

Uncovering Indigenous Diversity and Farmer Preferences in Pigeon Pea (*Cajanus cajan*): Insights from Germplasm Exploration, Ethnobotanical Surveys, and Digital Phenotyping for Climate-Smart Breeding

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Abstract

Pigeon pea (*Cajanus cajan* [L.] Millsp.) remains an underutilized legume in most African countries despite its potential for climate-resilient farming systems, food diversification, and nutritional value. Limited knowledge of its indigenous diversity and farmer trait preference constrains wider adoption, particularly in the West African sub-region. Between February and June 2025, a germplasm exploration was conducted across 18 Nigerian states, complemented by accessions from the International Institute of Tropical Agriculture (IITA) genebank, Ghana, the Republic of Benin, and the Gambia, bringing the total to 273 accessions. Ethnobotanical surveys captured farmer preferences, cultural uses, and local nomenclature while seed morphometric traits were assessed using Videometerlab4 multispectral imaging. Farmer surveys revealed cooking time (58.3%), commercial value (27.0%), and maturity cycle (14.7%) as preferred varietal traits. Gender and age differences were evident; women and older farmers prioritized cooking time, while men and youth emphasized the maturity cycle as a preferred trait. Vernacular names (e.g., *Otili*, *Fiofio*, *Waken Gwari*) highlighted deep cultural integration and cross-border exchange in Ogun State and the Republic of Benin, indicating transboundary diversity. Morphometric analyses revealed moderate variability in seed size, shape, and pigmentation. Seed area (14.2–46.0mm²), Compactness (0.590–0.998), and eccentricity (0–0.808) differentiated rounded from elongated seeds, while CIELab_A values (–0.04–29.98) captured pigmentation differences. The first two PCA axes explained 67.1% of total variation, and cluster analysis grouped accessions into four morphotypes. By integrating genetic and morphometric information, as well as farmer varietal preference insights, this study provides a robust foundation for the conservation and development of climate-resilient, fast-cooking, and market-preferred varieties for sub-Saharan Africa.

Introduction

Pigeon pea (*Cajanus cajan* [L.] Millsp.) is a versatile, drought-tolerant, nitrogen-fixing legume vital for smallholder resilience, particularly in sub-Saharan Africa (SSA) and South Asia, where it contributes significantly to food and nutritional security (Saxena et al. 2019; Jorin et al. 2021; Ouma et al. 2024). It serves as an important protein source, rich in essential amino acids such as lysine and methionine, and supplies micronutrients like iron and zinc (Akinola et al. 2020; Bohra et al. 2020). In Nigeria, it is an important crop for smallholder farmers because of its nitrogen-fixing capacity and compatibility with intercropping, especially with cereals, for enhanced resource-use efficiency (Ogbe and Bamidele 2007; Odeny et al. 2007; Egbe et al. 2011; Saxena et al. 2018). Additionally, it is a versatile crop that can sustain productivity under a prolonged drought spell due to its deep root system that enables it to access subsoil moisture (Odeny, 2007; Sloan et al. 2009; Renwick et al. 2020; Khoiri et al. 2025). Traditionally, pigeon pea is valued also for its cultural and ethnobotanical importance, where it is used in managing health conditions such as malaria, measles, and digestive disorders (Ayenan et al. 2017a).

Despite its widespread adaptability and importance, pigeon pea remains underutilized compared to cowpea and soybean in SSA, highlighting the need for conservation and characterization of indigenous accessions. (Mula and Saxena 2010; Popoola et al. 2022). Although its adoption is limited and

constrained by several factors, which include a lack of breeding interest, weak seed systems, and consumer concerns about long cooking times due to its seed coat hardness (Singh et al. 2003; Odeny 2007; Adepoju et al. 2019; Odeku et al. 2024). At the global level, a lot of work has been invested in its improvement, largely concentrated in India, which accounts for over 60% of the world's pigeon pea (Ojo 2024; Thakur et al. 2025). However, the West and Central Africa pigeon pea diversity remain marginally represented in international breeding pipelines and genebank collections (Upadhyaya et al. 2011; Khoury et al. 2015; Ayenan et al. 2017a; Nduche et al. 2023). This insufficient representation limits the discovery and deployment of novel alleles underlying priority traits such as short cooking time, early maturity, disease resistance, and market-preferred seed characteristics (Jarvis et al. 2011; Kinhoégbè et al. 2020).

Additionally, the growing recognition of pigeon pea as a strategic crop under programs such as the Vision for Adapted Crops and Soils (VACS) highlights its importance for food and nutritional security (Fowler, 2024; Karl et al. 2024; Herrick et al. 2024). Promoting its conservation and improvement aligns with broader goals of building climate-resilient crops that will help in expanding the food bracket, as well as supporting the livelihoods of smallholder farmers, particularly women, who are important actors in its production and utilization (Paliwal et al. 2021; Rokka et al. 2025). Hence, urgent action is required in SSA sub-region to explore and document, as well as conserve the remaining landrace diversity before it is eroded by land-use change, urbanization, and shifting crop preferences (Halewood et al. 2014; Chivenge et al. 2015; Kinhoégbè et al. 2020; Nduche et al. 2023). Unlike previous studies that were geographically restricted to a few southern states in Nigeria (Akande 2007), this present work sampled multiple agro-ecological zones, offering the most extensive germplasm exploration of pigeon pea to date.

Materials and methods

Study Sites and Geopolitical Coverage

Field exploration was carried out between February and April 2025 across Nigeria's agro-ecological zones. Sampling took place in selected Local Government Areas (LGAs) within 18 states, representing environments that differ in rainfall patterns, soil types, and cultural practices (Fig. 1). These locations were selected based on their long-standing involvement in the cultivation of pigeon pea, whether for subsistence, medicinal use, or commercial purposes. In addition to the landraces collected during the field exploration, 100 accessions were obtained from other sources, including the IITA Genebank (Ibadan, Nigeria), Ghana (Council for Scientific and Industrial Research-Plant Genetic Resources Research Institute (CSIR-PGRRI)), Benin Republic (Genetics, Biotechnology and Seed Science Unit (GBioS)), and the Gambia. These external accessions were incorporated into the study to broaden the diversity panel and enable comparative analyses across regions.

Sampling Design and Approach

An exploratory and purposive sampling design was adopted, guided by established protocols for germplasm collection (Tongco 2007; Guarino et al. 2011). The exploratory approach enabled the identification and documentation of pigeon pea diversity across a wide ecological and cultural

landscape, while the purposive sampling was used to select collection sites, LGAs, farmers' fields, and local farm markets where indigenous pigeon pea diversity was expected. A baseline survey involving informal consultations with agricultural extension officers and researchers at the local government Agricultural Development Programmes (ADP) guided the identification of pigeon pea-producing communities and sampling sites. Within each LGA, three to five villages were visited based on their established involvement in pigeon pea cultivation, except in some states.

Germplasm Collection, Spatial Analysis, and Ethnobotanical Survey

Pigeon pea germplasm was collected from both farmers' fields and local farm markets across 65 LGAs in Nigeria. The majority of the samples were landraces, with each farmer contributing one or more seed lots depending on availability and varietal diversity on their farm or at the market. In addition, eight advanced breeding lines (NGNCC-118 to NGNCC-125) were sourced from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Kano, Nigeria. Seeds were placed in breathable net bags labeled with a unique collection number, village or farm location, state, and LGA. Identification labels were inserted into the bags to ensure traceability, while the metadata were captured in the mobile Field Book application as a digital backup. GPS coordinates for each collection site were recorded using handheld GPS units, applying the WGS84 (EPSG: 4326) coordinate system for mapping.

Ethnobotanical data were collected through semi-structured interviews with 74 respondents, including male and female farmers as well as traders actively engaged in cultivation, processing, or marketing. Interviews were conducted in local languages (Yoruba, Igbo, Hausa, and Pidgin English), with trained local translators assisting where needed to ensure accuracy of information. All interview data were anonymized by replacing respondent names with unique codes and stored in password-protected files. Data captured included the source of each sample (farm or market), local variety names, planting duration, soil types, and farmer-preferred varietal traits. Ethnobotanical information focused on traditional culinary and medicinal uses, while demographic details such as gender, age group, and reasons for cultivation or trade provided context on farmer/trader practices and seed selection preferences. Respondents were grouped into three age categories: young farmers (15–34 years), adult farmers (35–54 years), and old farmers (55 years and above).

Multispectral Imaging Analysis

Seed morphometric traits were measured using the VideometerLab4™ imaging system (Videometer A/S, Herlev, Denmark), capturing multispectral images of 10 seeds per replication for each of the 273 accessions, giving a total of 20 seeds per accession. Traits measured included seed length, width, area, perimeter, form factor, eccentricity, rectangularity, CIELAB_A, and compactness. Morphometric data were processed and extracted using VideometerLab software v.3.14.9 as described by Bhadmus et al. (2023).

Data Analysis

Spatial analysis

Spatial plotting and diversity hotspot analysis were performed in ArcGIS Pro, using Shannon diversity index values aggregated by agro-ecological zones and states. A diversity hotspot was defined as any zone or state whose Shannon diversity index fell within the top quartile of all calculated values. Additional processing and map production were conducted in ArcGIS Pro (Esri). The “XY Table to Point” tool in ArcGIS Pro was used to convert the coordinate table into point features by importing longitude (x) and latitude (y) values, specifying the coordinate system, and creating a point feature layer. The mapped points visualized the spatial distribution of collected accessions and highlighted diversity hotspots across sampled states.

Coding framework

Qualitative responses, such as farmers’ trait preferences and cultural uses, were analyzed using a combined thematic coding and frequency count approach. Themes were derived inductively from the data, while frequency counts quantified the proportion of respondents citing each theme. Trait preference data were summarized as percentages by demographic category (gender, age group, agro-ecological zone).

Seed morphometric analysis

Statistical analyses, including Principal Component Analysis (PCA), Pearson correlation, and hierarchical clustering (Ward’s method, Euclidean distance), were performed in R software v4.3.2 using the *FactoMineR*, *corrplot*, and *stats* packages to evaluate the seed morphometric data.

Results and Discussion

Germplasm Collection, Distribution, and Ethnobotanical Insights of Pigeon Pea Production in Nigeria

A total of 173 pigeon pea accessions were collected from 18 states representing the major agro-ecological zones of Nigeria (Fig. 1; Table 1). The sampled locations spanned diverse ecological gradients, including the Humid Forest, Derived Savanna, Southern Guinea Savanna, Northern Guinea Savanna, and Semi-arid/Sudan Savanna. This broad coverage provides a strong foundation for downstream phenotypic, genetic, and ethnobotanical characterization.

The Humid Forest and Derived Savanna zones, particularly Edo, Kogi, and Ondo States, recorded the highest number of accessions (29, 28, and 16, respectively) (Mula and Saxena 2010). Edo and Ondo States also had the widest LGA coverage (7 LGAs each). In contrast, Kaduna, Kano, and Jigawa (Northern zones) yielded fewer accessions, reflecting the crop’s stronger cultural and agronomic relevance in the southern zones. Seed migration was evident in border LGAs such as Yewa North and Imeko-Afon (Ogun State), where exchange with farmers in the Benin Republic enriches local genetic pools, aligning with earlier reports of cross-border seed flow enhancing landrace diversity (Hoffman and Melly 2015; Labeyrie et al. 2016; Ayenan et al. 2017b; Kinhoégbè et al. 2020).

Despite broad coverage, states like Delta, FCT, and Imo produced only a single accession each, suggesting limited cultivation or possible genetic erosion. Similar concerns have been raised for minor pigeon pea growing regions (Zavinon et al. 2019; Palanga et al. 2025), underscoring the need for germplasm rescue and sensitization campaigns.

Table 1
Pigeon Pea Collection Data: Locations, Local Names, and Soil Types

State	Number of LGAs covered	Number of samples collected	local names	soil type
Edo	7	29	<i>Olene/Olele/Ikporoele</i>	sandy-clay-loam
Kogi	6	28	<i>Agugu</i>	sandy-clay-loam
Ondo	7	16	<i>Sese</i>	sandy-loam
Enugu	6	13	<i>Fiofio/Agbugbu</i>	clay-loam
Ekiti	6	12	<i>Feregede</i>	sandy-loam
Ogun	5	11	<i>Otini/ewa Ohoori</i>	sandy-loam
Kaduna	5	11	<i>Waken Gwari/Waken Mada</i>	sandy-clay-loam
Kano	2	11	<i>Waken Gwari/Waken Gida</i>	
Benue	6	10	<i>Alee/Agugu</i>	clay-loam
Oyo	4	8	<i>Otili</i>	sandy-clay-loam
Nasarawa	2	7	<i>Atushuru</i>	sandy-clay-loam
Jigawa	2	4	<i>Waken Gwari</i>	sandy-clay-loam
Osun	2	4	<i>Otili</i>	sandy-loam
Anambra	1	3	<i>Ihuohuo/Fiofio</i>	sandy-clay-loam
Abia	2	3	<i>Fiofio</i>	sandy-clay-loam
Delta	1	1	<i>Akpaka</i>	clay-loam
FCT	1	1		sandy-loam
Imo	1	1	<i>Fiofio</i>	sandy-clay-loam

The diversity in local nomenclature reflects the crop's deep cultural integration. Farmers consistently identified sandy-loam and sandy-clay-loam soils as favorable (> 80% of sites), confirming pigeon pea's adaptability to marginal yet well-drained soils (Table 2).

Pod morphotypes revealed extensive variation in size, shape, curvature, and color, confirming the phenotypic richness of Nigerian landraces. Seeds exhibited a broad spectrum of colors (white, cream, brown, red, and mottled patterns), indicative of strong selection preferences, local adaptation, and possible genetic divergence shaping pigeon pea populations (Fig. 2).

Farmers' Trait Preference

Three major farmer-preferred traits were identified: cooking time (58.3%), commercial value (27.0%), and maturity cycle (14.7%) (Fig. 3). Short cooking time dominated, reflecting reliance on firewood and the premium on fuel efficiency. Respondents emphasized that fast-cooking varieties conserve energy and time, enhancing palatability and increasing household consumption. This finding agrees with previous reports that culinary quality can outweigh yield in influencing adoption (Zavinon et al. 2018; Majili et al. 2020; Namuyiga et al. 2022).

Across all age categories, cooking time remained the most important trait sought in pigeon pea varieties, though the emphasis varied (Fig. 4). Old farmers (76.9%) prioritized it far more than adults (52.2%) and young farmers (45.5%). Commercial value ranked second for adults (28.9%) and young farmers (27.3%) but was less important to old farmers (23.1%). Maturity cycle was most emphasized by young farmers (27.3%) compared to adults (18.9%), while none of the old farmers selected it as a top priority. These demographics reflect established roles in food preparation (women), land use (men), and livelihood strategies (youth) (Teeken et al. 2018; Asante et al. 2023; Sanya et al. 2023; Asimwe et al. 2024). The long cooking time of traditional landraces has even led to negative perceptions, with pigeon pea being nicknamed "wicked beans" in some communities (Adepoju et al. 2019), underscoring why women and older farmers especially value fast-cooking varieties.

When the farmer demographic data was disaggregated by gender, both male and female farmers' prioritized short cooking time, though women expressed a stronger preference (61.9%) than men (54.2%) (Asante et al. 2022). Conversely, men valued the early-maturing varieties (18.6%) than women (10.7%). Preferences for commercial value were nearly identical (Female: 27.4%, Male: 27.1%) (Fig. 5).

Farmers' preferred varietal traits varied significantly by agro-ecological zone (Table 2). In the Derived Savanna and Humid Forest zones, cooking time was strongly prioritized (65.2% and 62.5%, respectively), whereas in the Northern Guinea Savanna, Southern Guinea Savanna, and Sudan Savanna, commercial value dominated (63.6%, 62.5%, and 60.0%, respectively), reflecting stronger market integration. Preference for the early-maturing varieties was relatively consistent across zones (12.5% to 20.0%). These patterns suggest that environmental and market conditions are likely to influence trait improvement priorities, creating a clear north-south divide that breeding strategies should account for (Ayanan et al. 2017b). Short maturity cycle, though less emphasized overall, appeared more relevant for

male and young farmers, likely due to its role in land turnover and risk avoidance in drought-prone ecologies (Adu et al. 2021; Marenya et al. 2022; Melese et al. 2025). These findings underscore the value of early-maturing, fast-cooking pigeon pea types in improving resilience and meeting farmer needs.

Table 2
Farmers’ Trait Improvement Preferences across Agro-ecological Zones

Agro-ecological zone	Commercial value (%)	Cooking time (%)	Maturity cycle (%)
Derived Savanna	20.9	65.2	13.9
Humid Forest	20.8	62.5	16.7
Northern Guinea Savanna	63.6	18.2	18.2
Southern Guinea Savanna	62.5	25.0	12.5
Sudan Savanna	60.0	20.0	20.0

Cultivation Purposes

Most respondents (51.9%) cultivated pigeon pea for both home use and commercialization, while 35% grew exclusively for home consumption and 11.9% for sale only (Figs. 6 & 7). This dual-purpose role underscores the importance of pigeon pea in both food security and income generation, reinforcing the need for breeding programs to deliver multi-trait “bundled” varieties that combine culinary, market, and agronomic attributes (Chivenge et al. 2015). A small fraction (1.2%) grew pigeon pea for soil enhancement in addition to food and trade.

Diversity index and spatial distribution

Varietal richness and diversity indices confirmed the Derived Savanna as the primary diversity hotspot ($S = 115$; $H' = 4.74$; $D = 0.99$). The Humid Forest followed ($S = 24$; $H' = 3.18$), while the Southern Guinea Savanna had the lowest richness ($S = 8$; $H' = 2.08$). At the state level, Edo ($S = 29$; $H' = 3.37$) and Kogi ($S = 28$; $H' = 3.33$) were most diverse, while Delta, FCT, and Imo had no measurable diversity ($S = 1$; $H' = 0$). High evenness values across most states suggest balanced landrace use, but low richness in some regions raises concerns over genetic erosion (Table 3).

Table 3
Varietal richness and diversity indexes of pigeon pea in Nigeria

	Varietal richness		Diversity indices	
Geographic locations	S	H'	E	D
Agro-ecological zones				
Derived Savanna	115	4.74	1	0.99
Humid Forest	24	3.18	1	0.96
Sudan Savanna	15	2.71	1	0.93
Northern Guinea Savanna	11	2.40	1	0.91
Southern Guinea Savanna	8	2.08	1	0.88
States				
Edo	29	3.37	1	0.97
Kogi	28	3.33	1	0.96
Ondo	16	2.77	1	0.94
Enugu	13	2.56	1	0.92
Ekiti	12	2.48	1	0.92
Kaduna	11	2.40	1	0.91
Kano	11	2.40	1	0.91
Ogun	11	2.40	1	0.91
Benue	10	2.30	1	0.90
Oyo	8	2.08	1	0.88
Nasarawa	7	1.95	1	0.86
Jigawa	4	1.39	1	0.75
Osun	4	1.39	1	0.75
Abia	3	1.10	1	0.67
Anambra	3	1.10	1	0.67
Delta	1	0		0
FCT	1	0		0
S = Number of landraces cited; H' = Shannon Weaver diversity index; E = Pielou's evenness; D = Simpson index				

	Varietal richness		Diversity indices
Imo	1	0	0
S = Number of landraces cited; H' = Shannon Weaver diversity index; E = Pielou's evenness; D = Simpson index			

Summary of trait variation

Summary statistics of key seed morphometric traits are presented in Table 4. Seed area ranged from 14.18 to 46.04 mm², while length and width varied between 4.41–8.10 mm and 3.63–7.38 mm, respectively. Compactness (0.59–0.998) and eccentricity (0–0.808) differentiated rounded from elongated forms, while CIELab_A values (–0.038 to 29.98) reflected pigmentation differences. These results indicate moderate but significant variability across the collection.

Table 4
Summary Statistics of seed morphometric traits across 273 pigeon pea accessions

Trait	Minimum	Maximum	Mean	Standard Deviation
Area (mm ²)	14.18	46.04	27.36	4.30
CIELab_A	-0.04	29.98	12.18	5.95
Compactness	0.60	1.00	0.89	0.07
Eccentricity	0.00	0.81	0.43	0.13
Length (mm)	4.41	8.10	6.30	0.50
Perimeter (mm)	12.27	24.93	17.07	1.39
RatioWidthLength	0.59	1.02	0.89	0.07
Width (mm)	3.63	7.38	5.61	0.53

Multivariate Analysis of Seed Morphometric Traits

Principal Component Analysis (PCA) showed that PC1 explained 42% of the variation and was associated with seed size traits, while PC2 (25.1%) was associated with seed shape traits (Fig. 8). The biplot indicated that size-related traits clustered closely, indicating strong interrelationships, whereas shape descriptors were positioned opposite eccentricity, confirming their inverse association. The color trait CIELab_A contributed minimally to the first two components and was positioned apart from major size and shape clusters, indicating its independent role in differentiating accessions.

Pearson correlation analysis further confirmed strong and significant associations among size-related traits (Fig. 9). Seed area showed very high positive correlations with length ($r = 0.89$), width ($r = 0.90$), and perimeter ($r = 0.96$), demonstrating that larger seeds are consistently longer, wider, and with greater

perimeters. Compactness was almost perfectly negatively correlated with eccentricity ($r = -0.94$) and strongly aligned with the ratio of width to length (RWL) ($r = 0.98$), indicating that elongated seeds are less compact while rounded seeds are more compact. These relationships highlight the redundancy among size traits and the contrasting role of shape descriptors in differentiating morphotypes. Seed color (CIELab_A) showed only weak and inconsistent correlations with size and shape traits, suggesting that pigmentation varies independently of seed morphology. Collectively, these patterns demonstrate that while seed size traits are tightly interrelated, shape and color contribute unique and independent axes of variation that can be exploited for discriminating pigeon pea accessions.

Hierarchical clustering grouped the 273 pigeon pea accessions into four distinct clusters (Fig. 10) (Supplementary Fig. 1. Cluster A ($n = 73$) comprised small- to medium-sized seeds (mean area = 24.43 mm^2), which were fairly compact (0.91) with moderate pigmentation (CIELab_A = 9.93). Cluster B ($n = 80$) contained small but elongated seeds (area = 26.6 mm^2 ; eccentricity = 0.53 , compactness = 0.83) with darkly pigmented seeds ($= 15.42$). Cluster C ($n = 52$) included large, rounded seeds (area = 32.33 mm^2 , width = 6.20 mm , compactness = 0.92 , eccentricity = 0.37) with intermediate pigmentation ($= 13.37$), while Cluster D ($n = 68$) represented medium-to-large seeds (area = 27.83 mm^2) that were compact ($= 0.92$) with light pigmentation ($= 9.42$). Overall, these clusters reflect clear contrasts in seed size, shape, and color, consistent with PCA loadings and correlation patterns, and highlight distinct morphotypes present in the collection. These structured variation points can serve as a basis for defining core collections and for identifying complementary parents in crossing programs. Similar clustering of accessions into distinct groups has been reported in chickpea, where seed and plant traits were used to delineate landraces from improved lines and support breeding strategies (Dehbaoui et al. 2024), as well as in pigeon pea germplasm from East Africa, where clustering based on molecular and morphological traits informed parent selection for pre-breeding (Yohane et al. 2022).

In conclusion, this study confirms Nigeria as a critical diversity hotspot for pigeon pea, revealing its rich genetic, morphological, and ethnobotanical variation. While the ethnobotanical survey of 74 respondents across 65 LGAs provided valuable insights, the relatively small sample size limits its representativeness, highlighting the need for future studies with broader coverage. Despite this limitation, the germplasm exploration identified important conservation centers in the Derived Savanna, particularly in Edo and Kogi States. By combining digital seed phenotyping with insights of farmers' preference trait, this study emphasizes the urgent need to develop climate-resilient, fast-cooking pigeon pea varieties. Across gender, age, and regional groups, cooking time consistently emerged as the most important primary preferred trait, while secondary preferences for commercial value and maturity cycle suggest the importance of multi-trait breeding approaches. The morphometric analysis, which distinguished clusters based on seed size, shape, and color, further provides a strong foundation for designing future pigeon pea improvement and conservation strategies.

Declarations

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Author Contributions

AAB, MTA, OAO, EOI, and OAB designed the study concept. AAB, OAO, and KAA conducted the exploration, AAB carried out the phenotyping study. AAB curated the data. AAB and OAB analyzed the data. AAB interpreted the data and prepared the first draft of the manuscript. All authors reviewed and approved the final manuscript.

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Data Availability

Data is available upon request from the authors.

Conflict of interest

The authors declare no competing interests.

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Figures

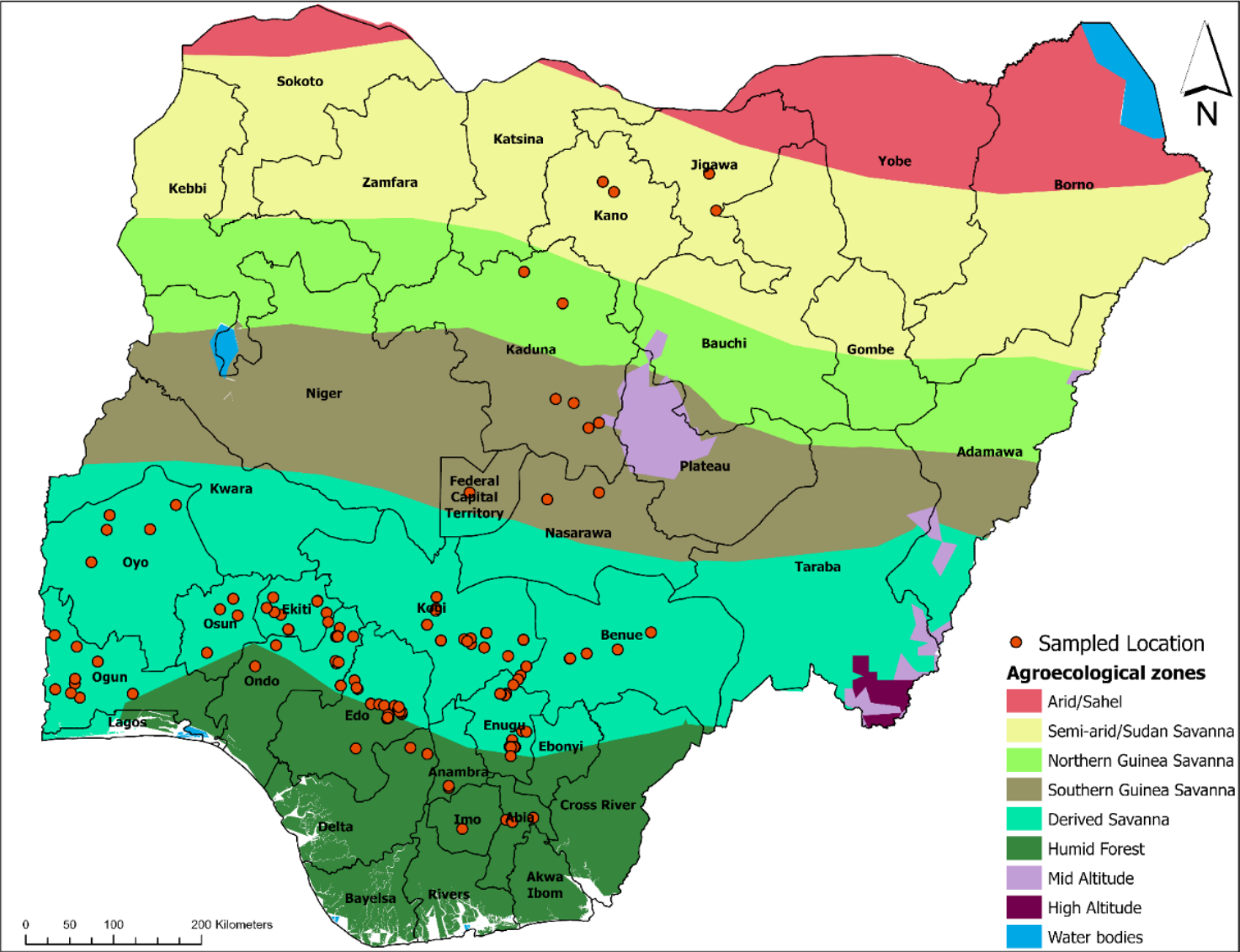


Figure 1

Spatial distribution of collected pigeon pea accessions and identified diversity hotspots



Figure 2

Pigeon Pea Pods and Seeds Displaying Variations in Shape, Size, Curvature, and Color

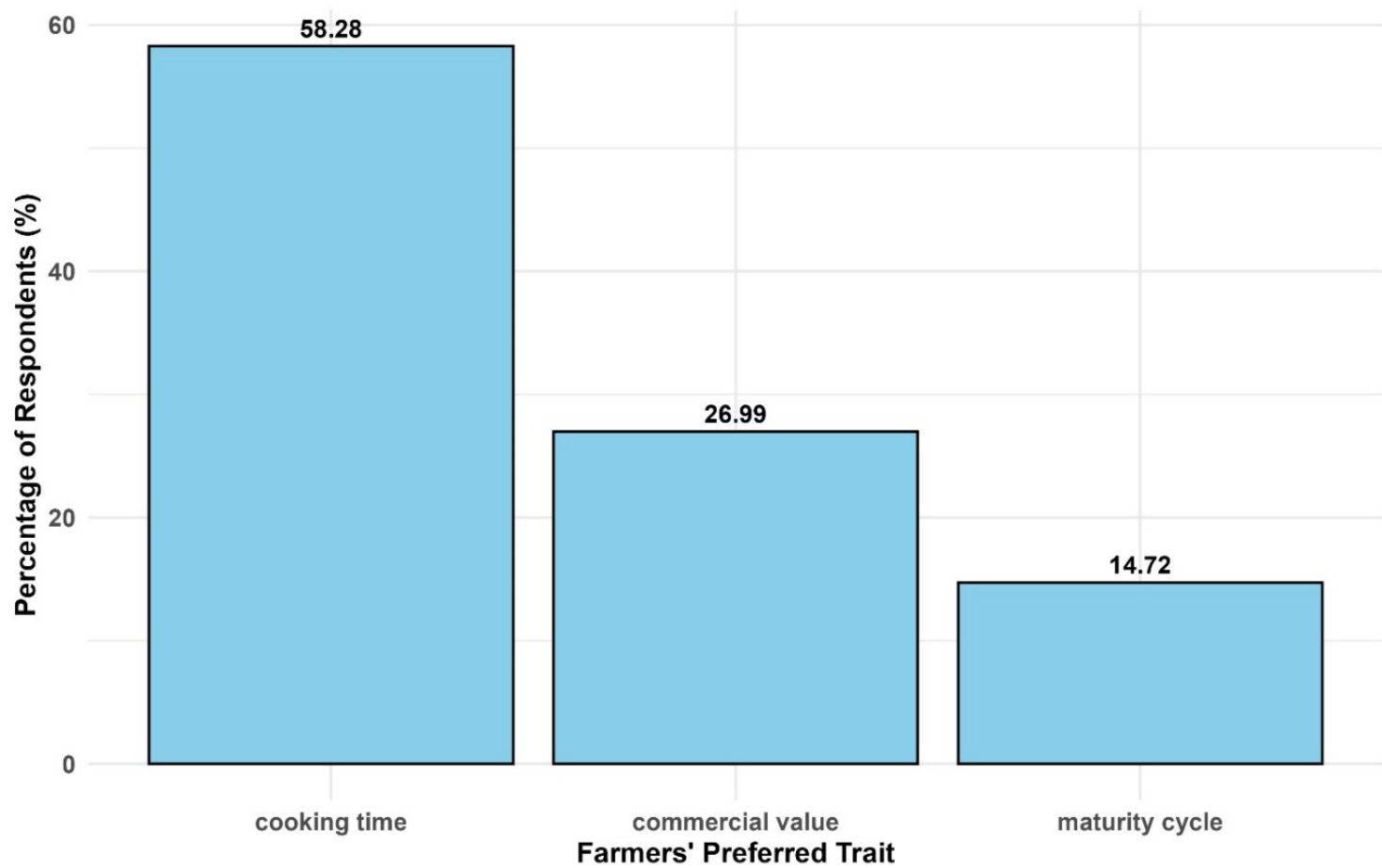


Figure 3

Percentage Distribution of Farmers' Trait Preferences

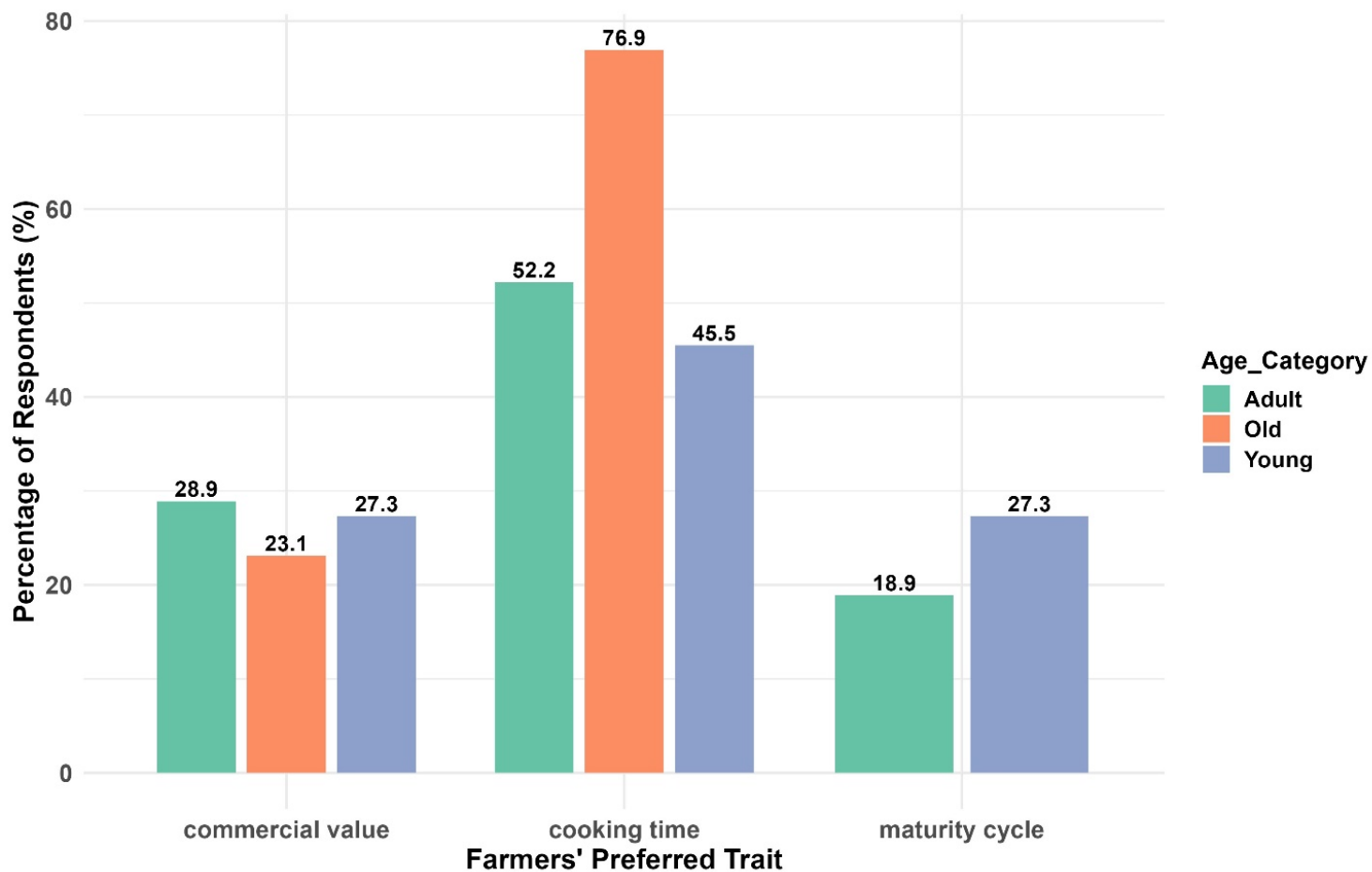


Figure 4

Farmers' Trait Preferences by Age Category

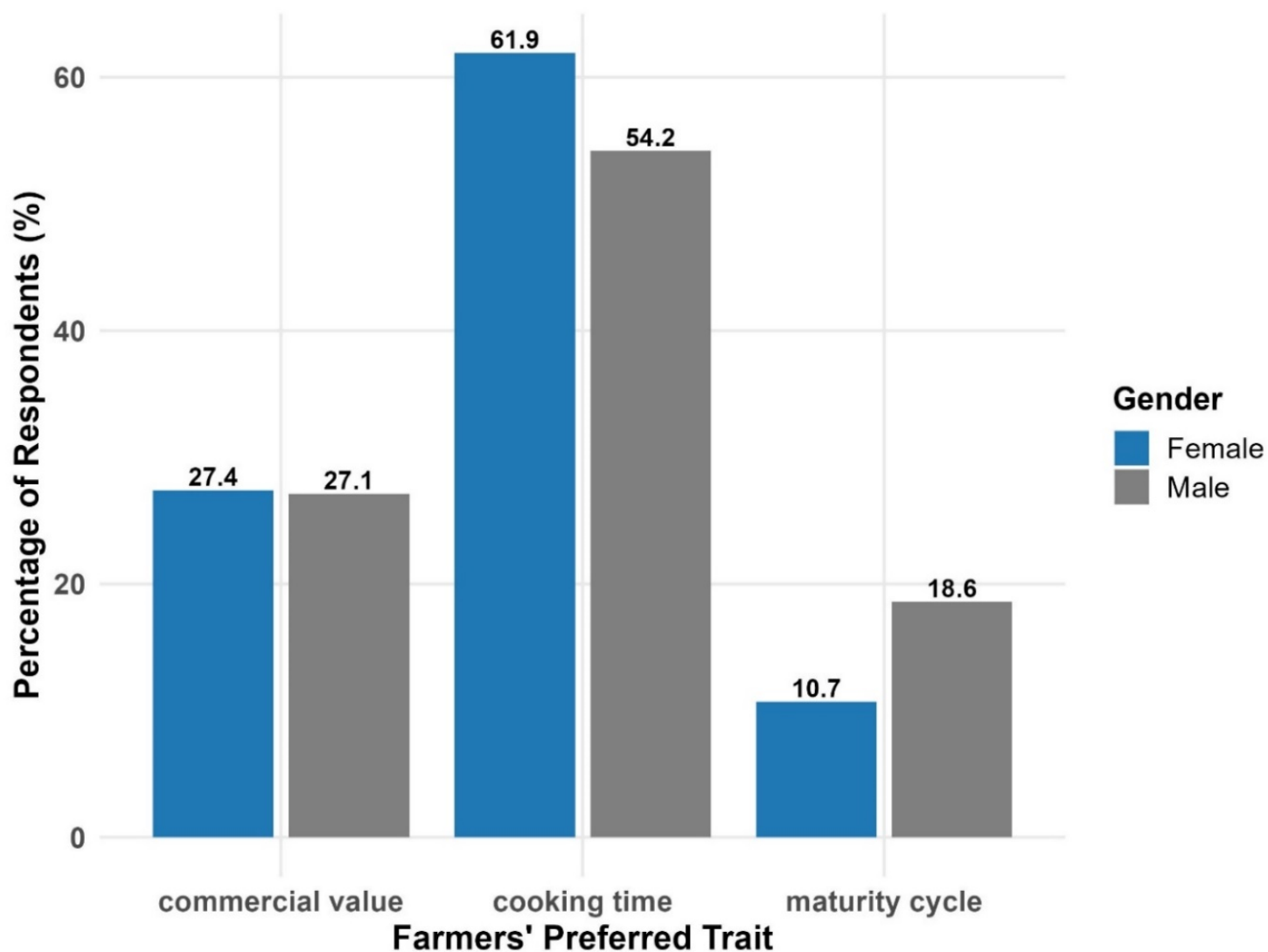


Figure 5

Gender-Based Comparison of Farmers' Trait Preferences

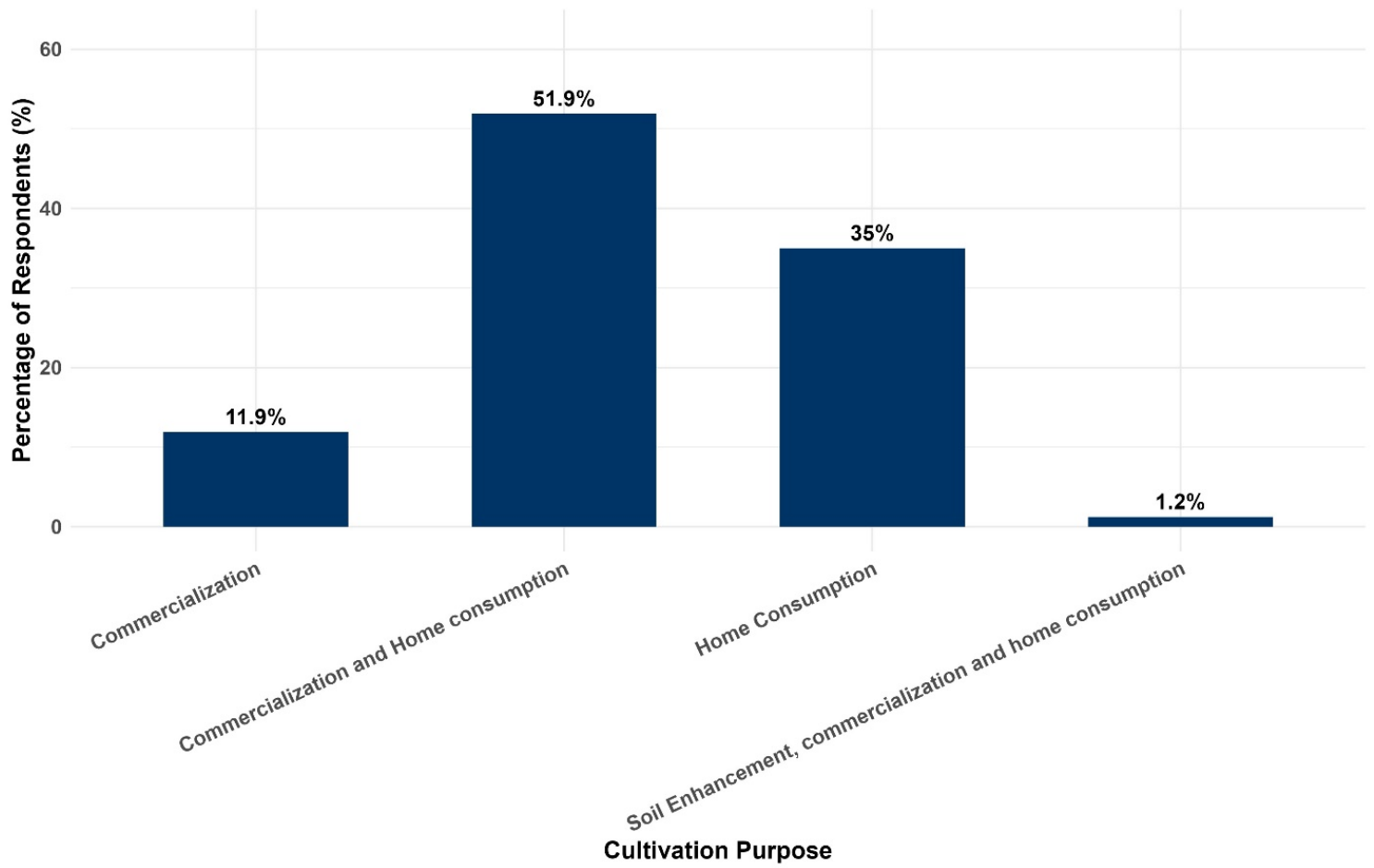


Figure 6

Cultivation Purpose of Pigeon Pea

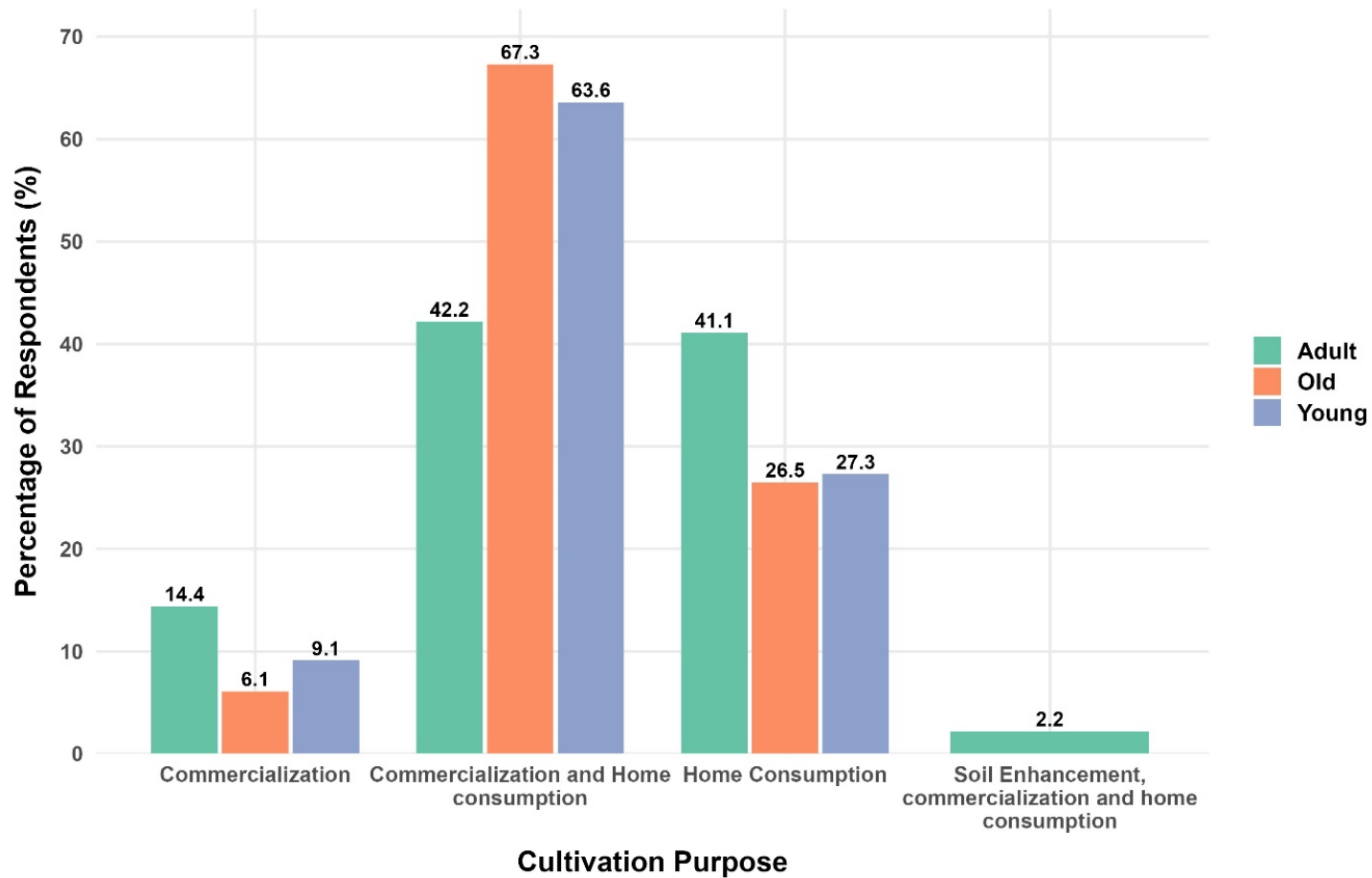


Figure 7

Distribution of Cultivation Purposes by Age Category

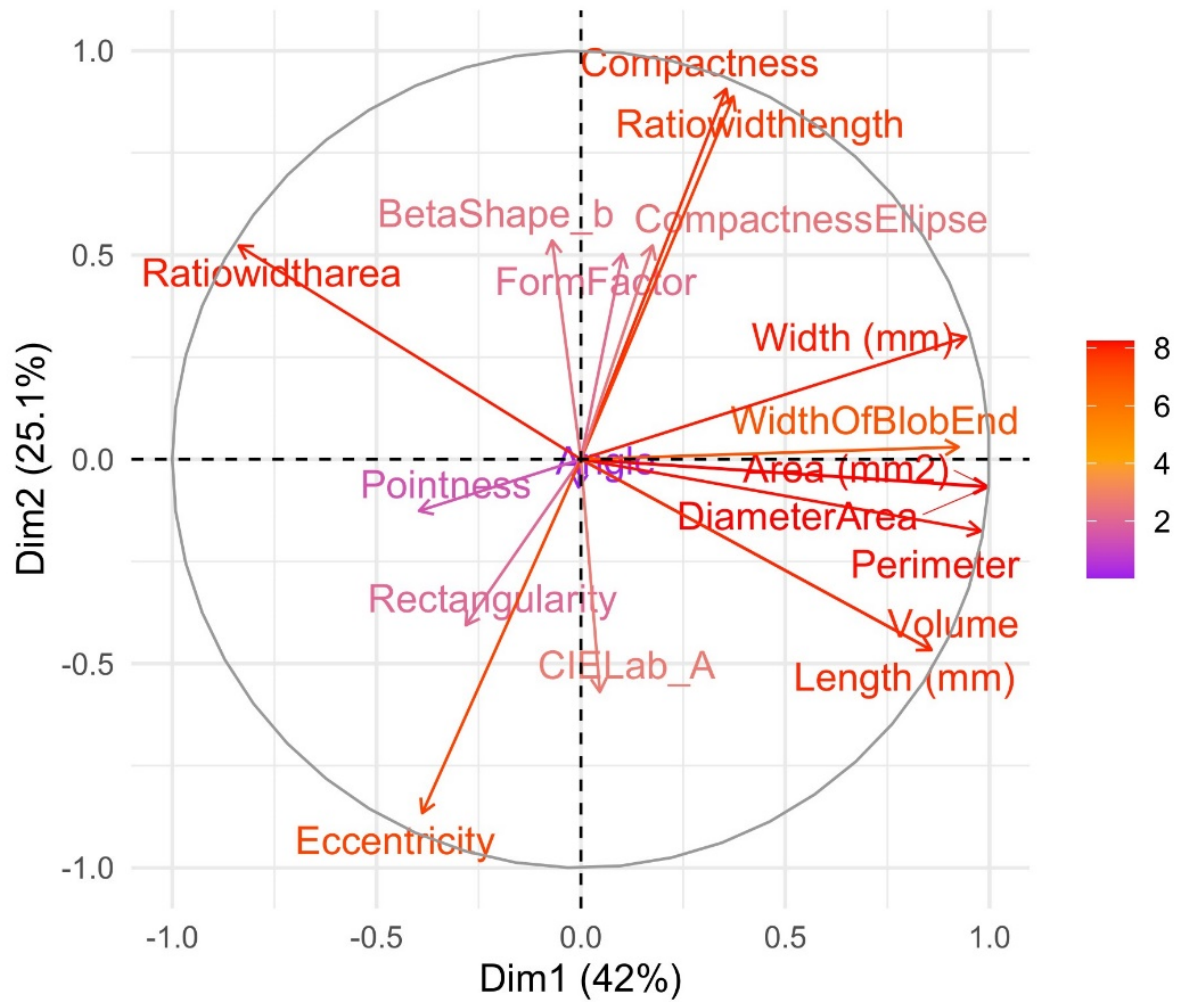


Figure 8

Principal component analysis (PCA) biplot of seed morphometric traits across 273 pigeon pea accessions

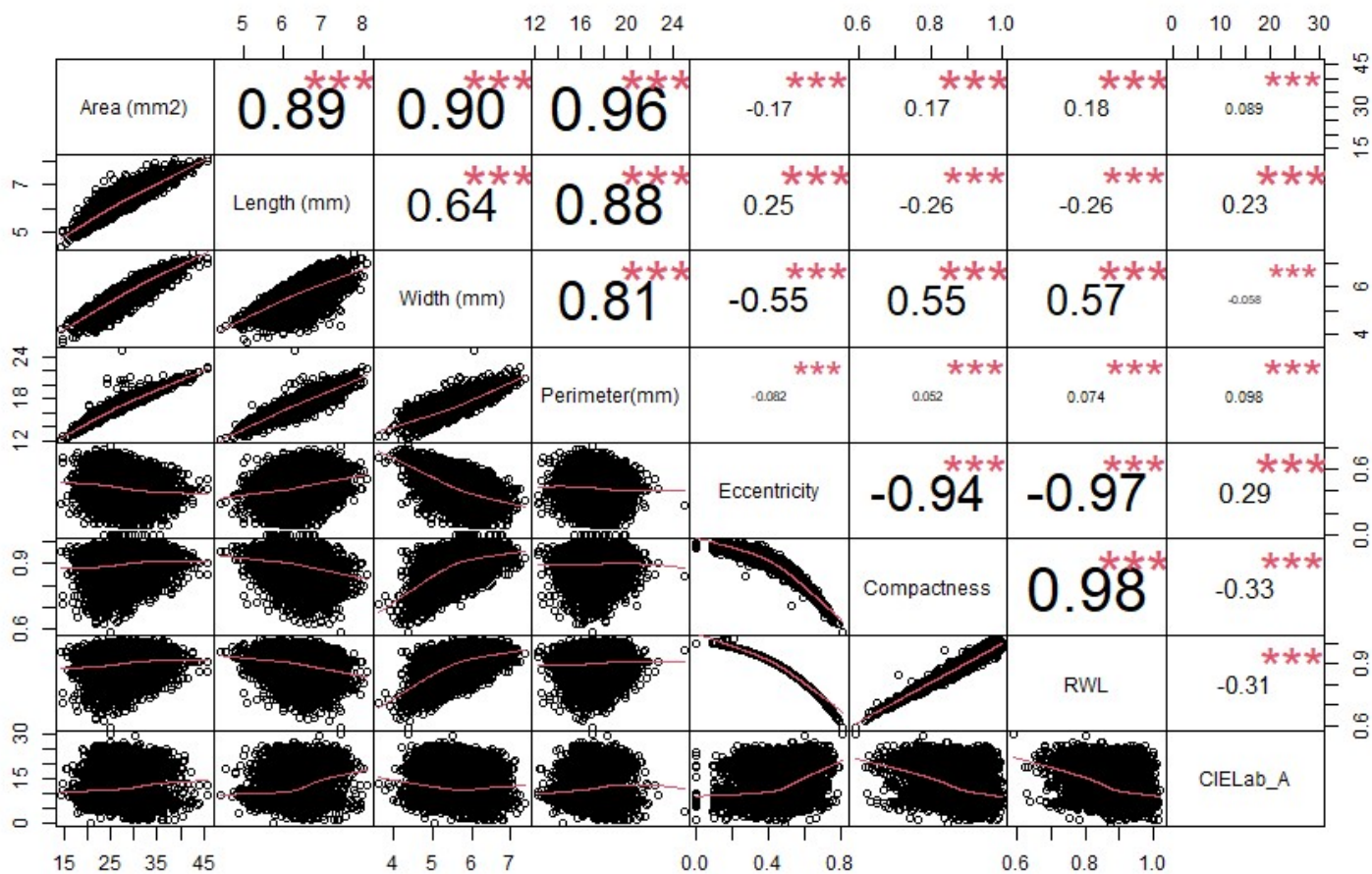


Figure 9

Correlation matrix of seed morphometric traits in 273 pigeon pea accessions

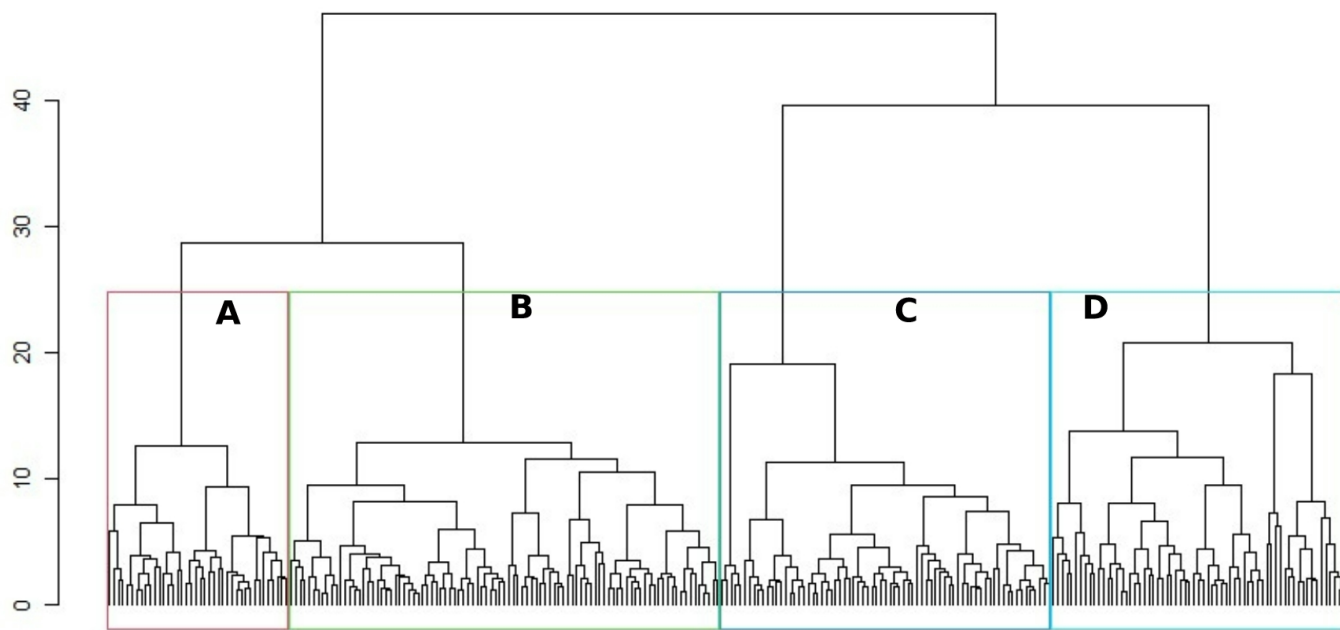


Figure 10

Hierarchical clustering of 273 pigeon pea accessions based on seed morphometric traits

Supplementary Files

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- [SUPPTablesBHADMUSPigeonPea2025.zip](#)