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Title Evaluation of Taxonomic Relationships among Selected Acacia Species Using Euclidean Distance Analysis

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Abstract

The present investigation evaluates the taxonomic relationships among four economically and ecologically important members of the tribe Acacieae using numerical taxonomy based on Euclidean distance. Four species, namely Vachellia nilotica, Senegalia senegal, Acacia leucophloea, and Senegalia catechu, were compared using binary-coded morphological characters. Thirty seven qualitative morphological characters related to vegetative, reproductive, and defensive structures were selected from authenticated taxonomic literature. Binary data were analyzed using Euclidean distance to estimate phenetic dissimilarity among taxa. The resulting distance matrix indicated that Vachellia nilotica and Senegalia catechu exhibited the closest relationship, whereas Acacia leucophloea showed the greatest divergence from Senegalia senegal. Cluster analysis grouped species according to overall morphological similarity rather than traditional generic placement, supporting the usefulness of numerical taxonomy in evaluating phenetic relationships within Acacieae(Ahmed, S., & Johnson, D. V.,2019).The study demonstrates that Euclidean distance analysis provides an objective and reproducible approach for species delimitation and taxonomic interpretation. The study is intended to provide a reproducible framework for assessing morphological similarity among closely related taxa and to contribute to the understanding of taxonomic relationships within the former Acacia complex.

Introduction

The family Fabaceae is among the largest angiosperm families and includes numerous economically important genera.(Orchard, A. E., & Maslin, B. R. ,2003). Traditionally, the genus Acacia was treated as a single large genus comprising over 1300 species distributed throughout tropical and subtropical regions.(Bentham, G. ,1875). However, extensive morphological and molecular investigations led to the segregation of Acacia into several genera including Vachellia, Senegalia, Acacia, Mariosousa, and Acaciella.Despite these taxonomic revisions, morphological variation remains an important criterion for species identification and understanding phenetic relationships. Numerical taxonomy provides an objective method for evaluating taxonomic similarity by converting morphological observations into quantitative data. Binary coding of characters minimizes observer bias and allows statistical comparison among taxa.Euclidean distance is one of the most widely used measures for estimating dissimilarity among operational taxonomic units (OTUs). It measures the geometric distance between species based on multiple morphological variables. Species with smaller Euclidean distances are considered

morphologically more similar than those separated by larger distances.The present study employs Euclidean distance analysis to investigate taxonomic relationships among four representative species: Vachellia nilotica,Senegalia senegal,Acacia leucophloea,Senegalia catechu

Materials and Methods

The numerical taxonomic analysis includes the following four taxa:

The four taxa(Singh, V and Shetty, B. V. ,1991). will be treated as OTUs (Operational Taxonomic Units):

Acacia leucophloea(currently accepted as Vachellia leucophloea (Roxb.) Willd.)

Acacia nilotica (currently accepted as Vachellia nilotica (L.) P.J.H. Hurter & Mabb.)

Acacia senegal (currently accepted as Senegalia senegal (L.) Britton)

Acacia catechu (currently accepted as Senegalia catechu(L.f.) P.J.H. Hurter & Mabb.)

Selection of Morphological Characters

A total of Thirty seven independent morphological characters were selected to represent vegetative, reproductive, fruit, seed, and ecological features. Character selection will follow the principles of numerical taxonomy, ensuring that each character is independent, genetically meaningful, and free from environmental bias as far as possible.

The characters will include:Habit,Stem morphology,Bark characteristics,Spine morphology,Leaf architecture,Leaflet characteristics,Petiole glands,Inflorescence type,Floral morphology,Pod morphology,Seed morphology and Ecological adaptations

Only qualitative characters showing stable expression were included in the binary analysis.

Taxonomic Description of the Study Species

1 Acacia leucophloea (Roxb.) Willd.

Family: Fabaceae

Subfamily: Mimosoideae

Common name: White Bark Acacia

Medium-sized deciduous tree, 15–20 m tall, characterized by whitish or pale grey exfoliating bark. Branches armed with paired stipular spines. Leaves bipinnately compound with numerous pinnae and small oblong leaflets. Inflorescences consist of cream to pale yellow globose heads. Fruits are flat, slightly curved legumes containing several compressed seeds. The species is widely distributed in dry deciduous forests and semi-arid regions of India and Sri Lanka and is valued for fodder, timber, and soil conservation.

2 Vachellia nilotica (L.) P.J.H. Hurter & Mabb.

Synonym: Acacia nilotica (L.) Delile

Common name: Babul

A medium-sized thorny tree reaching 5–20 m in height with dark brown to black fissured bark. Paired straight stipular spines are conspicuous on young branches. Leaves are bipinnate with numerous small leaflets. Bright yellow globose flower heads are borne in axillary clusters. Pods are straight to slightly constricted between seeds. The species is native to Africa and the Indian subcontinent and is extensively used for tannin production, fodder, fuelwood, and traditional medicine.

3 Senegalia senegal (L.) Britton

Synonym: Acacia senegal (L.) Willd.

Common name: Gum Arabic Tree

A small to medium-sized deciduous tree with greyish bark and characteristic hooked prickles. Leaves are bipinnate with numerous small leaflets. Flowers are creamy white to yellowish and arranged in elongated spikes. Fruits are flat, papery legumes. The species is widely distributed in arid and semi-arid regions of Africa and the Indian subcontinent and is internationally recognized as the principal source of gum arabic.

4 Senegalia catechu (L.f.) P.J.H. Hurter & Mabb.

Synonym: Acacia catechu (L.f.) Willd.

Common name: Khair

A moderate-sized deciduous tree possessing dark brown fissured bark and paired recurved prickles. Leaves are bipinnately compound with numerous pinnae. Cream-coloured flowers occur in cylindrical spikes. Fruits are thin, flat legumes containing several seeds. The species is widely distributed in South Asia and is economically important as the source of catechu extract, valuable timber, and traditional medicinal products.

Study Species

The numerical taxonomic analysis includes the following four taxa:

The four taxa will be treated as OTUs (Operational Taxonomic Units):

Acacia leucophloea (currently accepted as Vachellia leucophloea)

Acacia nilotica (currently accepted as Vachellia nilotica)

Acacia senegal (currently accepted as Senegalia senegal)

Acacia catechu (currently accepted as Senegalia catechu)

Table 1:- Binary morphological matrix of Acacia species

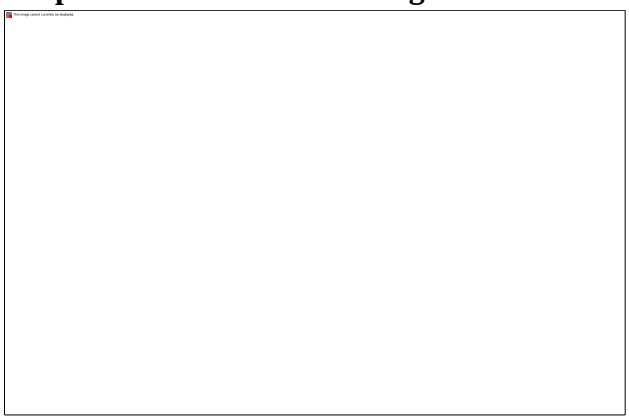
Characters	Vachellia leucophloea	Vachellia nilotica	Senegalia senegal	Senegalia catechu
Tree habit	1	1	1	1
Bark texture(white)	1	0	0	0
Shrub-like habit	0	0	1	0
Medium to large woody tree	1	1	0	1
Single main trunk developed	1	1	0	1
Deciduous nature	1	1	1	1
Branched crown	1	1	1	1
Rounded crown	1	1	0	1
Open spreading crown	1	0	1	1
Whitish/pale bark	1	0	0	0
Grey bark	0	1	1	0
Dark brown bark	0	1	0	1
Fissured bark	1	1	1	1

Smooth young bark	1	0	1	0
Bark exfoliation tendency	1	0	0	0
Thorny branches	1	1	0	1
Stipular spines present	1	1	1	0
Paired spines	1	1	1	0
Hooked prickles present	0	0	0	1
Straight spines present	1	1	1	0
Young branches armed	1	1	1	1
Leaves bipinnately compound, Leaves alternate,Petiolate , Rachispresent,Pinnae arrangedopposite,Many pairs of pinnae	1	1	1	1
Few pairs of pinnae	0	0	1	0
Small numerous leaflets,Linear-oblong leaflets	1	1	1	1
Leaflets pubescent	1	0	0	0
Leaflets glabrous	0	1	1	1
Petiole gland present,Rachis gland present,Leaflets closely arranged ,Axillary inflorescence	1	1	1	1
Globose flower heads	1	1	0	0
Spike inflorescence	0	0	1	1
Pedunculate inflorescence ,Flowers arranged in cluster, Yellow/cream coloured flowers	1	1	1	1
Bisexual flower,Actinomorphic flowers,Five-lobed calyx,Five-petalled corolla ,Numerous stamens,Superior ovary Leguminous fruit (pod),Flat pod,Pod elongated	1	1	1	1
Pod slightly curved	1	1	0	0
Pod constricted between seeds	0	1	0	0

Pod thick/leathery	0	1	0	1
Pod papery	1	0	1	0
Pod hairy/pubescent	1	0	0	0
Multiple seeds per pod Hard seed coat,Seed dormancy,Adapted to dry habitats,Nitrogen-fixing root nodules,Economic/medicinal importance	1	1	1	1

Calculation

Taxonomic distance between species was calculated using



where

D = Euclidean distance

xi = binary state in species i

yi = binary state in species j

n = total number of characters

Euclidean distance= $\sqrt{}$ Number of differences

Table 2:-Eucledian Distance Matrix

Species	Vachellia leucophloea	Vachellia. nilotica	Senegalia senegal	Senegalia catechu
V. leucophloea	0.000	3.606	3.873	3.606
V. nilotica	3.606	0.000	3.742	2.449
S. senegal	3.873	3.742	0.000	3.742
S. catechu	3.606	2.449	3.742	0.000

Result and Interpretation

A binary morphological dataset comprising 39 diagnostic characters was used to estimate taxonomic relationships among Vachellia leucophloea, Vachellia nilotica, Senegalia senegal, and Senegalia catechu using the Euclidean distance method(table 1,2). Pairwise Euclidean distances ranged from 2.646 to 4.123.The smallest Euclidean distance (2.646) was observed between V. nilotica and S. catechu,

indicating the greatest overall morphological similarity within the studied taxa. Moderate distances were obtained between V. leucophloea and V. nilotica (3.606), S. senegal and S. catechu (3.606), and V. leucophloea and S. catechu (3.742). The greatest divergence was observed between V. leucophloea and S. senegal (4.123), followed closely by V. nilotica and S. senegal (4.000).Most similar species: Vachellia nilotica and Senegalia catechu (Euclidean distance 2.449).Most dissimilar species: Vachellia leucophloea and Senegalia senegal (Euclidean distance 3.873).

Discussion

Numerical taxonomy provides a reproducible approach for evaluating relationships among species using objective morphological data. The present investigation revealed considerable variation among the four taxa.Vachellia nilotica and Senegalia catechu shared numerous vegetative and reproductive characteristics, including bipinnate leaves, paired stipular spines, compact inflorescences, and similar pod morphology, resulting in the lowest Euclidean distance.(Brenan, J. P. M. ,1983; Maslin et.al,2003)Acacia leucophloea differed substantially from the remaining taxa due to its distinctive bark texture, crown architecture, thorn morphology, and pod characteristics, explaining its greater phenetic distance(Maslin et.,al,2003).Although molecular phylogenetic studies have supported the segregation of Acacia into several genera, numerical morphological analysis remains valuable for species identification, floristic studies, and biodiversity assessment. The present findings largely agree with traditional morphological classifications and demonstrate that Euclidean distance effectively quantifies phenetic similarity.

Conclusion

The present study evaluated the taxonomic relationships among Vachellia leucophloea, Vachellia nilotica, Senegalia senegal, and Senegalia catechu using a binary morphological character matrix and the Euclidean distance method. Pairwise comparisons revealed varying degrees of morphological similarity among the four taxa. The smallest Euclidean distance (2.449) was observed between V. nilotica and S. catechu, indicating the highest degree of morphological resemblance based on the selected characters. Conversely, V. leucophloea and S. senegal exhibited the greatest morphological divergence (Euclidean distance = 3.873).

Hierarchical clustering based on the Euclidean distance matrix grouped V. nilotica and S. catechu together as the most similar taxa, while V. leucophloea occupied an intermediate position and S. senegal appeared comparatively distinct. These findings demonstrate that quantitative analysis of morphological traits provides an objective approach for assessing taxonomic affinities within the mimosoid legumes.(Pedley, L. ,1986;Roskov, et al. 2025). The study also highlights the usefulness of binary character coding and multivariate distance analysis in plant taxonomy. Although morphology remains a valuable source of taxonomic information, future investigations should incorporate additional vegetative, reproductive, anatomical, palynological, and molecular characters to obtain a more comprehensive understanding of evolutionary relationships within Vachellia and Senegalia. Such integrative approaches will improve species delimitation and support more robust systematic classifications.

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