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**InJAR**
Indonesian Journal of Agricultural Research
Journal homepage: https://injar.usu.ac.id

# Morpho-anatomical characterization of *Moringa oleifera* in Benue State, Nigeria

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**ARTICLE INFO**

**Article history:**
Received 15-08-2024
Revised 25-03-2025
Accepted 15-06-2025
Available online 22-07-2025

E-ISSN: 2615-5842
P-ISSN: 2622-7681

**How to cite:**
O. P. Okpara and N. Orkuma, "Morpho-anatomical characterization of Moringa oleifera in Benue State, Nigeria", Indonesian J. Agric. Res, vol. 8, no. 2, pp. 74–84, Jul. 2025.


https://doi.org/10.32734/injar.v8i2.17893

**ABSTRACT**

Morpho-anatomical investigations are invaluable tools for understanding plant ecological strategies and functional adaptations. This study aimed to evaluate the foliar micro and macro morphological variations in *Moringa oleifera* accessions in Benue State. Methods: Plant materials were collected from three Local Government Areas (Makurdi, Gboko, and Ushongo) in Benue State, Nigeria. Quantitative and qualitative foliar features were evaluated from 50 randomly selected trees comprising four plant stands in each population of accession. Epidermal characters were measured and statistically analysed using SIMINT. The macro morphological characters evaluated showed that ADGBK (Gboko) accessions had the longest leaflet length (24.00 mm), width (15.33 mm), and area (367.20mm$^2$). In contrast, the micro-morphological characters (epidermal cell) in NBMKD (Makurdi) accession had the longest cell length (52.10 µm), cell width (UAMKD = 18.44µm), and cell area (808.59 µm$^2$). The stomatal length (UTUSH = 48.00 µm) and width (LSUSH = 24.03 µm) of accessions from Ushongo were the highest. Percental stomatal index value was notably highest (27%) in WUMKD (Makurdi) accessions. The mean leaf morphological and anatomical characters analysed showed a significant difference at ($p \leq 0.05$). Conclusion: *Moringa oleifera* accessions evaluated showcased unique foliar morphological variations, which were due to tolerance and adaptation strategies by each accession to local environmental conditions.

**Keyword:** *Moringa oleifera*, morpho-anatomical, variations, accessions, Makurdi

## 1. Introduction

Morpho-anatomical characterization is the scientific study of both external and internal structural features of an organism to aid the identification, classification, and tracing of environmental adaptation strategies in organisms [1]. The morpho-anatomical characterization of members of the Moringaceae family is significant because it offers critical insights into the structure, function, and evolution of endemic tropical species. Morpho-anatomical investigations have long been traditionally an indispensable tool in the identification and characterization of species.

Although the meticulous examination of external morphological features and internal anatomical characteristics of plant specimens are mostly utilized to delineate species, classify taxa, and construct evolutionary relationship [2]. Accurate species identification is also fundamental for both ecological and conservation efforts, as well as for agricultural and horticultural practices [3]. Thus, evolutionary relationship among plants is often intertwined with their morphological and anatomical adaptations. Fossil evidence is mostly combined with comparative morpho-anatomical studies, to provide useful insights into the evolutionary processes that have shaped the formation of clade. The morpho-anatomic evaluation can aid the evolution of adaptation to changing environmental conditions and diversification over geological time scales [4].

Plant forms and structure are directly linked to their ecological roles, as well as their Nutrition, reproduction, and defence mechanisms [5]. Research on leaf morphology, for instance, can shed light on a plant's photosynthetic efficiency and water-use strategies, contributing to accurate comprehension of plant-environment interactions [6].

In the field of agronomy and crop science, morpho-anatomical studies are pivotal for crop improvement efforts [7]. The characterization of plant accessions and varieties enables breeders to select plants with desirable traits, such as disease resistance, drought tolerance, and increased yield efficiency. Understanding the anatomical features of roots, stems, and leaves can guide in the development of crops optimized for specific environmental conditions.

Morpho-anatomical studies are also vital for research in medicinal and pharmaceutical fields [8]. Analysing the anatomical features of medicinal plants can help confirm the presence of bioactive compounds and provide insights into the localization phytochemical metabolites within plant tissues [9]. This knowledge is essential for achieving sustainable harvest and in the cultivation of medicinal plants. It is also useful in the development of crude pharmaceutical products. In the context of conservation biology, morpho-anatomical studies contribute to the accurate assessment and preservation of biodiversity [10]. The study helps in the identification of threatened or endangered species and provide data for the establishment of conservation strategies. Detailed knowledge of the morphology and anatomy of plants are essential for ensuring the survival of rare and ecologically important plant species like *Moringa oleifera.*

*Moringa oleifera* belongs to the family Moringaceae, widely cultivated for seed, pods and leaves, they are utilized as vegetables, traditional herbal medicine and water purification [11]. *Moringa oleifera* is native to Asian continent but is known to survive in the tropical regions as they are able to survive in extreme hot environment, and are tolerant to acidic sand-loam soils with moderate amount of moisture. Although, recognized as an invasive species in some countries, *M. oleifera* "do not invade intact habitats or displace native flora", therefore, could be regarded as a widely cultivated species with low invasive potential.

The drought tolerant deciduous tree can reach a height of 10–12 m (33–39 ft) and trunk diameter of 45 cm (18 in). [12]. The bark has a single trunk and aesthetically rough texture with whitish-grey colour and is surrounded by a thick cork. Young shoots are purplish or greenish-white with hairy bark. The tree has an open crown of drooping, fragile branches, and the leaves build up a feathery foliage of tripinnate leaves. The flowers are fragrant and hermaphroditic, surrounded by five unequal, thinly veined, with yellowish-white petals. The flowers are ranges from 1–1.5 cm (3⁄8–5⁄8 in) long and 2 cm (3⁄4 in) broad.

They grow on slender, hairy stalks in spreading or drooping flower clusters, which have a length of 10–25 cm (4–10 in) [13]. Flowering only occurs once a year in late spring and early summer in more constant seasonal temperatures and with constant rainfall, flowering can happen twice or even all year-round. The fruit is a hanging, three-sided, brown, 20–45 cm (8–17+1⁄2 in) capsule, which holds dark brown, globular seeds with a diameter around 1 cm. The seeds have three whitish, papery wings and are dispersed by wind and water. In cultivation, it is often cut back annually to 1–2 m (3–6 ft) and allowed to regrow so the pods and leaves remain within arm's reach.

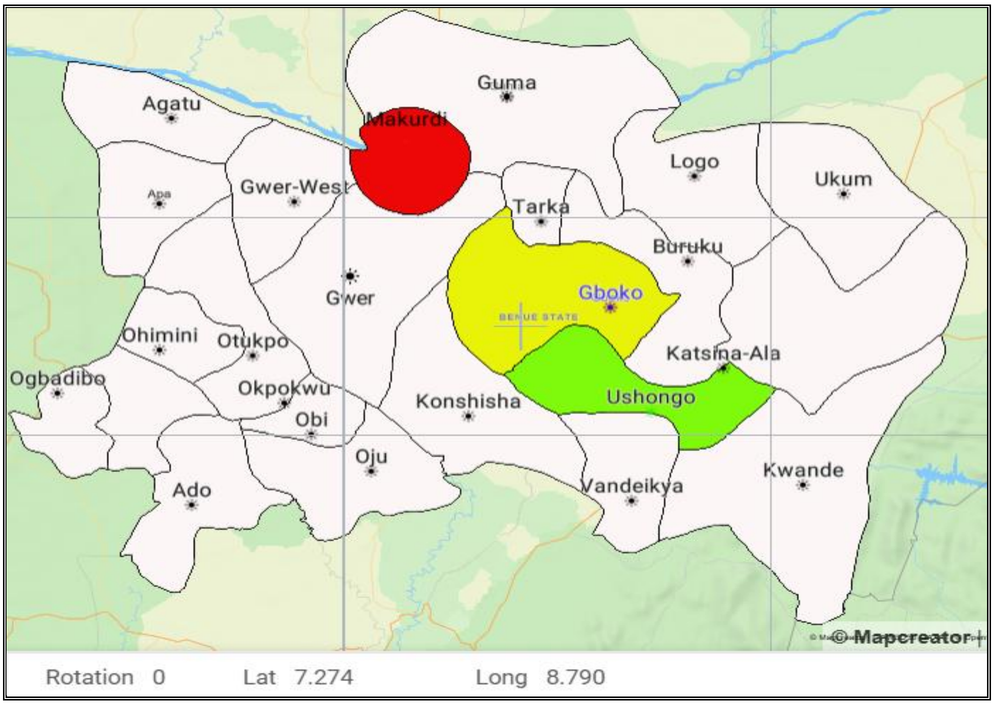
The Morpho-anatomical studies of plant such as *M. oleifera* are fundamental to advancing our understanding of evolution in Angiosperms, serving as a cornerstone for botanical research advancements. Investigations using morpho-anatomical tools are also invaluable in the understanding of plant ecological strategies and functional adaptations [14]. Traditional investigations using morpho-anatomical analysis are not obsolete they remain an essential tool in the facilitation of species identification, understanding of plant's evolution, offers insights into ecological adaptations, agricultural advancements, pharmaceutical research, and aid in conservation management practices [15].

As we delve deeper into the intricate world of plants, the importance of morpho-anatomical information remains undeniably paramount, since the compelling problems within the study includes the lack of comprehensive research documenting especially genetic variations, insufficient information on the factors driving morphology, plasticity and resultant limitations in genetic diversity and realizing its potentials in agriculture, human nutrition, and medicine. These issues are addressed through a comprehensive morphological and phylogenetic study of characters, being essential tools in bridging the existing knowledge gaps owing to the deficiency in the accurate documentation of morpho-anatomical information of most tropical trees species in west Africa, thus, undermining the multifaceted benefits of most tropical tree species. This research is aimed to evaluate the foliar morphological variations in *Moringa oleifera* accessions in Benue State. The specific objective of this work is to systematically investigation of the foliar variations in accessions of *M. oleifera*, encompassing aspects such as macro and micro morphological characteristics.

## 2. Methods

### *2.1. Study Area*

This research was carried out in three (3) local government areas (LGA) in Benue state, Nigeria, namely Makurdi, Ushongo, and Gboko. The area lies between latitude 7$^o$ 55” N and longitude 8$^o$ 32” E at an elevation of 97 m above sea level. The guinea savanna zone covers an area of about 34.059square/km and experiences a tropical climate with two distinct seasons (wet and dry). The state has an annual rainfall between 900-1200mm and a temperature ranging between 23$^o$C and 32$^o$C within the year [16].




| Keys | Study Area |
|---|---|
| (red) | Makurdi |
| (yellow) | Gboko |
| (green) | Ushongo |
| Source | https://app.mapcreator.io/project/1383362 |

**Figure 1.** Showing the map of Benue State

### *2.2. Collection of Plant Material and Morphological Studies*

Plant leaf materials were collected during field trips to the Makurdi, Ushongo and Gboko L.G.A of Benue State Nigeria in October 2023. Foliar morphological characters such leaflet length (mm), leaflet width (mm) and leaflet Area (mm) were inventoried using 10 randomly selected foliar materials from four plant stands in a population of each accession. [17]. Mean values of the morphological characters were measured and standard error of the mean was also determined.

### *2.3. Anatomical studies*

The epidermal leaf morphology was examined using fresh leaves fixed in formalin- acetic acid (FAA) and preserved in 70% ethanol. Peels were obtained using forceps with the fixed material in a water-filled petri dish, cleared with a camel hair brush and rinsed in distilled water for 5 minutes. The resultant epidermal peels were mounted on clean slides stained with safranin solution and mounted in glycerine then examined under an Olympus Light Microscope (HSC 447591 Model) [18]. Anomocytic stomata cells in adaxial surfaces where counted at X10 objective lens as described by Baker and Silverton [19], using an average of 10 randomly selected guard cells.

*2.4. Data Analysis*
The data were standardized, and a SIMINT study was performed and analysed with SAHN module to compute the various associations between the plant samples in this study. Data from morphological and anatomical characters were subjected to analysis using the NTSYS-pc vs 2.2e software package, which provides an effective method for multivariate data analyses [20].

## 3. Results and Discussion

Table 1 provides details of geographical coordinates (latitude and longitude) from 10 different study locations. Each entry includes an accession code, location name, latitude, and longitude. The coordinates represent precise geographical points of location of samples collected on the Earth's surface, expressed in degrees of latitude and longitude. These precise coordinates are essential for mapping and navigation purposes, aiding the accurate identification and location of specific points on the Earth’s surface.

**Table 1.** Locality of *Moringa oleifera* accessions and coordinates

| S/N | Accession Code | Location | Latitude | Longitude |
|---|---|---|---|---|
| 1 | UAMKD | Uniagric Makurdi | 7°45' 10.23” N | 8°33'0.0 ‘’E |
| 2 | WAMKD | Wadata Makurdi | 7°44' 13.45” N | 8°30' 10.1 ‘’E |
| 3 | NBMKD | Northbank Makurdi | 7°46'12.43” N | 8°35'10.2 ‘’E |
| 4 | WUMKD | Wurukum, Makurdi | 7°42' 12.23” N | 8°31' 11.3E |
| 5 | ADGBK | Adekaa Gboko | 7°21'13.63"N | 9°0'7.63"E |
| 6 | AGGBK | Agedam Gboko | 7°21'14.63"N | 9°0'7.63"E |
| 7 | ABGBK | Abagu Gboko | 7°21'15.63"N | 9°0'8.63"E |
| 8 | UTUSH | Ushongo Town | 7°46' 13.23’’N | 8°42'11.12 ‘’E |
| 9 | MBUSH | Mbele Ushongo | 8° 46' 12.21"E. | 8°43' 12.3’’ E |
| 10 | LSUSH | Lessel Ushongo | 7°21' 13.14’’N | 8°43' 12.4 ‘’E |

**Table 2.** Quantitative leaf macro-morphological characters of accessions of *Moringa oleifera*

| S/N | Accessions | Leaflet Length (Mm) | Leaflet Width (Mm) | Leaflet Area ($Mm^2$) | Fruit Length (Cm) |
|---|---|---|---|---|---|
| 1 | UAMKD | 16.30 | 9.30 | 151.59 | 10.10 |
| 2 | WAMKD | 14.30 | 8.70 | 124.41 | 11.22 |
| 3 | NBMKD | 23.30 | 11.7 | 272.61 | 10.33 |
| 4 | WUMKD | 23.30 | 14.0 | 326.20 | 60.22 |
| 5 | ADGBK | 24.00 | 15.3 | 367.20 | 52.22 |
| 6 | AGGBK | 17.70 | 10.0 | 177.00 | 58.50 |
| 7 | ABGBK | 13.30 | 9.00 | 119.70 | 44.33 |
| 8 | UTUSH | 18.00 | 11.3 | 203.40 | 54.30 |
| 9 | MBUSH | 19.30 | 12.3 | 237.39 | 31.00 |
| 10 | LSUSH | 13.70 | 9.30 | 127.41 | 57.45 |

Note: UAMKD = UNIAGRIC Makurdi, WAMKD = Wadata Makurdi, NBMKD = North-Bank Makurdi, WUMKD = Wurukum Makurdi, ADGBK = Adekaa Gboko, AGGBK = Agedam Gboko, ABGBK = Abagu Gboko, UTUSH = Ushongo, MBUSH = Mbele Ushongo, LSUSH = Lessel Ushongo.

Table 2 shows the quantitative leaf macro-morphological features of *M. oleifera* species evaluated. Quantitative characters such as leaflet length, width area and fruit length varied among different accessions. ADGBK (24.30 mm) was accession with longest leaflet length measurement and ABGBK (13.30mm) having the shortest across all study locations, while qualitative features such as leaflet arrangement, margin, leaflet shape, inflorescence, venation, and fruit shape were also examined. Qualitative features were fairly consistent within locations of study except leaf shape which ranged from elliptical to ovate. *Moringa oleifera* species encountered are habitually a small tree average height ranging from 10-12 m, with leaflet margin entire. Flowers are mostly pentamerous and zygomorphic with colours white to milk. Fruit green during growing season and brown at maturity, which consist mostly of three valve capsules ranging from 10 to 60 cm. The mature fruit splits open along an angle to expose seeds.

**Table 3.** Qualitative leaf macro-morphological characters of accessions of *Moringa oleifera*

| S/N | Accessions | Leaflet Apex | Leaflet Base | Leaflet Surface Above | Leaflet Surface Below | Leaflet Shape | Flower Colour | Leaflet Colour | Midvein Colour |
|---|---|---|---|---|---|---|---|---|---|
| 1 | UAMKD | Acute | Rounded | Glabrous | Pubescent | Elliptical to ovate | Cream | Green | Red-tinged |
| 2 | WAMKD | Acute | Rounded | Glabrous | Densely pubescent | Ovate | Cream | Green | Tinged |
| 3 | NBMKD | Acute | Rounded | Slightly pubescent | Pubescent | Ovate | Cream | Green | tinged |
| 4 | WUMKD | Acute | Rounded | Slightly pubescent | Pubescent | Obovate | White | Green | Tinged |
| 5 | ADGBK | Acute | Rounded | Slightly hairless | Pubescent | Obovate | Cream | Green | Tinged |
| 6 | AGGBK | Acute | Rounded | Glabrous | Pubescent | Ovate | Cream | Green | Tinged |
| 7 | ABGBK | Acute | Rounded | Glabrous | Pubescent | Ovate | White | Green | Red |
| 8 | UTUSH | Acute | Rounded | Slightly pubescent | Slightly pubescent | Ovate | Cream | Green | Tinged |
| 9 | MBUSH | Acute | Rounded | Glabrous | Slightly pubescent | Obovate | Cream | Green | Tinged |
| 10 | LSUSH | Acute | Rounded | Glabrous | Slightly pubescent | Obovate | Cream | Green | Red |

Tables 3 and 4 show the qualitative macro-morphological description of each accession encountered. Accessions were identified and characterized based on observable features, each intra specific characteristics observed represents an adaptation based on the unique environment influence in each habitat or study area. The midvein and flower colour were the most outstanding characteristics in each accession encountered. Figure 2 is a bar graph showing leaflet length, width, and area of *Moringa oleifera* studied. The most prominent leaflet area belongs to Adekaa Gboko (ADGBK).

Tables 5 and 6 show quantitative anatomical characteristics of accessions of *Moringa oleifera* from three Local Government Areas of Benue State. In Table 5, the characters examined include epidermal leaf cell length, width, and area. In NBMKD (52.10 µm) epidermal cell length was longest, while UAMKD (18.44 µm) had the widest width. NBMKD (808.59 µm) accessions had the most cell area in the epidermal leaf surface (adaxial). The result evidently shows that accessions in the Makurdi local government area (L.G.A), showed distinct anatomical characteristics especially in their epidermal cell properties. Also, Table 6 is showing the quantitative anatomical characteristics of accessions of the stomata length, width and index of *Moringa oleifera.* The stomatal cells of accessions from Ushongo L.G.A showed unique anatomical character variations. The stomatal length in UTUSH (48.00 µm) was the longest while stomatal width was highest in LSUSH (25.33 µm). Figure 2 is a bar graph showing the stomatal index percentage of ten accession investigated. WUMKD (27%) had the highest stomatal index percentage across all the study areas. Figure 3A-F displays the photomicrograph of the epidermal leaf (Adaxial surface) of *Moringa oleifera* accessions. Anatomical characters such as epidermal cell length and width, stomatal length and width were measured and evaluated. The stomata and epidermal cell characteristics displayed a range of apomorphic characters unique to species which shared same ecotype.

**Table 4.** Continuation of qualitative leaf macro-morphological characters of accessions of *Moringa oleifera*

| Accessions | Leaflet Arrangement | Leaflet Shape | Leaflet Texture | Inflores-cence Type | Venation | Fruit Shape | Tree Bark Colour | Seed Shape | Seed Colour |
|---|---|---|---|---|---|---|---|---|---|
| UAMKD | Tripinnately compound leaves | Elliptical | Fine | Panicles | Pinnate | Long slender | Whitish to Gray | Globular | Dark brown |
| WAMKD | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Slender | Gray | Globular | Light brown |
| NBMKD | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Gray | Globular | Light brown |
| WUMKD | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Whitish | Globular | Dark brown |
| ADGBK | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Whitish | Globular | Dark brown |
| AGGBK | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Gray | Globular | Dark brown |
| ABGBK | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Gray | Globular | Light brown |
| UTUSH | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Gray | Globular | Light brown |
| MBUSH | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Whitish | Globular | Light brown |
| LSUSH | Tripinnately compound leaves | Ovate | Fine | Panicles | Pinnate | Long Slender | Gray | Globular | Dark brown |

Note: UAMKD = UNIAGRIC Makurdi, WAMKD = Wadata Makurdi, NBMKD = North-bank Makurdi, WUMKD = Wurukum Makurdi, ADGBK = Adekaa Gboko, AGGBK = Agedam Gboko, ABGBK = Abagu Gboko, UTUSH = Ushongo, MBUSH = Mbele Ushongo, LSUSH = Lessel Ushongo

Table 5 and 6 is showing quantitative anatomical characteristics of accessions of *Moringa oleifera* from three Local Government Areas of Benue State. In Table 5 the characters examined includes epidermal leaf cell length, width, and area. In NBMKD (52.10 µm) epidermal cell length was longest, while UAMKD (18.44 µm) had the widest width. NBMKD (808.59 µm) accessions had the most cell area in the epidermal leaf surface (adaxial). The result evidently shows that accessions in the Makurdi local government area (L.G.A), showed distinct anatomical characteristics especially in their epidermal cell properties. Also, Table 6 is showing the quantitative anatomical characteristics of accessions of the stomata length, width, and index of *Moringa oleifera.* The stomatal cells of accessions from Ushongo L.G.A showed unique anatomical character variations. The stomatal length in UTUSH (48.00 µm) was the longest while stomatal width was highest in LSUSH (25.33 µm). Figure 2 is a bar graph showing the stomatal index percentage of ten accession investigated. WUMKD (27%) had the highest stomatal index percentage across all the study areas. Figure 3A-F displays the photomicrograph of epidermal leaf (Adaxial surface) of *Moringa oleifera* accessions. Anatomical characters such as epidermal cell length and width, stomatal length and width were measured and evaluated. The stomata and epidermal cell characteristics displayed a range of apomorphic characters unique to species which shared same ecotype.

**Table 5.** Quantitative anatomical characters (epidermal cells) of accessions of *Moringa oleifera* at three L.G. As in Benue State

| No | Accessions | Leaf Epidermal Cell Length (µm) | | Leaf Epidermal Cell Width (µm) | | Cell Area (µm) | |
|---|---|---|---|---|---|---|---|
| | | AD | AB | AD | AB | AD | AB |
| 1 | UAMKD | 28.87 ± 1.89$^{e}$ | 16.33 ± 1.53$^{cd}$ | 18.44 ± 1.40$^{bc}$ | 9.33 ± 0.58$^{a}$ | 532.36 ± 0.66$^{a}$ | 152.00 ± 23.8$^{ef}$ |
| 2 | WAMKD | 34.77 ±1.59$^{bc}$ | 14.33 ± 2.52$^{de}$ | 13.22 ± 1.11$^{b}$ | 8.67 ± 1.53$^{a}$ | 459.65 ± 0.89$^{a}$ | 124.24 ±27.68$^{f}$ |
| 3 | NBMKD | 52.10 ± 1.49$^{a}$ | 23.33 ± 1.53$^{a}$ | 15.52 ± 1.00$^{c}$ | 11.67 ± 0.58$^{a}$ | 808.59 ± 0.65$^{a}$ | 272.26 ± 6.66$^{b}$ |
| 4 | WUMKD | 31.80 ± 1.97$^{d}$ | 23.33 ± 0.58$^{a}$ | 15.34 ± 1.22$^{b}$ | 14.00 ± 1.00$^{a}$ | 487.81 ± 1.00$^{a}$ | 326.62 ± 30.81$^{a}$ |
| 5 | ADGBK | 25.97 ± 1.71$^{a}$ | 24.00 ± 1.00$^{a}$ | 16.66 ± 1.80$^{bc}$ | 15.33 ± 0.58$^{a}$ | 432.66 ± 0.88$^{a}$ | 367.92 ± 28.43$^{a}$ |
| 6 | AGGBK | 37.13 1.01$^{b}$ | 17.67 ± 1.53$^{bc}$ | 12.24 ± 0.67$^{b}$ | 10.00 ± 1.00$^{a}$ | 454.47 ± 0.95$^{a}$ | 176.70 ± 4.51$^{de}$ |
| 7 | ABGBK | 34.73 ± 1.36$^{bc}$ | 13.33 ± 1.53$^{e}$ | 13.45 ± 0.55$^{c}$ | 9.00 ± 1.00$^{a}$ | 467.38 ± 0.10$^{a}$ | 119.97 ± 27.22$^{f}$ |
| 8 | UTUSH | 32.67 ± 1.19$^{cd}$ | 18.00 ± 1.00$^{bc}$ | 14.70 ± 0.50$^{c}$ | 11.33 ± 1.53$^{a}$ | 480.25 ± 0.33$^{a}$ | 203.94 ± 36.83$^{cd}$ |
| 9 | MBUSH | 32.67 ± 1.56$^{cd}$ | 19.33 ± 0.58$^{b}$ | 10.80 ± 0.54$^{a}$ | 12.33 ± 0.58$^{a}$ | 352.84 ± 0.55$^{a}$ | 238.34 ± 9.61$^{bc}$ |
| 10 | LSUSH | 29.07 ± 1.11$^{e}$ | 13.67 ± 1.55$^{e}$ | 12.66 ± 1.20$^{e}$ | 16.00 ± 45. 04$^{a}$ | 368.02 ± 0.98$^{a}$ | 492.12 ± 32.13$^{f}$ |

**Table 6.** Quantitative anatomical characters (stomata) of accessions of *Moringa oleifera* at three L.G. As in Benue State

| No | Accessions | Stomatal Cell Length (µm) | | Stomatal Cell Width | |
|---|---|---|---|---|---|
| | | AD | AB | AD | AB |
| 1 | UAMKD | 20.33 ± 1.53$^{f}$ | 24.00 ± 1.00$^{b}$ | 15.21 ± 1.09$^{a}$ | 13.12 ± 1.33$^{c}$ |
| 2 | WAMKD | 25.67 ± 4.04$^{d}$ | 14.00 ± 1.00$^{de}$ | 19.88 ± 0.63$^{ab}$ | 18.32 ± 1.25$^{c}$ |
| 3 | NBMKD | 40.00 ± 1.00$^{c}$ | 41.00 ± 2.00$^{a}$ | 18.55 ± 1.09$^{ac}$ | 16.56 ± 1.00$^{c}$ |
| 4 | WUMKD | 25.67 ± 1.53$^{d}$ | 43.00 ± 3.61$^{a}$ | 17.89 ± 1.00$^{a}$ | 15.08 ± 1.02$^{c}$ |
| 5 | ADGBK | 44.67 ± 3.51$^{ab}$ | 18.87 ± 2.52$^{c}$ | 12.55 ± 1.40$^{a}$ | 14.04 ± 1.00$^{b}$ |
| 6 | AGGBK | 42.33 ± 3.51$^{bc}$ | 17.33 ± 2.52$^{cd}$ | 19.04 ± 1.00$^{a}$ | 17.55 ± 0.99$^{b}$ |
| 7 | ABGBK | 17.67 ± 1.53$^{e}$ | 11.00 ± 100$^{ef}$ | 09.10 ± 0.99$^{c}$ | 12.12 ± 0.99$^{b}$ |
| 8 | UTUSH | 48.00 ± 2.00$^{a}$ | 21.00 ± 2.65$^{bc}$ | 22.02 ± 1.07$^{c}$ | 14.58 ± 0.50$^{b}$ |
| 9 | MBUSH | 45.67 ± 1.53$^{ab}$ | 8.00 ± 2.00$^{f}$ | 24.03 ± 1.12$^{d}$ | 16.98 ± 1.00$^{b}$ |
| 10 | LSUSH | 28.67 ± 1.15$^{d}$ | 10.33 ± 1.53$^{ef}$ | 25.33 ± 1.09$^{e}$ | 18.44 ± 1.40$^{b}$ |

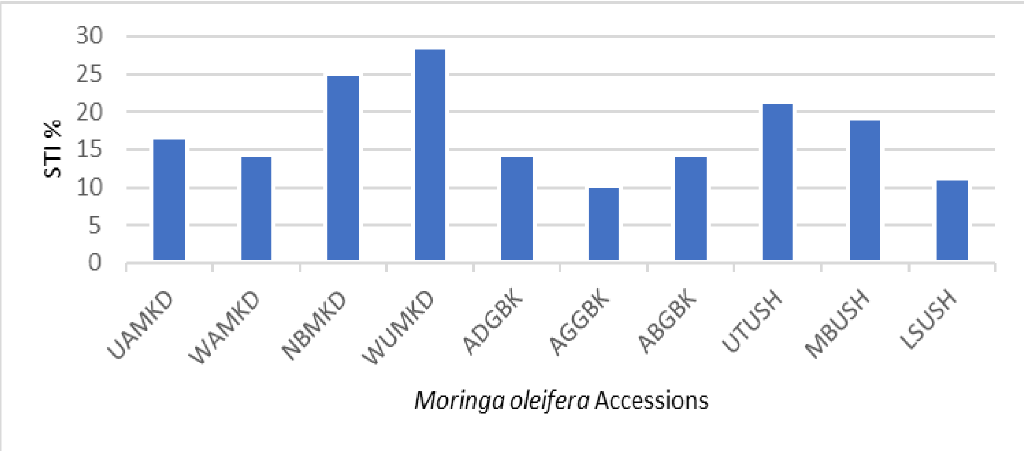



**Figure 2**. Stomatal index percentage (%) across studied accessions

Variations in *Moringa oleifera* species evaluated from the three local government areas apparently revealed the concealed uniformity and variability of species within different accessions [21]. Morphological variations encompass a multitude of differences observed in the structural appearances within the same species [22]. These variations emerge from a complex interplay of factors, such as the geographical origin of the plant, the environmental conditions, and selective pressures such as water and drought stress. From results in table 2, 3 and 4 the variations manifested across the accessions presents a rich spectrum of characteristics in the leaf, especially microscopic features like epidermal leaf characters. Recent studies have revealed that some accessions may produce larger, elongated leaves, while others display smaller, rounder leaves. [23]. Stems may also vary in thickness, texture, and shape. Also, flowers and fruits may differ in colour and shape. At the microscopic level the leaf epidermal cells showed variations in leaf tissues, and vascular structures in different accessions investigated [24].

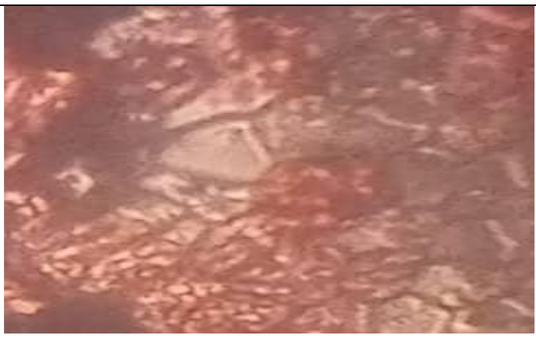


**Figure 3A.** UAMMKD Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Makurdi, L. G. A of Benue State

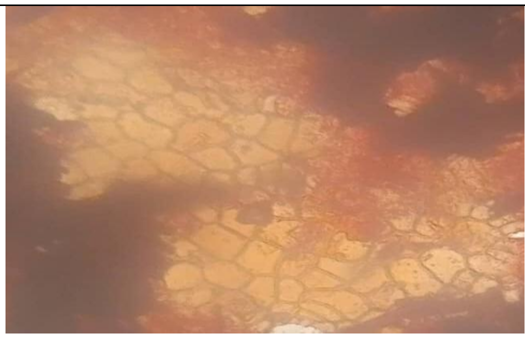


**Figure 3B.** NBMKD Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Makurdi, L. G. A of Benue State

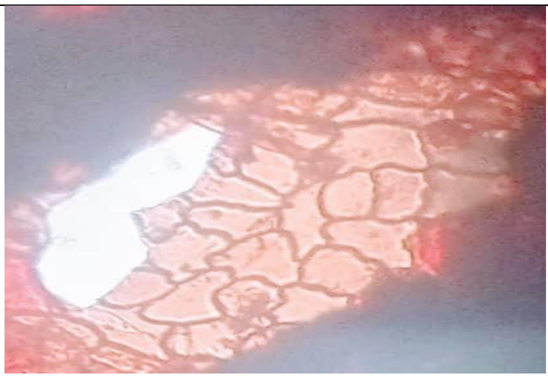


**Figure 3C.** AGGBK Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Gboko, L. G. A of Benue State

**Figure 3D.** ABGBK Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Gboko, L. G. A of Benue State

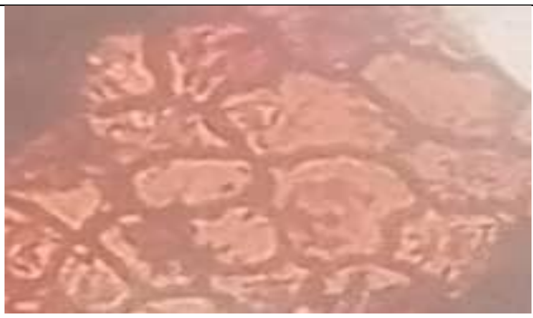


**Figure 3E.** UTUSH Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Ushongo, L. G. A of Benue State

**Figure 3F.** LSUSH Showing Epidermal Leaf Surfaces (Adaxial) of *Moringa oleifera* in Ushongo, L. G. A of Benue State

Note: UAMMKD-Uniagric Makurdi, NBMKD-Northbank Makurdi, AGGBK-Agedam Gboko, ABGBK-Abagu Gboko, UTUSH-Ushongo Town Ushongo, LSUSH-Lessel Ushongo.

The study of the macro and micro morphological variations in *M. oleifera* is profoundly important due to its extensive implications such as understanding the interactions of species with environment as it concerns adaptability, utility, and storage potentials of *M. oleifera* in addressing the recent global challenges, particularly in the domains of nutrition, food sustainability, and biodiversity conservation. The existing variations also hints at the rich genetic diversity within species, with each accession potentially harbouring unique genetic traits. These traits can be harnessed through the development of *M. oleifera* varieties that are excellent in specific aspects, such as enhanced nutritional content and availability, and improved and heightened resistance to pests and diseases. The investigation of comprehending variations can assist in the selection of best suitable and tolerant accessions to diverse environmental conditions, thereby, contributing to the sustainability and productivity in agriculture [25]. Different accessions may also possess distinct phytochemical profiles, opening doors to the isolation and identification of compounds that hold applications in the pharmaceutical industry. This, in turn, promotes the advancement of drug development and biotechnology [26].

The data obtained evidently provide substantial variability in the leaf morphological characteristics among the different accessions. For instance, the leaf length ranges from a minimum of 13.30 mm in the ABGBK accession to a maximum of 24.40 mm in the ADGBK accession. The perennial small tree has petiole thickened at the base of the leaves. This considerable range indicates diversity in the overall size of *Moringa oleifera* leaves across these accessions. Systematically, these measurements contribute valuable data for understanding the intraspecific variation within *Moringa oleifera*.

The observed differences in leaf morphology can have implications for the species' adaptability, ecological niche, and potential applications in agriculture and horticulture [26]. The micro morphological details such as leaflet area and dimensions, provided quantifiable information for researchers interested in the cultivation, breeding, and conservation of *Moringa oleifera*. Additionally, the results provide clarity by linking the accession codes to specific locations, facilitating further research or field application based on geographic distinctions. Leaflet area exhibited noteworthy differences.

The accession in Gboko study area for instance in ADGBK the accessions stood out with the largest leaflet area of 367.20 mm², while ABGBK accession had a smaller leaflet area of 119.70 mm². These variations in leaflet areas suggest diverse leaf structures, potentially influenced by genetic factors and environmental conditions. The study of Morpho-anatomical variation in *Moringa oleifera* is confronted with several compelling problems. Firstly, despite the informed significance of these variations, there exists a dearth of research gap in the documentation, analyses, and interpretation of the full spectrum of morphological and anatomical differences within different accessions of *M. oleifera*. This gap in research leaves a critical void in our understanding of the species, hindering our ability to harness the enormous genetic diversity present within the species. Moreover, the precise genetic, environmental, and physiological factors that drive the observed morpho-anatomical variation in *M. oleifera* remain poorly understood. This lack of understanding impedes efforts to optimize the cultivation of *M. oleifera*, a plant with immense potential for addressing pressing global challenges related to food security, nutrition, and health. Without having an in-depth insight into the underlying factors contributing to morphological variation, it becomes challenging to develop excellent targeted strategies necessary for improving *M. oleifera* cultivation and utilization.

There is an existing knowledge gap that poses limitations in the exploration of the multifaceted benefits of *M. oleifera*. This remarkable plant has the potential to contribute significantly to agriculture, providing nutrient-rich leaves and seeds, also, pharmaceutical benefits, as it contains compounds with varying therapeutic properties. However, a comprehensive understanding of the extent, drivers, and implications of morpho-anatomical variation, can help fully unlock its potential for vital applications. Other compelling problems within the study of morpho-anatomical variations in *Moringa oleifera* includes the lack of comprehensive research documenting especially in the aspects of genetic variations which has led to insufficient information on the factors driving morphological variation and resultant limitations in genetic diversity. These issues are addressed through a comprehensive morphological and phylogenetic study of characters, being essential tools in bridging the existing knowledge gaps thereby unlocking the multifaceted benefits from *M. oleifera*

## 4. Conclusion

The morphological and anatomical features of *M. oleifera* accessions examined in this work have affirmed the uniqueness and significance of foliar morphological variations. Thus, characterization of accessions obtained from each study location showcased key identification features for each accession examined. The variations in shapes, sizes, and textures of leaves, stomata, and epidermal cells occurred fundamentally because of selective pressure, evolutionary history, tolerance, and adaptations to microclimate or local environmental conditions. Changes in plant features, particularly the leaf organ, have been attributed to small-scale evolutionary processes and are basically associated with the pattern of distribution of leaf biomass in both support and functional tissues. Thus, the relatively homogeneous morphotypic accessions shared unique adaptation to climatic gradient and mostly impacted by farmers' management practices such as method of propagation and ethnobotanical use. The morphological features studied also provided evidence of the existence of heterogeneity within *M. Oleifera* population. The observed difference in phenotypic plasticity of morphological sizes can be compared with genetic variations within accessions. Thus, Stomatal features were found to correlate with variation in epidermal cell number, shape, and distribution. Further research with consideration to the observed morphological variations in relation to evolution and ecological behaviours is recommended. In addition, taxonomic delimitation efforts involving classification within species can be achieved using taxonomic numerical analysis comprising phytochemical, molecular and cytological evidences in combination with morphological characteristics to produce a more robust cladistic evidence. These recommendations are important for the preservation of genetic traits through conservation efforts and aimed to assist farmers in the acquisition of desirable traits during propagation while cojoining findings with Agricultural extension programs.

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