

**TAXONOMIC STUDY OF THE *Cyperus dives* DELILE COMPLEX IN EAST
AFRICA**

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DECLARATION

Declaration by the Student

This thesis is my original work and has not been submitted to any University or institution for any academic award; and shall not be produced in part or in full, in any format without prior permission from the author and/or University of Eldoret.

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Declaration by the Supervisors

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DEDICATION

To my family for unending support and patience.

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ABSTRACT

Cyperus dives complex comprises four taxa: *Cyperus alopecuroides* Rottb, *Cyperus dives* Delile, *Cyperus imbricatus* Retz and *Cyperus exaltatus* Retz; whose taxonomic recognition varies among different authors. This study investigated the morphological variation within and between taxa in the complex in the East African region. Herbarium Specimens deposited at the East African Herbarium (EA) and Makerere University Herbarium (MUH) were examined. Morphometric data on gross morphology was collected and analysed using Cluster, Principal Component, Discriminant and Univariate analyses, using the GenStat statistical package version 2014 by VSN International Ltd. Data on distribution patterns were gathered from herbarium specimen labels and Gazetteers consulted where coordinates details were missing. Arc Map 10.42 software was used to generate map to identify where various taxa within the complex are located. Examination of achenes using the scanning electron microscope (SEM) was also done. In Principal Component Analysis (PCA), the first axis accounted for 38.4% of the total character variation. Here *C. imbricatus* formed a distinct group; with the other three taxa exhibiting considerable overlap. Cluster analysis followed the same pattern for the 39 OTUs studied; where *C. imbricatus* formed a very distinct cluster, with the other three taxa showing high levels of intermixing to form one large cluster. Discriminant analysis also reveals a clear separation between *C. imbricatus* and the other three along root 2 while in univariate analysis it showed significant levels of statistical difference with the other three species in most of the characters used in the analysis. Based on these analyses *C. imbricatus* is clearly distinct from the rest of the taxa in the complex. Variations seen across the taxa were mostly in respect of length of the nutlet, stigma, filament and anther. Also, the leaf sheath width and inflorescence length. Based on these results, it can be concluded that, *Cyperus dives* complex consists of one distinct species (*C. imbricatus*) and three variables (*C. alopecuroides*, *C. exaltatus* and *C. dives*) that should be considered for ranking at the infraspecific level. The distribution patterns of the taxa within the complex are apparently based on their ecological preferences with some overlaps in the distribution, whereas the presumed distinct species showed a wide distribution and altitude range among all the taxa.

Key Words: Taxonomic study, *Cyperus dives* Delile, Morphological Variation, Taxa, Distribution Patterns

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LIST OF ABBREVIATIONS AND ACRONYMS

BRAHMS	Botanical Research and Herbarium Management System
CA	Cluster Analysis
DA	Discriminant Analysis
EAH	East African Herbarium'
FTEA	Flora of Tropical East Africa
LD	Lund University Botanical Museum
MUH	Makerere University Herbarium
MPU	Herbier de l' Université Montpellier
MNHN	Muséum National d'Histoire Naturelle
OTUs	Operational Taxonomic Unit
PCA	Principal Component Analysis
UPGMA	Unweighted Pair Group Method with Arithmetic Mean
WAG	Wageningen University

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Cyperaceae is one of the well-defined and uncontroversial families within Poales. *Cyperaceae* Juss. (Sedge family) is a family of graminoid monocotyledonous flowering plants, which occur at an altitude level of 5475 m (Stork and Lebrun, 2020). It is the third-largest monocot family after *Orchidaceae*. (orchids) and *Poaceae* Barn., with approximately 106 genera and 5600 species (Krishna Juss chandran, 2018; Larridon *et al.*, 2021). Thirty (30) genera and 450 species are in East Africa with the highest number found in southern Tanzania (Goetghebeur, 1998).

The classification of the *Cyperaceae* family at the tribal and generic levels relies on various morphological characters of the inflorescence, spikelet and flower (Elkordy *et al.*, 2020b; Larridon *et al.*, 2021). Nutlets are similar in most *Cyperaceae* though mature ones can easily be used to delimit species and similarly spikelets have also been found to be of systematic value (Stork and Lebrun, 2020). Studies on nutlets have previously been done in the genus *Carex* but not in *Cyperus*, until recently when Pashirzad, (2014) studied a *Cyperus* complex in Northeastern Iran and differentiated *Cyperus laevigatus* subspecies *distachyos* (All.) Ball, *Cyperus glabber* Linnaeus and *Cyperus fuscus* Linnaeus using nutlet length, nutlet width, nutlet colour and shape. Other diagnostic floral characters used in *Cyperaceae* include the flower reduction, stamen number, ovary position and inflorescence type (Goetghebeur, 1998).

Cyperus Linnaeus is the most diverse genus in the family *Cyperaceae* subfamily Cyperoideae in the tribe Cypereae, with about 950 species as currently circumscribed, of which 207 are in East Africa (Pashirzad, 2014; Pereira-Silva *et al.*, 2018; Larridon *et al.*, 2021; Azeez *et al.*, 2022). The genus is distributed throughout the world and in all tropical wetland habitats (Krishnachandran, 2018).

The classification of *Cyperus* and its infrageneric taxa is taxonomically complex and is still in a state of flux because of morphological variations that make delimitation of boundaries between taxa (e.g., between subgenera or species) difficult (Rad and Sonboli, 2005). The inflorescence in the genus is terminal pseudolateral, capitate or anthelate with primary or secondary branches which terminate in one or more digitate cluster of spikelets (spikes) that are linear to ovoid and laterally flattened. The inflorescence axis is persistent and spikelets fall off when the nutlets are ripened. The glumes are distichous, few or sometimes many, 2-ranked, spirally arranged, dehiscent, glabrous, with the keel obtuse to mucronate. The flowers are bisexual, lack a perianth and have a bifid or trifid style. The achenes or nutlets are lenticular or trigonous and dorsoventrally compressed against the rachilla which is rounded (Hoenselaar *et al.*, 2010).

The morphological characters that have been found to be of taxonomic value in subgenera, sections and species are the leaf blade, culm shape, inflorescence type, stamen number, style number, stigma number and length, nutlets (colour, shape and size), spikelet number, arrangement and vegetative anatomy (Lunkai *et al.*, 2010; Oliveira *et al.*, 2021; Bhandari *et al.*, 2021). Lowe and Carter (2023) recently found that anther length and filament length were the most important characters in distinguishing between *Cyperus squarrossus* Linnaeus and *Cyperus granitophilous* Mc Vaugh and the dark brown colour and small

width of the fruit were also found to be important characters in delimiting boundaries between *Cyperus imbricatus* Retz from *Cyperus Articulatus* Linnaeus and *Cyperus rotundus* Linnaeus (Shalabi and Gazer, 2015a).

Microscopic cellular structures have proven to be of taxonomic value in the classification of *Cyperaceae* both at generic and specific level (Schuyler, 1971). The Scanning electron microscope has been used in taxonomic studies of various genera within *Cyperaceae* (Shalabi and Gazer, 2015b). A recent study showed that closely related genera and species can be distinguished using scanning electron microscopy of nutlet characters (nutlet size, shape, surface, epidermal shape, anticlinal boundaries, pericardial cell walls and outer cell walls (Elkordy *et al.*, 2020a).

Studies on Italian *Cyperaceae* have shown that *C. dives* is a complex within section *Exaltati kunth* Benth (Kükenthal, 1935-1936) that comprises five closely related and often confused taxa, four of which are weedy. These are *Cyperus alopecuroides* Rottb, *Cyperus dives* Delile, *Cyperus exaltatus* Retz and *C. imbricatus* Retz. *Cyperus exaltatus* is similar to *C. imbricatus* in the laxer inflorescence with spikelets that are slenderer and do not obscure the rachis (Bryson and Carter, 2008; Verloove and Soldano, 2011).

Kükenthal (1935-1936) treated *C. dives* at varietal rank based on spikelet characters while Hoenselaar *et al.*, (2010) kept it as separate based on the crowded spikelets and shorter glumes. Similarly, Napper (1965) treated *C. imbricatus* as a separate species based on its crowded spikelets and shorter glumes. Napper (1966) also treated *C. alopecuroides* Rottb as a separate species based on its 2-fid style, and compressed nutlets. The habit and general

inflorescence pattern of *C. alopecuroides* was similar with *C. imbricatus* (Carter *et al.*, 1996).

1.2 Statement of the Problem

The current classification of the *C. dives* complex varies greatly due to different taxonomic interpretations and nomenclature given by various authors. Rottboell, (1773) treated *C. dives* as having a close relationship with *C. alopecuroides* based on specimens collected by Forsskål in Arabia. He observed that the two species often co-occur on the same habitat and hence one cannot be considered to be variety of the other. (Delile, 1813) treated *C. dives* and *C. alopecuroides* as being the same in habit and only distinguished them using some characters of the inflorescence and flowers. (Baker, 1884) treated *C. dives* as a variety of *C. alopecuroides* while Clarke & Baker, (1886) treated it as a variety of *C. exaltatus*. Kukenthal, (1936) considered *C. dives* to be close to *C. exaltatus* but Haines and Lye (1983) treated it as a distinct species. It is also considered to be close to *C. alopecuroides* though differing in having glumes with a rounded keel and flattened nutlets (Haines and Lye, 1983). Gordon-Gray (1995) treated *C. dives* and *C. imbricatus* as alike but distinguished them on robustness, with the former being taller with culms getting to more than 100 cm tall and having wider leaf blades and spikes. Boulos (2005) treated *C. dives* as a synonym of *C. alopecuroides*. The World Monocot Checklist (2006) treats *C. dives* as a valid name and *C. exaltatus* var. *dives* (Delile) C.B. Clarke, *C. alopecuroides* var. *dives* Boeckler and *C. alopecuroides* var. *dives* Boeck., as its synonyms.

Hoenselaar *et al.*, (2010) in their FTEA account of *Cyperus* treated *C. dives* as a variety of *C. exaltatus*. In this account, characters used by Haines and Lye (1983) to distinguish the

two were considered artificial hence the former was sunk in the latter as a variety. He also treated *C. dives* as being close to *C. alopecuroides*.

Species in the *Cyperus dives* (s.l) complex occur in bushlands, seasonal wetlands, swamps, disturbed terrestrial habitats and their distribution is thought to be widespread in Kenya and Tanzania (Northern and Tanga regions) while in Uganda they occur in the Western province and Buganda (Haines and Lye, 1983). Their distribution pattern in the East Africa region has not been fully documented. For example, *C. imbricatus* is known only from the type locality at lesser Kiboko river in Machakos district in Kenya. This collection was made by Clarke (1884). No more collections have been made from there ever since raising the concern that the taxon might be extinct (Hoenselaar *et al.*, 2010).

Based from the above it is evident that, the taxonomy of the species forming the complex is not clear; and therefore, difficult to tell whether the four taxa in the complex are distinct or a case of one variable species with several infraspecific taxa. The distribution pattern of members of the complex is also unclear. These are the two problems that this study sought to resolve.

1.3 Justification of the Study

This study addresses the need to revise the taxonomy of the *Cyperus dives* (s.l) complex in East Africa by focusing on overall similarity rather than relying on a limited set of characters, as previously done. Its aim is to clarify the boundaries between the four taxa in the complex. Additionally, studying the distribution patterns of these species will serve as a valuable reference for botanists, ecologists, and systematists working on sedge

distributions in the East African region. Understanding these patterns will also help identify collection gaps within the complex, guiding further research as needed.

1.4 Objectives of the Study

1.4.1 General Objective

To revise the taxonomy of the *Cyperus dives* Delile (s.l) complex in East Africa.

1.4.2 Specific Objectives

The specific objectives are:

1. To examine the morphological variation within and between taxa of *Cyperus dives* Delile complex.
2. To document the distribution patterns of the taxa within the complex.

1.5 Research Questions

The intention of this study was to answer the following two questions:

- 1). Is the *Cyperus dives* complex a single variable species with multiple infraspecific taxa, or does it consist of distinct species?
- 2). What is the distribution pattern of the taxa within the complex in East Africa?

CHAPTER TWO

LITERATURE REVIEW

2.1 Taxonomic History of the *Cyperus dives* (s.l) Complex

Taxonomic history of the *Cyperus dives* complex which comprises *C. exaltatus*, *C. alopecuroides*, *C. imbricatus* and *C. dives* is chequered. These taxa have been treated differently by different authors. *Cyperus alopecuroides* was described by Rottboell (1773) who later reduced it to a synonym of *Juncellus alopecuroides* Rottb. *Cyperus exaltatus* Retz was described by Clarke, (1884) who recognized two varieties, *C. exaltatus* var *exaltatus*, and *C. exaltatus* var *dives* within it and placed five species *C. immensus* C.B. Clarke, *C. partherickii* C.B. Clarke, *C. immensus* C.B. Clarke var *taylori* and *C. immensus* C.B. Clarke var *patherickii* in its synonymy.

Delile, (1813) described *C. dives* and considered it as an accepted name and placed *C. alopecuroides* var. *dives* and *C. exaltatus* var *dives* under its synonymy. Kukenthal (1935-1936) treated *C. dives* as a variety of *C. exaltatus* using the obliquely inserted spikelets to distinguish it from the typical *C. exaltatus* in which the spikelets were laxer and inserted at almost right angles. Retzius (1788) described *C. imbricatus* as a separate species while Napper (1966) treated *C. dives* as a synonym of *C. exaltatus*. Carke (1884) treated *C. alopecuroides* as a separate species based on the 2-fid style and nut compressed to rachilla while *C. dives* was treated to be close to *C. exaltatus* but similar to *C. alopecuroides* based on the size of the bracts and inflorescence. Napper, (1966) treated *C. imbricatus* as a separate species from the closely related *C. alopecuroides* with its narrow leaves, numerous inflorescences and compressed spikelets distinguishing it from the latter which was described by Brullo (2006) as having a compact, capitate inflorescence with cylindrical

spikes 1.5-3.5 cm long, spikelets 3-7mm long, nutlets 0.6 x 0.7 and 0.4-0.5mm, and trigonous with acute angles.

Accounts of the *Cyperus dives* complex in East Africa given in different taxonomic accounts of the *Cyperaceae* in East Africa (e.g., Haines and Lye 1983; Hoenselaar *et al.*, 2010) indicated that the taxonomy of the complex is quite confusing. Table 1 shows the close relationships that exist between members of the complex as recorded in Haines and Lye (1983) and Hoenselaar *et al.*, (2010).

Table 2.1: Relationships Existing Between Members of the *Cyperus dives* (s.l) Complex in East Africa

Taxa	Haines and Lye (1983)	Hoenselaar <i>et al.</i>, (2010)
<i>C. imbricatus</i>	Similar to <i>C. dives</i> and <i>C. alopecuroides</i>	Treated as a separate species
<i>C. dives</i>	Similar to <i>C. exaltatus</i> Taxonomic status is not known	Not related to any species
<i>C. exaltatus</i>	Related to <i>C. dives</i>	Two varieties, <i>C. exaltatus</i> var. <i>exaltatus</i> and <i>C. exaltatus</i> var <i>dives</i>
<i>C. alopecuroides</i>	Similar to <i>C. dives</i>	Close to <i>C. dives</i> and closely related to <i>C. exaltatus</i>

(Adopted from Haines & lye,1983; Hoenselaar *et al.*, 2010).

In the account by Hoenselaar *et al.*, (2010) *C. dives* and *C. alopecuroides* were treated as closely related but differed in the more crowded spikelets and slightly shorter glumes (1.2 mm-2.9 mm) in the former and in the glumes with a rounded keel and flattened nutlets in

the latter. Haines and Lye (1983) on their part treated *C. dives* as being closely related to all the other three members of the complex but also considered them to differ from *C. dives* in the more distant spikelets and larger glumes (*C. exaltatus*), the rounded keel, in-rolled margins on the glumes and flattened nutlets (*C. alopecuroides*) and in having shorter glumes and nutlets (*C. imbricatus*). They also considered *C. imbricatus* to be similar to *C. alopecuroides* in the shorter glumes and nutlets with two branched style and flattened nutlet.

2.2 Micromorphological Study of Achenes in *Cyperus*

In *Cyperus*, the seed surface micromorphology and seed shape are key characteristics that can be effectively studied using a scanning electron microscope to differentiate species. (Yigit, 2017; Patil, 2019). Recent studies done using the scanning electron microscope on the shape and colour of achenes of 11 species of *Cyperus*, revealed obovoid, rounded and elliptic shapes (Shalabi and Gazer, 2015a). Other characters examined in this study were the shape of the anticlinal walls which were showed to be straight, wavy, exocarp, reticulate, rugose or granulate. The species examined i.e., *C. bulboses*, *C. lavigatus* and *C. imbricatus* were separated from other taxa by their reticulate pattern of the anticlinal walls while a granulate pattern was seen in *C. alopecuroides*.

Patil, (2022) carried out a light and scanning microscopy of *Rhynchospora* Vahl and *Schoenoplectus* (Rchb.) Palla achenes and, the characters that proved to be of taxonomic importance were the epidermal cells (anticlinal or periclinal walls) and the epidermal surface patterns (papillose-tubercular, introrsely barbed, smooth-wrinkled surface, transversely wrinkled and transversely wavy-ridged).

2.3 Distribution Patterns of *Cyperus dives* (s.l) Delile Complex

Taxonomy is a discipline that plays a key role in the documentation and conservation of biodiversity and also provides information that helps in answering questions of what, where and how species are distributed at local, regional and global levels (Reddy, 2020). Knowledge of the geographical distribution of plants is very important, not only in accounting for rare taxa but also assisting in understanding the spread of noxious weeds (Bryson and Cater, 2008). Species distribution models and Geographical Information Systems (GIS) are useful tools that predict the area inhabited by particular species by use of very scarce information available on the occurrence of the taxa (Blake, 2008). A Geographic Information System (GIS) is an integrated system of computer software, hardware and geographical data designed to capture, manage, analyse and display various types of geographically referenced information (Reddy, 2020). Spatial or geographic data refers to information that includes X and Y coordinates, which allows it to be mapped. In this case, the data is sourced from herbarium records, with most recent specimens (less than 30 years old) providing latitude and longitude coordinates that estimate the locations where the plants were collected. Specimens older than 30 years rarely include coordinate information; instead, they typically have locality details written on specimen labels, along with the collector's name, collection number, and date, information which can be used to determine precise locations by consulting published and unpublished journals (Chadburn *et al.*, 2018; Reddy, 2020). Geo-referenced herbarium specimens can be utilized to model species ranges or distribution areas, providing valuable information for the IUCN Red List, the internationally recognized standard for assessing species' conservation status (Taylor *et al.*, 2011; Reddy, 2020).

Cyperus dives Delile (a robust, tufted sedge in the *Cyperaceae*) has a broadly tropical largely Old World native range stretching from southwestern Syria through much of Africa and eastward into South and Southeast Asia (e.g., Pakistan, India, Bangladesh and Vietnam). Authoritative taxonomic treatments and databases summarize this as its core native distribution and note that it is primarily associated with seasonally wet or marshy tropical habitats (Delile, 1813).

In the Americas the species is not widely native; most global checklists and herbarium compilations treat *C. dives* as principally an Old World taxon, although related *Cyperus* species occur widely in Central and South America and a few records or synonyms have appeared in global backbones and occurrence databases (GBIF) that reflect historical collections, synonymy and occasional introductions. In short: *C. dives* is not considered broadly native to temperate Britain or most of the Americas, where other *Cyperus* species are more typical (Delile, 1813).

For Britain specifically, standard floras and regional keys indicate that *Cyperus dives* is not part of the native British flora and has no established record as a wild, resident species in Great Britain; European records of *Cyperus* taxa instead tend to concern other species or occasional introductions (and, where present, records are often restricted to Macaronesian islands or very localized introductions rather than the British mainland). Thus, British floristic accounts treat *C. dives* as essentially absent from the UK (Verloove & Soldano, 2010).

In Asia the species is documented from South Asia and parts of Southeast Asia explicit sources list Pakistan, India, Bangladesh and Vietnam among countries where *C. dives*

occur, where it grows in wet fields, river margins and seasonally inundated ground and is sometimes used locally (e.g., stems for matting). These country-level occurrences are reported in major plant databases and floras that synthesize herbarium records and local floristic treatments (Delile, 1813).

Within West Africa *C. dives* is reported from multiple countries (for example Senegal, Côte d'Ivoire, Nigeria and Burkina Faso appear in regional checklists and compilation databases), and West African useful-plants accounts record its occurrence and local uses in parts of tropical West Africa. African herbarium compilations and regional floras consistently show a wide distribution across sub-Saharan Africa, including West Africa (Govaerts & Simpson, 2007).

Flora of Tropical East Africa is considered to be the most important world biodiversity area (Du *et al.*, 2023). Haines and Lye (1983) studied the diversity of sedges in East Africa and it has been found that areas with high species richness are characterised by low water depths, high rainfall and low elevations and therefore the distribution of a species like *C. papyrus* is influenced by water depth, and is known to colonise broader habitats as long as the area is flooded.

For East Africa in particular Uganda, Tanzania and Kenya explicit herbarium and flora records list *Cyperus dives* as a native or long-established component of wetland and swamp vegetation. Field surveys and site floras (for example vegetation accounts from Kenyan wetlands) document *C. dives* as a dominant or common sedge in some swamp and marsh communities (e.g., Lewa Swamp, Kenya), and national/regional databases treat it as present across East African countries (Giesen *et al.*, 2007).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out in the East African region i.e., Kenya, Uganda and Tanzania. In the Flora of Tropical East Africa (FTEA), the three countries have been subdivided into various regions based on boundaries shown on the official maps but which do not coincide with the current provincial boundaries (Figure 3.1).

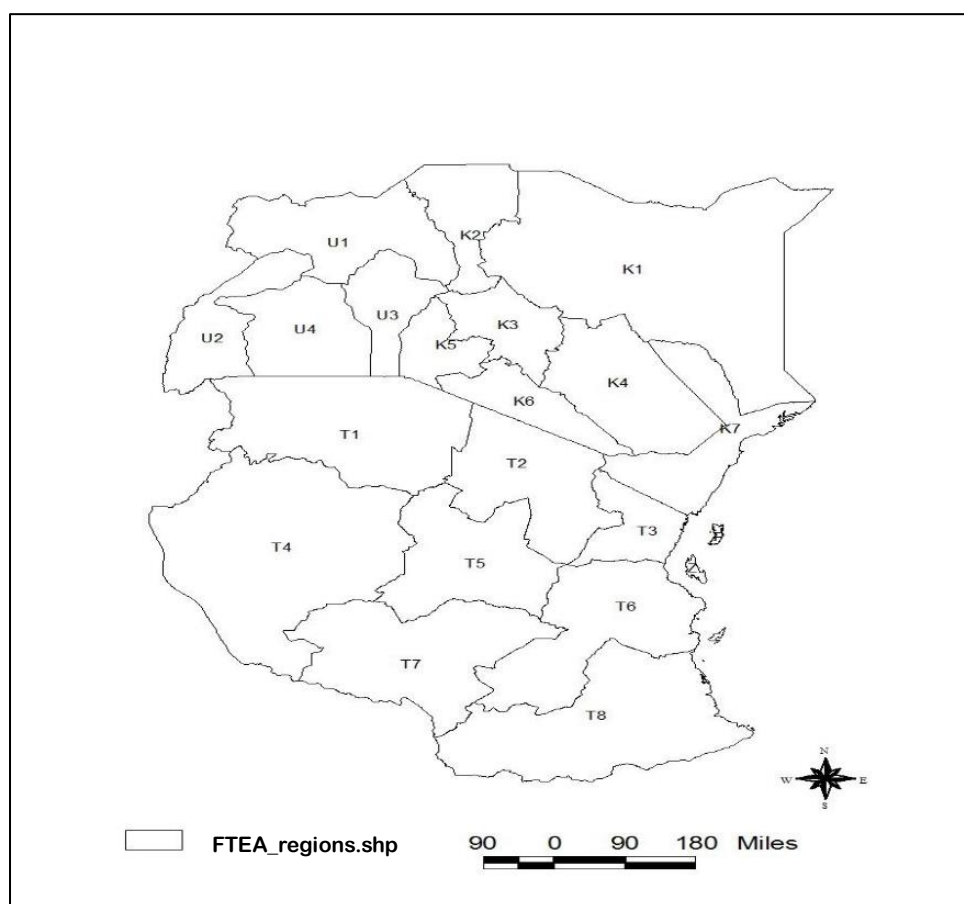


Figure 3.1: Map Illustrating the Regions of the Flora of Tropical East Africa

K=Kenya T=Tanzania U=Uganda (Source: Hoenselaar,2010)

3.2 Plant Material

The data for this study was gathered from mature dried specimens deposited at the East African Herbarium and laboratory studies. Additional specimens were borrowed on loan from the Makerere University Herbarium (MHU). Type images consulted for protologue information on the taxa under study were sourced from Herbier de l' universite Montpellier (MPU), Lund University Botanical Museum (LD), the Naturalis Biodiversity Centre, formerly Wageningen University (WAU), Herbarium Vadense (WAG), Herbarium Museum Paris, Muséum National d'Histoire Naturelle (MNHN) and Herbarium University Cadom (HUC). List of all specimens studied is in Appendix I.

3.3 Methods

3.3.1 Morphological Studies

Forty-three specimens (43) were examined but only 39 were selected because they were mature and complete with all parts intact. The characters that were selected for study were derived from relevant literature providing accounts of the *Cyperaceae* in East Africa e.g., Hoenselaar *et al.*, (2010) and Haines and Lye (1983). To identify the most significant quantitative traits for clarification of boundaries within the complex, 39 vegetative and floral characters (Appendix IV) were initially analysed, resulting in 17 key quantitative characters (Table 3.1). For qualitative characters, only those that showed distinction between species were selected (Sharma and Pandit, 2011) (Table 3.2).

Table 3.1: Quantitative Characters and Character States of *C. dives* (s.l) Complex

Character	Character states
Plant height	1. Plant length continuous (PLHE)
Stolon	2. *Stolon width at midpoints
Culm	3. Culm length (CULL) 4. Culm width (CULW)
Leaf	5. Leaf sheath length (LESL) 6. Leaf sheath width (LESW) 7. Leaf blade width largest (LEBW)
Inflorescence	8. Inflorescence length (INFL) 9. Inflorescence bract largest length (INFBL) 10. Inflorescence bract largest width (INFBW)
Spikelet	11. Spikelete length (SPLW)
Spike	12. *Primary spike peduncle length 13. *Secondary spike peduncle width
Glume	14. Glume length (GLML) 15. Glume width (GLMW)
Nutlet	16. Nutlet length (NUTL) 17. Nutlet width (NUTW)
Androecium	18. Filament (FILL) 19. Anther length (ANTL)
Gynoecium	20. Style length (STYL) 21. Stigma length (STGL)

Note: Characters with acronyms in parenthesis were used in the analysis. Characters with asterisk (*) were not used in the analysis.

Table 1.2: List of Qualitative Characters & Character States of *C. dives* (s.l) Complex

Character	Character states
Inflorescence	1. Inflorescence bract number
Glume	2. Glume number per spikelet 3. Glume colour 4. Glume nerves number 5. Glume apex shape 6. Glume margin
Nutlet	7. Nutlet shape flat or rounded 8. Nutlet surface smooth or reticulate
Stamen	9. Stamen number
Spikelet	10. Spikelete sessile

11. Spikelet stalked

12. Spikelet compressed

(Adopted from Hoenselaar *et al.*, 2010).

3.3.2 Scanning Electron Microscope of *Cyperus dives* (s.l) Complex

Dry achenes in each of the four taxa of the complex were prepared and mounted directly on metallic stubs, using double adhesive tape, then coated with gold for 4-6 minutes in sputtering chamber using JOEL JFC 1100E ion sputtering devise (Elkordy *et al.*, 2020a). The specimens were then examined using a JSM 7000LV SEM operated at voltage of 15kv and micrographs taken.

3.4 Data Analysis

Selected characters from Tables 2 and 3 were subjected to multivariate analysis, i.e., Principal component analysis, Cluster analysis, Discriminant analysis and One-way analysis of variance (ANOVA) using the GenStat Statistical Package, specifically Version 16.0 developed by VSN International Ltd. To analyse the data and explore the grouping of specimens into classes, cluster analysis (CA) was employed as an exploratory method. The specific method used for Cluster analysis was the Unweighted Pair Group Method with arithmetic mean and the dissimilarity coefficient utilized was the Average Taxonomic Distance Coefficient (Sokal and Mishner, 1958). Cluster analysis was used to determine whether specimens were grouped to assigned classes (Otieno *et al.*, 2006). Principal Component analysis was carried out to detect groups among specimens and estimate the contribution of each character in separating the species groups (Sharma and Pandit, 2011) and Discriminant analysis was used to evaluate the discriminating ability of the quantitative characters at interspecific level (Sharma and Pandit, 2011). One way analysis of variance (ANOVA) was conducted on each measured variable, Prio to analysis normality test was

conducted using Normality Q-Q Plots then Tukey test was employed for multiple comparison of means to assess the degree to which groups detected in PCA differed among each other character by character (Naczi *et al.*, 1998). Before performing the analysis, the data was standardized to have a mean of 0 and a variance of 1 to remove the effects of characters of large variance (Otieno *et al.*, 2006).

3.5 Distribution Patterns of *Cyperus dives* (s.l) Delile Complex

A comprehensive database was created by recording the information from specimen labels of each individual specimen. This information included details such as the specimen's locality coordinates (latitude/longitude), elevation, collection data (collector, collector number, and dates), and habitat information. In cases where coordinate data was not provided on the specimen label or to the accuracy of localities, gazetteers such as the FTEA index of collector's localities (Polhill, 1988) were consulted. For each examined specimen a form was filled (Appendix 4). The location data obtained from 39 specimens of all species within the complex were entered into the Botanical Research and Herbarium Management System (BRAHMS) and using Arc map 10.42 software, a distribution pattern map was generated to visualize the geographic distribution of the species across different regions (Figure 4.8).

CHAPTER FOUR

RESULTS

4.1 Morphological Characters of *Cyperus dives* (s.l) Complex in East Africa

4.1.1 Morphological Variations in *Cyperus dives* (s.l) Complex by Principal Components Analysis

Results of the PCA explained 49.2% of the total character variation in the complex with Principal Component 1 explaining 38.4% of the variation and Principal Component 2, 10.8%. Four principal components were retained for further analysis because they contributed significantly to the variance as displayed by the scree plot (Figure 4.1). The PCA results, indicate that along Principal Component 1, *C. imbricatus* is distinctly separated from the other three taxa in the complex (Figure 4.2), with the ellipse around it only marginally overlapping with that of *C. exaltatus*. The convex hull polygon of its data points also shows that it is clearly separated from the other taxa in the complex (Figure 4.3). In contrast, along Principal Component 2 there is no clear separation between all the taxa in the complex (Figures 4.2 & 4.3), even though the overlap between the convex hull polygon of *C. alopecuroides* and that of *C. dives* is only marginal (Figure 4.3). Variables with high factor loadings that influenced the clustering along Principal Component 1 include anther length (ANTL) at 0.3532, stigma length (STGL) at 0.336, glume length (GLML) at 0.3341, culm length (CULL) at 0.2740, plant height (PLHE) at 0.277, leaf sheath width (LESW) at 0.26501, and the width of the largest leaf blade (LEBW) at 0.284 (Table 4.1 and Figure 4.4). The most influential variables along Principal Component 2 were spikelet width (SPLW) at 0.5230, filament length (FILL) at 0.4477, nutlet width

(NUTW) at 0.3553, inflorescence bract length (INFBL) at 0.3446, and plant height (PLHE) at 0.294 (Table 4.1 and Figure 4.5).

Table 2.1: Factor Loadings on the First two Factor Coordinates for 15 Morphological Characters of the *C. dives* Complex used in PCA

Character	Factor 1	Factor 2
PLHE	-0.2777314	0.29540384
CULL	-0.2749236	0.13835678
LESL	-0.2541371	0.19344078
CULW	-0.21352792	0.05449516
LESW	-0.26501371	-0.0455306
LEBW	-0.28409261	-0.2081568
INFBL	-0.18441755	-0.3446368
SPLW	-0.2166485	0.5230796
GLML	-0.33412608	0.08321872
GLMW	0.02139332	-0.0278099
NUTW	-0.19518085	0.35534033
FILL	-0.24331319	-0.4477662
ANTL	-0.35320491	-0.1637217
STYL	-0.24121914	-0.0623234
STGL	-0.3360354	-0.2242026

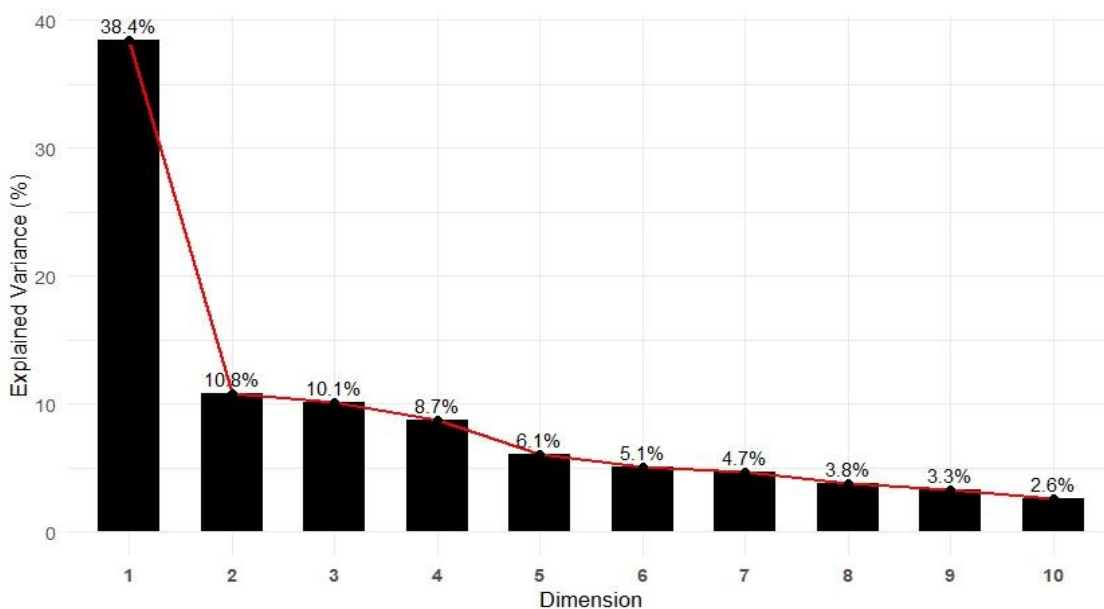


Figure 4.1: Scree Plot of Variances Associated With Each Principal Component Showing how Much Data each Component Captures.

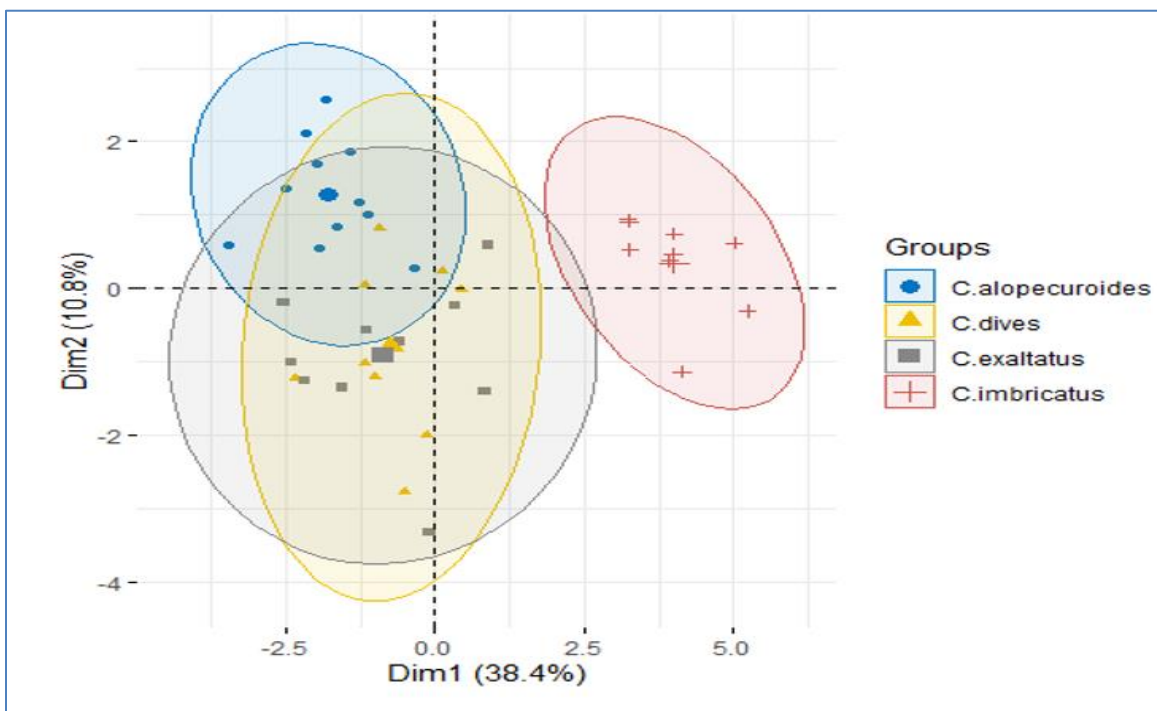


Figure 4.2: Ellipses in PCA Scatter Plot Showing the Spread, Variability and Separation of Data Clusters in the Reduced-dimensional Space When PC 1 is Plotted Against PC 2 Based on 15 Variables of 39 OTU's of the *C. dives* Complex.

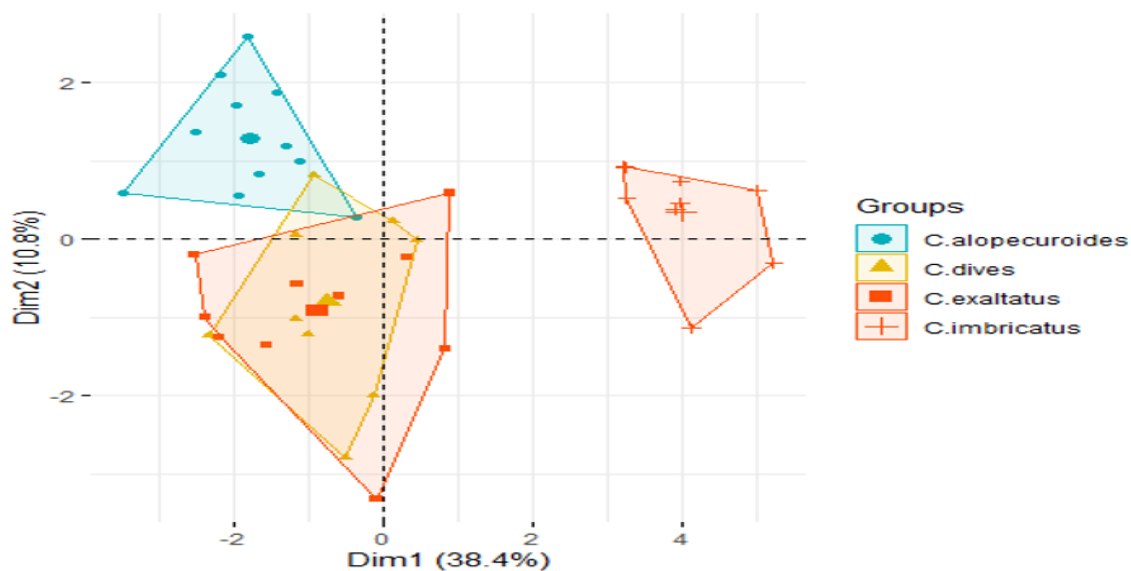


Figure 4.3: Convex Hull Showing the Boundaries of Data Points of Members of the Complex in Reduced Dimensional Space Based on 15 Variables of 39 OTU's when PC 1 is Plotted Against PC 2.

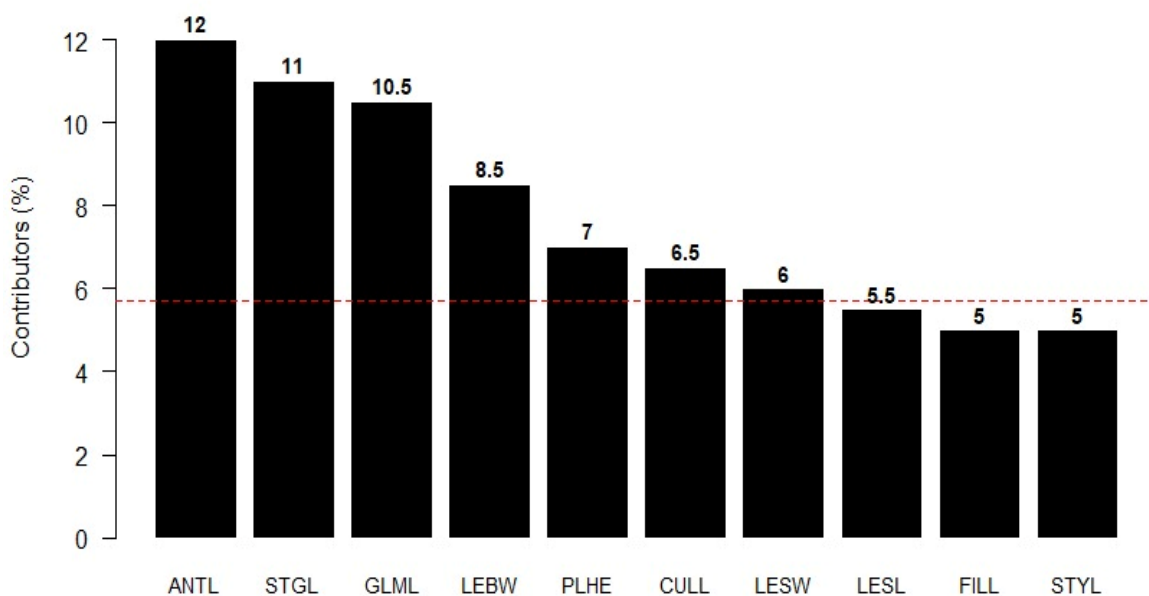


Figure 4.4: Percentage Contributions Made by Variables Along Principal Component 1. Variables whose bars go above the red horizontal line contributed the most to the variation.

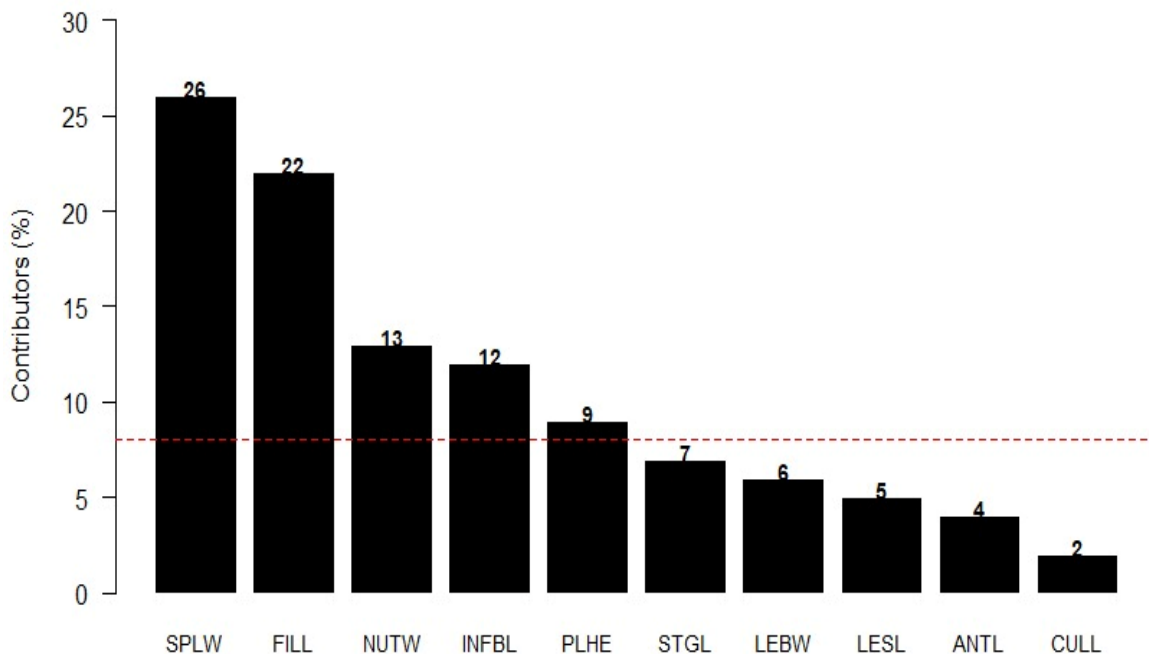


Figure 4.5: Percentage Contributions Made by Variables Along Principal Component 2. Variables whose bars go above the red horizontal line contributed the most to the variation.

4.1.2 Morphological Variations in *Cyperus dives* (s.l) Complex by Cluster Analysis

Cluster analysis of the entire morphological data set of the complex separated its OTU's into 2 primary clusters (Figure 4.6), a small cluster labelled 1 and a big cluster labelled 2 which separate at a taxonomic distance of 7.0. Cluster 1 comprised exclusively of OTU's belonging to *C. imbricatus* while cluster 2 comprised two subclusters and both subclusters comprised a mixture of OTU's of *C. alopecuroides*, *C. exaltatus* and *C. dives*. This agrees with the PCA results (Figure 4.2) in which these three species did not separate out as distinct entities.

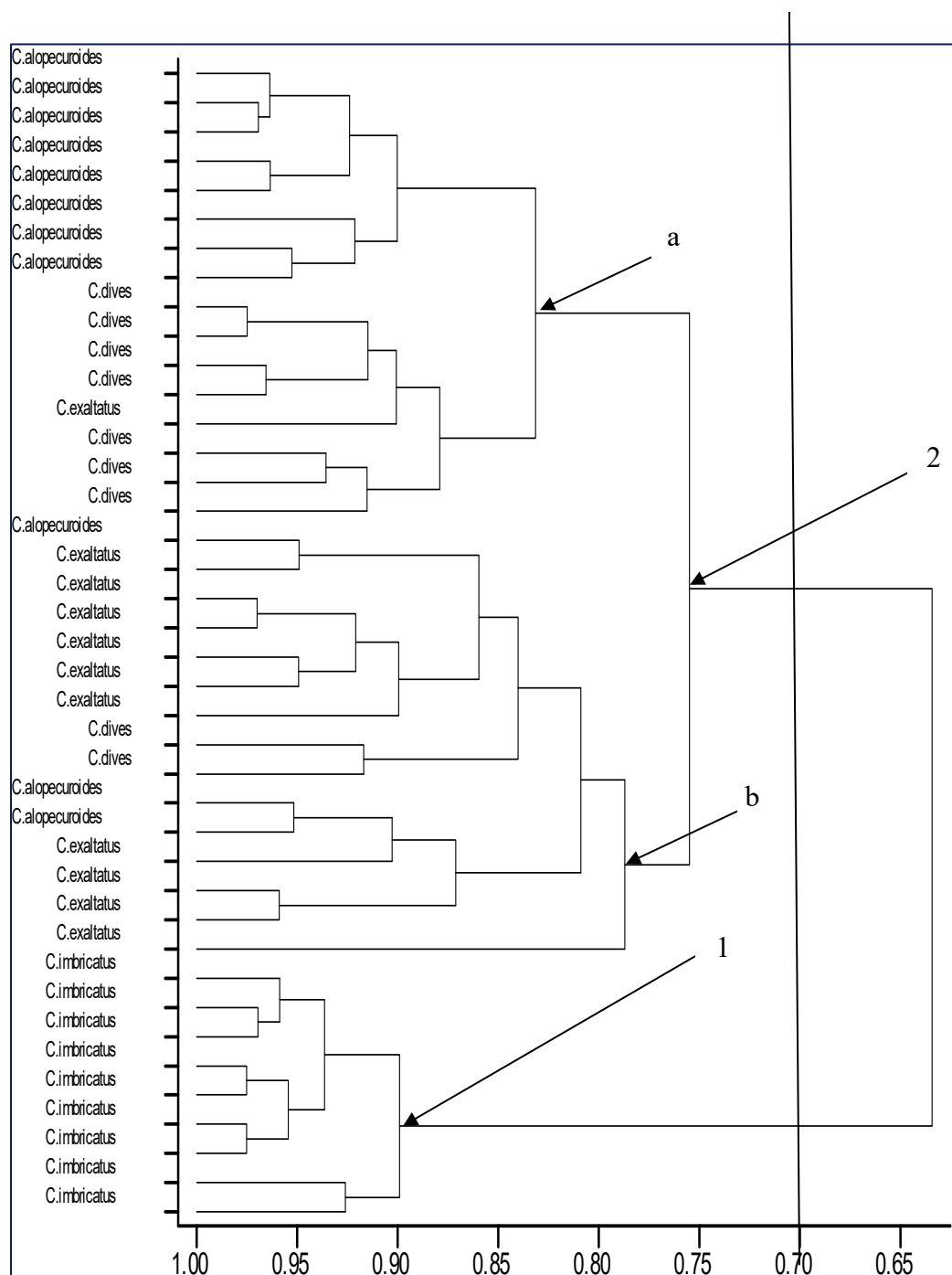


Figure 4.6: Dendrogram Resulting from Cluster Analysis of 39 OTU's of the *C. dives* Complex.

4.1.3 Discriminant Analysis

The plot of all the OTUs shows that Root 1 (horizontal direction) discriminates *C. exaltatus* from the other three species while along Root 2 (vertical direction) there is also a clear separation in multivariate space between *C. imbricatus* and the other three (Figure 4.7). This agrees with the results of PCA (Figures 4.4 and 4.5) and Cluster analysis (Figure 4.6). The factor loadings (> 0.2) that contributed most to the variation patterns along root 1 included anther length (ANTL- 0.304), stigma length (STGL - 0.3315), Glume length (GLML - 0.31950), Inflorescence length (INFL - 0.27533), culm length (CULL - 0.2690), plant height (PLHE- 0.26748), leaf blade width (LEBW - 0.26748), leaf sheath width (LESW - 0.24976), Filament length (FILL - 0.24375) and Spikelet width (SPLW - 0.20232) (Table 4.2).

Table 4.2: Canonical Factor Loadings of Root 1 and Root 2 in Discriminant Analysis

Variable	Root 1	Root 2
ANTL	0.34049	0.02412
CULL	0.2696	-0.1509
CULW	0.20252	-0.0332
FILL	0.24375	0.25351
GLML	0.3195	0.06768
GLMW	-0.0286	-0.544
INFBL	0.1789	0.03281
INFL	0.1789	0.03281
LEBW	0.26296	-0.0431
LESL	0.24862	0.01663
LESW	0.24976	0.0237
NUTL	0.00376	-0.5804
NUTW	0.1842	-0.3464
PLHE	0.26748	-0.3464
SPLW	0.20232	-0.1273
STGL	0.33151	0.20257
STYL	0.22543	-0.146

Along root 2 floral characters again had the greatest influence in discriminating between the species. The characters with the greatest influence were glume width (GLMW - 0.5440), nutlet length (NUTL - 0.58043), nutlet width (NUTW - 0.34536), filament length (FILL - 0.2535), plant height (PLHE - 0.20338) and stigma length (STGL - 0.20257).

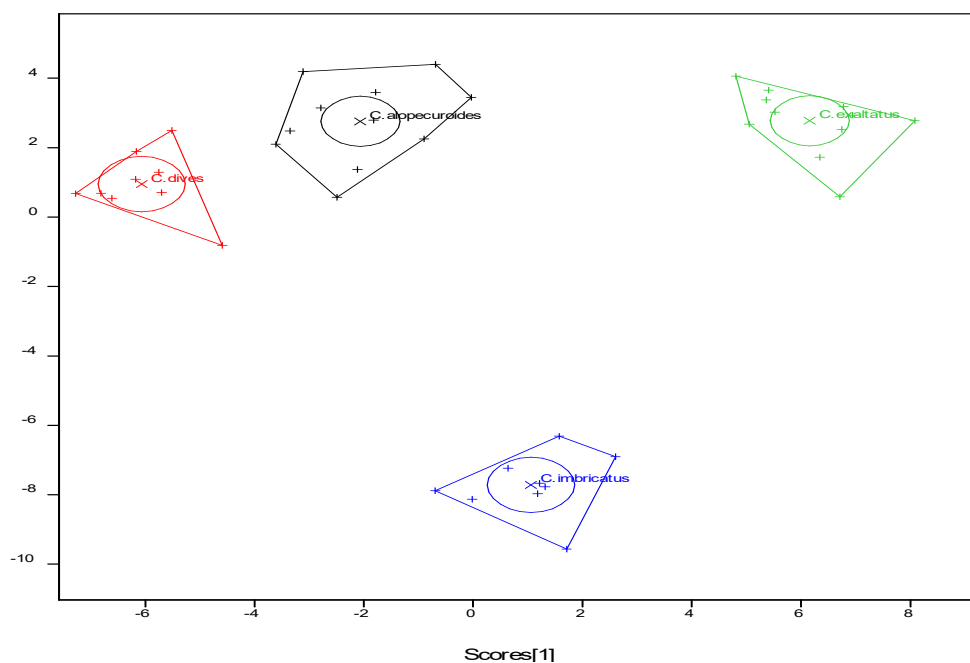


Figure 4.7: Discriminant Analysis Based on 16 Variables of 39 OTU's of *C. dives* Complex.

4.1.4 Univariate Analysis

The results from ANOVA followed by Tukey test at a significant level of $P \leq 0.05$ for all characters used in PCA, DA and OTUs showed no significant level of statistical difference between three of the species (*C. dives*, *C. exaltatus* and *C. alopecuroides*) in the complex in 8 variables out of the 15 used in the analysis (Table 4.7). The eight variables were culm length CULL($P=0.063$), Culm width CULW($P=0.082$), leaf sheath width LESW($P=0.056$), leaf bract

width LEBW(P=0.060), stigma length STGL (P=0.056), anther length ANTL(P=0.061), filament length FILL(P=0.054) and inflorescence length INFL(P=0.0061).

On the other hand, *C. imbricatus* differed significantly from the other three species in most characters as revealed in the box-plots of some selected leaf, culm and inflorescence characters e.g., Leaf sheath width (LESW – Figure 4.8), inflorescence length (INFL – Figure 4.9), Leaf bract width (LEBW – Figure 4.10), culm width (CULW – Figure 4.11) and culm length (CULL – Figure 4.12).

Table 4.3: Comparison of quantitative variables used in PCA, CA and DA.

	<i>C. alopecuroides</i>	<i>C. dives</i>	<i>C. exaltatus</i>	<i>C. imbricatus</i>	Df	F	P
Variable	Sample=11	Sample=9	Sample=11	Sample=9	n-1	Value	Value
	Mean/std	Mean/std	Mean/std	Mean/std			
PLHE	114.95(18.54) ^b	93.52(23.9) ^{ab}	95.18(42.4) ^{ab}	65.70(28.3) ^a	3	4.45	0.009
CULL	36.78(9.67) ^b	30.61(8.64) ^b	34.89(9.27) ^b	19.78(9.14) ^a	3	6.54	0.063
LESL	24.43(6.91) ^b	22.17(3.33) ^b	20.37(6.69) ^{ab}	14.53(4.19) ^a	3	5.35	0.056
CULW	1.57(0.90) ^a	1.39(0.65) ^a	1.59(0.74) ^a	0.81(0.49) ^a	3	2.42	0.082
LESW	1.36(0.37) ^b	1.23(0.64) ^b	1.39(0.71) ^b	0.58(0.22) ^a	3	4.93	0.056
LEBW	1.15(0.37) ^b	0.91(0.38) ^b	1.06(0.50) ^b	0.32(0.16) ^a	3	9.02	0.06
SPLW	2.27(0.36) ^c	1.48(0.17) ^b	1.23(0.17) ^{ab}	1.16(0.23) ^a	3	44.63	0.001
STYL	0.79(0.10) ^b	0.70(0.09) ^{ab}	0.77(0.13) ^b	0.60(0.09) ^a	3	6.39	0.061

STGL	1.18(0.14) ^b	1.34(0.24) ^b	1.20(0.13) ^b	0.51(0.14) ^a	3	48.28	0.056
ANTL	0.70(0.08) ^b	0.70(0.09) ^b	0.74(0.05) ^b	0.31(0.09) ^a	3	63.56	0.061
FILL	1.75(0.21) ^b	2.07(0.48) ^b	2.01(0.51) ^b	1.23(0.10) ^a	3	9.53	0.054
GLML	1.93(0.25) ^c	1.86(0.16) ^{b c}	1.68(0.14) ^b	1.31(0.16) ^a	3	21.33	0.001
GLMW	0.83(0.25) ^b	0.26(0.13) ^a	1.28(0.18) ^c	0.91(0.09) ^b	3	55.01	0.001
NUTL	0.82(0.13) ^b	0.53(0.06) ^b	0.88(0.12) ^b	0.77(0.17) ^b	3	9.79	0.001
NUTW	0.53(0.06) ^b	0.40(0.09) ^a	0.47(0.05) ^{a b}	0.39(0.11) ^a	3	7.18	0.001
INFBL	31.55(14.51) ^{a b}	40.82(16.2) ^{a b}	43.15 (12.2) ^b	25.79(9.89) ^a	3	3.54	0.061
INFL	17.54(4.78) ^b	22.73(7.35) ^b	19.83(7.29) ^b	7.48(3.13) ^a	3	11.37	0.061

Sample size, mean and Std (Standard deviation) are shown. Results of Turkeys test are summarized by the superscripts. Species having the same letter do not differ significantly for that character ($P \leq 0.05$).

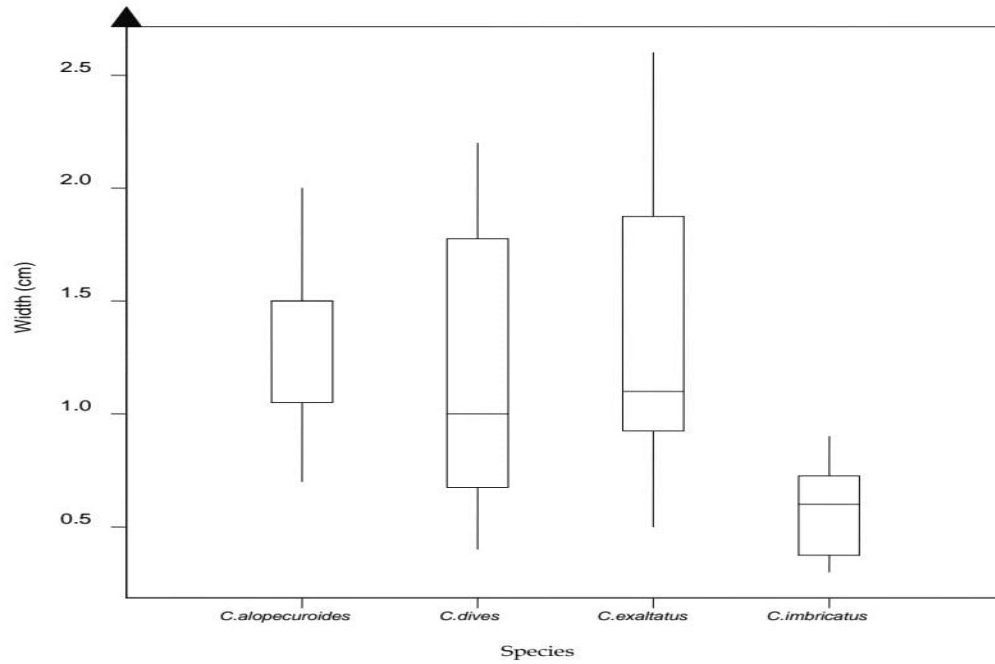


Figure 4.8: Box Plot of Leaf Sheath Width for Species in the *C. dives* complex

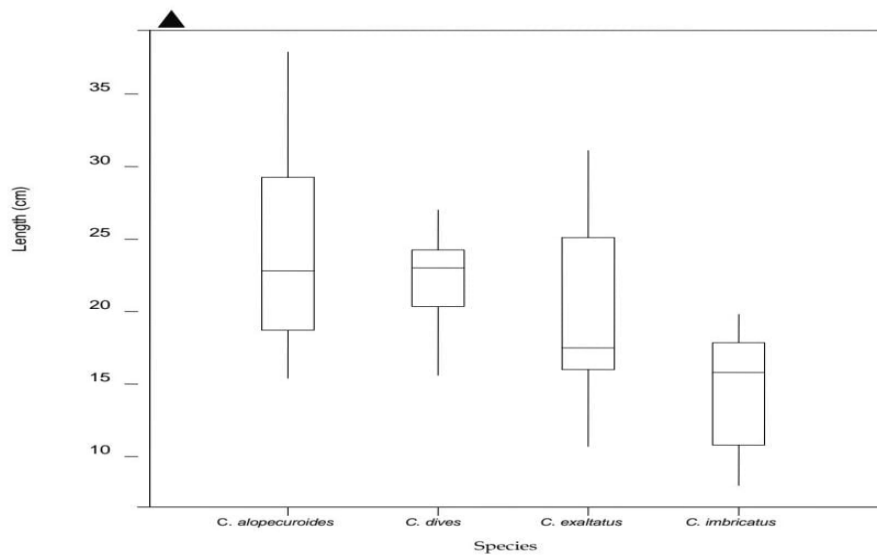


Figure 4.9: Box Plot of Inflorescence Length for Species in the *C. dives* Complex.

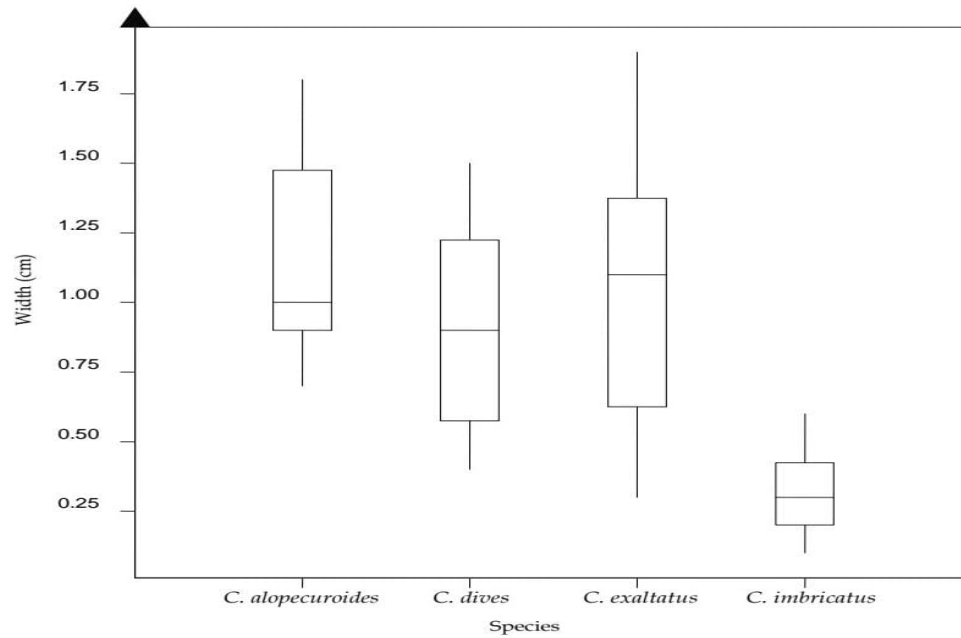


Figure 4.10: Box Plot of Leaf Blade Width for Species in the *C. dives* Complex.

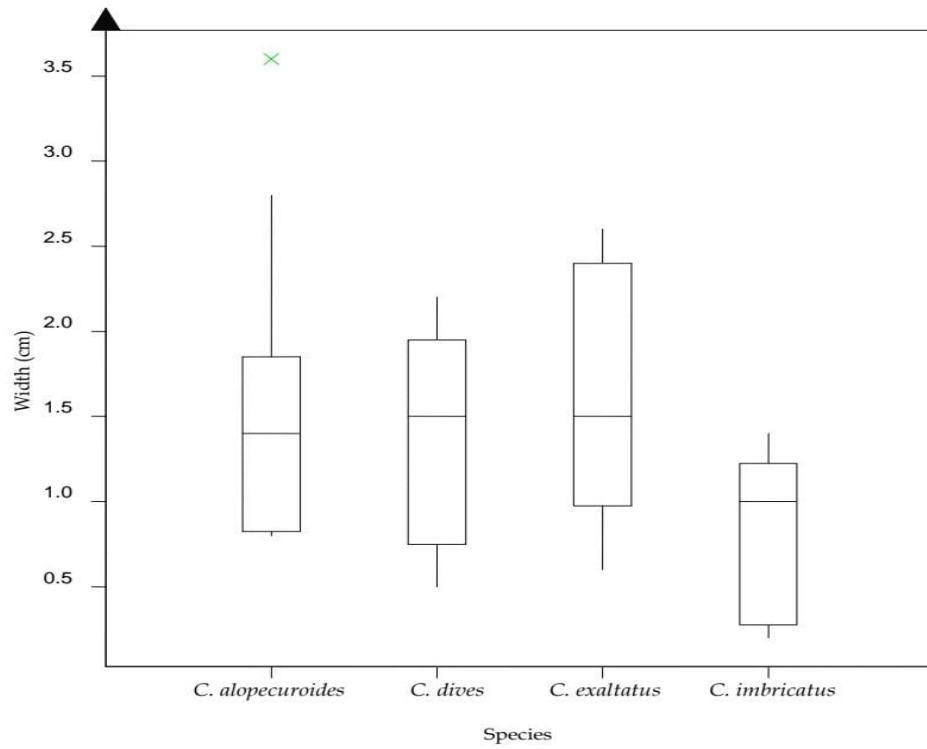


Figure 4.11: Box Plot of Culm Width for Species in the *C. dives* Complex.

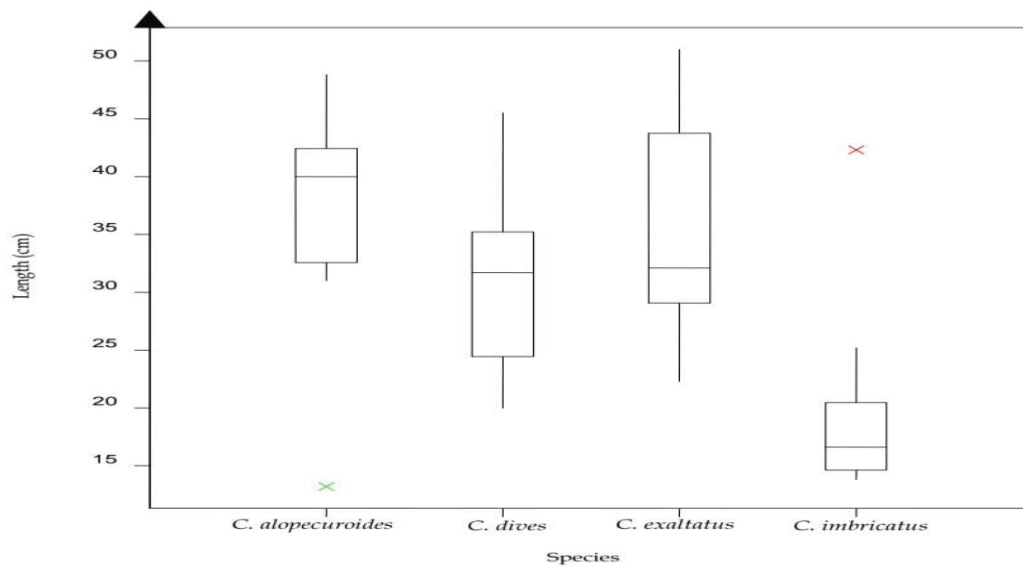


Figure 4.12: Box Plot of Culm Length for Species in the *C. dives* Complex.

4.1.5 Scanning Electron Microscopy of Achens of *Cyperus dives* (s.l) Complex

Micrographs from SEM revealed unique characters on the surface of the nutlets of the four taxa examined. The results showed two categories of nutlet shape; elliptic triangular (Figures 4.13 A1, 4.15 C1 and 4.16 D1) and obovoid to rounded shape (Figure 4.14 B1). Three surface topographies were revealed i.e., rugose (Figures 4.13 A2 and 4.14 B2) reticulate irregular pitted (Figure 4.15 C2), and almost smooth reticulate foveate (Figure 4.16 D2). Epidermal cell on the achene surfaces were either hexagonal (Figures 4.13 A2, 4.15 C2 and 4.16 D2) or pentagonal (Figure 4.14 B2).

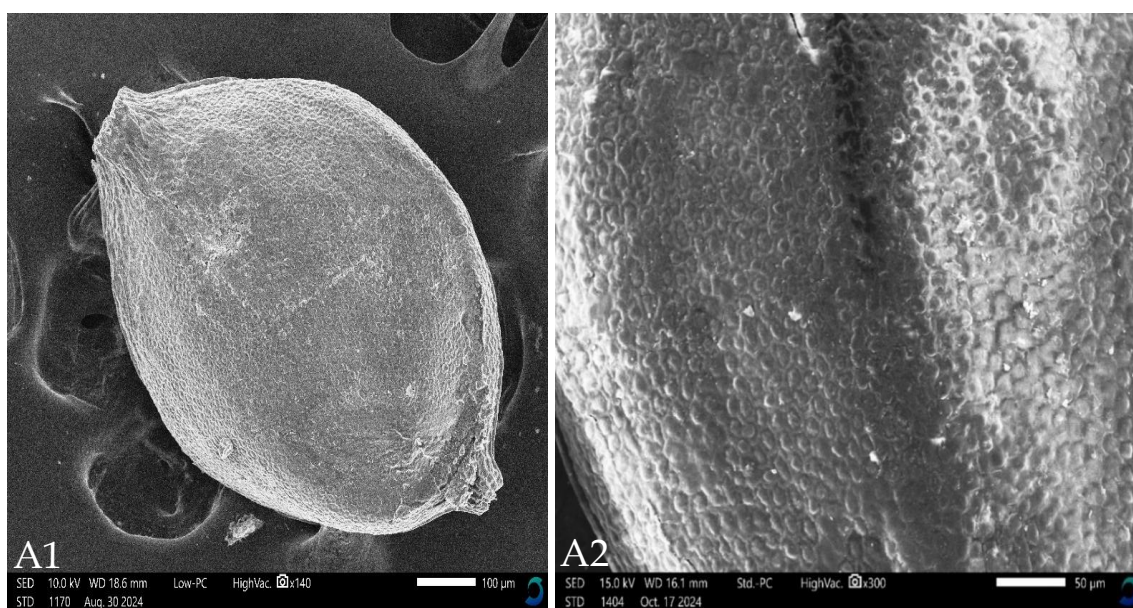


Figure 4.13: Achene Shape and Surface. A1. Mature achene of *C. dives* showing an elliptic triangular shape and a short stipe on both ends. A2. Achene of *C. dives* showing a rugose surface and hexagonal epidermal cells.

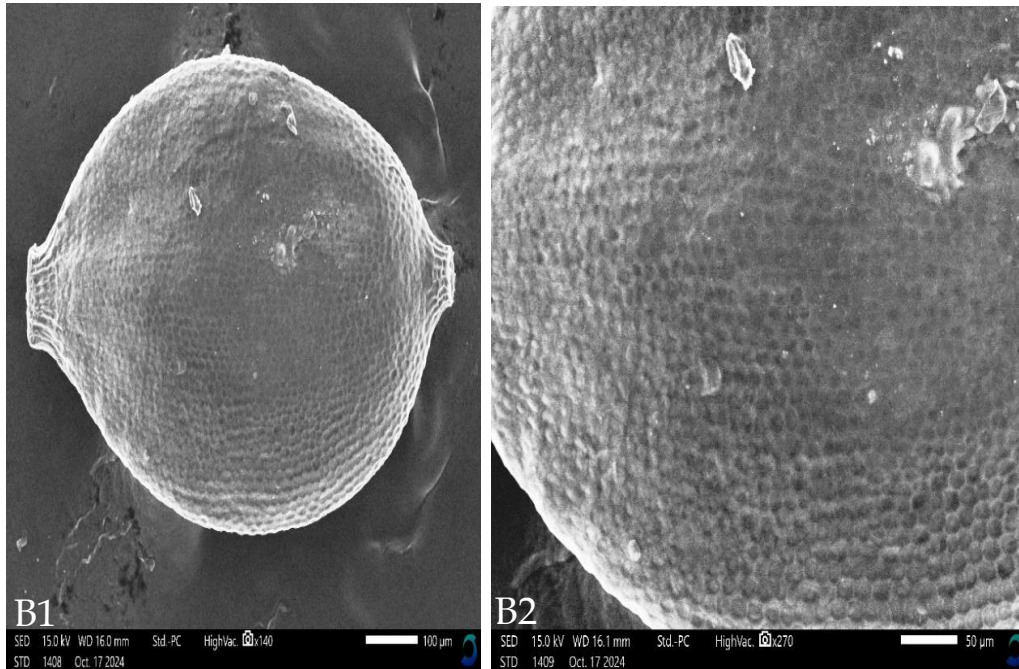


Figure 4.14: Achene Shape and Surface. B1. Mature achene of *C. alopecuroides* showing obovoid-rounded shape and a short stipe on both ends. B2 Achene of *C. alopecuroides* showing a rugose surface with pentagonal epidermal cells.



Figure 4.15: Achene Shape and Surface. C1. Mature achene of *C. imbricatus* showing an elliptic triangular shape and a short stipe on both ends. C2. Achene of *C. imbricatus* showing a reticulate, irregular pitted surface with hexagonal epidermal cells.



Figure 4.16: Achene Shape and Surface. D1. Mature achene of *C. exaltatus* showing an elliptic triangular shape and apiculate apex. D2. Achene of *C. exaltatus* showing hexagonal shaped epidermal cells and an almost smooth, reticulate foveate surface.

4.2 Distribution Patterns of *Cyperus dives* (s.l) Complex in East Africa

The distribution pattern of the species in the complex is shown in Figure 4.17. The data used in determining the distribution patterns for the species in the complex is shown in Appendix 1. The results show that the *C. dives* and *C. alopecuroides* are dominantly distributed in high-altitude areas while *C. imbricatus* is distributed along coastal planes of Tanzania and Uganda however, *C. exaltatus* though restricted in two countries, some individuals are in low land and others in highland areas.

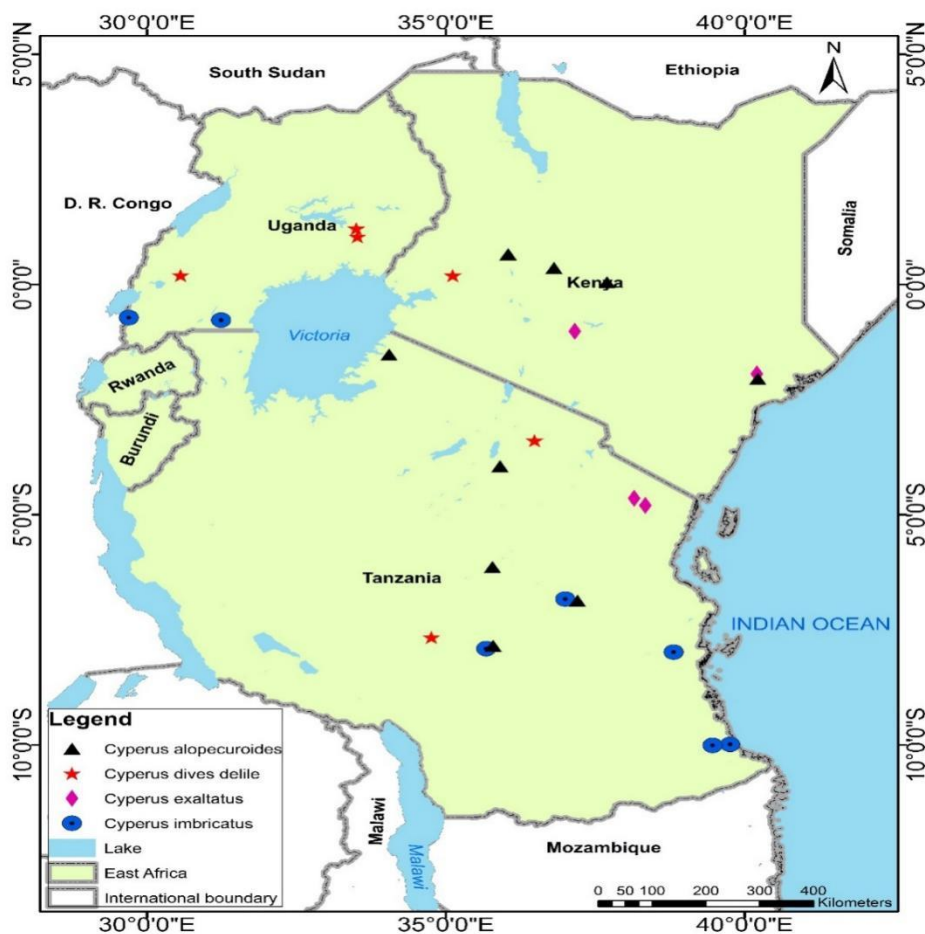


Figure 4.17: Distribution of Taxa in the *Cyperus dives* Complex in East Africa (Source: Google map,2024)

CHAPTER FIVE

DISCUSSION

5.1 Distribution Patterns of *Cyperus dives* (s.l) Complex in East Africa

The results demonstrates that the taxa within the *C. dives* complex are distributed in the region apparently based on their ecological preference. *C imbricatus* has a wide altitudinal range from sea level to 509m. The taxon has preference for low elevations restricted to the coastal planes of Eastern Tanzania (T6), Southern Highland (T8) of Tanzania and Western Uganda (U2). This reveals that it is adapted to low elevations in wet and hot climatic conditions. This study reveals that distribution pattern of *C. imbricatus* is much broader (now with additional locations: Iringa, Kilumi, Morogoro and Lindi in Tanzania) as opposed to what Haines and Lye (1983) reported, that it was confined to the Rufiji region (T8) in Tanzania.

Cyperus exaltatus is restricted to northern and southern highlands of Tanzania (T2 and T7 regions) and the coast and central regions of Kenya (K7 and K4 regions) with an elevation range of 5 to 600m. The taxon is restricted to two regions in East Africa with slightly lower elevation compared to *C. imbricatus*. The distribution of *C. alopecuroides* is confined to Tanzania (T7 and T2 regions) and Kenya (K4, K6 and K3 regions) with a higher altitudinal range of sea level-2650m higher than all the other three taxa. This suggests that it grows in highland regions with cool and wet climatic conditions. *Cyperus dives* is widespread, with its distributional range, spanning from the Tanzanian coast, central Kenya to western Uganda (150-1940m).

5.2 Taxonomy of *Cyperus dives* (s.l) Complex in East Africa

5.2.1 Morphological Variations in *Cyperus dives* (s.l) Complex in East Africa

The results of the morphometric analyses suggest that the *Cyperus dives* complex in East Africa comprises one distinct species and one variable species. This inference is supported by the degree of variation as observed in key characteristics, revealed by the phenetic analyses. In these analyses, *C. imbricatus* is distinguished from the other three taxa in the complex, which share some overlapping characters. The PCA (Figure 4.3), cluster analysis (Figure 4.6), discriminant analysis (Figure 4.7), and univariate analysis (Table 4.3) seem to delimit *C. imbricatus* from the rest of the taxa in the complex. This is supported by variations in the following characters: stigma length (Table 4.7), filament length (Table 4.7), anther length (Table 4.7), leaf sheath width (Figure 4.8, Table 4.7), Leaf blade width (Table 4.7, Figure 4.10) and culm length (Table 4.7, Figure 4.12). In a study on Italian *Cyperaceae*, Vervloove and Soldano, (2011) distinguished *C. imbricatus* from other taxa based on its smaller glumes, slender, narrower leaves, and saw-like spikes. The leaf sheath width character used to delimit *C. imbricatus* in this study supports this distinction. *Cyperus imbricatus* has also been distinguished from *C. alopecuroides* based on its small nutlet length and width (Brullo, 2006). Micromorphological evidence obtained from scanning electron micrography (SEM) also showed that the taxon differed from the other three taxa in having a reticulate irregularly pitted surface (Figure 4.5). Thus, based on this study of the East African taxa of the complex, we propose that *C. imbricatus* be recognized as a distinct species, as currently treated by Hoenselaar *et al.*, (2010). The other three taxa: *C. alopecuroides*, *C. exaltatus*, and *C. dives* should be treated at infraspecific rank, a view that was supported by Haines and Lye (1983), who regarded them as "similar." The

multivariate and univariate analyses conducted in this study do not reveal any clear distinction between these three taxa (Figures 4.4-4.12) and thus based on overall similarity, it seems none of them qualifies for recognition as a distinct species. The taxonomic inference that can be drawn from this is that *C. imbricatus* warrants recognition as a distinct species, whereas *C. alopecuroides*, *C. exaltatus*, and *C. dives* should be treated as infraspecific taxa, due to their overlapping morphological characteristics. With that in mind, the results support the hypothesis that the *Cyperus dives* complex consists of more than one variable species. However, whether to treat the three variable taxa as subspecies or varieties remains a matter of taxonomic opinion and individual interpretation. Here, we propose that these three taxa should be assigned the varietal rank due to their overlapping morphology and distribution. However, it is important to highlight that, formal nomenclatural changes cannot be made at this time, as the study only included material from East Africa, despite the complex being pantropical and highly polymorphic. Additionally, the actual specimens have not been physically examined, with only the Type specimens being consulted to assist in the delimitation of the taxa (Appendix IV).

5.2.2 Proposed Taxonomic key for *Cyperus dives* (s.l) Complex

1. Narrow leaves 0.1-0.6mm with compressed spikelet, small Glume length 1-1.4mm; nutlet length 0.6-0.69mm*C. imbricatus*
2. Wide leaves 1-1.9mm with spikelet obliquely inserted, lax and almost inserted at right angles, to numerous and crowded; Glume length more than 1.5mm; nutlet length more than 0.71 mm.....(*C. dives*, *C. alopecuroides* and *C. exaltatus*).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings of this study suggest that the *Cyperus dives* (s.l) complex consists of one clearly distinct species and three morphologically variable taxa, as evidenced by the following criteria:

- I. Overlapping morphological characteristics, except for *C. imbricatus*.
- II. Absence of geographical separation with *C. imbricatus* displaying the broadest distribution and occupying the widest altitudinal range.
- III. Observed ecological preferences.

However, formal nomenclatural changes are deferred pending a comprehensive global study of the complex across its entire range and a review of type materials. For this study, *C. imbricatus* is retained at the species level.

Thus, the proposed classification and nomenclature for the taxa within the *Cyperus dives* complex are as follows:

- I. *Cyperus imbricatus* Retz.
- II. *Cyperus dives* var. *dives* (Stat. Nov. Ined.)
- III. *Cyperus dives* var. *alopecoroides* (Stat. Nov. Ined.)
- IV. *Cyperus dives* var. *exaltatus* (Stat. Nov. Ined.)

The results indicate that the distribution patterns of taxa within the *C. dives* complex are primarily influenced by their ecological preferences, although there is significant overlap in their geographic distribution.

6.2 Recommendations

- (i). Undertake a comprehensive study encompassing the full geographic range of all taxa within the *C. dives* complex, combining both morphological and molecular data to definitively resolve their taxonomic relationships.
- (ii). Given the wide distribution of species in this complex, primarily influenced by ecological factors, additional field collections should be conducted in FTEA regions not covered in the current study. Also, the distribution patterns underscore the importance of further sampling in Uganda.

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APPENDICES

Appendix I: List of all Specimens Studied in *Cyperus dives* (s.l) Complex

Voucher number	Date	Collector	Habitat	Countries	Taxa	F.T.E . A	Administration	Exact locality in Gazetteer	Altitude	GPS Position
6135/H	19/2/1971	P. Capella	Rice fields	Tanzania	<i>C. exaltatus</i>	T6	Morogoro	Morogoro	550	65S 3750E
1148	10/1/1914	GR.C. Samean	River dam	Kenya	<i>C. exaltatus</i>	K4	Nairobi	Miotori	600	1°18'S, 36°25'E
4356	20/8/1931	Vollesen	Grassland black clay	Tanzania	<i>C. exaltatus</i>	T8	Kingupira	South game reserve	125	8°29'S 38°21'E
15247	26/6/1973	P.J Green	Margins of water holes	Tanzania	<i>C. exaltatus</i>	T6	Kilosa	Kilosa	518	447S 9048E
2514	11/5/1953	R.B Dummen <i>et al</i>	Riverside	Tanzania	<i>C. exaltatus</i>	T3	Lushoto	Lushoto	400	4°40'S 38°60'E
RRH 14- 1089	23/9/2001		Savanna bushland	Kenya	<i>C. exaltatus</i>	K3	Laikipia	Laikipia	1657	
13415	20/4/2009	L.Q Harmerlynic	River bank	Kenya	<i>C. exaltatus</i>	K7	Tana river	Tana river	12	4°30'S 93°0'E
3962	23/5/1930	P.J Green	Margins (seasonal ponds & rivers)	Tanzania	<i>C. exaltatus</i>	T3	Mkomazi	Lushoto	457	4°38'S 38°24'E
2139	5/7/2001	J. Kalema	Streamline	Uganda	<i>C. exaltatus</i>	U1	Kidepo valley NP	Karamoja		355N335 0E
95	7/8/2010	C.Leauthaud <i>et al</i>	Flood plains	Kenya	<i>C. exaltatus</i>	K7	Tana river	Tana river	5	1°30'S 39°18'E

9427	21/3/1975	P.A Luke and WRQ	River bank	Tanzania	<i>C. alopecuroides</i>	T2	Udzugwa	Iringa	520	2°57'S 33°30'E
5558	23/12/1969	Leipert	Damp border	Tanzania	<i>C. alopecuroides</i>	T2	Masai	Masai	1128	3°35'S 17°30'E
15396	10/7/1973	P.J Green & Mbagi <i>et al</i>	Sandy river	Tanzania	<i>C. alopecuroides</i>	T7	Kilosa	Mugumi	0	7°24'S 36°35'24'E
1592	11/6/1965	S.D Hacombe	Black cotton soil	Tanzania	<i>C. alopecuroides</i>	T2	Taangeru	Arusha		323S365 0E
15396	10/7/1973	P.J Greenway & Kanuri	Grey puff sand wash	Tanzania	<i>C. alopecuroides</i>	T6	Kilosa	Kilumi		724S365 9E
6318	21/8/1956	Vesey-FitzGerald	Water course pool	Tanzania	<i>C. alopecuroides</i>	T2	Mbulu	Tarangire	1038	3°41'S 53°34'E
13707	26/2/1963	P.J Green Way & Kanuri	Wet places in sandy rivers	Tanzania	<i>C. alopecuroides</i>	T7	Iringa	Mbagi		735S 3915E
34	24/12/2004	P. Musili <i>et al</i>	Open river channels	Kenya	<i>C. alopecuroides</i>	K4	Mbeere	Kabara	1124	0°74'S 37°25'48'E
14506	12/5/1970	P. Greenway & Kanuri	Sand bank	Tanzania	<i>C. alopecuroides</i>	T1	Mugumu	Ruaha River	747	
149	12/3/1990	C.Kabuye <i>et al</i>	Old cultivation and grassland	Kenya	<i>C. alopecuroides</i>	K7	Tana river	Tana River National Reserve	30	0°15'S 53°43'E
693	29/9/2005	G. Mwachala <i>et al</i>	Lake shore	Kenya	<i>C. alopecuroides</i>	K3	Baringo	Lake Baringo Soy lodge	980	0°03'N, 77°11'E
7796	21/6/1946	P.J Greenway	Dams (periodical flooding)	Tanzania	<i>C. alopecuroides</i>	T2	Masai	Maserani Dam hill	914	3°30'S 36°15E
198	24/12/2004	P. Musili <i>et al</i>	Seasonally wet area	Kenya	<i>C. alopecuroides</i>	K4	Thika	Nyeri, Nairobi near Makuyu	1631	0°45'S, 37°20E
6639	20/4/1970	Vesey-FitzGerald	Riparian sand bank damp depression	Tanzania	<i>C. alopecuroides</i>	T7	Mbagi camp Ruaha Park	Iringa	2650	7°39'S, 34°15E

SP-260	4/10/1949	Paul Ssegawa	Swamps	Uganda	<i>C. dives</i>	U3	Kamuli	Lake Nakuwa swamps	1045	0°57'N, 33°42'E
459	20/4/1964	G. Mwachala <i>et al</i>	Wetland	Kenya	<i>C. dives</i>	K3	Nandi	Nandi near kapsabet	1940	0°12'S 08°E
176	16/7/1974	Kirika <i>et al</i>	Seasonal wet land	Kenya	<i>C. dives</i>	K4	Meru	Meru district	1680	
5274	19/7/1933	Kayombo <i>et al</i>	Forest dominated	Tanzania	<i>C. dives</i>	T2	Mbulu	Tarangire	1050	3°43'S, 53°58'E
507	13/4/1961	Glover <i>et al</i>	Edge of water	Kenya	<i>C. dives</i>	K6	Narok	Mara river		107S, 5510E
43	13	Ezrom <i>et al</i>	Riverine forest	Tanzania	<i>C. dives</i>	T8	Lindi	Milola Rutamba	150	10°0'S, 39°00'E
999	19/7/1932	James Kalema	Wetland seasonal floods	Uganda	<i>C. dives</i>	U3	Lake Kyoga	Kidera	1045	0°59'N, 34°37'E
1152	10/7/1931	P. Chuchar	Muddy bank	Kenya	<i>C. dives</i>	K6	Masai Mara	Masai	1525	1°30'S, 35°36'E
JK999	20/6/1930	J. Kalema	Wetlands seasonal floods	Uganda	<i>C. dives</i>	U2	Lake Mburu MP	Karamoja	1035	15°9'W, 34°22'E
1002	3/10/1954	Anderson	Sand beach left by rescinding river	Tanzania	<i>C. imbricatus</i>	T6	Rufiji	Utete	200	8°01'S, 38°27'E
6817	20/11/1970	Njombe	River Sand deposit	Tanzania	<i>C. imbricatus</i>	T7	Njombe	Njombe R		935S 3425E
548	16/6/1964	J.M Lock	Silty sand	Uganda	<i>C. imbricatus</i>	U2	Kigezi	Ishasha	0	10°7'S 29°32'E
1824	3/1/1971	R. Wingfield	Shallow water at the edge of the river	Tanzania	<i>C. imbricatus</i>	T8	Ruaha	Lindi	490	10°06'S, 39°23'E
1003	19/7/1972	B. Clanderson	Sand bank left by rescinding river	Tanzania	<i>C. imbricatus</i>	T6	Rufiji	Utete	0	8°01'S, 38°26'E
21008	10/4/1930	M.Richards <i>et al</i>	Deep sand edge of the river	Tanzania	<i>C. imbricatus</i>	T7	Ruaha National Park	Iringa		
7364	25/1/1931	M.Richards <i>et al</i>	Seasonally flooded black cotton soil	Tanzania	<i>C. imbricatus</i>	T6	Morogoro	Morogoro	509	6°55'S, 37°30'E

1002	31/10/1964	B. Clanderson	Sand beach left by receding river	Tanzania	<i>C. imbricatus</i>	T6	Eastern Rufiji	Utete	0	8°01'S, 34°30'E
567	20/4/1964	J. Rhelter	Swampy with standing water	Tanzania	<i>C. imbricatus</i>	T2	Northern Mbulu	Magugu population		
548	16/6/1964	J.M Lock	Silty sand bank river	Uganda	<i>C. imbricatus</i>	U2	Kigezi	Ishasha R	0	10°7'S, 52°57 E
6817	20/9/1930	D.Vessy Fitzguard	River Sand deposit	Tanzania	<i>C. imbricatus</i>	T5	Several	Njombe R		758S 3553E
SP-814	17/1/2002	Paul Ssegawa	Riverine forest	Uganda	<i>C. imbricatus</i>	U2	Semleki wildlife reserve	Toro		008S, 2256E

Appendix II: Character data collection form

		<i>Cyperus imbricatus</i> Retz	<i>Cyperus dives</i> Delile	<i>Cyperus exaltatus</i> Retz	<i>Cyperus alopecuroides</i> Rottb
		Collector No.	Collector No.	Collector No.	Collector No.
		Name	Name	Name	Name
		Date	Date	Date	Date
Morphology					
Plant height (cm)					
Stolon W (at mid-point)					
Culm colour					
Culm L(cm)					
Culm W(cm)					
Leaf sheath Largest W (cm)					
Leaf blade largest W (mm)					
Inflorescence bract Number					
Inflorescence bract largest length (cm)					
Inflorescence bract W largest(cm)					
Inflorescence L(cm)					
Inflorescence W(cm)					
No of spikelet (sessile)					
No. of spikelet Stalked					
Primary spike stalk (peduncle) L(mm)					
Secondary stalk (peduncle) L					
Spike length(mm)					
Spike width(mm)					

Spikelet length and width				
Spikelet compressed (Yes or No.)				
Distance between 2 spikelet				
Glume L and W	L W			
Glumes apex shape				
Glume number per spikelet and colour				
Glume number of Nerves				
Glume colour				
Glume margin in rolled-Yes or No	Yes No			
Keel shape				
Nutlet Land W	L W			
Nutlet colour				
Nutlet shape flat or rounded				
Nutlet surface smooth or reticulate				
Stamen number				
Filament length				
Anther length				
Style length				
Stigma length				

Appendix IV : Images of Type Specimens used in the study



Plate A.: *C. alopecuroides* (Source: JSTOR, 2018)

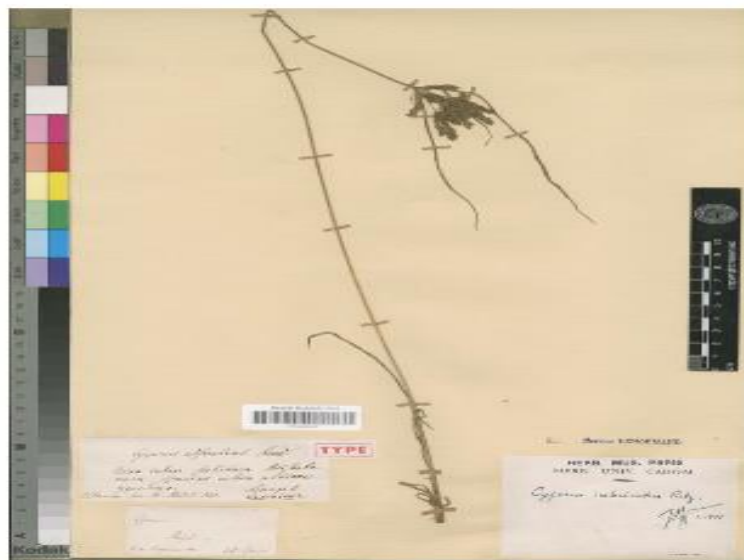


Plate B.: *C. imbricatus* (Source: JSTOR, 2018)

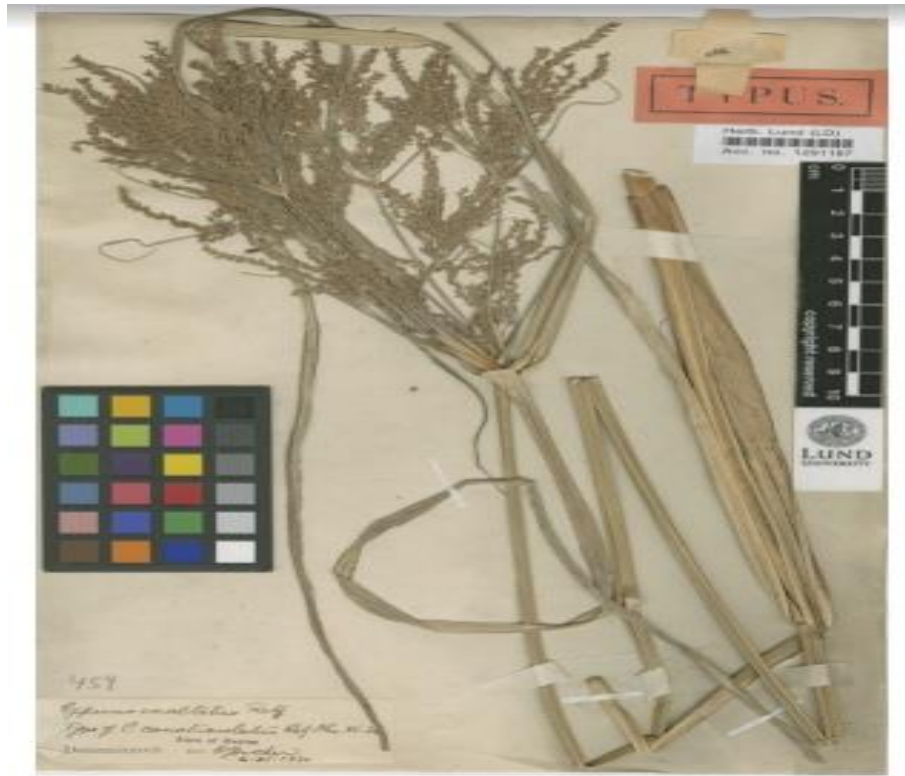


Plate C.: *C. exaltatus* (Source: JSTOR, 2018)



Plate D.: *C. dives*. (Source: JSTOR, 2018)

Appendix V: Vegetative Data

No.	Country	Specimens	PLHE	CULL	LESL	CULW	LESW	LEBW
1	Tanzania	<i>C. alopecuroides</i>	93	31	15.4	1.2	1.3	1
2	Kenya	<i>C. alopecuroides</i>	129	43	31.7	0.8	1.5	1.8
3	Kenya	<i>C. alopecuroides</i>	93.1	13.2	27	1.4	1.2	1.6
4	Kenya	<i>C. alopecuroides</i>	101.1	33.7	37.9	0.8	1.5	0.9
5	Kenya	<i>C. alopecuroides</i>	106	35.3	20.8	1.4	1.5	1
6	Kenya	<i>C. alopecuroides</i>	122.2	40.7	30	0.9	1	0.9
7	Kenya	<i>C. alopecuroides</i>	96.5	32.2	18.3	2.8	2	1.7
8	Tanzania	<i>C. alopecuroides</i>	139	46.3	17.8	1.9	1.5	0.9
9	Tanzania	<i>C. alopecuroides</i>	146.5	48.8	27	0.8	1	1
10	Tanzania	<i>C. alopecuroides</i>	121.2	40.4	20	1.7	1.8	0.7
11	Tanzania	<i>C. alopecuroides</i>	116.9	40	22.8	3.6	1.2	1.1
12	Kenya	<i>C.dives</i>	95	31.7	23	1.5	1.5	0.9
13	Kenya	<i>C.dives</i>	80	26.6	19.9	1.2	0.6	0.5
14	Kenya	<i>C.dives</i>	95	31.7	15.6	2.1	1.7	1.5
15	Kenya	<i>C.dives</i>	77.6	25.9	20.5	0.8	1	1.2
16	Kenya	<i>C.dives</i>	60	20	21.2	0.6	0.7	0.6
17	Tanzania	<i>C.dives</i>	136.5	45.5	23.3	1.9	0.4	0.4
18	Tanzania	<i>C.dives</i>	122	40.7	27	2.2	2.2	1.3
19	Tanzania	<i>C.dives</i>	75.5	20	25	0.5	1	1
20	Uganda	<i>C.dives</i>	100.1	33.4	24	1.7	2	0.8
21	Kenya	<i>C.exaltatus</i>	89.5	29.83	25.3	0.9	1	1.2
22	Kenya	<i>C.exaltatus</i>	100	33.3	16	1.6	0.9	0.3
23	Kenya	<i>C.exaltatus</i>	153	51	31.1	1.3	2.5	1.3
24	Kenya	<i>C.exaltatus</i>	90.1	30	21.2	2.1	1.1	1.1
25	Tanzania	<i>C.exaltatus</i>	26.3	28.8	10.7	0.7	0.7	1.9
26	Tanzania	<i>C.exaltatus</i>	125.1	25.4	30.5	2.5	2.6	0.5
27	Tanzania	<i>C.exaltatus</i>	67	22.3	24.5	2.6	1.1	1
28	Tanzania	<i>C.exaltatus</i>	135	45	17	1.2	0.5	0.7
29	Tanzania	<i>C.exaltatus</i>	138	46.1	16	2.5	1.8	1.4
30	Uganda	<i>C.exaltatus</i>	26.5	40	17.5	0.6	1.9	0.6
31	Tanzania	<i>C.exaltatus</i>	96.5	32.1	14.3	1.5	1.2	1.7


32	Tanzania	<i>C.imbricatus</i>	84	13.8	17.8	1.1	0.5	0.3
33	Tanzania	<i>C.imbricatus</i>	41	15.1	11.5	0.2	0.3	0.3
34	Tanzania	<i>C.imbricatus</i>	127	42.3	15.2	0.6	0.6	0.6
35	Tanzania	<i>C.imbricatus</i>	50	17.2	19.8	1.4	0.9	0.5
36	Tanzania	<i>C.imbricatus</i>	50	16.6	18	1.3	0.8	0.4
37	Tanzania	<i>C.imbricatus</i>	77	18.9	8.7	1.2	0.7	0.2
38	Uganda	<i>C.imbricatus</i>	42.4	14.1	15.8	0.3	0.3	0.1
39	Tanzania	<i>C.imbricatus</i>	44.4	14.8	8	0.2	0.4	0.3
40	Tanzania	<i>C.imbricatus</i>	75.5	25.2	16	1	0.7	0.2


Appendix VI: Floral Data

Country	Taxa	SPLW	STYL	STGL	ANTL	FILL	GLML	GLMW	NUTL	NUTW	INFBL	INFL
Tanzania	<i>C. alopecuroides</i>	1.8	0.7	1.3	0.6	2	1.9	0.8	0.8	0.5	20.5	14.7
Kenya	<i>C. alopecuroides</i>	1.9	1	1.2	0.7	1.8	2.1	1.1	0.7	0.6	54	19.2
Kenya	<i>C. alopecuroides</i>	2.5	0.8	1	0.8	1.6	2.2	0.9	0.9	0.5	26.6	13.5
Kenya	<i>C. alopecuroides</i>	2.6	0.7	1.4	0.6	1.7	2	1	0.6	0.6	15.6	19.2
Kenya	<i>C. alopecuroides</i>	1.7	0.9	1.2	0.8	2	2.3	0.7	1	0.5	14.7	14
Kenya	<i>C. alopecuroides</i>	2	0.8	1.3	0.6	1.9	1.9	1.2	0.9	0.4	19.3	19
Kenya	<i>C. alopecuroides</i>	2.3	0.7	1	0.7	1.5	1.8	0.6	0.8	0.5	37.5	11.4
Tanzania	<i>C. alopecuroides</i>	2.4	0.7	1	0.7	1.4	1.5	0.5	0.7	0.6	50.7	25.5
Tanzania	<i>C. alopecuroides</i>	2.7	0.7	1.3	0.8	1.6	1.6	1.1	1	0.5	46.3	25.7
Tanzania	<i>C. alopecuroides</i>	2.6	0.8	1.1	0.7	2	2.1	0.7	0.9	0.6	22.4	17.2
Tanzania	<i>C. alopecuroides</i>	2.5	0.9	1.2	0.7	1.7	1.8	0.5	0.7	0.5	39.5	13.5
Kenya	<i>C. dives</i>	1.5	0.6	1	0.6	1.3	1.8	0.5	0.5	0.3	38.5	15.5
Kenya	<i>C. dives</i>	1.4	0.8	1.5	0.8	2.5	2	0.3	0.3	0.5	44.6	14.5
Kenya	<i>C. dives</i>	1.7	0.6	1.6	0.7	2.4	1.7	0.4	0.4	0.4	22.2	19.2
Kenya	<i>C. dives</i>	1.4	0.7	1.4	0.8	2.6	1.6	0.2	0.3	0.3	26.3	20
Kenya	<i>C. dives</i>	1.7	0.8	1.5	0.7	1.6	2	0.2	0.6	0.5	22.6	30
Tanzania	<i>C. dives</i>	1.5	0.7	1.3	0.6	2	1.9	0.3	0.6	0.5	36.5	36.1
Tanzania	<i>C. dives</i>	1.3	0.6	1.2	0.6	2.4	2	0.1	0.8	0.4	64.7	28
Tanzania	<i>C. dives</i>	1.2	0.8	1.6	0.7	2.3	1.7	0.2	0.8	0.3	65	24.1

Uganda	<i>C. dives</i>	1.6	0.7	1	0.8	1.5	2	0.1	0.5	0.4	47	17.2
Kenya	<i>C. exaltatus</i>	1	0.6	1.2	0.7	1.4	1.6	1.3	0.9	0.5	34.8	15.7
Kenya	<i>C. exaltatus</i>	1.2	0.8	1	0.7	1.2	1.5	1.1	1	0.5	30	10.5
Kenya	<i>C. exaltatus</i>	1.3	0.7	1.2	0.8	1.3	1.7	1.2	0.9	0.4	66.4	16.8
Kenya	<i>C. exaltatus</i>	1.4	1	1.3	0.7	2	1.6	1	1	0.5	33	27
Tanzania	<i>C. exaltatus</i>	1	0.8	1.2	0.8	2.5	1.5	1.3	1	0.5	59	9.5
Tanzania	<i>C. exaltatus</i>	1.5	0.7	1.3	0.8	2.6	1.9	1.5	0.9	0.4	49.8	19.5
Tanzania	<i>C. exaltatus</i>	1.4	0.8	1	0.7	2.4	1.7	1.2	0.8	0.5	31.4	30
Tanzania	<i>C. exaltatus</i>	1.3	0.7	1.4	0.8	2.3	1.8	1.5	1	0.5	43.6	26.6
Tanzania	<i>C. exaltatus</i>	1	0.8	1.2	0.7	2.5	1.7	1.5	0.8	0.5	45	22
Uganda	<i>C. exaltatus</i>	1.2	0.6	1.1	0.7	2.1	1.6	1.1	0.7	0.4	31.9	27.5
Tanzania	<i>C. exaltatus</i>	1.2	1	1.3	0.7	1.8	1.9	1.4	0.7	0.5	49.7	13
Tanzania	<i>C. imbricatus</i>	1.3	0.5	0.5	0.4	1.1	1.5	0.8	1	0.5	41.2	11.6
Tanzania	<i>C. imbricatus</i>	1.2	0.7	0.7	0.4	1.2	1.4	0.9	0.7	0.5	16.5	4.6
Tanzania	<i>C. imbricatus</i>	1.1	0.6	0.4	0.3	1.3	1.3	1	0.6	0.3	15.3	11.7
Tanzania	<i>C. imbricatus</i>	1.4	0.5	0.3	0.3	1.1	1.2	0.8	0.7	0.4	30.7	6.4
Tanzania	<i>C. imbricatus</i>	0.8	0.7	0.6	0.2	1.3	1.3	1	0.6	0.2	36	7.3
Tanzania	<i>C. imbricatus</i>	0.9	0.6	0.5	0.4	1.2	1.5	0.9	1	0.4	15.4	7.9
Uganda	<i>C. imbricatus</i>	1.5	0.7	0.4	0.2	1.3	1	1	0.8	0.4	22.5	4.9
Tanzania	<i>C. imbricatus</i>	1.2	0.5	0.5	0.4	1.2	1.2	1	0.9	0.3	20.3	2.9
Tanzania	<i>C. imbricatus</i>	1	0.6	0.7	0.2	1.4	1.4	0.8	0.6	0.5	34.2	10

Appendix VII: Similarity Report


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