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Original Article

Morphological and Stomatal Characteristics Among Nigerian *Amaranthus* Species: Improving Species Identification and Classification

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ABSTRACT

The genus *Amaranthus* is difficult to classify because many of its species look very similar. They also show wide variation in their appearance, often cross with one another, and may have different numbers of chromosomes. These factors make it hard to identify species correctly. In this study, we compared the leaf surface features and visible plant characteristics of six Nigerian *Amaranthus* species: *A. caudatus*, *A. hybridus*, *A. blitum*, *A. viridis*, and the red and green forms of *A. spinosus*. We measured plant height, leaf shape and size, stem features, and stomatal characteristics. Three stomatal types were found: anisocytic, tetracytic, and anomocytic. The number, size, and distribution of stomata differed among the species. *Amaranthus caudatus* had the highest stomatal density (109.19 mm^2) and stomatal index (20.86%) on the lower leaf surface, while *A. hybridus* had the lowest values. The anomocytic stomatal type was found only in the red form of *A. spinosus*, making it a useful feature for identifying this plant. The species also differed in important visible characteristics such as plant height, branching pattern, petiole length, and stem diameter. By combining these visible features with leaf epidermal characters, we developed a dichotomous key that can be used to identify the species more accurately. Our findings show that both external plant features and microscopic leaf characters are useful for distinguishing *Amaranthus* species. These results will improve species identification and classification and provide valuable information for future studies on plant conservation, crop improvement, and the medicinal uses of *Amaranthus*.

Keywords: *Amaranthus,* Leaf epidermis, Micromorphology, Morphological traits, Species delimitation, Taxonomic identification, Dichotomous key, Nigeria

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INTRODUCTION

Amaranthus L. is a genus of flowering plants in the family Amaranthaceae. The genus was first described by Linnaeus [1] and includes approximately 60–80 species distributed throughout tropical and temperate regions of the world [2–4]. Species of *Amaranthus* are valued for their nutritional, ornamental, ecological, and economic importance. Historically, they served as staple food crops for ancient civilizations such as the Aztecs and Incas because of their high nutritional value and adaptability.

In Africa, particularly in Nigeria, *Amaranthus* species are widely cultivated and consumed as leafy vegetables. The are also used in traditional medicine and play important cultural and economic roles. The ability of these plants to grow under diverse environmental conditions and their rich nutritional composition have made them important food resources for many communities [5,6]. In Nigeria, these plants are commonly known as "Tètè" or "Efo Tètè" among the Yoruba, "Alayyahu" among the Hausa, and "Inine" or "Akwukwo nzu" among the Igbo. Similar indigenous names occur across Africa, reflecting their widespread cultivation and cultural significance [7,8].

Despite their importance, the taxonomy of *Amaranthus* remains one of the most challenging within the Amaranthaceae. Species often show considerable variation in their appearance, even within the same species, because many morphological traits are influenced by environmental conditions [9]. In addition, frequent hybridization between closely related species and the widespread occurrence of polyploidy further complicate species identification and classification [10–12]. As a result, different species may appear similar, while individuals of the same species may show remarkable morphological differences. These challenges have led to frequent misidentification and disagreements in species classification.

Another major challenge is the occurrence of cryptic species, which are genetically distinct species that are difficult to distinguish using visible characteristics alone. Traditional morphological methods are often insufficient for separating such species. Consequently, modern taxonomic studies increasingly rely on molecular approaches such as DNA barcoding and phylogenetic analysis to improve species identification and clarify evolutionary relationships [11,13]. Historical changes in classification systems have also resulted in numerous synonyms and incorrectly applied names, creating additional confusion within the genus [14,15].

To overcome these challenges, recent taxonomic studies combine traditional morphological observations with modern analytical techniques. Plant architecture, floral characteristics, fruit and seed morphology remain important diagnostic characters, but these are now complemented by molecular markers such as RAPD and ISSR, DNA barcoding, phylogenetic analyses, scanning electron microscopy (SEM), and chemotaxonomic investigations [13,16–18]. These integrated approaches have improved species delimitation and provided a better understanding of evolutionary relationships within *Amaranthus*. However, phytochemical markers remain relatively underutilized despite their considerable taxonomic potential.

In Nigeria, at least six *Amaranthus* species are commonly recognized, namely *A. hybridus*, *A. spinosus*, *A. cruentus*, *A. viridis*, *A. dubius*, and *A. caudatus* [19]. However, the exact diversity and distribution of these species remain uncertain because of the taxonomic complexities within the genus. *Amaranthus hybridus* is the most widely cultivated species, whereas *A. spinosus* commonly occurs as a weed. *Amaranthus viridis* is notable for its wide ecological adaptability. Despite the economic and nutritional importance of these species, relatively few studies have applied modern taxonomic tools to Nigerian populations, leaving important gaps in current knowledge.

The present study was designed to improve the delimitation and

identification of Nigerian *Amaranthus* species by integrating detailed morphological and leaf epidermal characteristics. Combining macromorphological and micromorphological evidence, this study provides a clearer understanding of species boundaries within the genus. The findings are expected to contribute to more accurate taxonomy, support biodiversity conservation, facilitate breeding programmes, and promote the sustainable utilization of these economically important plants.

MATERIALS AND METHODS

Selection of Plant Materials

Fresh plant materials were collected from six Nigerian *Amaranthus* taxa, namely *Amaranthus hybridus*, *A. viridis*, *A. caudatus*, *A. blitum*, and the red- as well as green-stemmed variants of *A. spinosus* (Figure 1; Table 1). The experimental field was established at the Botanical Garden of the Department of Plant Biology, University of Ilorin. The land was cleared, tilled, and divided into twelve vegetable beds, with two beds assigned to each taxon. The experimental plots were fenced to protect the plants from grazing animals. Seeds were broadcast on the prepared beds and watered daily until the plants reached maturity.

At maturity, healthy leaves and stems were collected from representative plants of each taxon. All samples were harvested during the same growing season to minimize environmental effects on plant characteristics. Information recorded for each specimen included the species name, plot number, collection date, and important morphological features. Representative specimens were pressed, dried, and deposited in the University of Ilorin Herbarium (UILH) as voucher specimens for future reference and taxonomic verification

.

Table 1: Nigerian species of *Amaranthus*

S/No.	Species	Common names
1	*Amaranthus hybridus* L.	Smooth Pigweed
2	*Amaranthus viridis* L.	Green Amaranth, Slender Amaranth
3	*Amaranthus caudatus* L.	Foxtail Amaranth, love-lies-bleeding, tassel flower, velvet flower
4	*Amaranthus blitum* L.	Purple Amaranth or Guernsey Pigweed
5	*Amaranthus spinosus* L. (Red variant)	Spiny Amaranth
6	*Amaranthus spinosus* L. (Green variant)	Spiny Amaranth

Amaranthus blitum

Amaranthus caudatus

Amaranthus hybridus

Amaranthus spinosus (green variant)

Amaranthus spinosus (red variant)

Amaranthus viridis

Fig. 1: Photographs of some *Amaranthus* species used in this study

Morphological Characterization

Morphological characterization was carried out using both qualitative and quantitative characters that are commonly used in plant taxonomy.

Qualitative Characters

Fresh plants were carefully examined for vegetative and reproductive characteristics. Leaf characters evaluated included leaf shape, arrangement, venation pattern, apex, base, margin, and surface texture. Stem characteristics such as colour, surface texture, and the presence or absence of hairs or spines were also recorded. Floral characters, including flower type, colour, and arrangement, were observed and documented.

Quantitative Characters

Quantitative measurements were obtained using calibrated rulers and digital calipers. The parameters measured included plant height, leaf length, leaf width, petiole length, number of leaves, stem diameter, stem girth, number of branches, filament length, and anther number. High-resolution photographs of fresh plants and herbarium specimens were taken to document colour variation and other diagnostic features.

Anatomical Studies

Leaf, stem, and root samples were sectioned using a sharp razor blade and a rotary microtome. The tissues were immediately fixed in Formalin–Acetic Acid–Alcohol (FAA; 5:5:90, v/v/v) for 24 hours to preserve cellular structures following the procedures described by Johansen **[20]** and Esau **[21]**. The samples were then dehydrated through a graded ethanol series (30%, 50%, 70%, 90%, and 100%), cleared in xylene, infiltrated with molten paraffin wax, and embedded for sectioning. Thin sections (5–10 μm) were mounted on microscope slides coated with Mayer's albumin.

The sections were stained with Safranin O and counterstained with Fast Green following standard botanical microtechniques **[20,21]**. After dehydration and clearing, the sections were permanently mounted in Canada balsam and allowed to dry before microscopic examination.

Leaf Epidermal Analysis

Leaf epidermal peels from both the upper (adaxial) and lower (abaxial) surfaces were prepared for microscopic examination. Stomatal and trichome types were identified using the classification system proposed by Dilcher **[22]**, while their frequency was determined according to the method of AbdulRahaman and Oladele **[23]**.

The frequency of each stomatal type was calculated as:

Frequency (%) = Number of a particular stomatal type/Total number of stomata observed x 100

Stomatal density was determined as the number of stomata per square millimetre of leaf surface following Stace **[24]**. Stomatal index was calculated using the equation:

$$SI = S/(E + S) \times 100$$

where **S** is the number of stomata per mm^2 and **E** is the number of ordinary epidermal cells per mm^2 **[24]**.

The size of each stoma was estimated by measuring the length and width of 30 randomly selected stomata using an eyepiece micrometer. Stomatal area was calculated using Franco's constant (K = 0.79) according to Franco **[25]** and Wilkinson **[26]**.

Microscopy and Scanning Electron Microscopy

Prepared slides were examined under a compound light microscope at different magnifications (10×, 40×, and 100×). Observations focused on stomatal anatomical features. Photomicrographs were captured using a digital camera attached to the microscope.

Statistical Analysis

Quantitative data were analysed using IBM SPSS Statistics. All measurements were expressed as mean ± standard deviation (SD). Differences among the studied species were assessed using one-way analysis of variance (ANOVA). Where significant differences were detected, Tukey's Honestly Significant Difference (HSD) post hoc test was used for multiple pairwise comparisons. Statistical significance was set at $p < 0.05$.

RESULTS

Morphological Variation Among Nigerian *Amaranthus* Species

The six *Amaranthus* taxa examined in this study showed significant differences in all measured morphological characters (Table 2). One-way analysis of variance (ANOVA) revealed that plant height, leaf length, leaf width, petiole length, number of leaves, stem diameter, stem girth, and number of branches differed significantly among the species ($p < 0.05$). These differences demonstrate substantial morphological diversity within the genus.

Plant Height

Plant height varied significantly among the species. *Amaranthus blitum* produced the tallest plants, with a mean height of 38.94 ± 11.77 cm, followed closely by *A. caudatus* (37.73 ± 11.15 cm). These two species did not differ significantly from each other. In contrast, the red variant of *A. spinosus* was the shortest (25.10 ± 6.33 cm), while the green variant, *A. hybridus*, and *A. viridis* showed intermediate heights.

Leaf Characteristics

Leaf morphology differed markedly among the taxa. *Amaranthus hybridus* produced the longest leaves (11.43 ± 2.55 cm) and the longest petioles (4.80 ± 1.30 cm), making it easily distinguishable from the other species. Conversely, the green variant of *A. spinosus* had the shortest leaves (3.97 ± 0.77 cm). Leaf width also varied significantly, with *A. caudatus* producing the broadest leaves (6.96 ± 4.00 cm), whereas *A. blitum* had the narrowest (2.25 ± 0.43 cm).

Leaf Production

The number of leaves differed greatly among species. *Amaranthus viridis* and the green variant of *A. spinosus* produced the highest numbers of leaves, averaging approximately 182 leaves per plant. In contrast, *A. hybridus* produced significantly fewer leaves, averaging only 30.78 ± 16.76.

Stem Characteristics

Stem dimensions also showed considerable variation. *Amaranthus hybridus* had the thickest stems, with the largest stem diameter (4.64 ± 1.89 cm) and stem girth (4.75 ± 2.25 cm). In comparison, *A. viridis* had the thinnest stems, with a diameter of 1.07 ± 0.57 cm and a girth of 2.01 ± 0.94 cm. The remaining species displayed intermediate stem sizes.

Branching Pattern

Branching pattern varied significantly among the taxa. *Amaranthus viridis* produced the highest number of branches (10.94 ± 3.24), indicating a highly branched growth habit. In contrast, *A. hybridus* had the fewest branches (4.00 ± 2.03). Both the red and green variants of *A.*

spinosus showed moderate branching, falling between these two extremes.

Table 2: Morphological parameter of six *Amaranthus* species

Species	Plant Height (cm)	Leaf Length (cm)	Leaf Breadth (cm)	Petiole length (cm)	No of Leaves	Stem Diameter (cm)	Stem girth (cm)	No of Braches
Amaranthus caudatus	37.73±11.15^{a}	9.08±2.21^{b}	6.96±4.00^{c}	3.84±1.33^{b}	119.93±67.53^{bc}	2.95±1.28^{b}	3.73±1.43^{b}	5.36±1.90^{c}
Amaranthus spinosus (Green variant)	27.20±6.83^{bc}	3.97±0.77^{e}	3.92±1.04^{d}	2.37±0.89^{cd}	182.12±176.75^{a}	2.13±0.55^{c}	2.23±1.31^{c}	6.68±1.97^{b}
Amaranthus blitum	38.94±11.77^{a}	7.31±5.67^{c}	2.25±0.43^{b}	3.66±1.40^{b}	90.74±31.14^{c}	2.89±1.99^{b}	1.61±1.39^{d}	5.46±1.99^{c}
Amaranthus hybridus	29.62±7.85^{b}	11.43±2.55^{a}	5.00±3.42^{a}	4.80±1.30^{a}	30.78±16.76^{d}	4.64±1.89^{a}	4.75±2.25^{a}	4.00±2.03^{d}
Amaranthus viridis	29.88±6.68^{b}	4.59±1.98^{de}	6.00±4.59^{c}	2.77±0.88^{c}	182.10±81.31^{a}	1.07±0.57^{d}	2.01±0.94^{cd}	10.94±3.24^{a}
Amaranthus spinosus (Red variant)	25.10±6.33^{c}	5.39±2.68^{d}	3.41±0.90^{d}	2.01±0.82^{d}	134.83±52.50^{b}	2.77±1.43^{b}	2.06±0.79^{cd}	7.07±2.17^{b}
N	50	50	50	50	50	50	50	50
F.	20.990	45.148	18.623	42.491	21.560	34.596	36.553	55.715
Sign.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Values represent mean ± standard deviation. Species with means having the same letter are not significantly at p≤0.05

Stomatal Characteristics of Nigerian *Amaranthus* Species

The leaf epidermis of the six *Amaranthus* taxa showed both shared and distinctive characteristics (Table 3; Figures 2–7). Three stomatal types were identified: anisocytic, tetracytic, and anomocytic. Anisocytic and tetracytic stomata occurred in all species, whereas anomocytic stomata were observed only on the lower (abaxial) surface of the red variant of *Amaranthus spinosus*. This unique feature provides an important diagnostic character for distinguishing this taxon from the others.

Anisocytic and tetracytic stomata occurred at very high frequencies in all species, often reaching 100% on both leaf surfaces. The red variant of *A. spinosus* was the only taxon in which anomocytic stomata were observed, accounting for 60% of the stomata on the abaxial surface.

Stomatal density and stomatal index were generally higher on the lower leaf surface than on the upper surface in all species. *Amaranthus caudatus* recorded the highest abaxial stomatal density (109.19 mm^{-2}) and stomatal index (20.86%). Similarly, *A. blitum* exhibited high stomatal density on both leaf surfaces. In contrast, *A. hybridus* had the lowest stomatal density (17.32 mm^{-2}) and stomatal index (3.80%) on the adaxial surface.

The size of stomata also differed among the species. *Amaranthus caudatus* possessed the largest stomata, reaching 38.30 µm, whereas the red variant of *A. spinosus* had the smallest stomata,

measuring approximately 14 µm. The remaining taxa showed intermediate stomatal sizes

.

Table 3: Leaf epidermal features of six *Amaranthus* species

Species	Leaf surface	Stomatal types	Frequency (%)	Stomatal density (mm²)	Stomatal index (%)	Stomatal size (µm)
Amaranthus caudatus	Adaxial	Anisocytic	93.33	49.34	12.24	32.92
		Tetractic	86.67			
	Abaxial	Anisocytic	100.00	109.19	20.86	38.30
		Tetractic	100.00			
Amaranthus spinosus (Red)	Adaxial	Anisocytic	96.67	58.11	10.74	13.93
		Tetractic	100.00			
	Abaxial	Anisocytic	83.33	79.75	12.53	14.34
		Tetractic	100.00			
		Anomocytic	60.00			
Amaranthus spinosus (Green)	Adaxial	Anisocytic	100.00	42.76	10.32	14.99
		Tetractic	100.00			
	Abaxial	Anisocytic	100.00	95.39	19.11	16.35
		Tetractic	100.00			
Amaranthus viridis	Adaxial	Anisocytic	100.00	67.76	14.87	15.38
		Tetractic	100.00			
	Abaxial	Anisocytic	100.00	71.93	17.01	16.41
		Tetractic	100.00			
Amaranthus blitum	Adaxial	Anisocytic	100.00	102.85	20.37	16.62
		Tetractic	100.00			
	Abaxial	Anisocytic	100.00	98.70	18.89	15.38
		Tetractic	100.00			
Amaranthus hybridus	Adaxial	Anisocytic	100.00	17.32	3.80	15.38
		Tetractic	100.00			
	Abaxial	Anisocytic	100.00	53.07	10.76	14.54
		Tetractic	100.00			

Each species displayed a distinctive combination of epidermal characteristics. *Amaranthus caudatus* combined high stomatal density, a high stomatal index, and large stomata. *A. blitum* was characterized by consistently high stomatal density on both leaf surfaces. *A. viridis* showed intermediate stomatal values but maintained high stomatal frequency. *A. hybridus* was distinguished by low stomatal density and index, particularly on the adaxial surface. The red variant of *A. spinosus* was unique in possessing anomocytic stomata, whereas the green variant was characterized by uniformly high frequencies of anisocytic and tetracytic stomata on both surfaces.

The leaf epidermis provided several diagnostic features for distinguishing the studied *Amaranthus* species. Although anisocytic and tetracytic stomata were common to all taxa, differences in stomatal density, stomatal index, stomatal size, and the occurrence of anomocytic stomata effectively separated the species. These micromorphological traits complement morphological characters and improve the accuracy of species identification.

Fig. 2: Leaf epidermal surface of *Amaranthus blitum,* adaxial (A) and abaxial (B) showing anisocytic and tetracytic stomata

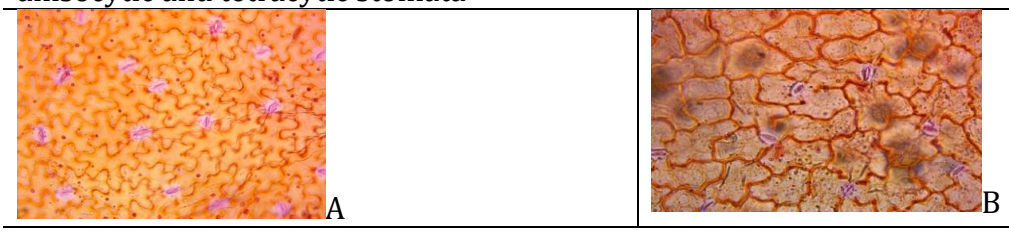

Fig. 3: Leaf epidermal surface of *Amaranthus caudatus,* adaxial (A) and abaxial (B) showing anisocytic and tetracytic stomata

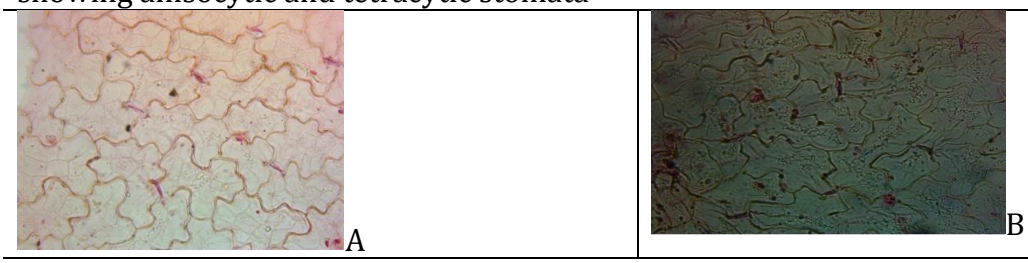

Fig. 4: Leaf epidermal surface of *Amaranthus hybridus,* adaxial (A) and abaxial (B) showing anisocytic and tetracytic stomata

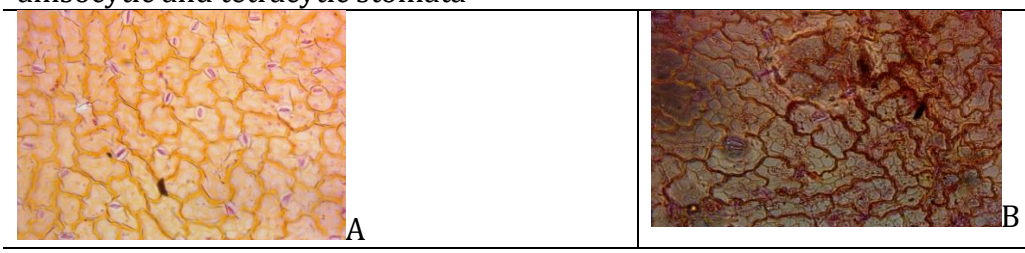

Fig. 5: Leaf epidermal surface of *Amaranthus spinosus* (Green), adaxial (A) and abaxial (B) showing anisocytic and tetracytic stomata

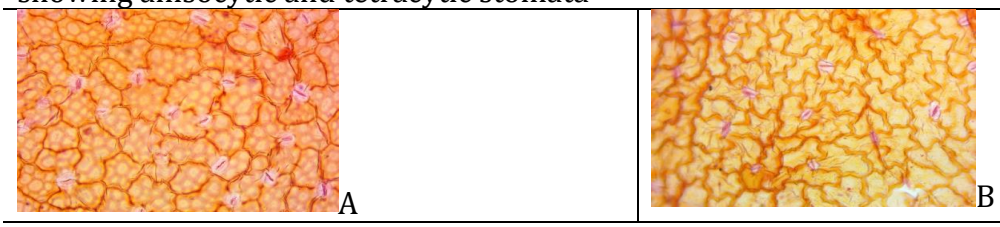

Fig. 6: Leaf epidermal surface of *Amaranthus spinosus* (Red), adaxial (A) and abaxial (B) showing anisocytic, tetracytic and anomocytic stomata

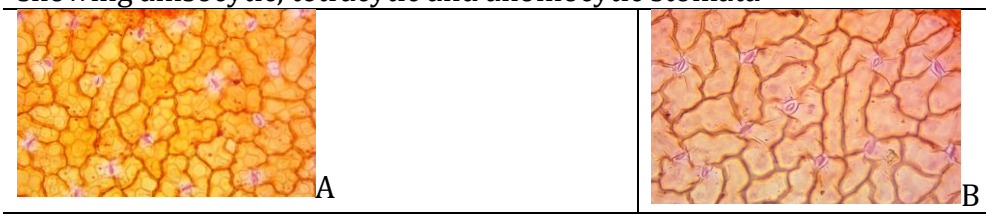

Fig. 7: Leaf epidermal surface of *Amaranthus viridis,* adaxial (A) and abaxial (B) showing anisocytic and tetracytic stomata

DISCUSSION

Morphological Diversity and its Taxonomic Significant

This study demonstrates considerable morphological variation among the six Nigerian *Amaranthus* taxa. Significant differences were observed in plant height, leaf dimensions, petiole length, stem diameter, stem girth, branching pattern, and leaf production, indicating that these species possess distinct growth forms that are useful for taxonomic identification. The combination of these characters provides a more reliable basis for species delimitation than reliance on any single morphological trait.

Plant height varied considerably among the species. *Amaranthus blitum* and *A. caudatus* were significantly taller than the remaining taxa, suggesting greater investment in vertical growth. Increased plant height is often associated with improved light interception and competitive ability in dense plant communities **[28,29]**. Conversely, the shorter stature of the red variant of *A. spinosus* may represent an adaptive response to habitats where rapid reproduction and reduced structural investment provide ecological advantages **[30]**. These differences highlight the influence of ecological adaptation on plant architecture.

Leaf morphology also varied substantially among the species. *Amaranthus hybridus* produced the largest leaves and longest petioles, whereas *A. spinosus* (green variant) had the smallest leaves. Larger leaves generally increase the photosynthetic surface available for light capture, while longer petioles improve leaf positioning within the canopy and reduce self-shading **[31]**. In contrast, the production of numerous smaller leaves by *A. viridis* and the green variant of *A. spinosus* may enhance canopy development and resource capture in disturbed environments, a strategy commonly associated with fast-growing herbaceous species **[27,32]**.

Stem characteristics further distinguished the taxa. *Amaranthus hybridus* possessed the greatest stem diameter and girth, reflecting greater mechanical support for its larger leaves and petioles. Similar relationships between stem robustness and canopy architecture have been reported in herbaceous plants **[33]**. In contrast, the relatively slender stems of *A. viridis* suggest greater allocation of resources to rapid vegetative growth rather than structural reinforcement. Likewise, branching patterns differed markedly among species. The extensive branching observed in *A. viridis* is consistent with the growth strategy of opportunistic species that maximize light interception and reproductive potential through increased canopy spread **[34]**.

Collectively, these morphological differences support the recognition of the six taxa as distinct entities. Although individual characters may overlap among species, the combination of vegetative traits provides a dependable framework for species identification and supports previous taxonomic treatments of the genus **[3,35]**.

Taxonomic Importance of Leaf Epidermal Characters

Leaf epidermal characteristics have long been recognized as valuable taxonomic markers because they are generally less influenced by environmental conditions than external morphological traits **[36,37]**. The present study demonstrates that epidermal features provide additional evidence for distinguishing closely related *Amaranthus* species.

All six taxa possessed anisocytic and tetracytic stomata, indicating that these stomatal types are conserved within the genus. Similar observations have been reported in other members of the Amaranthaceae and support the view that stomatal architecture has important systematic value [38]. However, the occurrence of anomocytic stomata exclusively on the abaxial surface of the red variant of *A. spinosus* represents a unique diagnostic character that distinguishes this taxon from the others. This finding may reflect underlying genetic differentiation or adaptive responses to specific environmental conditions and therefore deserves further investigation using molecular approaches [39].

Quantitative epidermal traits also varied significantly among the taxa. *Amaranthus caudatus* exhibited the highest stomatal density and stomatal index, whereas *A. hybridus* had the lowest values on the adaxial leaf surface. Such differences may reflect contrasting physiological strategies for regulating gas exchange and water loss [40,41]. The consistently higher stomatal density observed on the abaxial surface agrees with the typical dorsiventral leaf organization of most dicotyledonous plants, where the lower epidermis serves as the principal site of gas exchange [42].

Stomatal size also proved useful for species discrimination. *Amaranthus caudatus* possessed the largest stomata, whereas the red variant of *A. spinosus* had the smallest. Because stomatal size is often genetically controlled and relatively stable, it provides a reliable taxonomic character that complements visible morphological features [37]. These findings further demonstrate the value of integrating micromorphological characters into species delimitation.

Integrating Morphological and Anatomical Evidence

The principal contribution of this study lies in combining external morphology with leaf epidermal anatomy to improve species identification. Morphological traits alone may be influenced by environmental conditions and developmental stage, whereas anatomical characters generally remain more stable. The integration of these complementary datasets therefore provides greater confidence in species delimitation and reduces the likelihood of misidentification.

The dichotomous identification key developed in this study demonstrates the practical value of combining macroscopic and microscopic characters. Diagnostic features such as plant height, branching pattern, stem colour, stomatal density, stomatal size, and stomatal type allow rapid and reliable identification of the six Nigerian *Amaranthus* taxa. This approach follows the principles of integrative taxonomy, which recommend combining multiple sources of evidence to improve classification and better reflect evolutionary relationships [42].

Conclusion

This study demonstrated substantial morphological and leaf epidermal variation among six Nigerian *Amaranthus* taxa, confirming the value of these characters for species identification and taxonomic discrimination. Significant differences in plant height, leaf dimensions, petiole length, stem characteristics, branching pattern, stomatal type, stomatal density, stomatal index, and stomatal size provided reliable characters for distinguishing the taxa. Although anisocytic and tetracytic stomata occurred across all the studied taxa, indicating a degree of structural similarity within the genus, the occurrence of anomocytic stomata exclusively in the red variant of *Amaranthus spinosus* represents a useful diagnostic character. Variation in stomatal density, stomatal

index, and stomatal size further enhanced the discriminatory value of the leaf epidermal features. The integration of macromorphological and micromorphological characters therefore provided a more robust basis for species delimitation than reliance on external morphology alone and enabled the development of a practical dichotomous key for the identification of the six Nigerian taxa. The findings provide useful baseline information for biodiversity conservation, germplasm characterization, plant breeding, pharmacobotanical research, and the sustainable utilization of *Amaranthus* genetic resources. Nevertheless, a more comprehensive resolution of species boundaries and evolutionary relationships within the genus will require the integration of morphological and anatomical evidence with molecular markers, DNA barcoding, genome-wide analyses, phytochemical profiles, and ecological data. Such multidisciplinary approaches will strengthen the taxonomic framework for Nigerian *Amaranthus* and provide a more reliable foundation for its conservation, breeding, and sustainable utilization **[13,16]**.

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Author Contributions (CRediT Taxonomy)
- **Moses Dele Ake:** Conceptualization, Investigation, Methodology, Data Collection, Formal Analysis, Writing—Original Draft.
- **Abdullahi Alanamu AbdulRahaman:** Conceptualization, Supervision, Methodology, Validation, Data Interpretation, Writing—Review & Editing, Project Administration.

Conflict of Interest
The authors declare that they have no competing interests.

Data Availability
The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval
Ethical approval was not required for this study because it involved only plant materials.

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