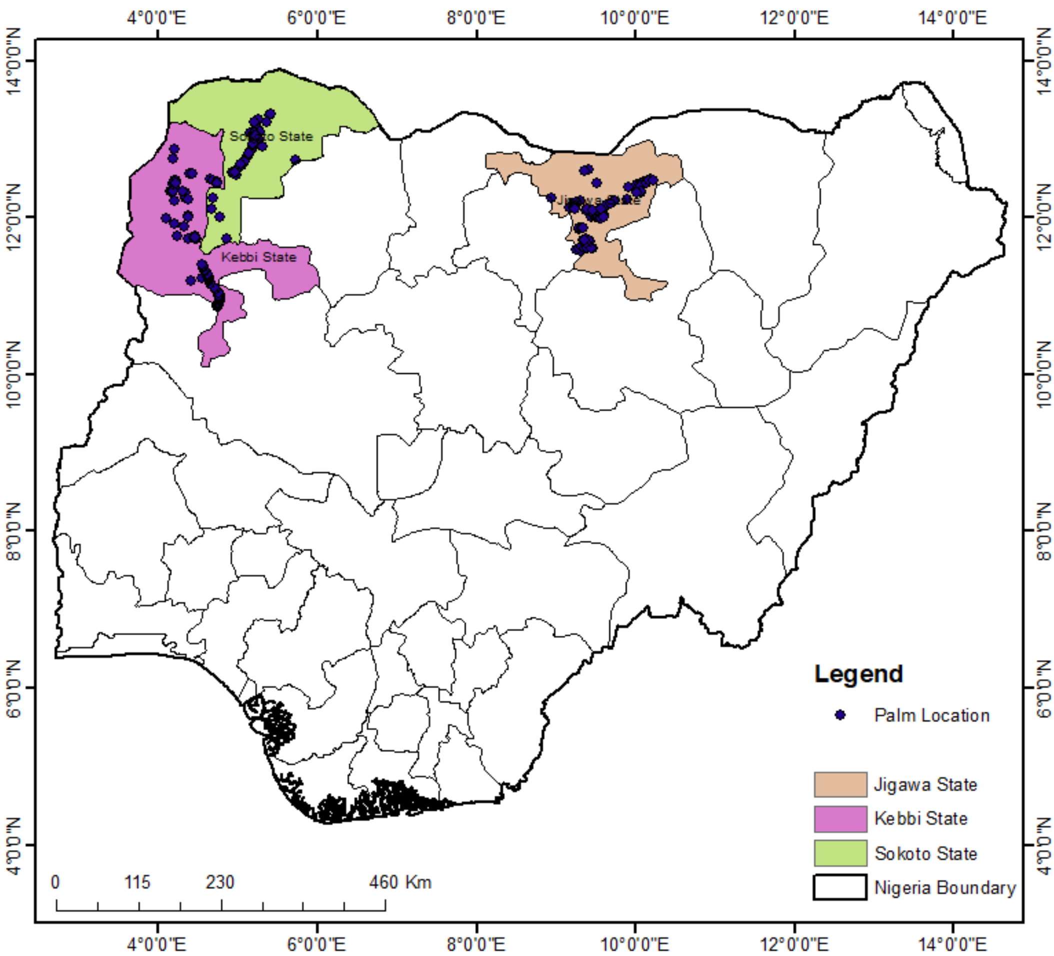

Figure 1 Diva-GIS distribution map of selected palm species in Kebbi, Sokoto, and Jigawa states of Northwest Nigeria

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purposive and respondent-driven sampling approaches (McCreesh et al., 2013; Klar and Leeper, 2019).

Participants were selected based on: long-term residency, active livelihood engagement, and recognition as ILK holders.

A total of 86 valid responses were analyzed (from 150 distributed questionnaires). The sample consisted of 79% male and 21% female participants across Hausa, Fulani, Kabbawa, and C'lella groups. Most respondents were aged 35–54 and had lived in their communities for 20–30 years. Primary occupations included trading (41%), farming (28%), and civil service (22%).

Data collection

Ecological data

Ecological data were collected using geo-referenced sampling via the Conota mobile application (v.1.2.6), complemented by Global Biodiversity Information Facility (GBIF) occurrence records and published vegetation surveys.

Voucher specimens were prepared following standard botanical procedures and deposited at the Federal University Birnin Kebbi Herbarium (FUBKH).

Ethnobotanical data

Ethnobotanical data were collected through structured questionnaires and free-listing interviews. Interviews were conducted in local languages to ensure cultural accuracy (Rainie et al., 2019). Quantitative data on income, harvest quantities, and subsistence use were also recorded. Complementary quantitative data on household income, harvest quantities, and subsistence reliance were also systematically recorded to support socioeconomic analysis. A total of 150 questionnaires were distributed, 86 of which met the validation criteria for completeness and internal consistency and were included in the final analysis.

Ethical considerations

The study followed the International Society of Ethnobiology Code of Ethics. Free, Prior, and Informed Consent (FPIC) was obtained from all participants.

Ethical procedures included: anonymization of data, voluntary participation, community-level approval, and continuous consent.

The study was approved by the Federal University Birnin Kebbi Ethics Committee. Communities were engaged as collaborators, with feedback sessions and knowledge-sharing activities (Vandebroek et al., 2025).

Questionnaire development

The questionnaire was co-developed with local stakeholders to ensure cultural validity and data sovereignty (Kelly, 2021). It included both open- and closed-ended questions addressing ethnobotanical knowledge, socioeconomic values, and resource management practices.

Refined versions were distributed in printed format to accommodate varying literacy levels. Sample questionnaires and validated responses are provided in Electronic Supplementary Materials (ESM 9 and ESM 10), respectively.

Statistical analysis

A mixed-methods analytical strategy was applied to evaluate the ecological, cultural, and economic significance of the studied species. Qualitative data from free-listing interviews were subjected to thematic analysis to identify recurring cultural domains and use categories. The analysis was conducted using the pandas library in a Google Colaboratory notebook (Google, 2023) to compute and validate the novel Indigenomics indices described in subsequent sections.

Development of indigenomics indices

Framework and rationale

The Indigenomics indices were developed to address limitations in commonly used ethnobotanical metrics such as Use Value (Phillips and Gentry, 1993a) and Cultural Importance (Tardío and Pardo-de-Santayana, 2008), which primarily aggregate individual-level responses and may underrepresent community-level dimensions, including stewardship, shared-access systems, and cultural governance.

The indices were derived through an iterative process combining literature review, consultations with IPLCs, and mathematical formalization (Obadiah et al., 2025; Rainie et al., 2019).

Ecological Integration Score (*EIS*)

The Ecological Integration Score (*EIS*) integrates ecological and ethnobotanical data to quantify species' ecological roles within IPLCs systems. It combines biodiversity metrics derived from the Importance Value Index (Curtis and McIntosh, 1951) with locally reported regeneration practices and ecosystem functions.

Formula: For species s, the score is calculated as the arithmetic mean of its normalized biodiversity (B_s), regeneration (R_s), and habitat interdependence (HI_s) values.

$$EIS_s = \frac{B_s + R_s + HI_s}{3}$$

Components:

- Biodiversity (B_s): Calculated as the normalized sum of relative frequency (RF), relative density (RD), and relative abundance (RA).

$$(B_s) \text{ or } (SIV) = normalized\ (RF_s + RD_s + RA_s)$$

- Regeneration (R_s): Proportion of respondents identifying species s as cultivated or semi-domesticated:

$$R_s = \frac{\sum_{j=1}^{N_{resp,s}} I_{cult/semi,j,s}}{\sum_{j=1}^{N_{resp,s}} I_{total\_responses,j,s}}$$

- Habitat interdependence (HI_s): Average number of ecological roles reported per respondent, normalized to a maximum reference value (e.g., 4):

$$HI_s = \frac{1}{N_{resp,s}} \sum_{j=1}^{N_{resp,s}} \left(\frac{count\ of\ distinct\ environmental\ roles\ by\ j\ for\ s}{4} \right)$$

Interpretation: The *EIS* identifies species that are ecologically foundational and actively regenerated, with scores near 1.0 signaling strong community consensus on ecological centrality and stewardship value.

Collective Well-being Index (*CWI*)

The Collective Well-being Index (*CWI*) measures species contributions to community-level livelihood systems.

Formula:

$$CWI_s = \frac{SA_s + N_s + H_s + Eq_s + TU_s}{5}$$

Components:

- Shared Access (SA_s): Derived from responses on reciprocity and sharing practices (Johnson, 2015).
- Nutrition (N_s): Binary indicator: N_s = 1 if food use is reported; otherwise 0:

$$N_s = \sum_{j=1}^{N_{resp,s}} I_{food\_use,j,s} > 0$$

- Health (H_s): Binary indicator: H_s = 1 if medicinal use is reported; otherwise 0.
- Equity (Eq_s): Indicator reflecting distribution of benefits within the community (Johnson, 2015).
- Traditional Use (TU_s): Binary indicator: TU_s = 1 if cultural or traditional uses are reported; otherwise 0.

$$TU_s = \sum_{j=1}^{N_{resp,s}} I_{traditional\_use,j,s} > 0$$

where: $N_{resp,s}$ represent the total number of respondents who provided any information about species *s* and $I_{use,j,s} > 0$ denotes the normalized index value of species s used by IPLCs.

Interpretation: *CWI* values range from 0 to 1, with higher values indicating greater representation of the species across shared access, nutrition, health, equity, and traditional use components.

Cultural Sovereignty Index (*CSI*)

The Cultural Sovereignty Index (*CSI*) quantifies the proportion of respondents reporting ceremonial, spiritual, or governance-related uses of a species, reflecting its role in cultural continuity and self-determination within IPLCs. In contrast to the Cultural Importance Index (*CI*), which assigns equal weight to all use categories (Tardío and Pardo-de-Santayana, 2008; da Silva et al., 2014a), the CSI focuses specifically on culturally embedded functions, following the conceptual framework outlined by Herrmann-Pillath (2024).

Formula:

$$CSI_s = \frac{N_{cultural,s}}{N_{total,s}} \times 100\%$$

where: $N_{cultural,s}$ is the number of respondents reporting specific ceremonial, spiritual, or governance uses, and $N_{total,s}$ is the total number of respondents citing the species.

Interpretation: *CSI* values range from 0 to 100%, with higher values indicating a greater proportion of respondents associating the species with cultural functions.

Monetary Value Score (*MVS*)

The Monetary Value Score (*MVS*) quantifies the economic value of a species based on market-related data derived from reported prices and usage or harvest quantities. The approach is informed by ecological economics valuation methods (Gómez-Baggethun and Martín-López, 2015).

To ensure comparability with non-monetary indices, *MVS* values were normalized prior to inclusion in the composite Indigenomics Index.

Formula:

$$MVS_s = \sum_{i=1}^{n} price_{i,s} \times quantity_{i,s}$$

where: $price_{i,s}$ – average market price, $quantity_{i,s}$ – annual frequency of use or harvest

Interpretation: *MVS* values increase with higher reported price and/or quantity of use. Normalized values are used for integration with other indices.

Indigenomics Index (II)

The Indigenomics Index (II) integrates four normalized sub-indices – Ecological Integration Score (*EIS*), Collective Well-being Index (*CWI*), Cultural Sovereignty Index (*CSI*), and Monetary Value Score (*MVS*) – to provide a composite measure of species value across ecological, cultural, and socioeconomic dimensions (Obadiah et al., 2025) (Figure 3).

The index is calculated using a weighted aggregation approach, where weights are assigned to reflect community-derived priorities. Alternatively, an equal-weight formulation is applied for comparative purposes (da Silva et al., 2014b).

Formula: the weighted index is expressed as:

$$II_{weighted} = w_{ec} \times EIS + w_{cw} \times CWI + w_{cs} \times CSI + w_{mv} \times MVS$$

Subject to the constraint, .

Hence, equal weighting can serve as an alternative. It is calculated as the arithmetic mean of the four sub-indices on a common scale:

$$II_{equal} = \frac{EIS + CWI + CSI + MVS}{4}$$

Interpretation: II values increase with higher combined scores across the four component indices. All sub-indices are normalized prior to aggregation to ensure comparability.

Indigenomics Value Rating (*IVR*)

The Indigenomics Value Rating (*IVR*) combines the baseline Indigenomics Index (II) with measures of species use dynamics. The approach is informed by conservation assessment frameworks (IUCN, 2024) and applies a multiplicative structure to integrate static and dynamic components.

The *IVR* incorporates two additional variables: usage frequency (*UF*) and cultural diversity (*CD*).

Formula:

$$IVR_s = II_s \times UF_s \times CD_s$$

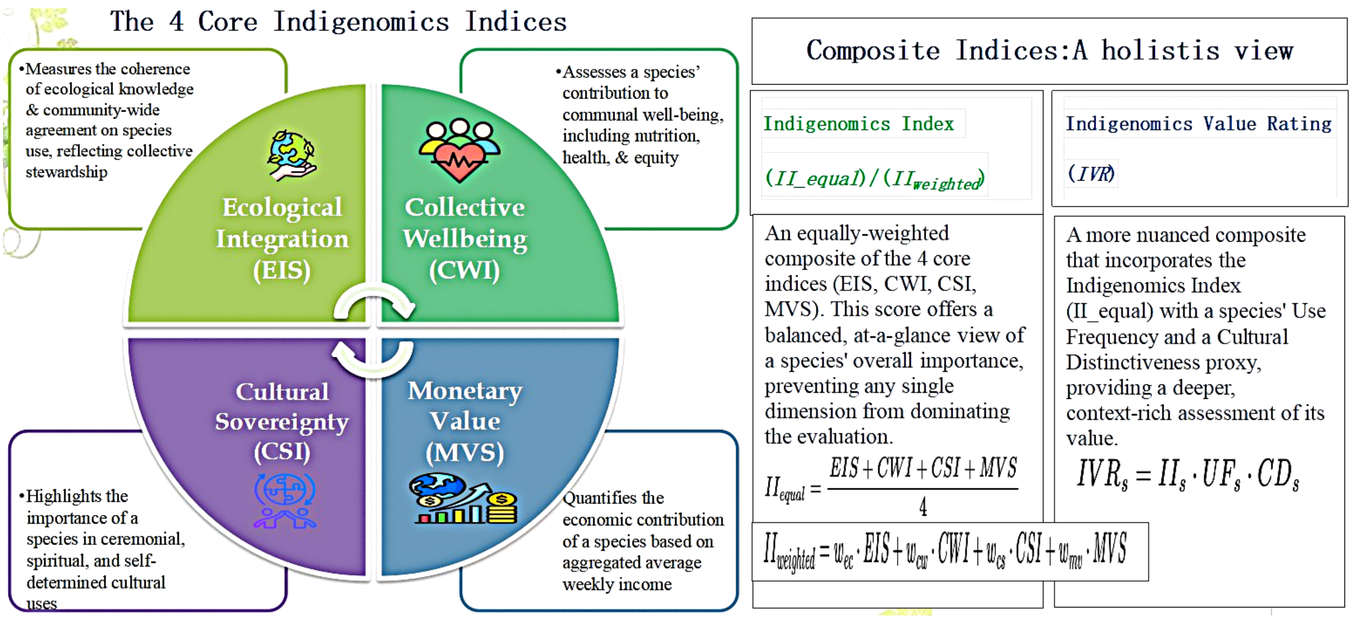

Figure 2 Conceptual model of the Indigenomics framework linking ecological, cultural, social, and economic dimensions of biocultural valuation

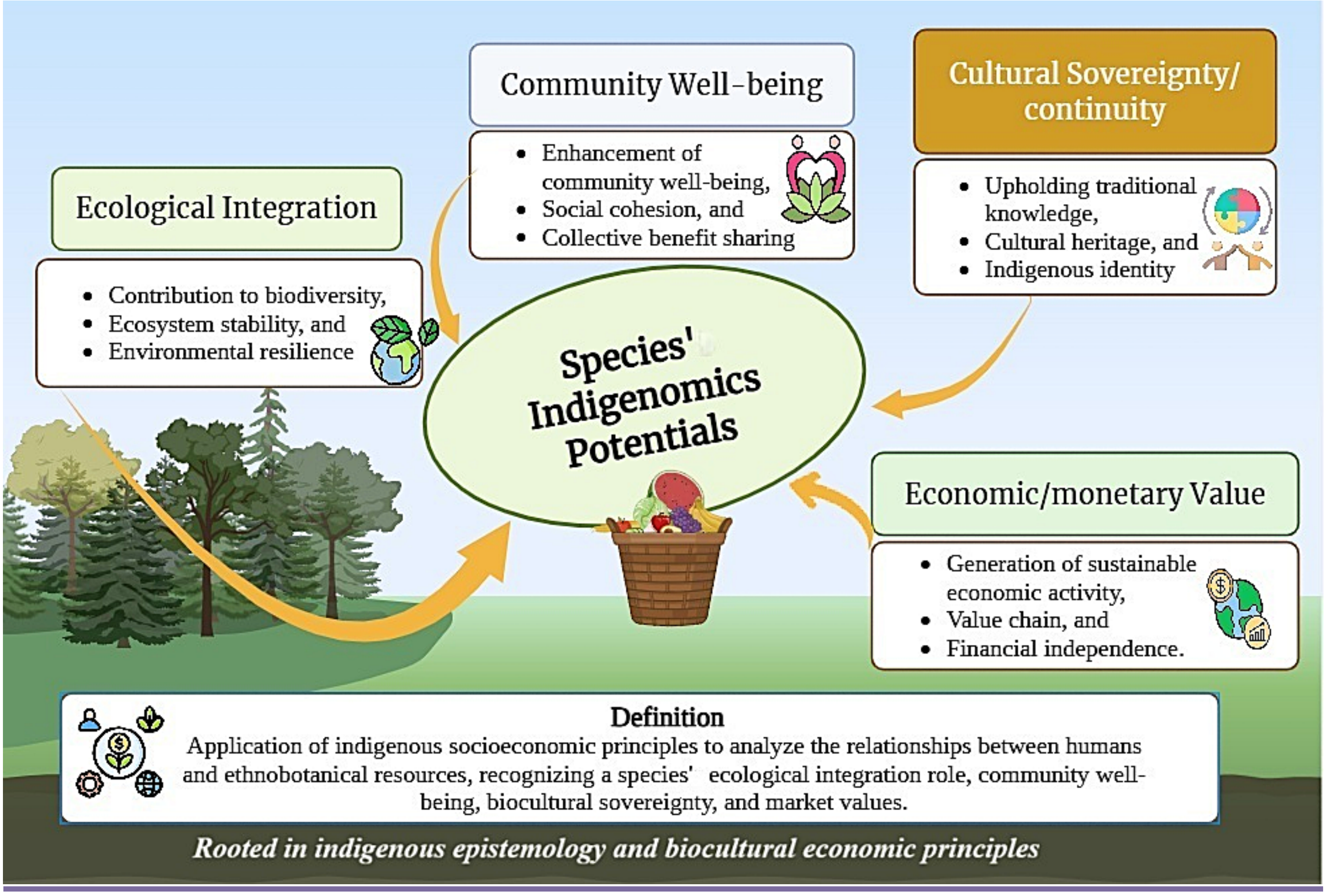

Figure 3 Indigenomics framework for species' potential (Obadiah et al., 2025)

Components:

- Usage Frequency (*UFs*): A scaled measure of use intensity (e.g., daily = 1.0, rare = 0.25).
- Cultural Diversity (*CDs*): A normalized measure of the distribution of species use across different ethnic groups or clans within the study area.

Interpretation: IVR offers a nuanced measure of a species' role by combining its Indigenomics Index with its usage frequency and cultural reach. Higher scores reflect stronger holistic values alongside broader and more consistent utilization

Results and Discussion

Results

The application of the Indigenomics framework to palm species in Northwest Nigeria revealed variation in ecological, cultural, social, and economic values across species. Quantitative indices and qualitative thematic analysis were used to assess species-specific patterns across ecological systems, livelihood contributions, cultural practices, and market participation.

Indigenomics indices of palm species in Northwest Nigeria

The application of the Indigenomics framework revealed substantial variation in ecological, cultural, social, and economic values among palm species across Northwest Nigeria (Table 1, Figure 4). Native species consistently showed higher integrated values compared to introduced species.

Phoenix dactylifera recorded the highest overall performance across multiple indices, followed by *Hyphaene thebaica* and *Borassus aethiopum*. Introduced species (*Caryota mitis* and *Roystonea regia*) consistently exhibited lower values across all indices.

Ecological Integration Score (*EIS*)

Ecological integration varied across species and states (Table 1, Figure 4). Native palms in Kebbi recorded the highest EIS values, particularly *Borassus aethiopum* (4.00) and *Hyphaene thebaica* (3.53).

Phoenix dactylifera showed moderate ecological integration in Jigawa (2.59), while lower values were recorded in Sokoto. Introduced species showed consistently low ecological integration, ranging from

Table 1 Indigenomics indices of palm species in Northwest Nigeria

State	Species Name	*EIS*	*CWI*	*CSI* (%)	MVS (₦)	II_equal	*IVR*
	Borassus aethiopum	2.47	5.26	100.00	5714600.00	0.62	1.19
	Caryota mitis	0.55	0.31	0.00	873000.00	0.05	0.00
Jigawa	*Hyphaene thebaica*	2.01	3.65	96.77	2860100.00	0.50	1.01
	Phoenix dactylifera	2.59	7.93	100.00	20578000.00	0.88	2.36
	Roystonea regia	1.05	0.45	0.00	143000.00	0.08	0.00
	Borassus aethiopum	4.00	8.50	96.97	13026500.00	0.88	1.77
	Caryota mitis	0.04	0.25	0.00	119500.00	0.01	0.00
Kebbi	*Hyphaene thebaica*	3.53	8.47	96.97	20802700.00	0.95	1.98
	Phoenix dactylifera	0.96	9.00	96.97	16697500.00	0.75	1.98
	Roystonea regia	0.28	0.30	3.03	318000.00	0.03	0.00
	Borassus aethiopum	1.90	6.93	81.82	1446000.00	0.53	0.58
	Caryota mitis	0.74	0.08	0.00	692500.00	0.05	0.00
Sokoto	*Hyphaene thebaica*	1.90	6.81	95.45	1456000.00	0.56	0.74
	Phoenix dactylifera	1.41	7.02	81.82	12399000.00	0.63	0.76
	Roystonea regia	1.69	0.03	0.00	120000.00	0.10	0.00

Notes: EIS – Ecological Integration Score; CWI – Collective Well-Being; CSI – Cultural Sovereignty Index; MVS – Monetary Value Score, II_equal – Indigenomics Index; IVR – Indigenomics Value Rating

0.04 (*Caryota mitis* in Kebbi) to 1.69 (*Roystonea regia* in Sokoto).

Complementary Importance Value Index (IVI) results are provided in ESM 2.

Collective Well-being Index (*CWI*)

The Collective Well-being Index varied across regions and species (Table 1). *Phoenix dactylifera* recorded the highest values in Kebbi and Jigawa, with scores of 9.0 and 7.93, respectively. *Borassus aethiopum* and *Hyphaene thebaica* consistently showed elevated CWI values in Kebbi. Introduced species, including *Roystonea regia* and *Caryota mitis*, consistently recorded low scores (<0.45), reflecting limited contributions to nutrition (ESM 5), traditional practices (ESM 6), and community-level use.

Cultural Sovereignty Index (*CSI*)

The Cultural Sovereignty Index, expressed as a percentage, underscores the species integral to IPLCs' self-determination and cultural preservation.

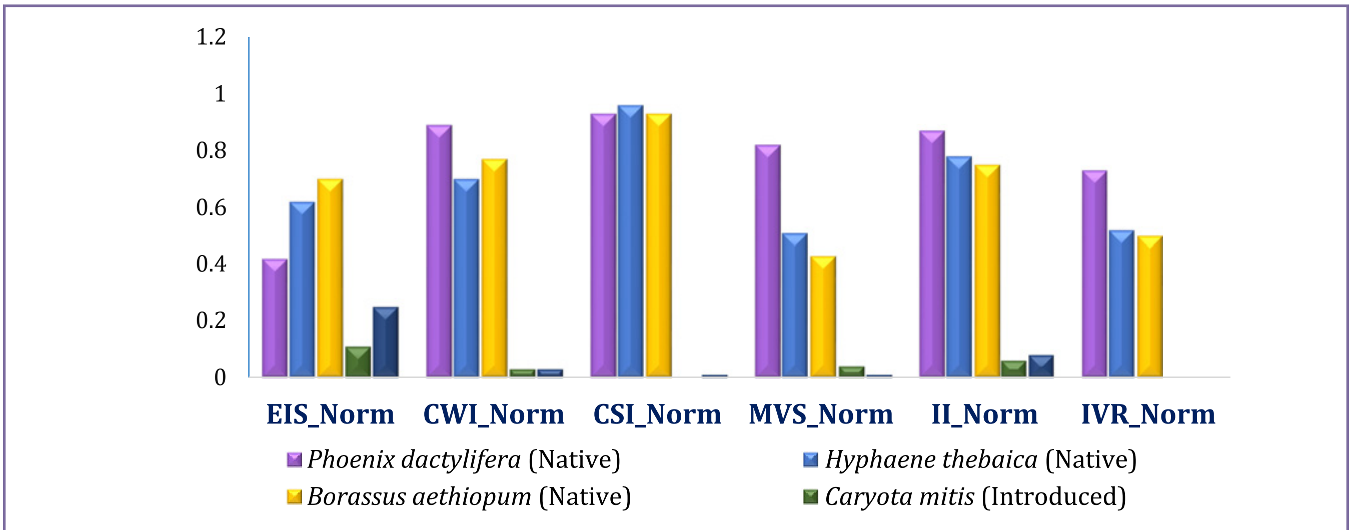

Figure 4 Indigenomics metrics comparison between native and introduced palm species in Northwest Nigeria
NB – All metric data on the Bar chart are normalized to a scale of 0–1

These results highlight the role of native palms as cultural keystone species supporting traditional knowledge systems (Table 1 and ESM 6). *Phoenix dactylifera* and *Borassus aethiopum* achieved 100% cultural sovereignty in Jigawa State, while maintaining high values in Kebbi (96.97%) and moderate values in Sokoto (81.82%). *Hyphaene thebaica* consistently demonstrated high cultural importance across all states. Conversely, introduced species scored 0%, reflecting negligible ceremonial or culturally specific uses among IPLCs in northwest Nigeria.

The Cultural Sovereignty Index (CSI), expressed as a percentage, varied across species and regions (Table 1, ESM 6).

Phoenix dactylifera and *Borassus aethiopum* achieved 100% CSI in Jigawa State, with values of 96.97% in Kebbi and 81.82% in Sokoto. *Hyphaene thebaica* consistently showed high CSI values across all states.

Introduced species (*Caryota mitis* and *Roystonea regia*) recorded a CSI of 0%, indicating no reported ceremonial, spiritual, or governance-related uses among IPLCs in the study area.

Monetary Value Score (MVS)

Market-based valuation of palm species varied across species and states (Table 1, ESM 7).

Phoenix dactylifera recorded the highest monetary value in Jigawa (₦20,578,000; $13,645.19), followed by values in Kebbi and Sokoto. *Hyphaene thebaica* showed high monetary value in Kebbi (₦20,802,700; $13,794.12). *Borassus aethiopum* demonstrated substantial monetary values across all states, ranging from ₦1,446,000 to ₦13,026,500 ($958.83 to $8,637.77). Introduced species (*Caryota mitis* and *Roystonea regia*) consistently recorded low monetary values, below ₦873,000 ($578.88), indicating limited market contribution.

Overall Indigenomics Value (II and IVR)

The composite Indigenomics Index (II_equal) ranged from 0.05 to 0.95 across species (Table 1). The highest values were recorded for *Hyphaene thebaica* (0.95) and *Borassus aethiopum* (0.88) in Kebbi State. *Phoenix dactylifera* showed relatively high values in Jigawa, while lower values were observed in Sokoto.

The Indigenomics Value Rating (IVR) ranged from 0 to 2.36. *Phoenix dactylifera* recorded the highest IVR in Jigawa (2.36) and Kebbi (1.98). *Caryota mitis* and *Roystonea regia* consistently recorded 0 values across all states.

Indigenomics index trends across ethnic groups in Northwest Nigeria

Variation in Indigenomics indices was observed across ethnic groups (Table 2a–2c, Figure 5).

Higher mean values of EIS, CWI, CSI, II_equal, and IVR were recorded among C'lella, Dendi, Kambawa, and Shangawa/Hausa groups. Lower mean values were observed among the Fulani and Hausa groups.

Across groups, EIS ranged from 1.67 to 1.76, while CWI ranged from 4.33 to 5.30 (Table 2a). CSI values ranged from 56.65 to 58.79%, with median values ranging from 81.82 to 96.97% (Table 2b). II_equal ranged from 0.44 to 0.52, while IVR ranged from 0.83 to 1.15 (Table 2c).

Table 2a Descriptive statistics of Ecological Integration Score (EIS) and Collective Well-being Index (CWI) across ethnic groups in Northwest Nigeria

Ethnic groups	EIS			CWI		
	mean	median	std	mean	median	std
C'lella	1.76	0.96	1.87	5.30	8.47	4.60
Dendi/Hausa	1.76	0.96	1.87	5.30	8.47	4.60
Fulani	1.67	1.69	1.14	4.33	5.26	3.70
Hausa	1.67	1.69	1.14	4.33	5.26	3.70
Hausa/Ariwa	1.76	0.96	1.87	5.30	8.47	4.60
Hausa/Fulani	1.67	1.69	1.14	4.33	5.26	3.70
Kabbawa	1.76	0.96	1.87	5.30	8.47	4.60
Kambawa	1.76	0.96	1.87	5.30	8.47	4.60
Shangawa/Hausa	1.76	0.96	1.87	5.30	8.47	4.60

Table 2b Descriptive statistics of Cultural Sovereignty Index (CSI) and Monetary Value Score (MVS) across ethnic groups in Northwest Nigeria

Ethnic groups	CSI			MVS		
	mean	median	std	mean	median	std
C'lella	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0
Dendi/Hausa	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0
Fulani	56.65	81.82	47.76	6,483,093.0	1,456,000.0	7,903,073.0
Hausa	56.65	81.82	47.76	6,483,093.0	1,456,000.0	7,903,073.0
Hausa/Ariwa	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0
Hausa/Fulani	56.65	81.82	47.76	6,483,093.00	1,456,000.00	7,903,073.0
Kabbawa	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0
Kambawa	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0
Shangawa/Hausa	58.79	96.97	52.29	10,192,840.0	13,026,500.0	9,511,756.0

Table 2c Descriptive statistics of the Indigenomics Index (equal weights) and Indigenomics Value Rating across ethnic groups in Northwest Nigeria

Ethnic groups	II_equal			IVR		
	mean	median	std	mean	median	std
C'lella	0.52	0.75	0.47	1.15	1.77	1.05
Dendi/Hausa	0.52	0.75	0.47	1.15	1.77	1.05
Fulani	0.44	0.53	0.35	0.83	0.74	0.86
Hausa	0.44	0.53	0.35	0.83	0.74	0.86
Hausa/Ariwa	0.52	0.75	0.47	1.15	1.77	1.05
Hausa/Fulani	0.44	0.53	0.35	0.83	0.74	0.86
Kabbawa	0.52	0.75	0.47	1.15	1.77	1.05
Kambawa	0.52	0.75	0.47	1.15	1.77	1.05
Shangawa/Hausa	0.52	0.75	0.47	1.15	1.77	1.05

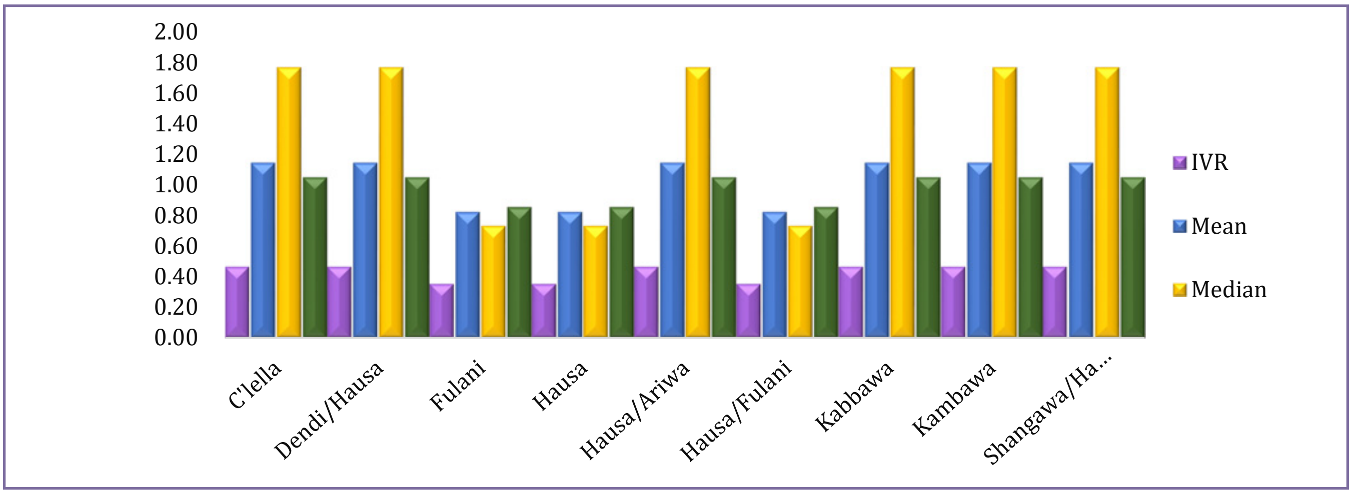

Figure 5 Indigenomics Value Rating (IVR) trends across ethnic groups in Northwest Nigeria

Thematic analysis of indigenomics

Ecological roles of palm species in Northwest Nigeria

Survey responses (ESM 10) indicate the role of native palms in agroecological systems in Northwest Nigeria.

Native palms provided multiple ecosystem services, including erosion control, land restoration, boundary demarcation, and habitat provision for pollinators. *Hyphaene thebaica* and *Borassus aethiopum* showed higher ecological integration based on reported uses. Introduced species (*Roystonea regia* and *Caryota mitis*) were primarily reported as ornamental, with limited ecological functions.

Nutritional and medicinal applications of palm species in Northwest Nigeria

Native species were widely reported for nutritional and medicinal uses (ESM 5, ESM 6).

Borassus aethiopum and *Phoenix dactylifera* fruits were consumed fresh or dried. Juvenile saplings of *Borassus aethiopum* were reported as food (mùrúúcí or gàzáríí). *Phoenix dactylifera* was also reported as a food source during Ramadan fasting periods. *Hyphaene thebaica* was reported in emergency food and medicinal preparations. Introduced species showed limited reported nutritional or medicinal use.

Cultural and traditional significance of palm species in Northwest Nigeria

Native palms were deeply embedded in IPLCs' practices, serving in handicrafts, construction, fuel, and spiritual activities. Introduced species lacked cultural significance, emphasizing the role of native palms as keystone species preserving traditional knowledge and practices (ESM 6).

Monetary contribution and market dynamics of palm species in Northwest Nigeria

The monetary value of palm species varied across species and use systems (ESM 7).

Phoenix dactylifera recorded weekly income ranging from ₦4,000 to ₦2,700,000 ($2.65–$1,790.34), generated through multiple processing and distribution channels, including online sales. *Borassus aethiopum* and *Hyphaene thebaica* recorded weekly incomes of ₦9,000–₦591,000 ($5.97–$391.89) and ₦4,200–₦520,000 ($2.78–$344.81), respectively.

Introduced species recorded lower income ranges, between ₦0–₦1,000,000 ($0–$663.09) for *Caryota mitis* and ₦0–₦400,000 ($0–$265.24) for *Roystonea regia*. These species were primarily reported as whole-plant nursery products with limited processing.

Challenges, conservation practices, and support needs for palm species in northwest Nigeria

Reported threats to palm species included land-use change, climate variability, expansion of industrial agriculture, urban development, and declining youth engagement (ESM 8).

Conservation practices reported by IPLCs included selective harvesting, cultural restrictions, and protection of sacred sites. However, respondents indicated that these practices alone were insufficient to prevent decline.

Across all communities, there was reported demand for policy, financial, and technical support to enhance sustainable management and conservation.

Discussion

This study presents the Indigenomics conceptual framework as a bioculturally grounded approach for revaluing ethnobotanical resources. Findings from the case study on palm species in Northwest Nigeria demonstrate the analytical and applied relevance of the framework, revealing structured patterns in Indigenous valuation systems and providing empirical support for biocultural approaches in resource governance. The results highlight the importance of integrating Indigenous knowledge systems into sustainability-oriented policy development.

Validity of the Indigenomics framework in ethnobotanical valuation

The Indigenomics framework addresses limitations of earlier ethnobotanical indices, including concerns regarding interpretive and methodological bias in metrics such as the Cultural Significance Index (da Silva et al., 2014a). It repositions ethnobotanical valuation by integrating principles from Indigenous economics (Hilton, 2021), ethnobotany (Hoffman and Gallaher, 2007), and traditional ecological knowledge systems (Sinthumule, 2023), while remaining grounded in established quantitative ethnobotanical approaches (Phillips and Gentry, 1993a,b; Phillips, 2006; Tardío and Pardo de Santayana, 2008; da Silva et al., 2014b).

Methodologically, the framework is also consistent with ecological assessment tools such as the Importance Value Index (Curtis and McIntosh, 1951) and ethnoecological approaches (Castañeda and Stepp, 2007). The resulting structure links Indigenous

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philosophical systems with measurable, community-derived ecological and socioeconomic indicators.

The Ecological Integration Score reflects relational ecological accountability by capturing species roles within ecosystem functioning (Obadiah et al., 2025). The Collective Well-being Index extends conventional Use Value approaches (Phillips, 1996) by incorporating communal distribution, nutrition, health, and equity dimensions. Together, these indices operationalize multidimensional Indigenous valuation systems that are not captured by conventional ethnobotanical metrics.

The ability of the Indigenomics framework to translate IPLCs economic principles into measurable values affirms its practical application and novel contribution to resource management discourse. As a descriptive tool, the indices demonstrate that native palm species consistently exhibit higher ecological, cultural, and economic integration than introduced species (Table 1, Figure 4). This pattern reflects established Indigenous economic principles emphasizing reciprocity, ecosystem stewardship, and collective benefit (Sinthumule, 2023). As a prescriptive tool, the quantified data can inform contemporary policy by enabling policymakers to translate Indigenous self-determination and foster collaborative governance, as suggested by Hilton, 2021.

Conceptual advancement over traditional ethnobotanical indices

The Indigenomics framework extends beyond traditional Relative Cultural Importance (RCI) metrics by integrating ecological, cultural, and economic dimensions into a unified analytical structure (Table 3).

The Collective Well-being Index refines Use Value (UV) by normalizing citation-based frequency and incorporating equity, nutrition, and health dimensions. The Cultural Sovereignty Index expands Cultural Significance Index approaches by explicitly prioritizing Indigenous governance, cultural continuity, and intergenerational knowledge transmission.

Similarly, the Ecological Integration Score differs from the Informant Consensus Factor (ICF) by aggregating ecological functions rather than focusing on agreement within single-use categories. The Indigenomics Index (II) differs from Cultural Importance (CI) by incorporating community-weighted prioritization across ecological and sociocultural domains, rather than assuming uniform weighting.

The Indigenomics Value Rating (IVR) further extends traditional indices by introducing a dynamic component that incorporates usage frequency and cultural diversity, allowing valuation to reflect both structural importance and actual engagement patterns.

Table 3 Traditional indices and their Indigenomics parallels

RCI index	Indigenomics metric	Conceptual alignment	Key differences
Use Value (UV)	Collective Wellbeing Index (CWI)	measures how often a plant appears in livelihood activities (food, medicine, handicrafts, etc.)	UV counts raw citations while CWI is normalized per capita and explicitly weighs social equity, nutrition, and health dimensions
Cultural Significance Index (CSI)	Cultural Sovereignty Index (CSI)	quantifies ceremonial/ spiritual uses and knowledge transmission	Both CSIs' weight cultural uses, but Indigenomics-CSI centers on Indigenous governance, intergenerational knowledge, and spiritual self-determination
Fidelity Level (FL)	Cultural Determinancy (CD) (in IVR)	proportion of respondents agreeing on a single principal use	FL focuses on a single use-purpose, whereas CD is embedded within IVR to capture cultural consensus as part of a dynamic rating
Informant Consensus Factor (ICF)	Ecological Integrity Score (EIS)	degree of community-wide agreement on which species are most important in each ecological/use domain	ICF is computed per use-category while EIS aggregates across ecological functions (biodiversity, regeneration, habitat interdependence)
Cultural Importance (CI)	Indigenomics Index (II)	holistic synthesis of ecological, social, and cultural values	CI often blends use-diversity and consensus. II is explicitly weighted by community-assigned importance values for each domain. Also, a nominalized scale is used in II to mitigate bias
Overall Use Value (OUV)	Use Frequency (UF) (in IVR)	intensity of actual use, similar to UV	OUV mixes part-specific citations; UF is scaled (daily–rare) and serves as a dynamic multiplier in the IVR formula

Notes: RCI – Relative Cultural Importance

Empirical implications for indigenous livelihoods and valuation systems

The higher Indigenomics Index values observed for native species (Table 1; Figure 4) reflect their integration into Indigenous livelihood systems, including food security, medicinal practices, cultural rituals, and ecological functions (Ariyo, 2023; Salako et al., 2018; Mahomoodally et al., 2024).

The Indigenomics Value Rating for *Phoenix dactylifera* (2.36) demonstrates how combined ecological, cultural, and economic indicators can identify species with high multifunctional importance. In contrast, lower IVR values for introduced species reflect limited integration into Indigenous ecological and cultural systems.

These findings confirm that valuation systems based solely on market metrics fail to capture the multifunctional roles of agrobiodiversity within Indigenous contexts.

Implications for indigenous self-determination and policy

The Indigenomics framework operationalizes Indigenous valuation systems in a form that can inform policy design (Hilton, 2021). By integrating ecological, cultural, social, and economic dimensions, the framework supports governance approaches aligned with Indigenous priorities and knowledge systems.

The Ecological Integration Score expands conventional ethnoecological indices (Castañeda and Stepp, 2007) by integrating ecological field data with Indigenous knowledge systems. The community-weighted structure of the Indigenomics Index strengthens Indigenous data sovereignty by ensuring that valuation reflects local governance priorities rather than externally imposed weighting systems (Rainie et al., 2019).

Overall, the framework provides a structured mechanism for aligning biodiversity conservation with Indigenous self-determination and sustainable resource governance.

Comparison with traditional indices

Table 3 summarizes conceptual correspondences between traditional ethnobotanical indices and their Indigenomics counterparts.

Overall, the Indigenomics framework extends existing metrics by integrating ecological, cultural, and socioeconomic dimensions into a unified valuation system, rather than treating them as separate or independent constructs.

These relationships highlight a shift from citation-based and use-frequency approaches toward community-weighted and multidimensional valuation systems that better reflect Indigenous knowledge structures.

Limitations and recommendations

Several limitations should be considered. First, cultural valuation is inherently context-dependent and may vary across ecological and social settings. Although grounding the framework in Indigenous knowledge improves relevance, knowledge erosion in some communities may affect the completeness of the data.

Second, the community-weighted structure of the Indigenomics Index enhances local relevance but limits direct cross-regional comparability. Equal-weight calculations were included only for methodological transparency and should not be interpreted as universal benchmarks.

Third, while the sample size (n = 86) meets ethnobotanical standards for saturation, broader application across multiple ecological and cultural regions is necessary for further validation.

Future research should focus on expanding geographic validation, refining participatory weighting protocols, and testing the framework under different ecological and socioeconomic conditions. Policy integration will require multi-level coordination to embed Indigenous valuation systems into biodiversity governance and agrobiodiversity conservation strategies.

Conclusions

The Indigenomics framework offers a transformative, bioculturally grounded method for assessing the socioeconomic significance of ethnobotanical resources. Its application in Northwest Nigeria demonstrates that native palm species consistently achieve high Ecological Integration Score (EIS), Collective Well-being Index (CWI), Cultural Sovereignty Index (CSI), and Monetary Value Score (MVS), thereby empirically validating Indigenous principles of relational accountability and collective benefit within IPLCs. The high Indigenomics Index (II) and Indigenomics Value Rating (IVR) scores for *Phoenix dactylifera* exemplify how these metrics operationalize Indigenous self-determination in conservation planning and resource governance. By integrating ecological, cultural, social, and economic dimensions into a unified analytical framework, the Indigenomics approach provides a more holistic and context-sensitive basis for evaluating ethnobotanical resources than conventional indices. Embedding these valuation systems within agrobiodiversity and economic policy frameworks is recommended to strengthen governance, support IPLCs' self-determination, and optimize the conservation of neglected and underutilized species.

Conflicts of interest

The authors have no competing interests to declare.

Ethical statement

This study followed the International Society of Ethnobiology Code of Ethics and received institutional ethical approval. Free, Prior, and Informed Consent (FPIC) was obtained from all participants, with data anonymization and continuous consent maintained throughout. Communities participated as active collaborators through feedback and knowledge-sharing sessions.

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