SYSTEMATICS OF THE GENUS *EULOPHIA* R. Br. (ORCHIDACEAE) IN GHANA

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(S.ID NO. 10563658)

A THESIS PRESENTED TO THE DEPARTMENT OF PLANT AND ENVIRONMENTAL BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY OF THE UNIVERSITY OF GHANA

DEPARTMENT OF PLANT AND ENVIRONMENTAL BIOLOGY

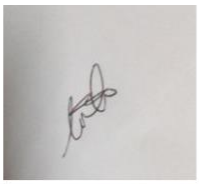
UNIVERSITY OF GHANA

LEGON

JANUARY, 2023

DECLARATION

This is to certify that the work presented in this thesis: "SYSTEMATICS OF THE GENUS *EULOPHIA* R. Br. ex Lindl. (ORCHIDACEAE) IN GHANA" was carried out under the supervision of Professor Alex Asase and Dr. Matthew Kweku Essilfie, Department of Plant and Environmental Biology, University of Ghana, Legon. I hereby declare that no part of this thesis has been presented for another degree of this University or elsewhere.



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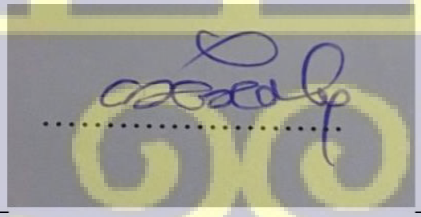

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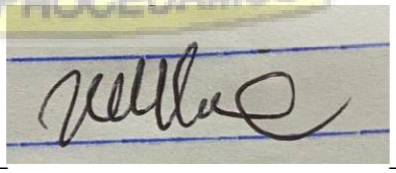

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DEDICATION

I dedicate this work to God almighty for His grace, guidance and protection, and to my mother, Ms. Rebecca Asmah, my sister, Ms. Mariam A. Williams and my guardian, Mr. Ebenezer Sackey who have supported me immensely in my entire education.

ACKNOWLEDGEMENTS

For the favour, health and patience during this project, I am most grateful to God. I wish to express my sincere appreciation to my supervisors, Professor Alex Asase and Dr. Matthew Kweku Essilfie for making it possible for me to complete this work. Their guidance was very instructive.

My earnest appreciation goes to Mr. Francis Asamoah and Mr. Patrick Eyiah for their companionship during my field work. My sincere thanks to Ms. Diana Banyeh, Ms. Anna Teye, Ms. Gladys Aboagye Asamoah, Ms. Christiana Peprah Oppong and Ms. Jacqueline Amoakoah Coffie for their encouragement and contributions during my analysis of data.

I am very grateful to Professor Gabriel Komla Ameka for all his encouragement throughout the dissertation writing and for constructive criticisms of this work.

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LIST OF ABBREVIATIONS

GBIF……... Global Biodiversity Facility Information

POWO……. Plants of the World Online

AOO……. area of occupation

EOO……extent of occurrence

IUCN……. International Union for Conservation of Nature

SD……. standard deviation

GC…… Ghana Herbarium

KUU…… herbarium in the Kwame Nkrumah University of Science and Technology

CCG……..... herbarium in the University of Cape Coast

PROTA……Plant Resources of Tropical Africa

ABSTRACT

The family Orchidaceae includes 850 genera and 24, 000 species, and it is arranged into 70 subtribes, 22 tribes, and five subfamilies on the basis of anther number and position. Many orchids are utilized in the traditional system of medication as medicines for several illnesses. There is no complete taxonomic revision of the genus *Eulophia* in Africa. A previous study based on morphological, ecological, and biogeographic characters of *Eulophia cristata* in Ghana has been reported by Lock and Profita (1975). However, the extent of morphological variations in species of the genus in Ghana has not been analyzed. The overall goal of this study is to undertake a systematic study of the genus *Eulophia* in Ghana for their sustainable utilization and conservation.

50 herbarium specimens of the genus *Eulophia* (35 specimens at GC, 10 specimens at CCG, and 5 specimens at KUU) were examined for morphological characters. Information from herbarium labels of the specimens examined were retrieved to understand aspects of the ecology such as phenology, habitat types and pollinator-flower relationship for the species of the genus *Eulophia*. Taxonomic studies focused on development of an authoritative checklist and construction of dichotomous keys for identification of species of the genus.

Morphological studies on the species of *Eulophia* from Ghana suggested eight species but records from the herbaria in Ghana provided nine species. The members of the *Eulophia* range from small to large herbs, lacking woody stems; plant height ranges from 560–2000mm, 2–16mm in width; has leaves that are often alternately arranged. Leaves are plicate, erect, often linear to lanceolate. Flowers are mostly in the shades of yellow and red, except shades of green in *E. euglossa* and *E. flavopurpurea*. Generally, the species of *Eulophia* have a cosmopolitan distribution across the country from the herbarium records.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The family Orchidaceae includes 850 genera and 24, 000 species, and it is organized into 70 subtribes, 22 tribes, and five subfamilies based on anther number and position (Kowsalya *et al.*, 2017). The Apostasioideae and Cypripedioideae are considered as group sister to the rest of the monadrous clade of Orchidoideae (including Spiranthoideae) and Epidendroideae (Cameron *et al.*, 1999; Kowsalya *et al.*, 2017). Unlike the Epidendroideae and Orchidoideae, the Vanilloideae lack pollinia (Shririam *et al.*, 2014). Epidendroideae is the largest of the five subfamilies (Shririam *et al.*, 2014). Plastid gene *rbcL* shows that Orchidaceae consists of five major monophyletic clades, and these clades, with a few exceptions, correspond to presently recognized subfamilies (Cameron *et al.*, 1999; Kowsalya *et al.*, 2017).

For many orchids, photosynthesis is the primary source of carbon. However, myco-heterotrophic species, which make up a small percentage of the Orchidaceae, include saprophytic species (Zhang *et al.*, 2015c). The CAM group, which is most common at low elevations and within the epiphytic clade, makes for around 10% of all orchid species in Panama and Costa Rica; C_3 photosynthesis being the ancestral condition (Sailo *et al.*, 2014; Zhang *et al.*, 2018).

Most orchids, especially species with thin leaves, assimilate CO_2 through the C_3 pathway. Those plants have fewer layers of smaller mesophyll cells and a larger number of stomata than the thick-leaved species. They also have high CO_2 compensation points and active glycolic acid activity, all of which are characteristics of plants with high rates of photorespiration (Sailo *et al.*, 2014; Zhang *et al.*, 2018).

The thick-leaved orchids usually have features typical of CAM plants, such as leaf and cell succulence, diurnal fluctuations in titratable acidity and nocturnal CO_2 fixation, and inverted stomatal physiology. Those genera include *Vanilla* Plum. ex Mill., *Cattleya* Lindl., *Thunia* Rchb.f., *Coelogyne* Lindl., *Laelia* Adans., *Dendrobium* Sw., *Calanthe* R.Br., *Bulbophyllum* Thouars, *Aerides* Lour., *Phalaenopsis* Blume, *Aranda* Anon., and *Aranthera* Anon. (Sailo *et al*., 2014; Zhang *et al*., 2018).

Members of the Orchidaceae have a cosmopolitan distribution. Major genera of the family include *Ophrys* L., *Oncidium* Sw., *Peristylus* Blume, *Stanhopea* J.Frost ex Hook., *Disa* P.J.Bergius, and *Vanilla* Plum. ex Mill. (Maridass *et al*., 2008). Many orchids are utilized in the traditional system of medication as medicines for several illnesses. For example, the tubers and pseudobulbs of *Orchis latifolia* L., *Orchis mascula* (L.) L., *Cymbidium aloifolium* (L.) Sw., and *Zeuxine strateumatica* (L.) Schltr. are used as a restorative and in the treatment of many diseases. The seeds of *Cymbidium aloifolium* are used for the healing of injuries (Maridass *et al*., 2008). Vanilla flavoring is extracted from the fruits of *Vanilla planifolia* Andrews. The leaves of one species of *Anoectochilus* Blume are sold as a vegetable, and the leaves of *Dendrobium salaccense* (Blume) Lindl. are cooked as a seasoning with rice. In certain parts of the Asian tropics, the tubers of some species of *Gastrodia* R.Br. are eaten like potatoes. The family is of great economic importance because of its numerous ornamentals *Cattleya* Lindl., *Dendrobium* Sw., *Epidendrum* L., *Paphiopedilum* Pfitzer, *Phalaenopsis* Blume, *Vanda* R.Br., *Brassia* R.Br., *Cymbidium* Sw., but to mention a few (Panwar *et al*., 2012).

1.2 Problem statement

The genus *Eulophia* R.Br. ex Lindl. (Orchidaceae, Cymbidieae) is the most diverse in the subtribe Eulophiinae. The genus consists of about 164 terrestrial species and shows a

pantropical distribution mainly in Africa (Central and Southern), Madagascar, and Asia, with seven species in Australasia and five in America (Ortúñez *et al*., 2020). There is no complete taxonomic revision of the genus *Eulophia* in Africa (Martos *et al.*, 2014). However, a taxonomic study on *Eulophia* in Nigeria, Cameroon, Equatorial Guinea, Gabon, and the Republic of the Congo has been conducted (Ortúñez *et al*., 2020). The genus has also been examined in Madagascar and South Africa (Peter & Johnson, 2009). But due to the wide distribution of the *Eulophia*, there is a high degree of interspecific morphological variation in both vegetative and reproductive characters of the genus (Ortúñez *et al.*, 2020). Furthermore, the lack of complete preserved material of many taxa of the genusin herbaria has led to misidentifications and an infrageneric classification that is not firmly settled at present (Panwar *et al*., 2012).

Owing to these gaps of knowledge and the high degree of interspecific morphological variation in the genus, a revision is needed.

1.3 Justification

Preliminary studies at the Ghana Herbarium in the Department of Plant and Environmental Biology at the University of Ghana show that there are ten species of *Eulophia* occurring in Ghana. Studies on members of the genus are scarce in Ghana. A previous study based on morphological, ecological, and biogeographic characters of *Eulophia cristata* in Ghana has been reported (Lock & Profita, 1975). However, the extent of morphological variations in species of the genus in Ghana has not been analyzed given that infra-generic classification of the genus *Eulophia* is complicated by morphological diversity (Cieslicka, 2006).

Furthermore, distributional ranges of the species in Ghana have not been investigated but according to Mota-Vargas & Octavio (2012), understanding biodiversity and making conservation decisions are fundamentally impacted by the delineation of species distribution

ranges. Also, understanding species' ability to colonize new habitats is a key knowledge that aid to predict species' survival in the changing landscapes (Vazačová & Münzbergová, 2014).

1.4 Objectives of the study

The overall goal of this study is to undertake a systematic study of the genus *Eulophia* in Ghana for their sustainable utilization and conservation. Specifically, the objectives of the study were to:

(1) determine the range of morphological variations within the genus in order to clarify the delimitation of the taxa in Ghana,

(2) evaluate aspects of the ecology and distribution of the genus in Ghana

(3) provide an updated identification key and checklist of species of the genus in Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Systematics and Taxonomy

Systematics is the study of the current diversity of biological life on earth as well as its evolutionary past. The framework, or categorization, that other biologists use to discuss species is also provided by systematics. This study is crucial to our comprehension of and communication about the natural world. The fundamental tasks of systematics include naming and classification, which are the oldest human approaches to handling data about the natural world. Systematics rely on a wide variety of species for organic materials like food, shelter, fiber, clothing, paper, medicines, tools, and dyes. The search for prospective commercially important plants is guided by systematics knowledge. The most fundamental and all-encompassing branch of biology is systematics since it serves as a reference framework for all of biology (Simpson, 2010; Pandey & Kasana, 2021).

Systematics is fundamental because it takes some level of classification to identify and name organisms before they can be addressed in a scientific context. Because it compiles and integrates all information on the features of species, including geographic, morphological, physiological, genetic, ecological, and molecular information, systematics covers the most ground (Pandey & Kasana, 2021).

Taxonomy is concerned with the concepts and methods of classification. Based on certain similarities and differences, taxa are identified, described, classified, and given new names in this biological discipline. De Candolle (1813) first used the Greek terms taxis (meaning arrangement) and nomos (meaning law, rule) to create the phrase "taxonomy." The word "taxonomy" literally means "order by rules" or "lawful arrangement of things." Description,

Identification, Nomenclature, and Classification are the four main parts of taxonomy (Pandey & Kasana, 2021).

Singh (2010) considers taxonomy and systematics to be synonymous while Pandey & Kasana (2021) considers systematics significantly more inclusive than taxonomy, which is frequently mistaken for it. In this study, the viewpoint of Singh (2010) will be consistently used.

2.2 Orchidaceae Juss.

One of the two largest families of flowering plants, Orchidaceae is possibly second only to Asteraceae in size (Chase *et al.*, 2015). In these families, new species are being discovered at a pace of about 500 each year. There are currently 736 genera of orchids known to science, and roughly 13 new genera are described each year (Chase *et al.*, 2015).

Most long-lived, evergreen or deciduous herbs are orchids. Some plants, like those of the *Cypripedium calceolus*, can live for 30 to 100 years. Most pre-flowering vegetative periods of the species typically last four to seven years, but they may endure considerably longer (Wang *et al.*, 2010; Cribb & Angell, 2014). They may have a naturally slow growth rate and a low photosynthetic capability, which could explain their extended lifespan.

One of two growth patterns, monopodial or sympodial, is typically followed by orchids. For monopodial orchids, a single bud develops into a stem that lengthens and produces leaves from the apex every year. The adjacent shoots of sympodial orchids grow in a sequence until they bloom and are then replaced (Sailo *et al.*, 2014).

The life form of the orchid can be terrestrial, saprophytic, epiphytic, or lithophytic. The epiphytic orchids, which grow on rocks or in tree canopies, differ greatly from terrestrial orchids, which grow in soil, in terms of their roots, stems, and leaves. Epiphytic orchids have modified aerial roots that can occasionally reach a length of more than 1 m. They also possess

a velamen made of dead cells. With the exception of the tip, this velamen covers the entire root and serves to quickly absorb moisture and nutrients from the humid environment around it (Zhang *et al.*, 2018).

Although certain species in the subfamily Vanilloideae display a reticulate venation, orchids typically have simple leaves with parallel veins. However, epiphytic orchids differ from terrestrial species in that they have smaller stomata and leaves with dense cell walls, cuticles, and a tiny substomatal chamber; thick, succulent leaves (Sailo *et al.*, 2014).

Despite the fact that orchid blooms are bilaterally symmetrical, the inferior ovary, or pedicel, typically rotates 180 degrees so that the labellum is placed on the lower section of the flower, creating a platform for pollinators. While flower color is greatly divergent across species of *Paphiopedilum*, the shape of the lip staminode and petal, as well as the width of the petal, are phylogenetically conserved (Zhang *et al.*, 2016).

For many orchids, photosynthesis is the primary source of carbon. However, myco-heterotrophic species, which make up a small percentage of the Orchidaceae, include saprophytic species (Zhang *et al.*, 2015c). The CAM group, which is most common at low elevations and within the epiphytic clade, makes for around 10% of all orchid species in Panama and Costa Rica; C_3 photosynthesis being the ancestral condition (Sailo *et al.*, 2014; Zhang *et al.*, 2018).

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glycolic acid activity, all of which are characteristics of plants with high rates of photorespiration (Sailo *et al*., 2014; Zhang *et al*., 2018).

The thick-leaved orchids usually have features typical of CAM plants, such as leaf and cell succulence, diurnal fluctuations in titratable acidity and nocturnal CO_2 fixation, and inverted stomatal physiology. Those genera include *Vanilla, Cattleya, Thunia, Coelogyne, Laelia, Dendrobium, Calanthe, Bulbophyllum, Aerides, Phalaenopsis, Aranda,* and *Aranthera* (Sailo *et al*., 2014; Zhang *et al*., 2018).

Orchids are well known for their economic importance and widely cultivated for ornamental purposes. Orchids are cosmopolitan in distribution. Due to its importance as a source of vanillin, a flavoring used in food products, *Vanilla planifolia* is an economically significant orchid. Orchids are frequently used in traditional Chinese medicine. Several of them have been the subject of pharmacological and phytochemical investigations (Kasulo *et al*., 2009).

Some work has been carried out in India on chemical analysis of some medicinally useful orchids. *Eulophia campestris, Orchis latifolia, Vanda roxburgii* are some important plants to mention. *Dendrobium macraei* is another important orchid from Ayurvedic point of view as it is reported to be source of Jivanti. *Cypripedium parviflora* is widely used as aphrodisiac and nervine tonic in Western Herbalism (Singh & Duggal, 2009).

Many medicinal orchids are reported to contain alkaloids. Antimicrobial activities of some orchids have been suggested although detailed investigations are still warranted. Recent works have reported isolation of anthocyanins, stilebnoids and triterpenoids from orchids.

Orchinol, hircinol, cypripedin, jibantine, nidemin and loroglossin are some important phytochemicals reported from orchids (Singh & Duggal, 2009).

The Indian *Vanda* orchid does indeed express antiproliferative effects against various types of cancers, including those from choriocarcinoma (cancer of germ cells), lung cancers, and stomach cancers (Ho & Chen, 2003). Still other orchids have been used in the treatment of epilepsy, flatulence, rheumatism and spasms. They have also been used for sedatives and flavor enhancers and for everything from cramps to increased virility (Dash *et al.*, 2008).

The present investigation has also brought to light the therapeutic value of orchids in curing scorpion and snake bites, as well as in the treatment of stomach disorders, chest pains, arthritis, tuberculosis, pregnancy, syphilis, paralysis, cholera, acidity, eczema, tumor, menstrual disorder, spermatorrhea, leucoderma, wounds and sores, diahorrhea, muscular pain, blood dysentery, bone fractures, rheumatism, asthma, malaria, earache and sexually transmitted diseases (Dash *et al.*, 2008).

Orchid cultivation which started as a hobby in the early part of 20th century transformed into a commercial enterprise in late sixties. They rank among the top ten sought after plant for cut flower production (Vij, 2002). The flowers of some modern hybrids have a shelf life of 8-12 weeks, surpassing all other flowers in this respect. The international trade in floriculture product is rapidly developing especially orchids which command a high price in world market. South East Asian countries are the major player in orchid trade. Thailand as the largest producer with an export destination to USA and Europe earning as high as 4 million US dollar by 1995 (Imchen & Imchen, 2011).

There was a 1.3-billion-unit plant stock demand for orchids grown for the manufacture of cut flowers and potted plants in 1995. More than $500 million was spent on orchids (potted plants) worldwide in 2000. China, Germany, Japan, The Netherlands, Taiwan, Thailand, and the United States are among the nations that produce potted orchids on an extensive scale. Recently, India, Costa Rica, and the Dominican Republic started growing orchids for export (Laws, 2004).

Many orchids primarily obtain carbon through photosynthesis. But saprophytic species, which make just a small percentage of the orchid family (Orchidaceae), are myco-heterotrophic (Zhang et al., 2015c). Most frequently found at low elevations and within the epiphytic clade, the CAM group accounts for around 10% of all orchid species in Panama and Costa Rica. C_3 photosynthesis is the ancestral state (Sailo *et al.*, 2014; Zhang *et al*., 2018).

The most expensive crop sold in pots in The Netherlands is now *Phalaenopsis*; the number of potted orchids sold at Dutch flower auctions increased from 50,000 to 18 million pots between 1983 and 2003. (Laws, 2004; Wang, 2004). Orchids were regarded as a small crop by the U.S. Department of Agriculture (USDA), and data on output was not gathered until 1997. The value of U.S. potted orchid production climbed by 170% between 1996 and 2004, with an estimated $128 million in wholesale sales in that year (USDA, 2005).

The second most valuable flowering potted crop in the United States right now is orchids, of which 70 to 90 percent are *Phalaenopsis*. Over 85% of all orchids sold in the United States in 2004 were grown by farmers in California, Florida, and Hawaii, with wholesale prices reported at $50, $47, and $17 million, respectively (USDA, 2005).

The majority of orchids are cultivated for their aesthetically pleasing blossoms. The majority of orchid genera' flowering physiology in controlled conditions has only received a little amount of published research, though. Therefore, it is impossible to time the flowering process to coincide with specified sales dates, with the exception of a few species (such as *Phalaenopsis* and some *Cattleya*) (Bullough *et al*., 2021).

2.2.1 Taxonomy of the Orchidaceae

Dressler (1993) recognized five subfamilies, but he split Spiranthoideae from Orchidoideae and included *Vanilla* and relatives in Epidendroideae. Vanilloideae into two tribes, Pogonieae and Vanilleae. No changes were made to the four tribes of the Orchidoideae: Cranichideae, Diurideae, Orchideae, and Codonorchideae. In Epidendroideae, there has been a great deal of change in the generic limits in many tribes/subtribes since Chase *et al.* (2003). Little has changed in the groups with mostly mealy (primitive) pollinia, the formerly recognized Neottioideae. In Triphoreae, we recognize two subtribes in parallel with the treatment in Pridgeon *et al.* (2005), with the addition of heteromycotrophic *Pogoniopsis*. Likewise, in Nervilieae, *Nervilia* was recognized to be in a separate subtribe from the rest. Major taxa within the family are as follows.

The *Cattleya* genus includes 48 species that are native to tropical areas of Central and South America. From sea level to 1500 m in height, epiphytic plants can be found growing on top of trees in moist and wet woods. The growth of many genera of tropical orchids is accelerated by high temperatures. Different times of the year are when different *Cattleya* species and hybrids bloom. Some *Cattleya* species begin to form flower buds in the spring as a result of the low temperatures and short photoperiod, but the buds do not grow and attain anthesis until the fall or winter (Lopez & Runkle, 2005).

There are roughly 44 species in the genus *Cymbidium*, which is endemic to Australia, the tropical parts of southeast Asia, and the Himalayas. For rapid growth and pseudobulb maturity, the terrestrial, epiphytic, lithophytic, and semi-epiphytic species need long days and day/night temperatures of 30/25 °C. Several orchid taxa, including *Cymbidium*, are frequently transferred from lowland production sites to higher altitudes in Japan during the warm summer. This method exposes plants to milder temperatures and lighter for blossom initiation, preventing high-temperature stress during vegetative growth (Lopez & Runkle, 2005).

Cymbidium have a wide geographic distribution; hence they are frequently categorized into the three horticultural groups of chilly, moderate, and warm depending on how well they tolerate different temperatures. A noticeable chilly period during which the nighttime temperature is maintained at between 10 °C and 14 °C encourages the majority of the large-flowered *Cymbidium* species from the Himalayas and China to flower. Summer is the typical flowering season for *Cymbidium* orchids that are native to warm climates like Taiwan and Southern China. In *Cymbidium ensifolium* var. *misericors*, pseudobulb development and flower production were sped up at warm day/night temps of 30/25 °C and 25/20 °C, but were slowed down at 20/15 °C. Plants with 1- to 2-year-old mature pseudobulbs produced 2.3, 1.6, and 1.1 inflorescences at 30/25 °C, 25/20 °C, and 20/15 °C, respectively (Lopez & Runkle, 2005).

There is no evidence from research that photoperiod affects floral induction. *Cymbidium niveomarginatum* Lindl. was able to blossom in vitro thanks to a combination of root excision, cytokinin (6-benzylaminopurine), restricted nitrogen, and enhanced phosphorus (Lopez & Runkle, 2005).

The second-largest genus in the family of orchids, *Dendrobium* (also known as the spray orchid), has more than 1,200 epiphytic species that are indigenous to tropical and subtropical Asia, Australia, and a number of Pacific Islands. Rapid vegetative development occurs for the majority of *Dendrobium* orchids between 24 °C and 30 °C (Lopez & Runkle, 2005).

Miltoniopsis is a genus of six species that is either epiphytic or lithophytic and is found from Peru to Costa Rica's moist cloud forests (610 to 2100 m). *Miltoniopsis* thrives in environments with light intensity between 150 and 300 mol m^{-2} s^{-1}. When *Miltoniopsis* is young, flowering doesn't start until the pseudobulbs are ready to detect inductively low temperatures (Lopez & Runkle, 2005).

More than 50 species under the genus *Phalaenopsis* are native to tropical and subtropical regions of Asia and the South Pacific Islands. From southern India to Australia, their range includes China, Taiwan, and the Philippines. *Phalaenopsis* orchids may withstand temperatures as high as 32 °C to 35 °C for brief durations before showing indications of heat stress, but they remain vegetative above 27 °C to 29 °C (Lopez & Runkle, 2005). For all developmental phases, the predicted base temperature for *Phalaenopsis* is between 10.8 and 11.2 °C. Phalaenopsis displayed indications of chilling injury, such as sunken, yellow, water-soaked patches on upper leaf surfaces, after being subjected to 2, 4, or 7 °C for 1, 2, 4, or 8 hours. *Phalaenopsis* must be exposed to temperatures around 26 °C for a certain amount of time in order to start spiking, or the beginning of the inflorescence. The third and frequently the fourth node beneath the apical leaf is where the inflorescence typically appears. If the environment is favorable, the spike begins to form flower buds when it is about 5 cm long (Lopez & Runkle, 2005).

About 20 species of the sympodial, terrestrial, and epiphytic South American genus *Zygopetalum*, also known as the ladybird orchid, can be found there. They are native to neotropical mid-elevation mountains (1300 to 1700 m) in Brazil, Guiana, Venezuela, and Peru, However, a temperature of 23 °C is recommended to balance growth pace with optimal development features because vegetative growth is most rapid at 26 °C (e.g., long leaves). When light intensity is more than 500 $\mu.mol.m^{-2}s^{-1}$, black necrotic lesions can develop (Lopez & Runkle, 2005).

The Old-World tropics of Africa, Asia, and Australasia are home to the subtribe Eulophiinae (Cymbidieae, Epidendroideae, Orchidaceae), which has about 270 species grouped into nine genera and few taxa in the Neotropics (Bone *et al*., 2015). This extraordinarily diverse population lacks recognizable diagnostic traits (Pridgeon *et al*., 2009). Phylogenetic investigations of molecular data, however, are starting to clarify relationships in Eulophiinae and between this and related subtribes of Cymbidieae (Bone *et al.*, 2015).

Of the nine currently accepted Eulophiinae genera, four (*Cymbidiella, Eulophiella, Grammangis* and *Paralophia*) are endemic to Madagascar. Each comprises fewer than seven species that are mostly large, lush epiphytes, including *Eulophiella roempleriana* (Rchb.f) Schltr., described by Hermans (*Pridgeon et al*., 2009) as 'one of the giants of the orchid world' with plants exceeding 2 m in height.

Cymbidiella and *Eulophiella* each comprise a single terrestrial species. Hermans & Cribb (2005) recognized *Eulophia epiphytica* P. J. Cribb, Du Puy & Bosser and *E. palmicola* H. Perrier; as a new genus, *Paralophia*. The remainder of the subtribe comprises five terrestrial genera (*Acrolophia* Pfitzer, *Eulophia* R. Br. ex. Lindl., *Geodorum* Jacks., *Oeceoclades* Lindl. and *Orthochilus* Hochst. Ex A. Rich) that occupy a range of habitats, from the semi-arid conditions of sub-Saharan Africa and the Arabian Peninsula, deciduous woodland and

seasonally inundated grasslands of south-central Africa, to a range of habitats on Madagascar, including humid pockets on karst limestone ('tsingy'), and dry, littoral and mesic forests (Cribb & Hermans, 2009).

Of these genera, *Eulophia* is the most diverse, representing c. 60% of species richness in the subtribe. Martos *et al.* (2014) focused on South African *Eulophia* and including comprehensive sampling of the South African endemic genus *Acrolophia*, their study found evidence for a clade of morphologically well characterized taxa of *Eulophia* that corresponded to the 'nigricans alliance.' *Eulophia* nevertheless remains the largest genus of the subtribe (164 species) and is a conspicuous element of the terrestrial African orchid flora. No complete taxonomic account for the genus exists and an infrageneric classification is required to provide a practical framework for the identification and further classification of species (Bone *et al.*, 2015).

The next largest genus after *Eulophia* is *Oeceoclades* (39 species), which has a distribution that is primarily Madagascan but also includes continental eastern Africa, the western Indian Ocean islands, and beyond away. Many have broad, plicate leaves that are more resemblant of *Eulophia*, which are xerophytes with thick, coriaceous leaves (Bone *et al.*, 2015).

This latter, widely distributed species has been referred to by various authors as *Eulophia pulchra* (Thouars) Lindl. and *Oeceoclades pulchra*, but Martos *et al.* (2014) resolved it as sister to a monophyletic *Oeceoclades* and suggested that it should be treated as a member of this genus until broader taxon sampling could be finished for more in-depth analysis.

2.2.2 Distribution and Ecology of Orchidaceae

Numerous ecological variables including the emergence of holobionts, which are crucial for colonization and the development of ecological communities, have an impact on the distribution and population dynamics of orchids. Mycorrhizal fungi are essential for orchid species' seed germination, seedling establishment, reproduction, and survival, and cheating by mycorrhizal fungus in photosynthetic orchids is becoming more common. As a result, changes in the diversity and composition of orchid mycorrhizal fungus can have a significant impact on the distribution and fitness of orchids (McComick *et al*., 2018; Li *et al*., 2021).

Amazing morphological features in orchids, including the labella and modified petals, show how adaptable they are to their surroundings (Zhang et al., 2018). Orchid reproduction is aided by interactions with particular pollinators, but soil exploitation needs the presence of symbiotic fungus. The diversity of orchid species typically rises as a result of increased environmental heterogeneity and a larger range of resource availability. As a result, understanding how environmental factors affect the distribution and abundance of orchids is necessary for the effective conservation of these species (McComick *et al*., 2018).

Djordjevi & Tsiftsis (2020) have conducted a systematic analysis of the relationships between environmental conditions and the distribution, abundance, and richness of orchid species. For instance, the rainfall and light regime of the habitat have a direct impact on the flowering cycles of orchids and population dynamics, and the physical and chemical characteristics of the soil (such as pH, soil moisture, nutrients, etc.) have a big impact on how well orchid populations do. Curiously, there is mounting evidence that suggests coexisting orchid species typically display strongly spatially segregated distribution patterns due to strong clustering within individual species and little overlap between species, and that they are frequently associated with various orchid mycorrhizal fungi communities, which is largely explained by variations in soil moisture and pH.

2.3 Orchidaceae in West Africa including Ghana

There are 401 orchid species in West Africa, which includes Cameroon, Nigeria, and the nations to the west. However, many of these have special scientific and horticultural value. The key determinants of their distribution are moisture availability, which depends on rainfall, air humidity, the length of the dry season, and the presence of undisturbed areas. These parameters are mainly influenced by man and his agricultural and logging operations (Sanford, 1969; Bothalia, 2013).

West Africa is extremely variable in moisture availability. Furthermore, dense population, shifting agriculture, and timber exploitation, have made the area very variable in vegetation cover. For these reasons, the orchids of the region often show discontinuous distributions. Of the 401 species of orchids recorded in West Africa, 19 species, or 4.7 per cent of the total, are found only in Nigeria, and these should receive particular attention for conservation. Thirteen of these are epiphytes of extremely limited distribution, while the remaining 6 are terrestrial species. In general, the epiphytes are more demanding as to habitat, more easily destroyed by man's activities, and consequently in greater danger than the terrestrial species (Sanford, 1969; Bothalia, 2013).

Habenaria keayi and *H. nigerica* are quite widespread and common. Another group of orchids has a slightly less restricted distribution, found in Nigeria and one other country as well. In all but five instances, the other country is in West Africa. The exceptions are particularly interesting: *Nervilia reniformis* is found in Tanzania, *Angraecum egertonii* and *Rangaeris trilobata* are in Gabon, *Microcoelia microglossa* is in Uganda, and *Eulophia adenoglossa* is in Kenya. There are 27 species, or 6.7 per cent of the West African total, belonging to this category. These include 19 epiphytic and 8 terrestrial species. Only one, the terrestrial *Nervilia reniformis*, is actually common enough to give no cause for conservation worry, although

Habenaria lelyi and *Eulophia sordida*, also terrestrial, are quite widespread within Nigeria (Sanford, 1969; Bothalia, 2013).

Eight of the species, which are unique to Nigeria, are found in the northern highlands of Zaria Province (Jos and Bauchi), four are found in the eastern highlands (Obudu and Oban), two are found in the Idanre Hills, two are found in Sapoba, three are found in the Cross River region (Calabar and Itu), and two are found in Lagos and Eket, the last of which is in the Calabar region. The Obudu-Mambila Plateau and the Oban Hills are part of the eastern highlands, which continue the Cameroon highlands (Sanford, 1969; Bothalia, 2013).

The 31 species that are exclusive to a single adjacent nation are present in Cameroon-Fernando Poo. The highlands that extend from Zaria Province in the east through the Jos and Bauchi Plateau and into Cameroon, running south through Bamenda to Mt. Isabel (Clarence Peak) in Fernando Poo, with western branches into southeastern Nigeria from Obudu to the Mambila plateau area and, further south, into the Oban Hills, are without a doubt the area of highest priority for orchid conservation. It is environmentally intriguing that such a region would be abundant in orchids and house several extinct species due to the region's overall West African distribution (Sanford, 1969; Bothalia, 2013).

In Ghana, orchids have a cosmopolitan distribution. Several genera like *Disa* P.J. Bergius, *Disperis* Sw., *Eulophia* R. Br., and *Bulbophyllum* Thouars. can be found in 12 of the 16 regions in the country. A few like *Polystachya* Hook. and *Cheirostylis* Blume can be found in only 3 regions.

2.4 Genera of Orchids in Ghana

According to records from the Ghana Herbarium, there are 23 genera of orchids in Ghana. These are *Aerangis* Rchb.f., *Ancistrorhynchus* Finet, *Ancistrochilus* Rolfe, *Angraecum* Bory, *Ansellia* Lindl., *Auxopus* Schltr., *Bolusiella* Schltr., *Brownleea* Harv. ex Lindl., *Bulbophyllum*

Thouars., *Calyptrochilum* Kraenzl., *Corymborkis* Thouars., *Cheirostylis* Blume, *Cyrtorchis* Schltr. *Diaphananthe* Schltr., *Didymoplexis* Griff., *Disa* P.J. Bergius, *Disperis* Sw., *Eggelingia* Summerh., *Epipogium* Borkh., *Eulophia* R. Br., *Manniella* Rchb.f., *Microcoelia* Lindl., and *Polystachya* Hook. Owing to little research carried out on the orchidaceae of Ghana, information of the genera of orchids in Ghana were obtained from the Ghana Herbarium and the Plants of the World Online. Each of the genera have been reviewed below.

2.4.1 *Aerangis* Rchb.f.

There are 3 species in Ghana, these orchids are mostly distributed in the Eastern, Greater Accra, and Ashanti regions. They are mostly epiphytic plants with woody stems that are either short or tall and have several long aerial roots at the base. Epiphytic plants have woody stems that are either short or tall and have several long aerial roots at the base. Distinctive, fleshy or coriaceous, basally sheathing, mostly oblanceolate, occasionally linear or ligulate, and unequally 2-lobed at the apex leaves. Racemose, lateral, few to many-flowered inflorescence. White, occasionally tinged with green, brown, or pink resupinate flowers. Whether free, spreading, or reflexed, sepals and petals. Lip whole, frequently resembling tepals, spurred at base. Pollinia 2, sessile on a single stipe; viscidium variously shaped; stigma an oval or rhomboid sticky depression. Column short and stout or elongated and small, frequently narrow at the base and enlarged at the level of the stigma. Androclinium straight or sloping, the anther cap occasionally beaked (POWO, 2022).

2.4.2 *Ancistrorhynchus* Finet

The genus *Ancistrorhynchus* has 5 species in Ghana mostly distributed in Eastern, Western, and Ashanti regions. They are mostly herbs with monopod epiphytes. Short stems that are sheathed in old leaf bases; roots grouped at stem base. Imbricate, ligulate, or tapering leaves with occasionally dentate lobes that are unequally 2-lobed at the apex. Bracts are papery and

typically as long as the flowers; inflorescences are sessile, axillary, and grow from the lower leaves or the bases of the leaves. Flowers are white, occasionally with a green lip. Free, subsimilar sepals and petals; oblong orbicular, whole or 3-lobed, ecallose lip; straight, sigmoid or geniculate spur; occasionally enlarged at apex and/or mouth. Anthers are hemispherical with a short, truncate appendage in front; the column is short; the rostellum projects downward before suddenly rising in the apical half; the stipites are either two and subspathulate or one and bifid; and the viscidium is one (POWO, 2022).

2.4.3 *Ancistrochilus* Rolfe

Ancistrochilus is a monospecific genus in Ghana which is mostly distributed in the Oti region. Members of this genus are small epiphytic herbs. Pseudobulbs clustered, orbicular to conical, ± dorsiventrally flattened, bearing 1–2 apical leaves. Leaves thin-textured, plicate. Inflorescences arising from base of pseudobulbs, arcuate-spreading, 1–5-flowered, pubescent. Flowers showy, white to rose-pink or purple, marked with brown on column. Sepals spreading, subsimilar, pubescent on outer surface. Petals smaller but similar in shape. Lip 3-lobed, recurved apically, with erect side lobes on each side of column. Column clavate, porrect, pubescent, with a short foot; pollinia 8, of two sizes, lacking a stipe and viscidium; rostellum pointed (POWO, 2022).

2.4.4 *Angraecum* Bory

There are 8 species of this genus in Ghana, these are mostly distributed from the Eastern to Ashanti regions. Members of this genus are herbs that are small to large and are epiphytic, lithophytic, or very rarely terrestrial. Short to elongate, branching or unbranched, upright to pendent stems that are covered by leaf bases. Unevenly bilobed at the apex, thin-textured, fleshy or coriaceous, flattened or infrequently iridiform, frequently twisted at the base, articulated to persistent leaf-bases. Axillary, one to many-flowered, racemose, or infrequently

paniculate inflorescences. Large to tiny, fleshy flowers that are frequently stellate; sessile or pedicellate ovary that is frequently rotated through 180 degrees. Petals and sepals are separate and comparable. Concave, whole to three-lobed, and spurred at the base, the lip encloses the column at the base. Pollinia 2, globose, sulcate, joined to a common viscidium or each attached to a distinct viscidium; column fleshy, very short, missing a foot; clinandrium somewhat shallow, split in front with a tiny tooth-like rostellum in the sinus (POWO, 2022).

2.4.5 *Ansellia* Lindl.

Ansellia is monospecific genus in Ghana with a distribution from the Western to the Eastern regions. Plants range from medium to large-sized epiphytic, lithophytic, or very rarely terrestrial herbs. Pseudo-bulbs are grouped together, fusiform, several-noded, ridged as they age, leafy in the apical half, and are encircled by many tall bristly roots at the base. In the apical region of the pseudobulb are numerous, large, plicate leaves. Axillary, paniculate, paniculately arcuate, and laxly many-flowered inflorescence from apical nodes. Large, beautiful, pale greenish yellow or pale to rich yellow flowers with red or dark maroon spots that are frequently heavy. petals and sepals are similar but stretch out. Three-lobed, upright lip with numerous longitudinal ridges; upright side lobes on both sides of column. Column porrect; pollinia, four in two pairs, ovoid and of two sizes, attached to viscidium that is difficult to discern (POWO, 2022).

2.4.6 *Auxopus* Schltr.

There are 2 species from this genus in Ghana, these are mostly distributed in the Western, Eastern, and Ashanti regions. Members of this genus are herbs without leaves; achlorophyllose saprophytes and have globular to narrowly cylindrical tubers. Erect, unbranched, thin, and barely flexible stems. Small, fugacious, unspurred, yellow or brown flowers are in bloom. Tepals produce a brief tube by partially adnating. Simple, without a lip, and with a thin claw. Anthers declinate, pollinia 4, caudicle, and viscid disc absent; column elongated; little

expanded at apex; arms and foot absent; stigma close to column apex. The pedicel grows significantly longer as the erect capsule develops. Racemose, terminal, and single-flowered inflorescences (POWO, 2022).

2.4.7 *Bolusiella* Schltr.

There are 4 species in Ghana. They are mostly distributed towards the border of Togo. Plants are monopodial epiphytic herbs with few, fine basal roots and short stems. Equidistant, imbricate, fan-shaped, meaty leaves. At the base of the plant, inflorescences that are densely or laxly several- to many-flowered emerge from the axils of old leaf sheaths. White, tiny resupinate flowers. Free, equal tepals. Lip spurred, generally shorter than the lip, and whole or subtly 3-lobed. Pollinia 2; stipites 2; viscidium 1; column oblong, fleshy, constricted above, without a foot; rostellum subulate, hooked; anther quadrate, cucullate (POWO, 2022).

2.4.8 *Brownleea* Harv. ex Lindl.

Brownleea is a monospecific genus in Ghana with a narrow distribution in the Ashanti region. They are terrestrial herbs with sessile undivided tubers. Stems unbranched, leafy. Leaves few to several. Inflorescence terminal, 1- to many-flowered, lax or dense. Flowers resupinate, white, rose, lilac or purple. Dorsal sepal hooded, extending into a dorsal conical or narrowly conical spur, the laterals spreading, free or united in the lower part. Petals erect, adherent to the edges of the dorsal sepal, united at their base to the column. Lip very small, entire, often curved upwards and adpressed to the column, ecalcarate. Column short; anther reclinate, horizontal or reflexed, the loculi parallel, canals short; pollinaria 2, each with sectile pollinium, caudicle and viscidium; auricles on each side of rostellum, ± rugulose; stigmas united into a cushion in front on the anther, rostellum erect, ± 2-lobed. Capsules cylindrical or ellipsoid, ribbed (POWO, 2022).

2.4.9 *Bulbophyllum* Thouars.

This is the largest genus in terms of number of species (26) in Ghana. They are widely distributed in the Western, Eastern, Ashanti, Bono East, Ahafo, Greater Accra, and Volta regions. Members in this genus are epiphytic or lithophytic herbs with sympodial growth. Rhizomes creeping, often woody, sometimes branched. Pseudobulbs each comprising 1 internode (representing the main axis of a sympodial branch), clustered or spaced out along the rhizome, 1–2(3)-leaved at the apex. Leaves mostly coriaceous or fleshy, rarely thin-textured. Rhachis sometimes swollen or flattened; flowers white, cream, yellow, green, orange or purple, ± fleshy. Inflorescences arising from base of the pseudobulb, racemose or rarely umbellate, (1) few- to many-flowered. Sepals usually free and subequal, the lateral sepals united at the base to the column foot to form an obscure mentum. Petals usually smaller than the sepals. Lip often much smaller than the sepals, hinged to end of the column foot, usually motile, often fleshy and tongue-like, sometimes fringed with long or short hairs. Column short, usually with apical lateral extensions (stelidia), and often winged. Pollinia 2 or 4 in 2 pairs (POWO, 2022).

2.4.10 *Calyptrochilum* Kraenzl.

There are 2 species of this genus in Ghana. They are mostly located in the Volta region. Members of this genus are monopodial, epiphytic herbs with long woody stems. Leaves alternate, fleshy, twisted at the base to lie in one plane. Inflorescences short; flowers resupinate, white. Sepals and petals free, similar, spreading, the petals slightly shorter than the sepals. Lip 3-lobed, spurred, the spur inflated at the apex. Column short and stout with a small foot. Rostellum prominent; anther apiculate; pollinia 2, globose, joined to a long linear caudicle; viscidium 1, large, triangular, grooved at base to clasp the rostellum (POWO, 2022).

2.4.11 *Corymborkis* Thouars.

Corymborkis is monospecific genus in Ghana, they are distributed mostly in the Atewa range (Eastern region). These are plants that grow on land with short rhizomes. Several, rigid, tall, and leafy stems. Distinctive but frequently spiral-appearing leaves that are sessile to quickly petiolate, plicate, lanceolate to elliptic. Inflorescences 1-4 few-many-flowered axillary panicles. White to greenish white flowers. Tepals are long, linear, subequal, and connivent at the base. Similar lips, but with a broad oval peak. Pollinia 2, thin, sectile, on a long, slender caudicle attached to a peltate viscidium falling behind the column; stigma large, deeply 2-lobed; rostellum upright, bifid; column long, slender, straight; dilated at apex with 2 lateral auricles. Perianth and column remains are preserved in the capsule (POWO, 2022).

2.4.12 *Cheirostylis* Blume

This is a monospecific genus mostly distributed in the Eastern region. Plants are small terrestrial herbs with upright stems and leaves develop from robust rhizomes. petiolate leaves with a basal coating and thin texture. an upper stem bearing a terminal, erect inflorescence with few sheaths. little flowers that are mostly white. Petals cling to the dorsal sepal, which is joined for about half of its length. A lip that is erect, joined to the base of the column, saccate at the base with 2 calli, and lobed at the apex with a diverging lobe or a whole tooth. It should also be longer than the tepals. Short, upright column with apical appendages parallel to the long rostellum and two lateral stigmas. Viscidium is oblong, caudicle is short, and the dorsal anther is acuminate in pollinia two (POWO, 2022).

2.4.13 *Cyrtorchis* Schltr.

There are 5 species of this genus, they are distributed mostly towards the border of Togo. Members of this genus are herbs; mostly epiphytic or, less frequently, lithophytic, having short to long, erect or pendent stems, distichous leaf bases, and roots that emerge all along the stem

and branch out along it. Distinctive, coriaceous or fleshy, flat or conduplicate leaves that are longer than they are wide, unevenly bilobed at the apex, articulated at the base to a sheathing base, and deciduous, exposing the obvious sharp edges of the leaf bases. Inflorescences are often one to numerous, shorter than the leaves, few to many-flowered, and axillary on the upper part of the stem. The peduncle is small and frequently covered in massive, typically sterile sheathing bracts. White, stellate, sweet-smelling flowers with the occasional green, pink, or brown spur. In general, petals and sepals are recurved, free, linear-lanceolate, and acuminate. Lips are similar, full, or highly obscure It has three lobes, is ecallose, and has a sigmoid- or slightly incurved-shaped long tapering spur at the base. Pollinia 2; stipites 2; viscidium either hyaline or consisting of an indurated saddle-shaped top part and a hyaline lower part; anther-cap elongated at apex. Column short, fleshy; rostellum 3-lobed, pendent, outer lobes considerably longer than the mid-lobe, frequently papillate towards apex. Fruit a capsule with 3–6 wings (POWO, 2022).

2.4.14 *Diaphananthe* Schltr.

There are 6 species of this genus in Ghana, with a distribution from the Eastern region towards the border of Togo. Members of this genus are monopodial herbs that are ephiphytic and rarely lithophytic. Long or short stem that is coated in the old leaf bases. Long, generally numerous, and frequently clearly visible white streaked roots that emerge along the stem. Distichous leaves with an uneven 2-lobed apex, articulated to a sheathing base, and frequently twisted to lie in a single plane. One to more inflorescences, typically with several to many flowers. Translucent, mostly small-sized, white, greenish, pale yellow, straw-orange, or, sporadically, pinkish and purplish flowers are also common. free of sepals and petals. Pollinia 2, stipites 2, viscidia 1 or 2, spurred lip that is whole or obscurely lobed, pollinia 2, and stipites 2. Rostellum was unique (POWO, 2022).

2.4.15 *Didymoplexis* Griff.

In Ghana, there is one species from this genus, they are mostly found in the Eastern region. Plants from this genus are herbs with no leaves that are saprophytic and lack chlorophyll; horizontal, meaty tubers. Unbranched, tall stems; racemose, terminal inflorescences with one to several flowers. Tepals create a short tube at the base of the little flowers' free-floating lip, which is attached to the foot of the column. Stigma close to apex; anther declinate; column long, broader at apex, with thin arms. Pollinia 4 is caudicle-less. As the capsule develops, the pedicel quickly lengthens (POWO, 2022).

2.4.16 *Disa* P.J. Bergius

There 2 species of *Disa* in Ghana, mostly distributed in Ashanti and Eastern regions. Members of this genus are tuberous-rooted herbs that grow on the ground. Unbranched, leafy stems. leaves dispersed on many sterile shoots or along the flowering stalk. terminal inflorescence with one to several flowers. Flowers reseed and come in a variety of colors. The dorsal sepals are free, the laterals are spreading, and the dorsal is upright, hooded, or helmet-shaped. The base petals are irregularly shaped, adnate to the column, and frequently incorporated in the dorsal sepal. Lips are typically thin and without any spurs. Pollinaria 2; each with sectile pollinium, caudicle, and naked viscidium; column short; anther erect, horizontal, or reflexed; loculi parallel; anther short; stigmas united into a cushion below the rostellum; rostellum small; 3-lobed; middle lobe small; folded; side lobes short; fleshy; often adnate to petals. Twisted and nearly terete ovary. cylindrical, club-shaped, or narrowly elliptical in shape (POWO, 2022).

2.4.17 *Disperis* Sw.

There are two species of the genus *Disperis* in Ghana, they are mostly distributed in the Eastern region. Members of this genus are erect largely tiny terrestrial herbs that grow typically in extremely shallow soil or leaf-mold in forests. They develop from little tubers. stems at the

base of which have one or more sheathing scale-leaves (cataphylls). Leaves are sparse, alternate or opposite, and usually never almost obsolete. Flowers are tiny, typically less than 2.5 cm long, white, yellow, green, pink, or magenta, solitary, or in many-flowered racemes; bracts resemble leaves. Lateral sepals have prominent spurs or pouches on the inner margins, while the dorsal (middle) sepal is fused with the petals to form a structure that can range in shape from a nearly flat limb to an extended spur. Differently formed petals that are occasionally auriculate at the base and frequently falcate, obliquely acute, or lobed at the apex. Lip strikingly modified, its claw attached to the column's face and rising above it, varyingly curved into the spur if present, frequently dilated into a smooth or papillate, straight or reflexed limb, and typically bearing a simple or 2-lobed appendage, the shape of which varies greatly between species. Column erect, mostly stout; rostellum large, membranous, 2-lobed, produced in front into 2 rigid cartilaginous arms (fitting into the lateral sepal-pouches when in bud) holding the glands of the pollinia at their apices; anther-bearing part of column horizontal or ascending; anther-loculi distinct, parallel, approximate; pollinia-granule stigma two lobes, with lobes situated on either side of the adnate claw of the lip (POWO, 2022).

2.4.18 *Eggelingia* Summerh.

This is a monospecific genus which is mostly distributed in the Eastern region. Plants in this genus are mostly herbs that are epiphytic or very rarely lithophytic have long monopodial stems, few branches, and are leafy along their length. The roots in the base are aerial and elongate. Distichous, spreading, ligulate, unevenly bilobed at apex, articulated to persistent leaf-sheaths, opposite leaf's leaf-sheath sporting a hair-like ligule. Very brief and sparsely flowered axillary inflorescences. Small, pedicellate flowers. Petals and sepals are separate and comparable. At the base, the lip may be whole or obscurely 3-lobed, ovate, sharp, ecallose, or spurred; the spur may be cylindric or subclavate and be as long as the lip. The rostellum is deflexed, triangular, and deeply bifid; the column is short and fleshy; the anther-cap is

hemispherical and is produced in front; the pollinia are two and oval or subpyriform-ovoid; the stipes are ligulate and dilated at the apex; and the viscidium is rectangular-elliptic (POWO, 2022).

2.4.19 *Epipogium* Borkh.

This is a monospecific genus which is mostly distributed in the Eastern and Ashanti regions. Members of the genus are saprophytic, leafless, achlorophyllose herbs with scapes that emerge from tuberous rhizomes. Simple, upright scape with a few basal sheaths. Lax, terminal inflorescence. Flowers form pedicels. Subequal and free tepals. Concave, spurred, and with beautifully warted crests, the lip is wider than the tepals. Short column; short, broad anther; two sectile pollinia, each with a thin, curved caudicle linked to a single, broad viscidium; prominent, broad stigma; no rostellum. Ovoid and pendulous capsule (POWO, 2022).

2.4.20 *Eulophia* R. Br.

Little research has been conducted on the genus *Eulophia* in Ghana. There are eight species currently according to POWO (2022) but nine species were recorded in the Ghana Herbarium. In 1975, Lock and Profita conducted a survey to investigate the pollination patterns of *E. cristata* in southern Ghana. They confirmed that the inflorescence is approximately 1 m. tall, and produces up to 30 flowers. The flower is zygomorphic, held horizontally at maturity. It is resupinate, reversing quickly after pollination. The reflexed sepals, the upper petals and the spur are pinkish-violet, variable in depth of colour. The centre of the labellum and the ovary are deep violet, and the inverted boundaries of the labellum are greenish (Lock & Profita, 1975).

The genus *Eulophia* R. Br. Lindl is one of the most notable representatives of the Orchidaceae family. More than 230 species make up this group, which is found in southern and tropical

Africa, Madagascar, Australia, subtropical and tropical Asia, and 1 species in tropical America. 500 of the 723 entries for *Eulophia* in the International Plant Names Index (IPNI) are synonyms, according to Cieslicka, (2006).

Members of the genus can be found in a several habitat ranges. Most of them grow on land in the savanna and scrub, but epiphytic species can also occur in grasslands and in the lowland and equatorial forest. A large number of species exhibit sympodial growth, except for *Eulophia epiphytica* from Madagascar, which is monopodial and should maybe be placed in a separate genus (Cieslicka, 2006). The morphological diversity of the genus further complicates its infrageneric classification. Their perennating organs mostly are pseudobulbous or tube-like (Cieslicka, 2006).

The leaves are oblong and plicate, narrow and grass-like, or thin yet robust. Some species are saprophytic and lack green leaves. *Eulophia* is home to two different kinds of flowers. The sepals and petals of the first kind are remarkably alike in size, shape, and color. In the second, the sepals frequently recurve and are much reduced than the petals. The lip continues into a spur, which can take on a wide variety of shapes, in both types. The adaptation to various pollinators leads to modified floral components, particularly spurs (Cieslicka, 2006).

The genus *Pteroglossaspis* Rchb.f. was distinguished from *Eulophia* based on the lack of a spur. Lips typically have three lobes, crests, papillae, and basal callus appendages on the top surface. With or without a column foot, an arcuate lip can be connected to the column. An important character in an infrageneric treatment of *Eulophia* appears to be the presence or lack of a column foot. Pollinia are numbered four or two, similarly in the genus *Cymbidium* Sw. (Szlachetko, 2003).

Genus *Eulophia* was formally described by John Lindley in 1823 within Botanical Register. Few years later, in 1833, he suggested three sections. Section *Genuinae* Lindl. consisted of

19 species, from which three were moved to the genus *Graphorkis* Thouars, and one species, *Eulophia artrovirens* Lindl. was added to the genus *Oeceoclades* Lindl. Four species from section *Desciscentes* Lindl. are now a part of the genus *Acrolophia* Pfitzer. Three species from section *Aphylae* Lindl. are now synonyms of *Eulophia dabi* (D. Don) Hochr (Cieslicka, 2006).

In 1833, Lindley described genus *Cyrtopera*, which was differentiated from *Eulophia* based on the presence of a column foot. *Cyrtopera* consisted of 9 species: *C. plantaginea* Lindl., *C. woodfordii* Sims, *C. scabrilinguis* Lindl., *C. flava* Lindl., *C. obtusa* Lindl., *C. bicarinata*Lindl., *C. plicata* Lindl., *C. pedicellata* (L.f.) Lindl. and *C. gigantea* (L.f.) Lindl. Currently, *Cyrtopera* has been added to *Eulophia*, even though some authors recommended that itshould keep, the status of a section. Kraenzlin in 1897 described section *Pulchra* thatcontained *Eulophia pulchra* (Thouars) Lindl. and similar species. List of names for thatsection was published by Garay and Taylor in 1976, although most of them are currentlyconsidered as synonyms of *E. pulchra* (Cieslicka, 2006).

The most current infrageneric classification was proposed by Perrier de la Bâthie in 1935, who reviewed the Madagascan *Eulophia* species. He differentiated three sections. First section, *Saprolophia*, contained just 1 species, *Eulophia hologlossa* Schltr.; second section *Lissolophia*, was composed of 7 species. Third section, *Eulophia*, contained 25 species, with most of them presently included in the genera *Graphorkis* and *Oeceoclades* (Cieslicka, 2006).

In 1941, Perrier de la Bâthie moved all *Eulophia* species to the genus *Lissochilus*, and raised sections *Eulophidium* Kraenzl. and *Lissolophia* H. Perrier to the subgeneric rank. He also differentiated subgenus *Stiriolophia*. At present, taxa from section *Lissolophia* are found in section *Eulophia*; *Eulophidium* is a synonym of *Oeceoclades*, and species from the subgenus *Stiriolophia* are now placed into *Eulophia* and *Graphorkis*. Since the review by Perier de la

Bâthie, there were no attempts to propose a different infrageneric treatment of the genus (Cieslicka, 2006).

2.4.21 *Manniella* Rchb.f.

There are 2 species of this genus in Ghana, with a narrow distribution mostly in the Ashanti region. Members of this genus are mostly herbs that grow on the ground with thick, meaty roots. With a rosette of radical leaves and very small stems. Membranous, long-petioled leaves. A few membrane sheaths are present on the erect, long, and many-flowered scape. fewer than 1 cm long in the flowers. For at least half of their length, the lateral sepals are connected to one another, the petals, and the lip. The base of the free section has two reflexed marginal appendages, and the lip is attached to the sepals and has a thin claw. Anthers are subsessile between the column wings, broad, and concave, and the pollinia are loosely granular. The column is long, attached to the perianth tube, and free at the apex (POWO, 2022).

2.4.22 *Microcoelia* Lindl.

This is a monospecific genus in Ghana, they are mostly distributed in the Volta region. Plants are mostly short-stemmed, leafless epiphytic or, occasionally, lithophytic herbs. Unbranched or with a few branches, typically elongate roots that are firmly or loosely linked to the substrate, generally thick, terete or less frequently dorso-ventrally flattened, smooth or rarely verrucose. Acute to rostrate scales on the stem protect the stem apex. Few- to many-flowered inflorescences that are axillary, racemose, and concentrated at the tip of the stem; long or short peduncles; rhachis that are terete or angular, smooth or with processes; and bracts that are sheathed or not. Flowers on spur and other segments are small to minute, sessile or pedicellate, and often white with varying green, brown, or pink tints. Petals and sepals are separate and comparable. Lips closed or masked; spurs can be globose, cylindrical, or have differently shaped swellings. They are 3-lobed, free, and typically include fleshy calli at the base on either

side of the mouth of the spur. Column fleshy, androclinium short to long, anther-cap hemispherical, frequently elongated at the apex, pollinia 2 to pyriform, stipes linear to oblanceolate, whole or bifid at the apex, viscidium linear or oblong, short to long, and rostellum bifid, short to as long as the column (POWO, 2022).

2.4.23 *Polystachya* Hook.

There are 25 species of this genus in Ghana, they are mostly distributed in the Eastern, Bono East, Volta, and Western regions. Members of this genus are perennial herbs that are epiphytic, occasionally lithophytic, or terrestrial. On a creeping rhizome, stems that typically form pseudobulbs are clustered or less frequently spaced apart, occasionally branched or superposed (emerging from nodes above the base of the preceding pseudobulb), and have one to several nodes and leaves. Linear, lanceolate, oblanceolate, or elliptic leaves with a variety of textures. An inflorescence can range from one to many blooms, and it can be simple or branched. Setiform, lanceolate, ovate or obovate, acute or acuminate to mucronate, floral bracts that are upright to reflexed. The majority of flowers are non-resupinate, small to medium in size, very rarely large, fragrant, frequently pubescent, and colored green, yellow, white, pink, mauve, or orange, very never red. The lateral sepals are oblique and connected to the column-foot to form a mentum; the dorsal sepal is oblong to ovate. Petals are obovate to linear. Lips are often 3-lobed but occasionally entire, glabrous, pubescent, or farinose, sometimes meaty, and challenging to flatten without breaking. They may also have a basal callus. Pollinia 2, ovoid; stipe 1, square or subtriangular to oblong or linear; viscidium small to large, spherical or ellipsoid; rostellum often obscure, bifid in front, rarely somewhat elongated or beak-like (POWO, 2022).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Morphological Studies

Morphological studies were based mainly on herbarium specimens of the genus *Eulophia* collected in Ghana. Three herbaria, namely, Ghana Herbarium (GC) at the University of Ghana, herbarium in the University of Cape Coast (CCG), and herbarium in the Kwame Nkrumah University of Science and Technology (KUU) were visited to undertake the morphological studies. Herbarium code follows Index Herbariorum (http://www.sweetgum.nybg.org/science/ih/herbarium-list/).

50 herbarium specimens of the genus *Eulophia* were examined for morphological characters. 35 specimens at GC, 10 specimens at CCG, and 5 specimens at KUU. The number of specimens examined per species ranged from 2 specimens for *E. angolensis* to 15 specimens for *E. cristata* (Appendix A). From studies under the dissecting microscope (Leicazoom 2000 model) and using 30cm transparent ruler, eleven quantitative characters were measured (Table 3.1) and seven qualitative characters assessed (Table 3.1). Selection of the characters for assessment was based largely on the of work Ortúñez *et al.* (2020).

Additional morphological data were gathered from online databases such as the Plants of the World Online (https://powo.science.kew.org/), Global Biodiversity Information Facility (https://www.gbif.org/) as well as taxonomic literature (Ortúñez *et al.*, 2020; Hutchinson & Dalziel, 1963).

Plate 3.1 Morphological studies of herbarium specimens

Table 3.1: Morphological characters assessed, source and number of species

Character	Source of information	Number of species
Leaf length	Herbarium voucher specimens	8
Leaf width	Herbarium voucher specimens	8
Tepal length	Herbarium voucher specimens	8
Tepal width	Herbarium voucher specimens	8
Interfloral spaces	Herbarium voucher specimens	8
Fruit length	POWO, 2022	8
Fruit width	POWO, 2022	8
Bract length	Herbarium voucher specimens	8
Interbractal spaces	Herbarium voucher specimens	8
Stem width	Herbarium voucher specimens	8
Lip shape	Herbarium voucher specimens	8
Midlobe shape	Ortúñez et al. (2020)	7
Interveinal length	Herbarium voucher specimens	8
Perennating organ	Ortúñez et al. (2020) & POWO, 2022	8
Leaf shape	Herbarium voucher specimens	8
Tepal colour	Ortúñez et al. (2020) & POWO, 2022	8
Leaf base	Herbarium voucher specimens	8
lip ridge number	Ortúñez et al. (2020)	7

Table 3.1 continued

Spur colour	Ortúñez et al. (2020) & POWO, 2022	8
Leaf apex	Herbarium voucher specimens	8
Spur shape	Ortúñez et al. (2020) & POWO, 2022	8
Leaf margin	Herbarium voucher specimens	8
Spur apex	Ortúñez et al. (2020)	7
Leaf surface	Herbarium voucher specimens	8
Anther cap shape	Ortúñez et al. (2020)	7
Leaf arrangement	Herbarium voucher specimens	8
Lip colour	Ortúñez et al. (2020) & POWO, 2022	8
Midlobe margin	Ortúñez et al. (2020)	7
lip pappillae colour	Ortúñez et al. (2020)	7
callus shape	Ortúñez et al. (2020)	7
callus colour	Ortúñez et al. (2020)	7
lip ridge colour	Ortúñez et al. (2020)	7

3.2 Ecological and Distributional Studies

Field work was conducted at Aburi Botanical Gardens, Shai Hills, Achimota Forest and Legon Hills based on information obtained from voucher specimens about occurrence of species of the genus in Ghana. However, none of the *Eulophia* species were found after careful consideration of the phenology and the help of local guides. As such, information from herbarium labels of the specimens examined were retrieved to understand aspects of the ecology such as phenology, habitat types and pollinator-flower relationship for the species of the genus *Eulophia*. Data were also downloaded from Global Biodiversity Facility Information (GBIF) and Plants of the World Online (POWO).

Species distribution maps were developed using ArcGIS Pro 2.8 software for the genus and individual species of *Eulophia* in Ghana. Data on species collection localities on herbarium specimens and those from GBIF as well locality data from local field guides in Ghana (Hall, 1980; Hawthorne, 1990) were used. In total, 55 locality points (20 from herbarium data, 25 from GBIF and 10 from field guides) were used after removing duplicate points for species and georeferencing to ensure accuracy of the points. The number of georeferenced points for each species is shown in Table 3.2.

Table 3.2: Species of *Eulophia*, sources of information and collection sites

Species	Source of locality information	Collection sites
E. alta	Herbarium voucher specimens, GBIF	2
E. angolensis	GBIF	1
E. buettneri	Herbarium voucher specimens	2
E. cristata	Herbarium voucher specimens, GBIF	19
E. cucullata	Herbarium voucher specimens, GBIF	10
E. euglossa	Herbarium voucher specimens, GBIF	5
E. flavopurpurea	Herbarium voucher specimens, GBIF	8
E. milnei	Herbarium voucher specimens, GBIF	7

In order to estimate the area of occupancy (AOO) and extent of occurrence (EOO) for each species, a rapid geospatial conservation assessments was conducted using GeoCat (http://geocat.kew.org/). Rapid geospatial analysis for Red List assessment was also performed through the open source, browser-based GeoCat. The methodology, which was created to employ spatially referenced primary occurrence data, concentrates on two characteristics of a taxon's geographic range: the extend of occurrence (EOO) and the region of occupation (AOO). The IUCN Red List includes these measures as part of its categories and criteria, although obtaining them in a precise, dependable, and reproducible manner has frequently proven difficult.

3.3 Taxonomic Studies

Taxonomic studies focused on development of an authoritative checklist and construction of dichotomous keys for identification of species of the genus. In order to develop a checklist of the species of *Eulophia* in Ghana, type specimens, nomenclature, ethnobotanical uses and vernacular names besides that of morphology, ecology and distributional are essential (Utteridge, 2016). Type specimens of the various species of *Eulophia* especially holotypes were studied from available online databases, mainly Biodiversity Heritage Library (https://www.biodiversitylibrary.org/) and Global Plants on JSTOR (https://plants.jstor.org/). Information on nomenclature changes were obtained Plants of the World online (https://powo.science.kew.org/), International Plant Names Index (https://www.ipni.org/), and Catalogue of Life (https://www.catalogueoflife.org/). Ethnobotanical information and vernacular names were retrieved from PROTA (2022) and iNaturalist (2022).

To construct dichotomous key for identification of species, a data matrix of the various taxonomic characters examined was used. The matrix consisted of species plotted against 35 characters. Good characters whose attributes were contrasting and could separate the taxa into two groups were selected. Couplets with contrasting statements ended in an identified taxon or the next set of couplets to visit. The bracketed key was used in order to exhaust every alternative statement for each couplet. A total of 7 couplets were used to delimit the species of *Eulophia* occurring in Ghana.

3.4 Data Analysis

Cluster analysis was employed to analyse the various samples of each species to verify significant patterns of the various morphological quantitative characters using STATA

version 15 and R/R-studios (version 4.2.2). The significance of variations in morphological characters among the *Eulophia* species was determined by subjecting the data to one-way and two-way analysis of variance (ANOVA) using R/R-studios (version 4.2.2). All data were recorded in Microsoft Excel 2019 for preliminary data analysis before imported into R/R-studios (version 4.2.2) for final analyses.

CHAPTER FOUR

4.0 RESULTS

4.1 Morphological Studies

4.1.1 Leaf and Stem morphology

The members of the *Eulophia* range from slender to large herbs, lacking woody stems; plant height ranges from 560–2000mm, 2–16mm in width; has leaves that are often alternately arranged. Leaves are plicate, erect, often linear to lanceolate except in in *E. alta, E. cristata* and *E. euglossa* where the leaves are elliptical. Leaves are either acute or acuminate at the apex, *ca.* 90–730 × 2–60 mm in size. Leaves have 4–9 veins with margin entire. Leaf surfaces are aciculate to striate except in *E. alta* where leaves are glaucous. Leaf sheaths *ca.* 23–70 mm; most members have closed leaf sheaths expect in *E. angolensis*, *E. cucullata,* and *E. euglossa*, where leaf sheaths are opened (Tables 4.1 & 4.2).

4.1.2 Inflorescence, Flower and Fruit Morphology

Inflorescence are often densely flowered ranging from 3–21 flowers except in *E. buettneri, E. cucullata, E. dilecta,* and *E. euglossa* where flowers are mostly above 21. Peduncle diameter ranges from 4–12mm except for smaller diameters (2–3mm) observed for *E. milnei.* Bracts are reflexed, often linear except in *E. buettneri* and *E. cristata* where bracts can be lanceolate to elliptical. Bract is acute to acuminate at the apex, 5–25 mm long except for longer bracts observed for *E. euglossa* (27–29mm). Distances between successive bracts range from 4–80 mm (Tables 4.3 & 4.4).

Flowers are mostly in the shades of yellow and red, except shades of green in *E. euglossa* and *E. flavopurpurea*. The distance between successive flowers ranges from 6–45 mm. Sepal colour is mainly yellow but green in *E. cristata*. The shape of dorsal sepal is obovate-

lanceolate to obovate with a narrow base, *ca.* 10–18 ×4–7 mm, apex acuminate while lateral sepals are obovate-lanceolate, asymmetrical, *ca.* 16–20 × 3–7 mm. The spur is pale green to rose, with red spots in *E. milnei,* saccate to conical and subnull to conical at the apex. Petals range from deep pink to bright yellow, occasionally with brown spots, oblong-ligulate except linear-lanceolate in *E. cristata* and *E. euglossa,* acute to acuminate at the apex, *ca.* 5–29 × 1.5–20 mm. Lip is trilobed near the apex, pale yellow to dark rose often white rose in *E. alta* and *E. buettneri, ca.* 5.5–7.5 × 4–5 mm, ridges yellow to purple, 3–11; midlobe oblong to elliptical but semi-circular in *E. alta,* margins undulate to crenulate but entire in *E. buettneri*. Fruit pendent, *ca.* 10–50 × 4–22 mm (Tables 4.3 & 4.4).

Table 4.1: Quantitative vegetative morphological characters of *Eulophia* species

SPECIES	Leaf length (cm)		Intervenal length (cm)		Leaf width (cm)		Stem width (cm)		Leaf size (cm^2)	
	Range	mean±SD	Range	mean±SD	Range	mean±SD	Range	mean±SD	range	mean±SD
E. alta	50.1-61.8	56.14±6.47	0.25-0.75	0.50±0.25	5.59-5.89	5 .64±0.25	0.69-1.17	0.93±0.24	313.10-320.78	316.63±3.56
E. angolensis	55.3-63.2	59.95±4.42	0.31-0.41	0.36±0.05	0.95-1.68	1.22±0.39	0.41-0.49	0.45±0.04	68.67-75.12	71.78±3.74
E. buettneri	24.3-34.7	29.45±5.45	0.15-0.19	0.17±0.02	0.42-0.64	0.53±0.11	0.34-0.56	0.45±0.11	11.23-20.15	15.35±4.54
E. cristata	29.34-33.65	31.56±2.25	0.48-0.54	0.51±0.03	2.54-2.76	2.65±0.11	0.78-0.90	0.84±0.06	61.34-65.45	63.78±1.56
E. cucullata	21.76-27.89	24.67±3.38	0.51-0.61	0.56±0.05	2.33-3.08	2.72±0.39	0.69-1.01	0.85±0.16	61.87-67.53	64.65±2.76
E. dilecta	23.12-27.67	25.17±2.25	0.28-0.32	0.30±0.02	1-1.2	1.10±0.10	0.70-0.84	0.77±0.07	25.37-28.35	27.12±1.71
E. euglossa	21.34-25.51	23.36±2.20	0.12-0.16	0.14±0.02	0.31-0.37	0.34±0.03	0.46-0.52	0.49±0.03	7.02-9.34	7.82±1.79
E. flavopurpurea	17.87-19.06	18.44±0.74	0.08-0.12	0.10±0.02	0.33-0.43	0.38±0.05	0.79-0.89	0.84±0.05	6.77-6.90	6.84±0.06
E. warneckeana	46.50-52.54	49.52±3.02	0.39-0.47	0.43±0.04	1.52-1.84	1.68±0.16	1.0-1.26	1.13±0.13	77.86-80.21	78.40±2.65

Table 4.2: Qualitative vegetative morphological characters of *Eulophia* species

SPECIES	Leaf arrangement type	Leaf shape	Leaf apex	Perennating organ type
E. alta	alternate and closed sheathing	lanceolate to elliptical	acuminate	rhizome
E. angolensis	alternate and opened sheathing	lanceolate to linear	acute	rhizome
E. buettneri	alternate and closed sheathing	Linear	acute	tuber
E. cristata	alternate and closed sheathing	lanceolate to elliptical	acuminate	tuber
E. cucullata	alternate and opened sheathing	linear to lanceolate	acute	tuber
E. dilecta	alternate and closed sheathing	linear to lanceolate	acute	tuber
E. euglossa	alternate and opened sheathing	lanceolate to elliptical	acuminate	pseudobulb
E. flavopurpurea	alternate and closed sheathing	Linear	acuminate	tuber
E. warneckeana	alternate and closed sheathing	Linear	acute	tuber

Table 4.3: Quantitative reproductive morphological characters of *Eulophia* species

SPECIES	Tepal width (cm)		Tepal length (cm)		Floral spacing (cm)		Bract length (cm)		Interbractal spacing (cm)	
	Range	mean±SD	range	mean±SD	Range	mean±SD	Range	mean±SD	Range	mean±SD
E. alta	0.50-0.58	0.54±0.04	2.14-2.3	2.22±0.08	2.78-3.88	3.33±0.55	1.49-1.75	1.62±0.13	0.46-0.54	0.50±0.04
E. angolensis	0.74-0.92	0.83±0.09	1.84-2.02	1.93±0.09	1.86-2.10	1.93±0.17	0.58-0.66	0.62±0.04	0.93-1.27	1.10±0.17
E. buettneri	1.19-1.45	1.32±0.13	2.12-2.36	2.24±0.12	1.60-2.98	2.28±0.68	0.99-1.17	1.08±0.09	1.25-3.31	2.28±1.03
E. cristata	0.59-0.65	0.62±0.03	1.64-1.74	1.69±0.05	1.87-2.21	1.99±0.12	1.77-2.01	1.89±0.12	1.66-2.16	1.91±0.25
E. cucullata	0.25-0.29	0.27±0.02	1.62-1.72	1.67±0.05	1.71-1.97	1.84±0.13	2.34-2.42	2.43±0.09	1.65-1.89	1.77±0.12
E. dilecta	0.68-0.74	0.71±0.03	2.06-2.18	2.12±0.06	2.08-2.42	2.25±0.17	1.19-1.31	1.26±0.07	1.85-2.23	2.04±0.19
E. euglossa	0.16-0.18	0.17±0.01	0.69-0.73	0.71±0.02	1.46-1.74	1.60±0.14	0.54-0.64	0.59±0.05	0.81-1.09	0.95±0.14
E. flavopurpurea	1.21-1.31	1.26±0.05	1.83-1.99	1.91±0.08	2.14-2.42	2.23±0.19	1.83-2.05	1.94±0.11	2.45-3.29	2.87±0.42
E. warneckeana	1.36-1.44	1.40±0.4	2.04-2.10	2.07±0.03	1.71-1.97	1.84±0.13	5.06-6.30	5.68±0.62	3.02-3.64	3.33±0.31

Table 4.4: Qualitative reproductive morphological characters of *Eulophia* species

SPECIES	Tepal colour	Spur colour	Spur shape	Anther cap shape	Lip shape	Lip colour	Midlobe shape	Midlobe margin
E. alta	brown with yellow parts	pale green	saccate	unicorn	trilobed	white rose	semicircular	undulate
E. angolensis	yellow	Yellow	conical	bicorn	trilobed	Yellow	oblong	crenulate
E. buettneri	deep pink	Green	saccate	unicorn	trilobed	Rose greenish	bilobed	entire
E. cristata	pink-purplish	pale rose	conical	unicorn	trilobed	purple	oblong-ovate	crenulate
E. cucullata	deep pink	Rose	broadly saccate	unicorn	trilobed	dark rose	obovate	undulate
E. dilecta	deep pink	Rose	broadly saccate	unicorn	trilobed	dark rose	obovate	undulate
E. euglossa	green with brown apex	pale green	clavate	unicorn	trilobed	pale yellow	ovate-elliptical	entire
E. flavopurpurea	pale greenish-yellow with purple	pale yellow	narrowly conical	unicorn	trilobed	pale yellow	orbicular	undulate
E. warneckeana	bright yellow	yellow with red spots	cylindrical	bicorn	trilobed	primrose	oblong-obovate	entire

4.2 Ecology and Distribution

Species of *Eulophia* in Ghana were found in six habitat types (savannah, swamp, open field, grassland, urban areas, and forest). The grassland was the commonest habitat type where the *Eulophia* species in Ghana were found. Habitat types, for example the forest and urban areas were unique to *E. euglossa* and *E. cristata.* Two and three species of *Eulophia* were found growing in the swamp and open field habitat types respectively (Table 4.5).

Table 4.5: Habitat types of *Eulophia* species growing in Ghana

Species	Habitat types					
	savannah	swamp	open field	grassland	under trees	Forest
E. alta	–	+	–	–	–	–
E. angolensis	+	+	–	–	–	–
E. buettneri	+	–	+	–	–	–
E. cristata	+	–	+	+	+	–
E. cucullata	+	–	–	+	–	–
E. dilecta	–	–	–	+	–	–
E. euglossa	–	–	+	–	–	+
E. flavopurpurea	–	–	–	+	–	–
E. warneckeana	–	–	–	+	–	–
Percentage total	44%	22%	33%	55%	11%	11%

Present (+); Absent (–)

The species of the *Eulophia* produce flowers and fruits between March to May. However, *E. cristata* produce flowers in January as well. Also *E. buettneri* has been observed to produce flowers in February while *E. angolensis, E. alta,* and *E. dilecta* have been observed to produce flowers around June to August. None of the species was observed to produce flowers from September to December. The broadest flowering and fruiting periods are observed for *E. buettneri, E. cristata,* and *E. euglossa* while the narrowest range was observed for *E. alta.*

Table 4.6: Flowering and fruiting periods of *Eulophia* species

	Flowering/Fruiting Period											
SPECIES	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E. angolensis												
E. alta												
E. buttneri												
E. cristata												
E. cucullata												
E. dilecta												
E. euglossa												
E. flavopurpurea												
E. warneckeana												

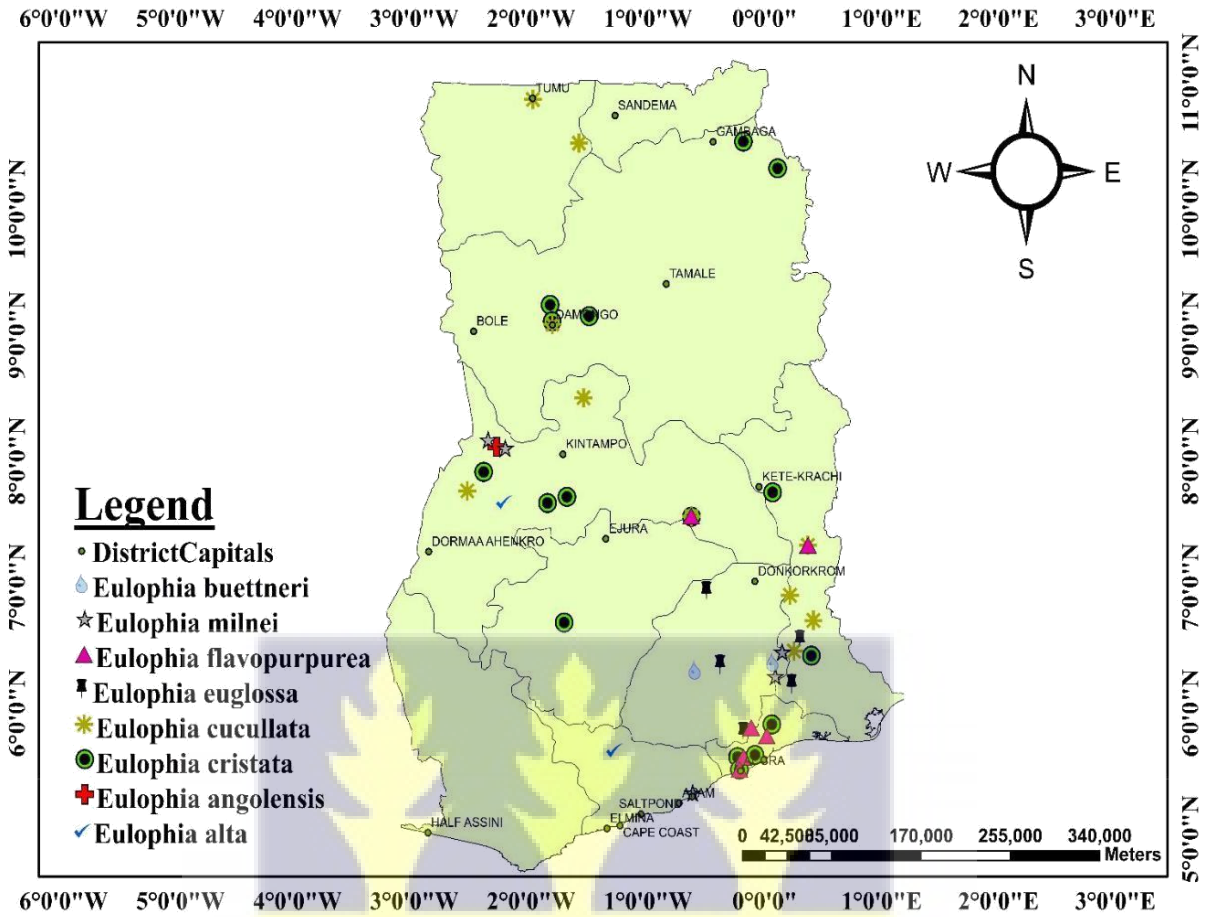

Fig 4.1: Distribution of *Eulophia* species in Ghana

Generally, the species of *Eulophia* have a cosmopolitan distribution across the country with the least distribution around the western part. Their greatest distribution lies within areas from the Southeast towards the middle belt of the country. The northern belt of the country recorded fewer collection sites compared to the southern and middle belts; two collection sites were recorded each for the Upper West and East regions. However, the Savannah and Northern region recorded relatively higher numbers of the species of *Eulophia*. Regions around Bono East and Ahafo regions recorded higher numbers of the species as well.

The *Eulophia* species were highly distributed in Guineo-Congolio-Sudanian ecoregion and fewer of them were distributed in Guineo-Congolian ecoregion and least distribution was observed in Sudanian ecoregion. This distribution confirms the habitat chart from Table 4.5 and Fig. 4.2. Most *Eulophia* species prefer more grasslands than forests.

From the distribution maps, *Eulophia* species are absent from the moist and wet evergreen vegetation zones. The least distribution is found in the Sudan savannah followed by distribution in the deciduous forest. *Eulophia* species were distributed well in the Guinea savannah followed by a greater distribution in the Transitional zone. The greatest distribution was observed in the coastal savannah.

The greatest distribution of the species of *Eulophia* was observed for *E. cristata* (Fig 4.1) followed by a lesser distribution of *E. cucullata* (Fig 4.1). *E. flavopupurea* (Fig 4.1) recorded the next least distribution then followed by *E. milnei* and *E. euglossa* (Fig 4.1). *E. buettneri* and *E. alta* both recorded the next least distribution (Fig 4.1) and the least of the distribution was recorded for *E. angolensis* (Fig 4.1).

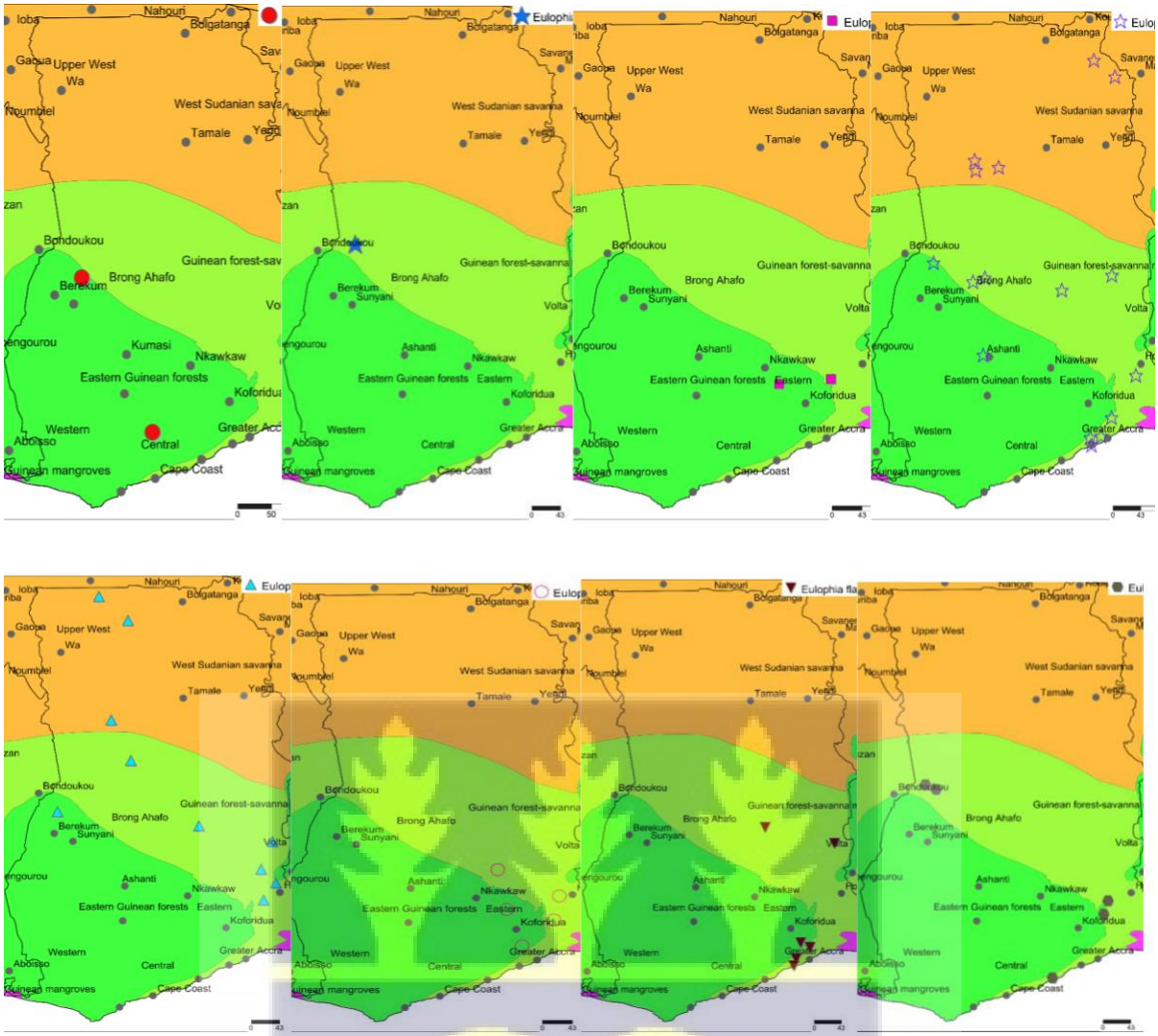

Fig 4.2: Distribution of *Eulophia* species in the vegetation zones of Ghana (following the species alphabetical order)

4.3 Taxonomic Studies

4.3.1 Identification Key to *Eulophia* speicies

1a. Plant with leaf apex acuminate; bract length 1.62-1.89cm……..2

1b. Plant with leaf apex acute; bract length above 1.93cm……3

2a. Plant leaf length>58cm; mostly in swampy grassland ……***E. angolensis***

2b. Plant leaf length<58cm; mostly not in swampy grassland ……4

3a. Perennating organ is a tuber with spur conical and pale rose; flowers in February……***E. cristata***

3b. Perennating organ is a psudobulb with spur saccate and pale green; flowers in June……..…***E. alta***

4a. Floral midlobe margin entire……5

4b. Floral midlobe margin undulate……6

5a. Tepal width range 1.32±0.13cm; mostly in wet tropical biome(s)……***E. buettneri***

5b. Tepal width range 0.71±0.02cm; mostly in dry tropical biome(s)……***E. euglossa***

6a. Lip colour yellow……..…..***E. flavopurpurea***

6b. Lip colour dark rose……7

7a. Bract length range 5.68±0.62cm; medicinally used as stimulant……***E. milnei***

7b. Bract length range 2.43±0.09cm; not medicinally used as stimulant ……..……...***E. cucullata***

4.3.2 Checklist of *Eulophia* species in Ghana

All conservation status of the species in this study were verified from IUCN redlist of Threatened Species as of January, 2023. The distribution of the species is strictly from Ghana. The ethnobotanical uses are worldwide in origin.

***Eulophia alta* (L.) Fawc. & Rendle Fl. Jamaica 1: 112 (1910)**

Type: *Anon., s.n.* 1421 (lectotype LINN-HL1058-2, designated by Smith & Edward, 2011).

Basionym: *Limodorum altum* L**.** Syst. Nat. ed. 12 (1767)

Synonyms: All synonyms are listed below.

Bletia alta (L.) Hitchc. in Rep. (Annual) Missouri Bot. Gard. 4: 132 (1893); *Cyrtopera alta* (L.) Stehlé in Bull. Agric. Martinique 8: 155 (1939); *Limodorum altum* L. in Syst. Nat., ed. 12. 2: 594 (1767); *Platypus altus* (L.) Small in Fl. S.E. U.S., ed. 2: 329 (1913); *Cypripedium epidendricum* Vell. in Fl. Flumin. 9: t. 64 (1831); *Cyrtopera amazonica* (Barb.Rodr.) Barb.Rodr. in Gen. Spec. Orchid. 2: 180 (1882); Cyrtopera longifolia (Kunth) Rchb.f. in W.G.Walpers, Ann. Bot. Syst. 6: 668 (1863); *Cyrtopera longifolia* var. *amazonica* (Barb.Rodr.) Cogn. in C.F.P.von Martius & auct. suc. (eds.), Fl. Bras. 3(5): 355 (1901); *Cyrtopera longifolia* var. *pachystelidia* Rchb.f. in Bot. Zeitung (Berlin) 10: 734 (1852); *Cyrtopera vellosiana* Barb.Rodr. in Gen. Spec. Orchid. 2: 179 (1882), nom. superfl.; *Cyrtopera woodfordii* (Sims) Lindl. in Gen. Sp. Orchid. Pl.: 189 (1833); *Cyrtopera woodfordii* var. *pachystelidia* Rchb.f. in Bot. Zeitung (Berlin) 10: 734 (1852); *Cyrtopodium woodfordii* Sims in Bot. Mag. 43: t. 1814 (1816); *Dendrobium longifolium* Kunth in F.W.H.von Humboldt, A.J.A.Bonpland & C.S.Kunth, Nov. Gen. Sp. 1: 360 (1816); *Eulophia alta* var. *alba* L.C.Menezes in Bol. CAOB 33: 70 (1998); *Eulophia alta* f. *flavescens* (Schltr.) F.Barros in Orchid Memories: 20 (2004); *Eulophia alta* var. *pachystelidia* (Rchb.f.) G.A.Romero in Vanishing Beauty, Native Costa Rican Orchids 1: 318 (2005); *Eulophia alta* f. *pallida* P.M.Br. in N. Amer. Native Orchid J. 1: 132 (1995); *Eulophia alta* f. *pelchatii* P.M.Br. in N. Amer. Native Orchid J. 4: 46 (1998); *Eulophia longifolia* (Kunth) Schltr. in Orchideen Beschreib. Kult. Zücht.: 347 (1914); *Eulophia longifolia* var. *amazonica* (Barb.Rodr.) Cogn.

in F.C.Hoehne, Fl. Brasílica 12(6): 4 (1942); *Eulophia longifolia* var. *flavescens* Schltr. in Anexos Mem. Inst. Butantan, Secç. Bot. 1(4): 62 (1922); *Eulophia woodfordii* (Sims) Rolfe in D.Oliver & auct. suc. (eds.), Fl. Trop. Afr. 7: 68 (1897); *Govenia barbata* Poepp. & Endl. in Nov. Gen. Sp. Pl. 2: 5 (1836); *Lissochilus amazonicus* Barb.Rodr. in Gen. Spec. Orchid. 1: 89 (1877); *Maxillaria longifolia* (Kunth) Lindl. in Gen. Sp. Orchid. Pl.: 150 (1832); *Paphiopedilum epidendricum* (Vell.) Pfitzer in Bot. Jahrb. Syst. 19: 42 (1894); *Platypus papillifer* Small & Nash in J.K.Small, Fl. S.E. U.S.: 329 (1903); *Xylobium longifolium* (Kunth) Lindl. ex Spreng. in Syst. Veg., ed. 16. 3: 733 (1826) (Plants of the World Online, 2022).

Description: A large terrestrial herb 1–2 m (1000-2000mm) tall with white roots 1.5 mm in diameter. Perennating organ a fleshy elongate subterranean rhizome ± 10 mm diameter. Leaves are plicate, erect, lanceolate to elliptical, acuminate, up to 490–690 × 49–60 mm, with alternate and closed sheathing at base and stem width up to 5–16mm. Inflorescence are many-flowered ranging from 3–8; peduncle diameter 5–8 mm, bracts reflexed, linear-aristate, acuminate, 13–20 mm long and spaced 4–6mm. Flowers spaced 20–45mm. Petals brown with yellow spots, oblong-ligulate, acute, 21–25 × 4–8 mm. Fruit pendent, 25–50 × 10–18 mm.

Distribution: Foso (Eastern region), Avu (Volta region), and Nkawkaw (Eastern region).

Conservation Status: not evaluated. The EOO is 94,883,889.362 km²; the AOO is 1,730.000 km² (GeoCat, 2022).

Phenology: flowers in June.

Habitat and Ecology: occurs mostly in swampy areas.

Vernacular names: wild coco

Ethnobotanical uses: None

Specimens examined:

Ghana, Foso, Eastern region Fl./Fr. s.n., *Adomako, J.K.* (GC); Ghana, Nkawkaw, Eastern region, Fl., 9 June 1958, *Morton, J.K.* A3406 (GC); Ghana, Avu lagoon, Volta Region, Fl. 19 February 1966, *Hall, J.B.* CC 1228 (GC).

Plate 4.1: Image of a voucher specimen of *Eulophia alta*

***Eulophia angolensis* (Rchb.f.) Summerh. Kew Bull. 13: 76 (1958)**

Type: ANGOLA, Huilla. *Welwitsch F.M.J.* 734 (Isotype P00538767!).

Basionym: *Cymbidium angolense* Rchb.f., Flora 48: 188 (1865)

Synonyms: All synonyms are listed below.

Cymbidium angolense Rchb.f. in Flora 48: 188 (1865); *Cyrtopera angolensis* (Rchb.f.) Szlach. in Orchid. W.-Centr. Africa 3: 75 (2021); *Lissochilus angolensis* (Rchb.f.) Rchb.f. in Otia Bot. Hamburg.: 64 (1878); Cyrtopera stolziana Kraenzl. in Bot. Jahrb. Syst. 33: 69 (1902); *Eulophia buchananii* (Rchb.f.) Bolus in J. Linn. Soc., Bot. 25: 185 (1889); *Eulophia lindleyana* (Rchb.f.) Schltr. in Westafr. Kautschuk-Exped.: 279 (1900); *Eulophia stolziana* (Kraenzl.) Engl. in H.G.A.Engler & O.Drude, Veg. Erde 9(II): 444 (1908); *Lissochilus antunesii* Rolfe in Bol. Soc. Brot. 7: 237 (1889); *Lissochilus buchananii* Rchb.f. in Otia Bot. Hamburg.: 64 (1878); *Lissochilus eylesii* Rendle in J. Bot. 43: 53 (1905); *Lissochilus katentaniensis* De Wild. in Bull. Jard. Bot. État Bruxelles 6: 91 (1919); *Lissochilus latus* Rolfe in D.Oliver & auct. suc. (eds.), Fl. Trop. Afr. 7: 79 (1897); *Lissochilus lindleyanus* Rchb.f. in Otia Bot. Hamburg.: 65 (1878); *Lissochilus mildbraedii* Kraenzl. in Bot. Jahrb. Syst. 43: 338 (1909); *Lissochilus paludicola* Rchb.f. in Otia Bot. Hamburg.: 63 (1878); *Lissochilus platypterus* Rchb.f. in Flora 65: 533 (1882); *Lissochilus stolzianus* (Kraenzl.) Schltr. in Bot. Jahrb. Syst. 53: 588 (1915); *Lissochilus ugandae* Rolfe in Bot. Mag. 131: t. 8044 (1905); *Lissochilus validus* Rendle in J. Bot. 33: 197 (1895); *Lissochilus validus* var. *minor* Rendle in J. Bot. 33: 197 (1895) (Plants of the World Flora Online, 2022).

Description: A terrestrial herb 60–210 cm (600-2100mm) tall. Perennating organs fleshy, underground, rhizomatous, stout, cylindrical, many-noded, branching, 10–50 mm diameter, with white, 2 mm diameter roots emerging all over surface. Leaves plicate, erect, lanceolate to linear, acute, up to 530–730 × 8–24 mm, with alternate and opened sheathing at base and stem width up to 4–6mm. Inflorescence densely many-flowered ranging from 5–10; peduncle diameter 3–5 mm, bracts reflexed, linear, acute, 5–7 mm long and spaced 6–15mm. Flowers spaced 13–22mm. Petals yellow, ligulate, acute, 17–23 × 6–10 mm. Fruit pendent, 26–30 × 4–7 mm.

Distribution: Ho (Volta region) and Ngure (Western region)

Conservation Status: not evaluated. The EOO is 16,495,051.677 km²; the AOO is 1,140.000 km² (GeoCat, 2022).

Phenology: flowers in May & June.

Habitat and Ecology: occurs mostly in swampy grassland

Vernacular names: yellow water orchid (English) and itarra (Yoruba)

Ethnobotanical uses: None

Specimens examined:

Ghana, South Ho, Keta, Volta Region, Fl., 30 May 1956, *Morton, J.K.* A2233 (GC); Ghana, Ngure, Western region, Fl., May 1982, *Gordon; Amponsah, J.Y.* (GC).

Plate 4.2: Image of a voucher specimen of *Eulophia angolensis*

***Eulophia buettneri* (Kraenzl.) Summerh. J.Hutchinson & J.M.Dalziel, Fl. W. Trop. Afr. 2: 446 (1936)**

Type: TOGO: *R. Buettner* 415 (holotype: B†). *Lissochilus ledermannii* Kraenzl. (Kraenzlin 1912: 396) – *Eulophia ecarinata* Butzin (Butzin 1975: 588).

Basionym: *Lissochilus buettneri* Kraenzl., Bot. Jahrb. Syst. 17: 53 (1893)

Synonyms: All synonyms are listed below.

Lissochilus buettneri Kraenzl. in Bot. Jahrb. Syst. 17: 53 (1893); *Eulophia ecarinata* Butzin in Willdenowia 7: 588 (1975); *Lissochilus ledermannii* Kraenzl. in Bot. Jahrb. Syst. 48: 396 (1912) (Plants of the World Flora Online, 2022).

Description: Small terrestrial herb 20–32 cm (200-320mm) tall. Perennating organs subterranean, tuberous, 16–25 mm tall, 5–10 mm in diameter; roots slender, up to 2 mm in diameter. Leaves plicate, erect, linear, acute, up to 195–425 × 3–7 mm, with alternate and closed sheathing at base and stem width up to 2–7mm. Inflorescence many-flowered ranging from 3–15; peduncle diameter 4–7 mm, bracts reflexed, lanceolate, acute, 8–13 mm long and spaced 5–49mm. Flowers spaced 6–45mm. Petals deep pink, oblong-cordate, obtuse, 17–29 × 11–17 mm. Fruit pendent, 16–18 × 18–22 mm.

Distribution: Jaketi (Volta region) and Afram plains (Greater Accra region).

Conservation Status: not evaluated. The EOO is 763,323.664 km²; the AOO is 48.000 km² (GeoCat, 2022).

Phenology: flowers in February.

Habitat and Ecology: grows primarily in the savannah and sometimes sprouting from pseudobulb on bare ground.

Vernacular names: None

Ethnobotanical uses: None

Specimens examined:

Ghana, Jaketi road, Volta region, Fl. 12 February 1958, *Morton, J.K.* A3022. (GC); Ghana, Afram plains, Greater Accra region, Fl. [1900], *Johnson, W.H.*, 852 (GC).

Plate 4.3: Image of a voucher specimen of *Eulophia buettneri*

***Eulophia cristata* (Afzel. ex Sw.) Steud. Nomencl. Bot., ed. 2, 1: 605 (1840)**

Type: SIERRA LEONE: *A. Afzelius s.n.* (lectotype: S, n.v., designated by Szlachetko 2008: 230).

Basionym: *Limodorum cristatum* Afzel. ex Sw., Neues J. Bot. 1: 86 (1805)

Synonyms: All synonyms are listed below.

Cyrtopera cristata (Afzel. ex Sw.) Szlach. in Orchid. W.-Centr. Africa 3: 80 (2021); *Graphorkis cristata* (Afzel. ex Sw.) Kuntze in Revis. Gen. Pl. 2: 662 (1891); *Limodorum cristatum* Afzel. ex Sw. in Neues J. Bot. 1(1): 86 (1805); *Eulophia articulata* (Schumach.) Lindl. in Gen. Sp. Orchid. Pl.: 181 (1833); *Eulophia longibracteata* (Lindl.) T.Durand & Schinz in Consp. Fl. Afric. 5: 22 (1894); *Galeandra longibracteata* Lindl. in J. Proc. Linn. Soc., Bot. 6: 133 (1862); *Graphorkis articulata* (Schumach.) Kuntze in Revis. Gen. Pl. 2: 662 (1891); *Limodorum articulatum* Schumach. in Beskr. Guin. Pl.: 399 (1827); *Lissochilus heudelotii* Rchb.f. in Otia Bot. Hamburg.: 63 (1878); *Lissochilus purpuratus* Lindl. in J. Proc. Linn. Soc., Bot. 6: 133 (1862); *Lissochilus uliginosus* Rolfe in Bull. Misc. Inform. Kew 1913: 340 (1913) (Plants of the World Flora Online, 2022).

Description: A terrestrial herb 60–130 cm (600-1300mm) tall. Perennating organs underground, tuberous, potato-like, cylindric-ellipsoidal, 30–90 mm long, 13–40 mm diameter, whitish, in chains; roots 2 mm diameter. Leaves plicate, erect, lanceolate to elliptical, acuminate, up to 220–455 × 22–30 mm, with alternate and closed sheathing at base and stem width up to 5–11mm. Inflorescence densely many-flowered ranging from 12–20; peduncle diameter 6–8 mm, bracts reflexed, lanceolate, acute, 13–25 mm long and spaced 15–30mm. Flowers spaced 12–32mm. Petals pink with purple spots, linear-lanceolate, acuminate, 15–21× 6–10 mm. Fruit pendent, 40–52×16–21 mm.

Distribution: Nakpanduri (Northern region), Manhyia (Ashanti region), Shai hills (Greater Accra region), Mole (Northern region), Elmina (Central region), Achimota (Greater Accra region), Legon hill (Greater Accra region), Winneba (Central region), and Nungua (Greater Accra region).

Conservation Status: not evaluated. The population trend is unknown. The EOO is 5,389,304.623 km²; the AOO is 792.000 km² (GeoCat, 2022).

Phenology: flowers in February to May.

Habitat and Ecology: grows primarily in savannah sometimes also under trees, on bare ground, and in grasslands.

Vernacular names: None

Ethnobotanical uses: Ornamentals

Specimens examined:

Ghana, Nakpanduri, Northern region, Fl. 18 April 1970, *Easterly, N.W.* CC 255 (GC); Ghana, Manhyia, Eastern region, Fl. February 1970, *Hall, J.B.* 40077 (GC); Ghana, Shai Hills, Greater Accra region, Fl. 22 February 1977, *Hall, J.B.*; *Swaine*, 460067 (GC); Ghana, Mole National Park, Northern region, Fl. 8 April 1976, *Lieberman, D.*, 46384 (GC).

Plate 4.4: Image of a voucher specimen of *Eulophia cristata*

***Eulophia cucullata* (Afzel. ex Sw.) Steud. Bot., ed. 2, 1: 605 (1840)**

Type: Malawi, Nyassa Hochland and Station Kyimbila, *Stolz, A.*, 480 (Holotype K000078555!)

Basionym: *Limodorum cucullatum* Afzel. ex Sw., Neues J. Bot. 1: 86 (1805)

Synonyms: All synonyms are listed below.

Limodorum cucullatum Afzel. ex Sw. in Neues J. Bot. 1(1): 86 (1805); *Lissochilus cucullatus* (Afzel. ex Sw.) Szlach. in Orchid. W.-Centr. Africa 3: 158 (2021); *Eulophia arenaria* (Lindl.) Bolus in J. Linn. Soc., Bot. 25: 185 (1898); *Eulophia cucullata* var. *dilecta* (Rchb.f.) Pérez-Vera in Orchidées Côte D'Ivoire: 321 (2003); *Eulophia dilecta* (Rchb.f.) Schltr. in Westafr. Kautschuk-Exped.: 279 (1900); *Eulophia kondensis* Butzin in Willdenowia 7: 589 (1975); *Eulophia monteiroi* (Rolfe) Butzin in Willdenowia 7: 589 (1975); *Eulophia stylites* (Rchb.f.) A.D.Hawkes in Orchid Rev. 72: 27 (1964); *Lissochilus amabilis* Schltr. in Ann. Transvaal Mus. 10: 240 (1924); *Lissochilus arenarius* Lindl. in J. Proc. Linn. Soc., Bot. 6: 133 (1863); *Lissochilus dilectus* Rchb.f. in Otia Bot. Hamburg.: 62 (1878); *Lissochilus dilectus* f. minor Rchb.f. in Flora 65: 533 (1882); *Lissochilus euanthus* Schltr. in Bot. Jahrb. Syst. 53: 588 (1915); *Lissochilus kassnerianus* Kraenzl. in Bot. Jahrb. Syst. 51: 391 (1914); *Lissochilus monteiroi* Rolfe in D.Oliver & auct. suc. (eds.), Fl. Trop. Afr. 7: 83 (1897); *Lissochilus roscheri* Rchb.f. in Otia Bot. Hamburg.: 62 (1878); *Lissochilus stylites* Rchb.f. in Otia Bot. Hamburg.: 61 (1878) (Plants of the World Flora Online, 2022).

Description: A terrestrial herb 40–130 cm (400-1300mm) tall. Perennating organs irregularly fusiform-conical potato-like tubers, 40–55 mm. long, 20–30 mm diameter; roots emerging all over tuber and at base of new growth, 1–2.5 mm diameter, white. Leaves plicate, erect, linear to lanceolate, acute, up to 173–600 × 2–20 mm, with alternate and opened sheathing at base and stem width up to 6–14mm. Inflorescence many-flowered ranging from 6–10; peduncle diameter 8–12 mm, bracts reflexed, linear, acute, 9–23 mm long and spaced 11–45mm. Flowers spaced 12–35mm. Petals deep pink, oblong-cordate, acuminate to obtuse, 15–24×

11–19 mm. Fruit pendent, 12–19×4–8 mm.

Distribution: Salaga (Northern region), Digya (Bono East region), Damango (Northern region), Vane (Volta region), and Kpandu-Fesi (Volta region).

Conservation Status: not evaluated. The population trend is unknown. The EOO is 69,214,787.221 km²; the AOO is 1,696.000 km² (GeoCat, 2022).

Phenology: flowers in February to August.

Habitat and Ecology: grows primarily in the savannah; sometimes in grasslands.

Vernacular names: None

Ethnobotanical uses: Ornamentals, medicinal: stimulant.

Specimens examined: Ghana, Wute, Volta region, Fl. 14 July 1970, *Akpablah, G.K.* 2059 (GC); Ghana, Salaga, Northern region, Fl. 13 April 1964, *Hall, J.B.* VBS 1217, (GC); Ghana, Digya, Northern region, Fl. 3 March 1996, *Merello, N.; Schmidt, H.; Amponsah, J.; Welsing, A.; Baah, K.* 1485 (GC); Sierra Leone, Tingy Hills, Fl. 12 April 1965, *Morton; Gledhill*, SL 1835 (GC); Cameroun, Bamenda, Fl. 4 April 1955, *Morton, J.K.* K290 (GC).

Plate 4.5: Image of a voucher specimen of *Eulophia cucullata*

***Eulophia euglossa* (Rchb.f.) Rchb.f. ex Bateman Bot. Mag. 92: t. 5561 (1866)**

Type: Sierra Leone: *van Hees 1288* (holotype: W, n.v.). *Eulophia dusenii* Kraenzl. (Kraenzlin 1894: 254).
Basionym: *Galeandra euglossa* Rchb.f., Bot. Zeitung (Berlin) 10: 935 (1852)

Synonyms: All synonyms are listed below.

Cyrtopera euglossa (Rchb.f.) Szlach. in Orchid. W.-Centr. Africa 3: 87 (2021); *Galeandra euglossa* Rchb.f. in Bot. Zeitung (Berlin) 10: 935 (1852); *Eulophia dusenii* Kraenzl. in Bot. Jahrb. Syst. 19: 254 (1894) (Plants of the World FloraOnline, 2022).

Description: A terrestrial herb 60–150 cm (600-1500mm) tall. Perennating organs above ground, pseudobulbous, cylindrical-conical, swollen at base, 5–10-noded, 160–250 mm long, 10–15 mm diameter; roots basal, 3 mm diameter, white. Leaves plicate, erect, lanceolate to elliptical, acuminate, up to 90–365 × 15–40 mm, with alternate and opened sheathing at base and stem width up to 6–13mm. Inflorescence many-flowered ranging from 7–14; peduncle diameter 4–9 mm, bracts reflexed, linear, acute, 15–32 mm long and spaced 9–36mm. Flowers spaced 8–29mm. Petals green with brown apices, linear-lanceolate, acute, 14–22× 1.5–4 mm. Fruit pendent, 12–19×10–14 mm.

Distribution: Dafo (Volta region), Aburi (Eastern region), and Begoro (Ashanti region).

Conservation Status: not evaluated. The population trend is unknown. The EOO is 22,509,333.043 km²; the AOO is 148.000 km² (GeoCat, 2022).

Phenology: flowers in March to July.

Habitat and Ecology: grows primarily on the bare ground from pseudobulb; sometimes in forests.

Vernacular names: None

Ethnobotanical uses: None

Specimens examined:

Ghana, Dafo, Volta region Fl. 10 March 1968, *Bowling, J.C.* 38139 (GC); Ghana, Begoro, Ashanti region, Fl. 1 June 1967, *Bowling, J.C.* 36567 (GC); Ghana, Adaklu, Volta region, Fl.

16 June 1972, *Hall, J.B.* 43387 (GC); Ghana, Aburi, Fl. 23 July 1902, *Johnson, W.H.* 1065 (GC).

Plate 4.6: Image of a voucher specimen of *Eulophia euglossa*

***Eulophia flavopurpurea* (Rchb.f.) Rolfe D.Oliver & auct. suc. (eds.), Fl. Trop. Afr. 7: 65 (1897)**

Type: GHANA. *Johnson, W.H.*, 851 (Holotype K000078564!).

Basionym: *Cyrtopera flavopurpurea* Rchb.f., Otia Bot. Hamburg.: 68 (1878)

Synonyms: All synonyms are listed below.

Cyrtopera flavopurpurea Rchb.f. in Otia Bot. Hamburg.: 68 (1878); *Eulophia andersonii* (Rolfe) A.D.Hawkes in Orchid Rev. 72: 27 (1964); *Eulophia millsonii* (Rolfe) Summerh. in J.Hutchinson & J.M.Dalziel, Fl. W. Trop. Afr. 2: 446 (1936); *Eulophia tuberifera* Kraenzl. in Bot. Jahrb. Syst. 28: 169 (1900); *Lissochilus andersonii* Rolfe in Bull. Misc. Inform. Kew 1910: 159 (1910); *Lissochilus corbisieri* De Wild. in Bull. Jard. Bot. État Bruxelles 6: 80 (1919); *Lissochilus johnsonii* Rolfe in Bull. Misc. Inform. Kew 1910: 160 (1910); *Lissochilus lacteus* Kraenzl. in Bot. Jahrb. Syst. 43: 398 (1909); *Lissochilus millsonii* Rolfe in D.Oliver & auct. suc. (eds.), Fl. Trop. Afr. 7: 79 (1897); *Lissochilus ochroleucus* A.Chev. in Études Fl. Afr. Centr. Franç. 1: 295 (1913), not validly publ.; *Lissochilus seretii* De Wild. in Ann. Mus. Congo Belge, Bot., sér. 5, 3: 180 (1910) (Plants of the World Flora Online, 2022).

Description: A terrestrial herb 60–95 cm (600-950mm) tall. Perennating organs underground, tuberous, irregularly shaped, 30–40 mm long, 10–20 mm diameter, 2–3-noded; roots scattered, 1 mm diameter. Leaves plicate, erect, linear, acuminate, up to 210–300 × 9–12 mm, with alternate and closed sheathing at base and stem width up to 6–11mm. Inflorescence densely many-flowered ranging from 12–21; peduncle diameter 6–11 mm, bracts reflexed, linear-lanceolate, acute, 6–16 mm long and spaced 6–30mm. Flowers spaced 16–40mm. Petals pale yellow with purple spots, elliptical-oblong, acuminate, 15–25× 4–9 mm. Fruit pendent, 15–20×5–6 mm.

Distribution: Digya (Bono East region), Elmina (Central region), Legon hill (Greater Accra region), and Ayikuma (Volta region).

Conservation Status: not evaluated. The population trend is unknown. The EOO is 6,290,649.373 km²; the AOO is 308.000 km² (GeoCat, 2022).

Phenology: flowers in February to May.

Habitat and Ecology: grows primarily in grasslands.

Vernacular names: None

Ethnobotanical uses: Ornamentals

Specimens examined:

Ghana, Digya, Northern region, Fl. 3 March 1996, *Merello, N.; Schmidt, H.; Amponsah, j.; Welsing, A.; Baah, K.* 1484 (GC); Ghana, Abodi, Fl. 14 March 1956, *Morton, J. K.* A1949 (GC); Ghana, Accra plains, Greater Accra region, Fl. 4 March 1926, *Howes, F.N.* 1133 (GC); Nigeria, Enugu, Fr. 27 March 1952, *Morton, J.K.* 6679 (GC); Ghana, Elmina plains, Central region, Fl. February, 1965, 36141 (GC).

Plate 4.7: Image of a voucher specimen of *Eulophia flavopurpurea*

***Eulophia milnei* Rchb.f. Otia Bot. Hamburg.: 116 (1881)**

Type: South Africa, Natal. Clairmont. *Wood, J.M.*, 4075 (Holotype K000410558!).

Synonyms: All synonyms are listed below.

Cyrtopera milnei (Rchb.f.) Szlach. in Orchid. W.-Centr. Africa 3: 123 (2021); *Graphorkis milnei* (Rchb.f.) Kuntze in Revis. Gen. Pl. 2: 662 (1891); *Orthochilus milnei* (Rchb.f.) Bytebier in Taxon 63: 19 (2014); Eulophia bulbinoides Schltr. in Ann. Transvaal Mus. 10: 234 (1924); *Eulophia corallorhiziformis* Schltr. in Beibl. Bot. Jahrb. Syst. 50: 9 (1895); *Eulophia dictyostegoides* Kraenzl. in Bot. Jahrb. Syst. 28: 168 (1900); *Eulophia gracillima* Ridl. in J. Bot. 24: 292 (1886); *Eulophia lujaeana* Kraenzl. in Bull. Soc. Roy. Bot. Belgique, Compt.-Rend. 38: 217 (1899); *Eulophia lutea* Lindl. in J. Proc. Linn. Soc., Bot. 6: 132 (1862), nom. illeg.; *Eulophia microdactyla* Kraenzl. in Bot. Jahrb. Syst. 51: 389 (1914); *Eulophia pusilla* Rolfe in Bull. Misc. Inform. Kew 1914: 212 (1914); *Eulophia warneckeana* Kraenzl. in Bot. Jahrb. Syst. 33: 67 (1902); *Graphorkis lutea* Kuntze in Revis. Gen. Pl. 2: 662 (1891) (Plants of the World Flora Online, 2022).

Description: Small terrestrial herb 25–52 cm (250-520mm) tall. Perennating organs subterranean, tuberous, 10–13 mm tall, 8–10 mm in diameter, ovoid, forming chains; roots slender, up to 1 mm in diameter. Leaves plicate, erect, linear, acute, up to 150–273 × 3–4 mm, with alternate and opened sheathing at base and stem width up to 4–8mm. Inflorescence many-flowered ranging from 4–10; peduncle diameter 3–4 mm, bracts reflexed, linear, acute, 4–14 mm long and spaced 3–25mm. Flowers spaced 11–31mm. Petals bright yellow, ligulate, acute, 5–10× 1–3 mm. Fruit pendent, 10–18×3–6 mm.

Distribution: Adidome, Winneba, Dakpa, Kete-Krachi, and Banda-Wenchi. Adidome (Volta region), Winneba (Central region), Dakpa (Volta region), Kete-Krachi (Oti region), and Banda-Wenchi (Ahafo region).

Conservation Status: not evaluated. The population trend is unknown. The EOO is 13,489,676.382 km²; the AOO is 372.000 km² (GeoCat, 2022).

Phenology: flowers in February to May.

Habitat and Ecology: grows primarily in grasslands.

Vernacular names: None

Ethnobotanical uses: Ornamentals

Specimens examined:

Ghana, Bimbilla, Northern region, Fl. 19 March 1958, *Morton, J.K.; Hepper* A3114 (GC); Ghana, Kete-Krachi, Fr. 12 April 1953, *Morton, J.K.* 9113 (GC); Ghana, Afram plains, Greater Accra region, Fl. [1900], *Johnson, W.H.* 853 (GC); Ghana, Banda, Fr. 23 March 1953, *Morton, J.K.* 8639 (GC); Ghana, Adidome, Volta region, Fr. 12 April 1958, *Morton, J.K.* A3219 (GC).

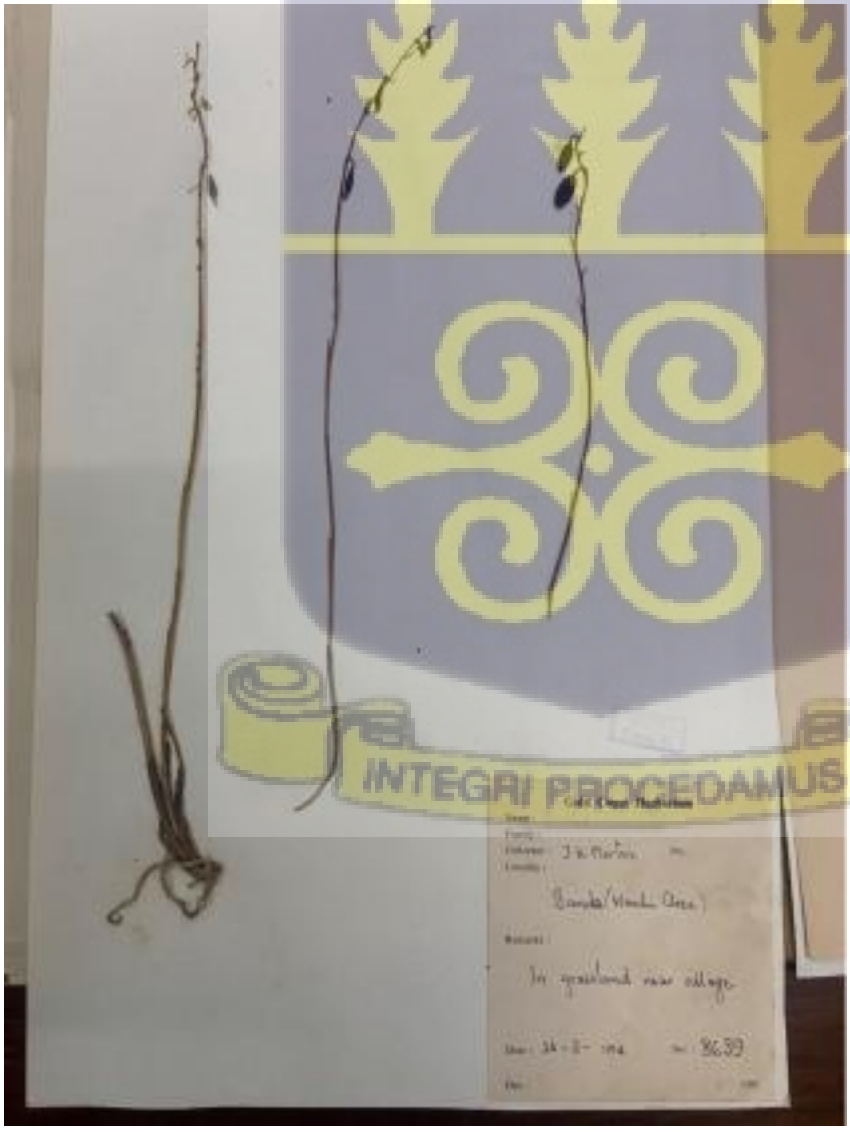

Plate 4.8: Image of a voucher specimen of *Eulophia milnei*

CHAPTER FIVE

5.0 DISCUSSION

5.1 *Eulophia* species Delimitation

The morphological species concept by Stuessy (2009) is applicable in the species delimitation of *Eulophia* in Ghana.

The first morphological analysis focused on the delimitation of *Eulophia dilecta* and *Eulophia cucullata*. According to earlier studies, these two species were placed into different taxa, however, reproductive morphology from this study suggest otherwise.

Morphological studies on the species of *Eulophia* from Ghana suggested eight species. Results from a student t-test analysis on the lip width and length, petal length and width, sepal length and width, and bract length between *E. dilecta* and *E. cucullata* show that these species are not significantly different (Appendix M); this outcome is buttressed by current classification of the Plants of the World Online, Global Biodiversity Information Facility, Tropicos, and Catalogue of Life.

The second morphological analysis focused on the other seven species (*E. alta, E. angolensis, E. buettneri, E. cristata, E. euglossa and E. flavopurpurea,* and *E. milnei*). Significant differences were observed after analyses of morphological characters. For all morphological characters analysed, these seven species recorded significant differences which suggested they were rightfully different species (Appendices B- F).

Another alteration discovered during the study was the change in the nomenclature of *E. waneckeana* into *E. milnei.*

5.2 Morphology and Phylogeny of *Eulophia* species

The species of *Eulophia* in Ghana share a common character with the Arecaceae. Leaves of the species studied were all plicate. Notwithstanding the *Eulophia* species do not share the distinct leaflets of many of the palms. *Eulophia* species possess however simple plicate leaves. Also, the average leaf width of the *Eulophia* species is *ca.* 60±6.98mm while most leaves of the Arecaceae measure *ca.* 100±10mm (Simpson, 2010).

The smaller sized petals (23.5×10.6mm) of the *Eulophia* species in Ghana as compared to larger sized petals (73.5×46.6mm) of other orchid species like *Vanda, Dendrobium, Cypripedium* and *Cymbidium* may perhaps be the reason why these species are rarely used as ornamentals. However, the smaller sized petals correlate with increased number of flowers per peduncle (15±5) as compared to fewer flowers per peduncle (10±2) for the above-mentioned genera of the Orchidaceae (Kowsalya *et al*., 2017).

Most of the species of *Eulophia* possessed monochromatic petals and rarely with multicoloured petals as observed in species of *Dendrobium* and *Cyprepedium.* However, the petal colours observed for the species of *Eulophia* in Ghana are similar to the most of the other orchid species (Rindyastuti *et al*., 2018).

The colour and size of the lip of the species of *Eulophia* in Ghana were very distinct except for members of *E. dilecta* and *E. cucullata* which were dark rose and *E. euglossa* and *E. flavopurpurea* which were pale yellow (Table 4.4). This same observation was recorded for the same group of *Eulophia* species sharing similar spur colouration. The spur shape of the *Eulophia* species delimited the various members into eight clades (*E. dilecta* and *E. cucullata* shared the same character state).

The shapes of spur, lip, midlobe, and anther cap were less significant in distinguishing the various species of *Eulophia,* however these characters were helpful in distinguishing the species of *Eulophia* collected by Ortúñez *et al*. (2020).

Seven species out of the eight species of *Eulophia* recorded from this study were also recorded by Ortúñez *et al*. (2020), their study failed to record *E. milnei.* It is likely the area of occupancy of *E. milnei* currently is lacking towards central Africa or the ravaging biodiversity loss due to climate change and anthropogenic activities have caused this observation. According to POWO (2022), *E. milnei* is distributed towards central Africa.

The colouration of the lip and the shapes of spur, lip, midlobe, and anther cap agreed with observations made by these authors. However, the colouration of the petals and sepals for *E. angolensis* and *E. buettneri* were dissimilar from the two observations. This study recorded homogenous colour patterns while Ortúñez *et al*. (2020) recorded heterogenous colour patterns between the petals and sepals. This disparity in the observations may have been due to the subjectivity attached to visual records. It is also likely that the pigmentation of these members of the species observed during the two studies were lacking. Under poor atmospheric conditions, orchid flowers may appear different from the expected (Norah, 2014). It is safe to say that the qualitative characters used in the two studies are plastic due to the inconsistency in the observations.

5.3 Ecology of *Eulophia* species

The flowering and fruiting periods (January to August; Table 4.4) of the species of *Eulophia* in Ghana suggest that the members of these taxa reproduce in the wet season. Records from Ortúñez *et al*. (2020) suggest likewise with a few exceptions of flowering and fruiting in January and February just as observed in this study as well. From this similarity in phenology between *Eulophia* species in Ghana, Nigeria and the Central African countries, it is safe to deduce that these species reproduce best in high humidity. Similar observations were made by Sourav *et al*. (2017) on the *E. obtusa.* Members of the taxon flowered from May to July but the researchers failed to observe fruits, however, locals confirmed fruiting in the same period.

The distribution of *Eulophia* species in Ghana is similar to that observed in Uganda (Norah, 2014). Most of the members were highly distributed towards wetlands where lakes and swamps were common. This observation is replicated by the species of *Eulophia* in Ghana. However, these species were distributed more in forests in Uganda than they were in Ghana. This disparity could be due to the distinct species of *Eulophia* occurring in Uganda. According Norah (2014), Uganda shares only one species (*E. angolensis*) with Ghana.

Eulophia alta was observed to be a terrestrial, large plant producing a subglobose, subterranean corm and loosely many-flowered, racemose inflorescence. The species was found in open areas, along roadsides and on cleared land reverting to bush lower montane forest, usually in heavy, moisture-retentive soils by Kolanowska & Szlachetko (2014). Information from the herbarium labels (Table 4.3) recorded about the habitat types of *E. alta* stated that these members predominantly grew around swamps, which agreed with observation of the species growth in heavy, moisture-retentive soils.

Eulophia angolensis was found from the north-eastern parts of the former Transkei through the coastal parts of KwaZulu-Natal and thence inland to the Lowveld of Mpumalanga and into tropical Africa (Peter and Johnson, 2013). Information from herbarium labels were scanty concerning the habitats of *E. angolensis*, however, a crosscheck in GBIF database suggested that the species grew predominantly in savannahs.

According to Peter and Johnson (2013), *Eulophia cucullata* occurred in moist coastal grasslands from near Durban in the south, northwards into tropical Africa. Flowering occurred mostly after fire, with inflorescences attaining *ca.* 50 cm and bearing a few large, deep pink pouch-like flowers. Members of this species were recorded to grow luxuriantly in grasslands, and savannahs according to the herbarium labels. Also, from Fig. 4.2, it can be observed that some collection sites of the species were along the lower Volta region towards the coastal regions. However, majority of the collection sites disagreed with observations made by Peter and Johnson (2013). This anomaly could be due to the fire regime in areas

towards the northern part of Ghana. The Sahel and Guinea savannahs towards the northern belt might be key to the survival of *E. cucullata.*

CHAPTER SIX

6.0 SUMMARY, CONCLUSION, AND RECOMMENDATIONS

6.1 Summary

- There are eight species of *Eulophia* in Ghana (*E. alta, E. angolensis, E. buettneri, E. cristata, E. cucullata, E. euglossa, E. flavopurpurea* and *E. milnei*).
- *Eulophia* species have a cosmopolitan distribution in Ghana.
- Most of the species produce flowers and fruits between January to August.
- The species of *Eulophia* in Ghana preferred grasslands and savannahs to forests, swamps, open ground and under trees.
- The species of *Eulophia* in Ghana are mostly used as ornamentals.
- Leaves of *Eulophia* species in Ghana are plicate, erect, often linear to lanceolate except elliptical in *E. alta, E. cristata* and *E. euglossa.*
- Inflorescence of the genus are often densely flowered except in *E. buettneri, E. cucullata,* and *E. euglossa.*
- Flowers in the shades of yellow and red, except green in *E. euglossa*.

6.2 Conclusion

This study investigated the species of *Eulophia* in Ghana. It was observed that there were eight species, as supposed to earlier collections from the major herbaria in Ghana. This current knowledge served as the basis for the construction of the key and checklist of species of *Eulophia*. The extent of morphological variations within the genus was investigated using 38 morphological characters which generated eight taxa.

Ecological data from herbarium labels buttressed with data from GBIF assisted in generating the distribution maps; it was observed that species of *Eulophia* have a cosmopolitan distribution in Ghana from the herbarium records.

6.3 Recommendations

- Field collection of orchids could enlighten the scientific community on the accuracy of the herbaria data and the current distribution of the family in Ghana.
- Research should be conducted on other genera of the Orchidaceae in Ghana.
- Anatomical and palynological data from collected orchids would help ascertain the changes in the circumscription of the genus.

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APPENDICES

APPENDIX A: Data collected from herbarium labels on *Eulophia* species

SPECIES	LOCALITY	REMARKS	DATE
E. angolensis	South of Ho; road to Keta	In marshy guinea savannah	30/5/1956
E. angolensis	Ngure; Axim district	A terrestrial orchid in marshy soil	17/6/1982
E. alta	Foso	Perianth is greenish-yellow in open swamps	None
E. alta	Avu lagoon near Dabala	Floating swamp on water; erect herb about 2m with greenish-yellow but lip is purplish	None
E. alta	Nkawkaw	Floating swamp on water; erect herb about 2m with greenish-yellow but lip is purplish	09/6/1958
E. buettneri	Jaketi road	Growing in savannah	24/6/1958
E. buettneri	Jaketi road	Stem 2.5-3ft high, sepals are dark-green, petals are bright pink and spur is pale yellow	12/2/1958
E. buettneri	Afram plains	Terrestrial orchid; lip yellow	None
E. cristata	Nakpanduri	Growing under a tree	8/4/1970
E. cristata	Near Manhyia	Ground orchid with purple flowers in grassland between thicket clumps	02/1970
E. cristata	Shai hills; alt. 200m	Leafless in grassland	22/02/1977
E. cristata	Mole Nat. Park	Top petals white;	8/4/1976

		bottom dark lavender	
E. cristata	Afram plains	3.5 ft tall, flowers mauve	14/3/1926
E. cristata	Elmina plains	Flowers are pink	8/3/1956
E. cristata	Elmina	None	30/5/1954
E. cristata	Accra plains	2-3 ft high	19/3/1934
E. cristata	Achimota-Accra plains	Root tuberous	19/2/1976
E. cristata	Bawku-Wenchi	In morasses savannah	21/3/1953
E. cristata	9 miles from north of Tamale	None	29/3/1956
E. cristata	Legon hill	None	28/1/1956
E. cristata	Winneba plains	Flowers are pink to purple	8/3/1956
E. cristata	Agricultural research station, Nungua	No leaves during collection	10/5/1962
E. cristata	Legon hill	Tip purple, petals mauve, wing tip olive	19/4/1953
E. cucullata	Salaga	Purple flowers with no leaves	None
E. cucullata	Digya Nat. Park; 07^{O}33’27’’N; 00^{O}37’37’’W;110m	Bulb is whit; stalk is greenish-purple with brown patches	3/4/1996
E. cucullata	Tingi Hills; Sierra Leone	Flowers pink, spur yellow; calyx olive. Not fragrant; common in grassland	12/4/1965
E. cucullata	Wum crater lake; Bamenda area, Cameroun	Flowers pink	4/2/1955
E. cucullata	Damango scarp.	Growing in savannah	24/3/1953
E. cucullata	Damango-Kplesi	Flowers bright	31/3/1956

		mauve, sepals brownish-green	
E. cucullata	Damango; roadside from Kpirri lake	Flowers bright mauve	3/3/1956
E. dilecta	Vane	Growing in open grassland	1/7/1958
E. dilecta	Kpandu-Fesi	Flowers are large and purple but plant is leafy	15/8/72
E. euglossa	Dafo; V. Region	Growing in shaded forest flower at 1500' alt. Flowers purple	103/1968
E. euglossa	Begoro; floor of dense forest	Flowers pinkish, leaves present at time of flowering	1/6/1967
E. euglossa	Aburi	Terrestrial orchid	23/7/1902
E. flavopurpurea	Digya Nat. Park; 07^{O}33'27''N; 00^{O}37'37''W;110m	App. 1m tal, bulb is white and 7cm long, 5cm wide. Fowering stalk is purplish-grey; outer perianth is pale lavender and inner green	3/4/1996
E. flavopurpurea	Enugu; Nigeria	Flowers are cream, spathe yellow	27/3/1952
E. flavopurpurea	Elmina plains	Lacking leaves during harvest, flowers are white and sweet-scented	2/1965
E. flavopurpurea	Ayikum to Doyum grassland	Plicate leaves; rhizome parallel to surface	14/5/1956
E. flavopurpurea	Legon hill	In sandy grassland; flowers yellow and spur orange	17/3/1956
E. warneckeana	Anum; in grassland on serpentine	Herb with yellow flowers	14/3/1974

E. warneckeana	Afram plains	Dark yellow lip	None
E. warneckeana	Banda-Wenchi	In grassland near village	23/3/1953
E. warneckeana	Kete-Krachi	No leaves at harvest	12/4/1953
E. warneckeana	Adidome	Pale yellow flowers with purple markings	12/4/1958
E. warneckeana	Winneba	Cream flowers	27/2/1955
E. warneckeana	Dakpa; V. Region	Flowers yellow	22/5/1971

APPENDIX B: One way ANOVA of the leaf length of the species of *Eulophia*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	9506.981	8	1188.373	16.07004	$1.98e^{-10}$	2.173989
Within Groups	3031.933	41	73.94959			
Total	12538.91	49				

APPENDIX C: One way ANOVA of the leaf width of the species of *Eulophia* ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	113.6313	8	14.20392	54.83756	$3.45e^{-18}$	2.200826
Within Groups	9.583667	37	0.259018			
Total	123.215	45				

APPENDIX D: One way ANOVA of the tepal length of the species of *Eulophia*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32.85696	8	4.10712	62.58641	$3.03e^{-40}$	2.012654
Within Groups	8.268522	126	0.065623			
Total	41.12548	134				

APPENDIX E: One way ANOVA of the tepal width of the species of *Eulophia*

ANOVA

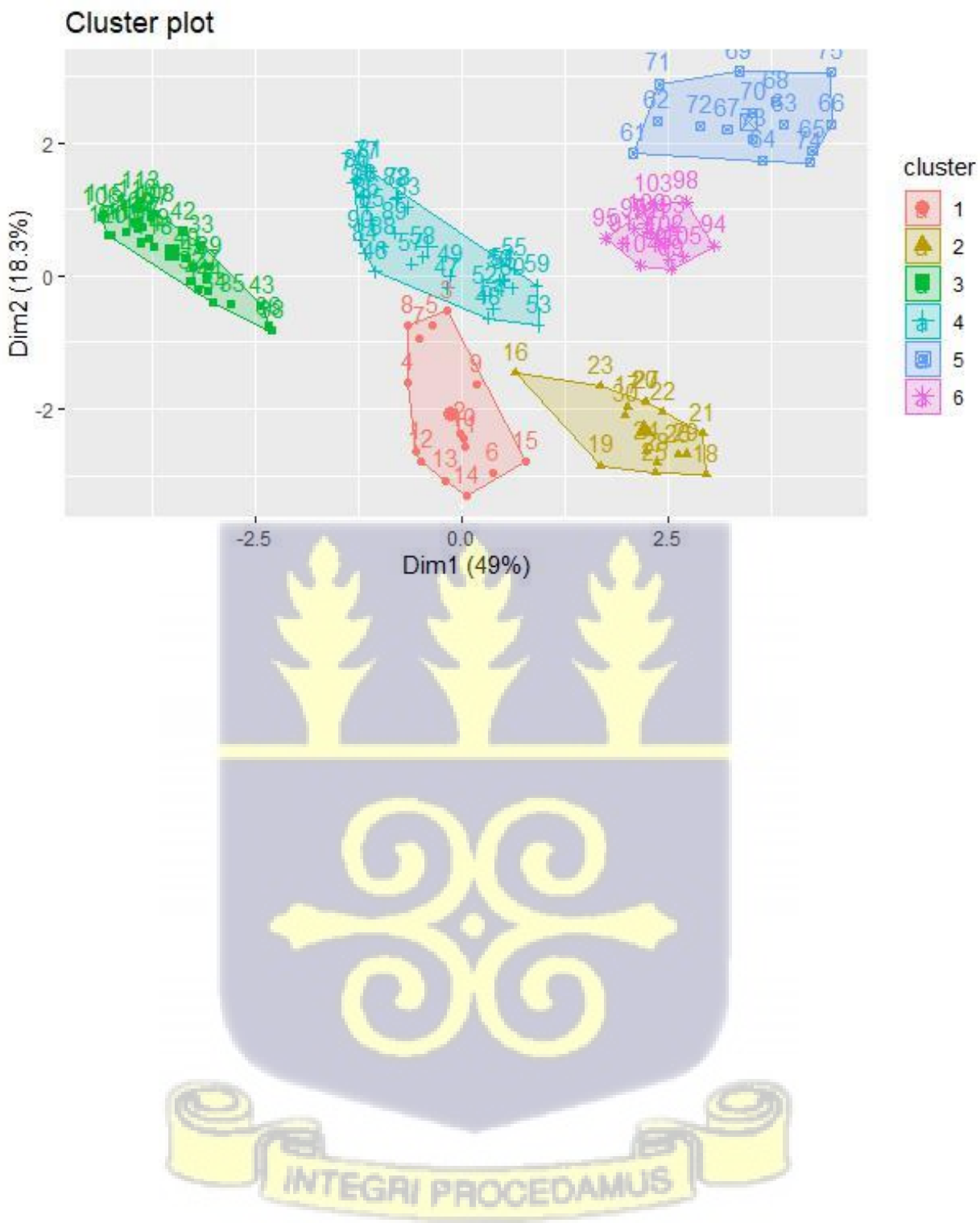
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.43524	8	2.304405	81.68292	$1.43e^{-41}$	2.027774
Within Groups	2.962216	105	0.028212			
Total	21.39745	113				

APPENDIX F: One way ANOVA of the tepal length of the species of *Eulophia*

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	20.03008	8	2.503759	36.77902	$5.52e^{-11}$	2.396503
Within Groups	1.497667	22	0.068076			
Total	21.52774	30				

APPENDIX G: Scatterplot for cluster analysis



APPENDIX H: Mean ±standard error of the morphological characters measured

SPECIES (mean±s.e)	Leaf length/cm	Leaf width/cm	Spaces between veins/cm	Stem width/cm	Bract length/cm	Interbractal spacing/cm	Tepal length/cm	Tepal width/cm	Interfloral spacing/cm	Fruit length/cm	Fruit width/cm
E. alta	56.14±6.47	5.64±0.25	0.50±0.25	0.93±0.24	1.62±0.13	0.50±0.04	2.22±0.08	0.54±0.04	3.33±0.55	3.00±0.34	1.60±0.15
E. angolensis	59.95±4.42	1.23±0.39	0.36±0.05	0.45±0.04	0.62±0.04	1.10±0.17	1.93±0.09	0.83±0.09	1.93±0.17	1.75±0.67	0.60±0.04
E. buettneri	29.45±5.45	0.53±0.11	0.17±0.02	0.45±0.11	1.08±0.09	2.28±1.03	2.24±0.12	1.32±0.13	2.28±0.68	3.00±0.16	2.10±0.85
E. cristata	31.56±2.25	2.65±0.11	0.51±0.03	0.84±0.06	1.89±0.12	1.91±0.25	1.69±0.05	0.62±0.03	1.99±0.12	4.60±0.34	1.93±0.28
E. cucullata	18.44±0.74	0.38±0.05	0.10±0.01	0.84±0.05	1.94±0.11	2.87±0.42	1.91±0.08	1.26±0.05	2.23±0.19	1.80±0.69	0.50±0.13
E. dilecta	49.52±3.02	1.68±0.16	0.43±0.04	1.13±0.13	5.68±0.62	3.33±0.31	2.07±0.03	1.40±0.40	1.70±0.28	1.90±0.12	0.90±0.42
E. euglossa	24.67±3.38	2.72±0.39	0.56±0.05	0.85±0.16	2.43±0.09	1.77±0.12	1.67±0.05	0.27±0.02	1.84±0.13	1.86±0.56	1.10±0.21
E. flavopupurea	25.17±2.52	1.10±0.1	0.30±0.02	0.77±0.07	1.26±0.07	2.04±0.19	2.12±0.06	0.71±0.03	2.25±0.17	1.75±0.24	0.55±0.05
E.warneckeana	23.36±2.20	0.34±0.03	0.14±0.02	0.49±0.03	0.59±0.05	0.95±0.14	0.71±0.02	0.17±0.01	1.60±0.14	1.39±0.06	0.39±0.02

APPENDIX I: Cluster data of morphological characters measured

SPECIES	sub_grp	HT (mm)	POD (mm)	LL (mm)	LW (mm)	BL (mm)	LIL (mm)	LIW (mm)	PL (mm)	PW (mm)	SL (mm)	SW (mm)	CL (mm)	FL (mm)	MLL (mm)
a1	1	1000	10	1200	510	10	15	8.4	14	3	18.5	4.7	9.8	20	5.2
a2	1	1290	9.5	1100	500	15	16	9.2	19	5	18.3	4.8	8.5	21	5.7
a3	1	1300	4	100	560	20	19	9.9	16	4.4	19.5	5.2	9.3	26	6
a4	1	1500	8	300	650	13	18	10	15	3	19.4	4.9	7.1	29.6	5.2
a5	1	1540	9.6	250	610	13	21	11.7	16	3.9	18.4	4.3	8.9	21	5.7
a6	1	1600	3	1000	590	16	23	11.5	19	5	19.7	5.1	7.5	29	5.2
a7	1	1300	5.9	230	560	10	17	9.5	18	3	20	4.5	10	24	5.7
a8	1	1230	6	250	545	12	16	12	15	4.6	18.2	4.1	9.6	25	5.4
a9	1	1540	12	560	600	17	23	11.7	16	5	18.5	4.2	8.9	26	5.7
a10	1	1230	14.5	800	610	19	22	9.2	14	3.5	18.4	4.8	7.5	29.1	5.8
a11	1	1000	5	900	620	13	20	9.8	19	4.7	18.9	5.5	7.8	23.4	5.2
a12	1	2000	7	1000	560	11	16	10.6	14	3	20	4.3	8.9	28.9	5.3
a13	1	1800	8	1200	500	13	19	10.6	14	5	18.6	4.2	7.4	29.5	5.9
a14	1	1900	9	1150	600	15	17	9.1	15	3	19.6	5.4	9.6	30	6
a15	1	1500	10	1000	540	20	20	12	19	4	20	5.5	10	29.7	5.6
an1	2	600	12.6	650	7.5	10.5	16.5	11.6	22.4	9.5	15.6	5.3	10.5	31.7	4.3
an2	2	700	34.8	780	8.9	23.5	17.5	12.5	16.7	10.5	26.5	6.5	11	34.7	2.1
an3	2	750	50	730	10	12.5	18.9	13.7	23.6	12.5	23.5	7.3	10.5	44.5	4.2
an4	2	2000	23.6	780	33.4	13.6	17.6	12.4	22.7	11.6	17.9	7.1	10.6	41.6	1.5
an5	2	2050	46.7	675	23.5	19.6	18.7	11.5	25.7	10.6	18.5	5.6	10.4	34.9	3.5
an6	2	1950	35.7	660	40.6	23.6	23.5	10.7	26.8	12.3	26.7	6.3	10.3	38.9	1.9
an7	2	890	34.8	569	34.7	10.7	24	14.4	21.8	13.7	18.9	6.8	11	36.7	4.3
an8	2	700	12.4	650	23.6	11.3	24.7	12.4	24.6	12.7	17.5	5.7	10.5	31.7	4.6
an9	2	950	34.7	750	35.6	15.6	17.8	13.6	23.6	13.6	19.3	6.9	10.1	40.6	2.1

an10	2	1010	24.7	765	33	12.5	20.5	12.3	25.4	11.6	21.5	7.2	10.3	43.7	4.5
an11	2	1500	34.8	630	23.6	13.6	21.5	14.7	23.1	10.6	22.4	7.5	10.2	44.9	5.1
an12	2	2000	23.5	560	24.6	16.8	23.6	12	19.6	13.4	23.7	6.7	10.6	37.9	4.3
an13	2	1900	45.7	780	23.6	17.8	22.6	13.5	17.8	12.5	20.9	5.6	10.5	45	2.6
an14	2	1600	45.6	720	24.6	14.6	23.6	15.8	24.6	13.4	16.7	5.4	11	44.3	3.4
an15	2	1500	11.3	650	25.7	19.7	17.8	12.4	23.5	12.5	26.4	7.3	10.4	37.1	1.7
b1	3	210	6.4	210	12.3	6.5	8.2	5.6	6.3	1.7	2.2	1.7	1.7	22.1	2.1
b2	3	260	9.2	420	10.5	7.3	9.6	6.4	7.5	4.5	7.5	1.9	2.5	25.3	2.5
b3	3	300	6.3	310	12.2	12	9.5	6.1	8.4	3.6	10.6	2.1	2.8	21.7	2.4
b4	3	310	7.1	360	13.5	11.6	8.4	4.8	6.8	2.5	11.3	3.4	3.4	30	2.2
b5	3	316	8.2	400	19.5	10.6	8.3	6.2	6.2	1.9	10.6	5.6	3.1	24.6	2.1
b6	3	250	5.8	415	21.6	9.9	9.6	6.5	10	4.3	9.5	5.8	2.7	28.4	2.6
b7	3	270	5.7	390	23.8	8.6	10	5.7	9.8	2.6	10.5	2.5	2.9	23.6	2.7
b8	3	290	8.9	410	25.6	11.2	9.5	5.9	7.6	4.5	11.2	6.7	1.5	27.8	2.3
b9	3	280	7.5	215	14.6	10.6	9.3	4.4	8.2	2.3	7.6	5.6	1.7	21.3	2.1
b10	3	318	9.6	220	11.5	12	8.9	4.8	7.5	2.8	4.6	3.6	2.4	24.6	2.2
b11	3	320	10	350	10.7	11.4	8.4	5.9	7.7	3.5	3.9	2.8	3.5	30	2.5
b12	3	240	6.9	240	12.3	11.7	9.3	5.1	8.3	2.8	7.9	1.8	3.7	21.5	2.6
b13	3	250	5.7	280	13	10.6	10	6.1	8.2	5	8.3	6.7	2.1	26.7	2.1
b14	3	290	8.5	370	25	7.8	9.7	5.7	9.5	4.6	5.2	3.5	2.5	24.8	2
b15	3	300	7.7	410	21	11.8	8.2	4.8	6.2	2.3	11.5	2.7	3.5	21.5	2.1
m1	3	250	8	150	11.2	6.9	5.7	3	4.8	2.6	4.9	1.7	2	20	2
m2	3	400	10	140	15.4	7.9	6.7	3.9	8	2.1	9.2	1.8	2.6	19.4	2.5
m3	3	370	8.6	170	13.7	8.4	6.2	5	7.6	2	9.4	2.4	2.6	17.5	2.5
m4	3	390	9.4	210	12.6	7.2	6.5	3	7.9	2.1	4.5	2.2	2.7	17.9	2.7
m5	3	480	8	170	26.9	8.5	5.7	4.4	8	2.5	6.7	2.1	2.3	16.7	2.3
m6	3	300	8.1	410	28.7	8.3	5.9	4.5	7.2	2.4	5.8	2.6	2.1	12.5	2.1
m7	3	360	8.9	215	24.6	7.8	7	3.5	6.5	2.2	5.1	2.7	2.2	17.3	2.5
m8	3	515	10	220	22.6	9.1	6.4	4.1	6.3	2.1	5.4	3	2.5	12.6	2.6
m9	3	450	9.4	350	15.3	6.8	5.9	3.4	7.8	2.6	4.3	2.9	2.3	16.5	2.3
m10	3	480	9.5	240	12.5	7.5	5.2	3.7	4.2	2.7	5.6	1.5	2	17.5	2.1

m11	3	410	8.5	280	15.9	8.9	5.4	3.5	5.6	2.3	6.7	1.7	2.7	20	2.2
m12	3	400	8.1	370	16.4	9.3	6.8	4.5	6.2	2.1	8.6	1.8	2.3	15.8	2.5
m13	3	500	9.4	410	12.5	10	5.9	4.2	8	2.2	8.2	2	2.1	18.4	2.3
m14	3	520	9	300	11.3	9.8	7	4.1	6.1	2.5	7.3	2.3	2.5	19.3	2
m15	3	310	8.5	240	30	6.5	5.5	3.7	4.2	1.7	6.9	1.9	2	20	2.1
c1	4	600	23.8	300	7.6	11.5	12.5	11.4	12.5	6.7	15.7	3.4	7	24.6	2.7
c2	4	670	23.7	350	20.5	13.4	13.7	12.5	14.8	8.5	22.5	3.1	7.1	28.4	4.6
c3	4	1300	33.6	540	31.5	15.6	20.4	13.5	12.6	8.3	17.8	4.7	7.2	23.6	2.8
c4	4	1250	14.9	310	20.8	23.4	14.6	10.9	18.5	7.8	19.4	3.6	7.5	27.8	2.5
c5	4	1190	15.9	570	21.6	30	15.4	12.5	16.9	9.1	21.5	5.1	7	21.3	2.4
c6	4	700	39.7	455	25.7	29.8	16.8	13.4	15.8	6.8	17.9	3.9	7.1	24.6	2.2
c7	4	890	40	470	31.8	21.6	18.3	11.7	13.4	7.5	14.9	5.2	7.2	21.5	2.1
c8	4	780	37.8	620	32.6	24.5	17.4	12.4	18.5	8.9	22.1	3.7	7.3	26.7	2.6
c9	4	650	29.6	630	33.4	25.6	19.8	11.6	13.7	9.3	16.8	3.8	7.4	24.8	2.7
c10	4	1000	24.7	400	32.7	23.7	20.5	12.9	16.8	9	15.8	5.2	7.5	21.5	4.5
c11	4	1050	14.8	350	8.6	26.8	21.6	11.6	13.6	9.2	17.9	4.9	7.2	30	5.6
c12	4	600	15.7	370	9.5	14.7	12.5	13.1	18.6	7.8	14.5	3.6	7.1	22.8	3.5
c13	4	700	20.5	420	32.5	23.8	13.7	12.7	13.8	6.9	16.8	3.8	7.2	21.8	2.8
c14	4	1200	37.8	500	34.2	21.6	22	13.5	13.7	8.2	20.4	4.8	7.1	20.6	4.9
c15	4	1300	33.6	510	20.6	30	12.6	13.1	12.6	7.6	21.3	5.1	7.3	27.9	5
e1	4	700	12.6	240	34.6	16.7	13.4	7.6	18	3.3	19.5	3	4.5	13.5	7.8
e2	4	850	10.4	235	45	33.4	13.7	7.9	16.2	2.5	18.3	2.1	4.7	17.4	7.2
e3	4	1400	15	320	46.6	29.8	14	8.5	17	2.1	19.2	3.1	5.1	16.7	7.6
e4	4	1350	13.8	280	25	21.6	13.6	7.8	17.4	1.7	18.9	2.3	5	12.5	7.1
e5	4	1200	14.7	260	39	24.5	13	9	15.6	2.8	20.1	1.2	4.8	17.3	8
e6	4	1400	12.7	250	48.6	25.6	13.4	8.2	16.4	3.2	21.6	2.2	4.8	12.6	7.2
e7	4	1450	11.5	235	27	23.7	14	7.5	18	3	22.7	3.1	5.2	16.5	7.3
e8	4	1500	12.6	325	36.5	26.8	13.8	8.9	17.9	2.8	23.1	3	4.7	17.5	7.5
e9	4	650	14.3	320	51.6	14.7	13.6	8.4	16.7	2.1	21.5	2.5	4.8	22.8	7.2
e10	4	760	15	300	40.5	23.8	13.9	7.6	17.2	2.7	18.6	2.1	4.2	21.8	8
e11	4	700	13.4	235	33.6	21.6	13.4	9	17.9	1.6	21.4	1.7	5	20.6	7.3

e12	4	840	12.6	256	26.9	16.7	13	8.2	18	3	20.6	2.8	4.3	14.3	7.9
e13	4	900	14.3	250	28.7	18.9	13.5	8.7	15.3	2.1	23.4	3.2	4.7	24.7	7
e14	4	930	12.3	245	24.6	20.8	13.6	9	16.9	3.1	22.4	3	5	23.8	7.5
e15	4	1040	10.1	298	22.6	21.3	13.9	7.8	16.7	2.3	16.5	2.8	4.6	25	7.8
cu1	5	400	30	420	7.5	36.8	18.7	21.5	15.6	13.4	14.5	3.4	13.4	17.5	11.1
cu2	5	550	20.6	310	8.9	37.6	21.5	22.3	17.5	12.5	16.4	4.3	14.5	12.4	11.6
cu3	5	450	26.8	360	10	45.6	22.7	34.6	20.9	15.3	17.4	5.6	13.7	16.4	11.5
cu4	5	630	23.8	400	12.4	40.5	23.6	23.7	23.6	14.4	17.8	6.7	13.6	13.6	12
cu5	5	670	25.6	415	14.6	36.9	20.5	40	22.5	11.4	21.6	8	14.8	13.5	11.7
cu6	5	720	27.8	390	13.8	50.4	15.9	34.5	16.6	20.4	22.5	7.4	15	17.4	11.5
cu7	5	590	25.6	410	16.7	51.6	12.8	21.4	17.9	16.9	23.6	5.6	13.1	16.7	12
cu8	5	1000	27.5	215	16.3	38.7	18.6	35.6	15.3	17.5	21.7	7.1	14.5	12.5	11.4
cu9	5	970	24.6	220	12.9	52.6	21.4	37.6	17.4	13.4	15.4	4.3	13.5	17.3	11.7
cu10	5	1090	23.8	350	15.3	53.8	22.3	21.6	19.4	15.6	17.3	5.8	15	12.6	11.2
cu11	5	675	29.5	240	12.5	51.7	10.1	23.8	20.4	10.2	18.9	3.6	14.3	16.5	12
cu12	5	890	27.8	280	15.9	37.1	15.6	31.6	21.5	13.6	16.7	4.5	13.7	17.5	11.3
cu13	5	1200	25.6	370	16.4	37.2	12.8	37.5	20.3	14.5	20.4	6.7	13.9	17.3	11.7
cu14	5	1300	23.6	410	12.5	42.6	22.3	35.6	21.7	12.4	21.6	7.9	13.4	17.1	11.8
cu15	5	1250	21.3	300	11.3	50.9	21.6	40	21.3	20.2	23.4	3.4	15	16.9	12
f1	6	650	13.6	320	3.3	16.9	23.7	13.5	20.6	7.6	22.5	5.4	12.5	24.5	14.7
f2	6	760	12.5	280	2.5	25.6	24.8	13.1	21.5	7.9	21.6	5.7	12.6	25.6	14.3
f3	6	830	18.5	260	2.1	23.7	23.7	11.7	22.4	8.4	31.5	4.5	12.4	24.7	14.7
f4	6	940	19.4	250	2.8	26.8	25.6	12.7	20.4	7.2	32.6	6.7	12.5	26.7	15
f5	6	925	10.6	235	2.1	15.7	23.1	11.8	21.5	8.5	22.5	4.3	13	27.4	14.7
f6	6	950	12.5	325	2.7	23.8	29	10.9	20.3	8.3	23.6	5.8	12.7	27.8	14.9
f7	6	760	15.9	215	7.3	21.6	28.4	12.5	21.7	7.8	21.7	3.6	12.5	28	15
f8	6	630	12.3	220	2.9	29.8	23.5	13.4	21.3	9.1	34.4	4.5	12.8	24.3	14.3
f9	6	750	18.9	350	4.3	21.6	25.8	11.7	23	6.8	21.4	6.7	12.6	26.4	14.8
f10	6	800	15.7	240	5.6	24.5	23.9	12.4	22.1	7.5	20.6	5.8	13	24.7	14.9
f11	6	810	17.6	280	6.9	25.6	23.5	11.6	20.5	8.9	23.4	5.1	12.8	26.7	14.5
f12	6	950	12.4	370	7.1	23.7	26.8	12.9	21.6	9.3	22.4	5.4	12.4	25.5	15

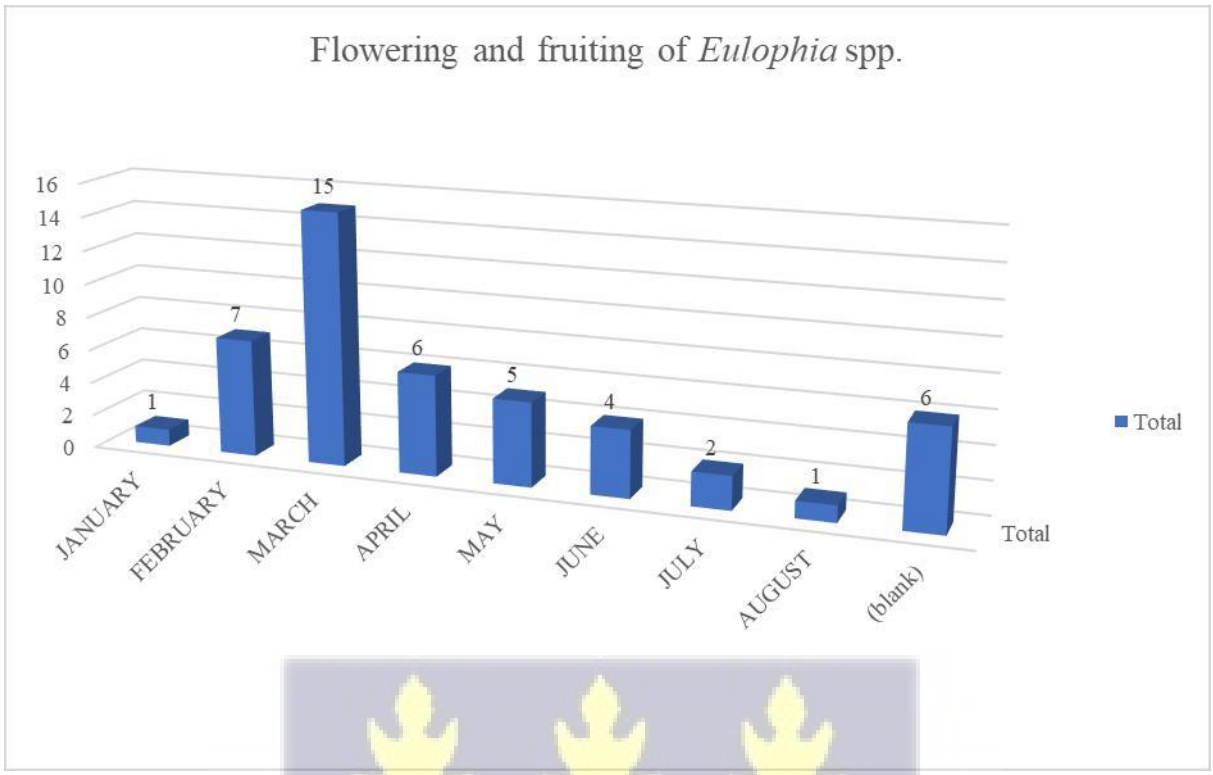
f13	6	920	13	195	7.5	26.8	20.4	11.6	23	9	31.6	4.3	12.5	24.7	14.3
f14	6	735	12.6	345	7.1	15.7	24.4	13.1	22.6	9.4	20.5	5.6	13	26.9	14.2
f15	6	600	11.5	340	7.3	20.6	23.5	12.7	21.4	7.3	32.4	6.7	12.6	24.6	15

HT=Height of plant, POD=Perennating organ diameter, LL=Leaf length, LW=Leaf width, BL=Bract length, LIL=Lip length, LIW=Lip width, PL=Petal length, PW=Petal width, SL=Sepal length, SW=Sepal width, CL=Column length, FL=Fruit length, MLL=Midlobe length

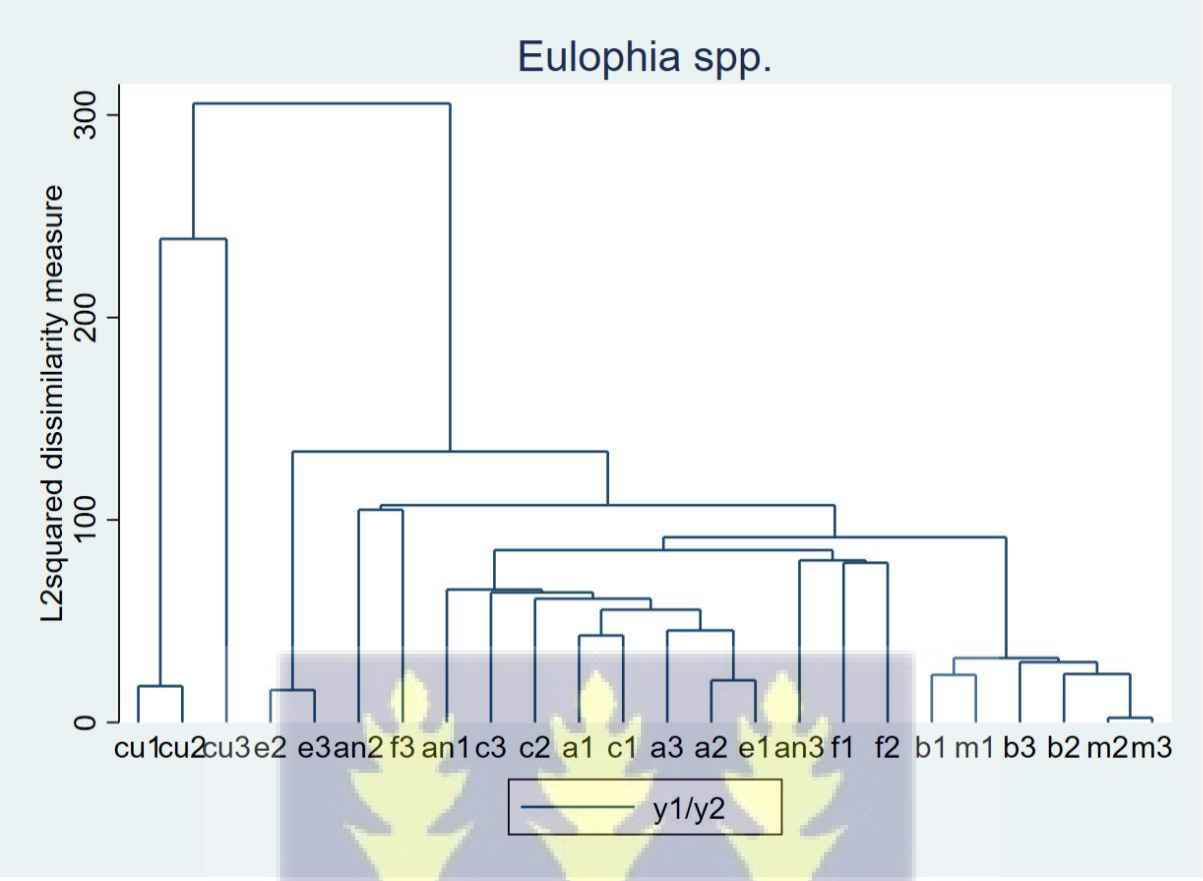
APPENDIX J: Distribution of *Eulophia* species in Ghana (GBIF, 2022)

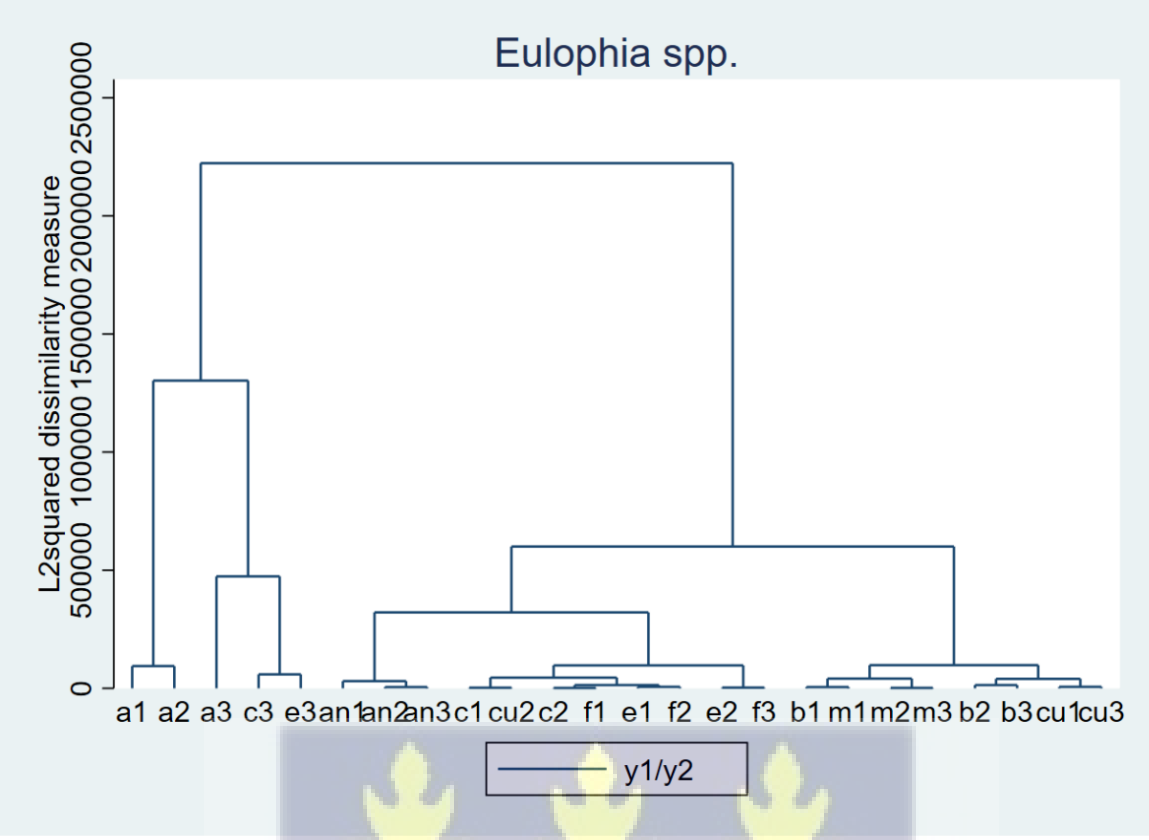
SPECIES	COORDINATES
E. alta	7.9N, 2.3W; 7.5N, 2.2W
E. angolensis	0.0N, 0.0E
E. buettneri	
E. cristata	6.5N, 0.4E; 9.2N, 1.8W; 5.9N, 0.1E; 7.7N, 1.9W; 9.1N, 1.8W; 7.8N, 2.2W; 7.9N, 2.4W; 7.6N, 0.6W; 9.2N, 1.9W; 5.7N, 0.2W; 5.5N, 0.0E; 9.1N, 1.5W; 6.7N, 1.7W; 10.5N, 0.2W; 10.3N, 0.1E; 5.6N, 0.2W; 5.3N, 0.1E; 5.7N, 0.1W; 5.4N, 0.1E; 5.8N, 0.0E
E. cucullata	7.6N, 0.6W; 7.8N, 2.5W; 7.3N, 0.4E; 8.5N, 1.6W; 0.0N, 0.0E; 6.9N, 0.2E; 6.7N, 0.4E; 6.5N, 0.3E; 9.1N, 1.8W; 10.9N, 2.0W; 10.5N, 1.6W
E. euglossa	0.0N, 0.0E; 7.0N, 0.5W; 6.6N, 0.3E; 6.4N, 0.4W; 6.2N, 0.2E; 5.9N, 0.2W
E. flavopurpurea	7.6N, 0.6W; 7.3N, 0.4E; 5.9N, 0.1W; 5.8N, 0.0E; 5.5N, 0.1E; 0.0N, 0.0E; 5.7N, 0.2W; 5.4N, 0.1E; 5.6N, 0.2W
E. milnei	6.5N, 0.2E; 6.3N, 0.1E; 5.3N, 0.6W; 5.2N, 0.4E; 8.2N, 2.4W; 8.1N, 2.2W; 5.4N, 0.6W

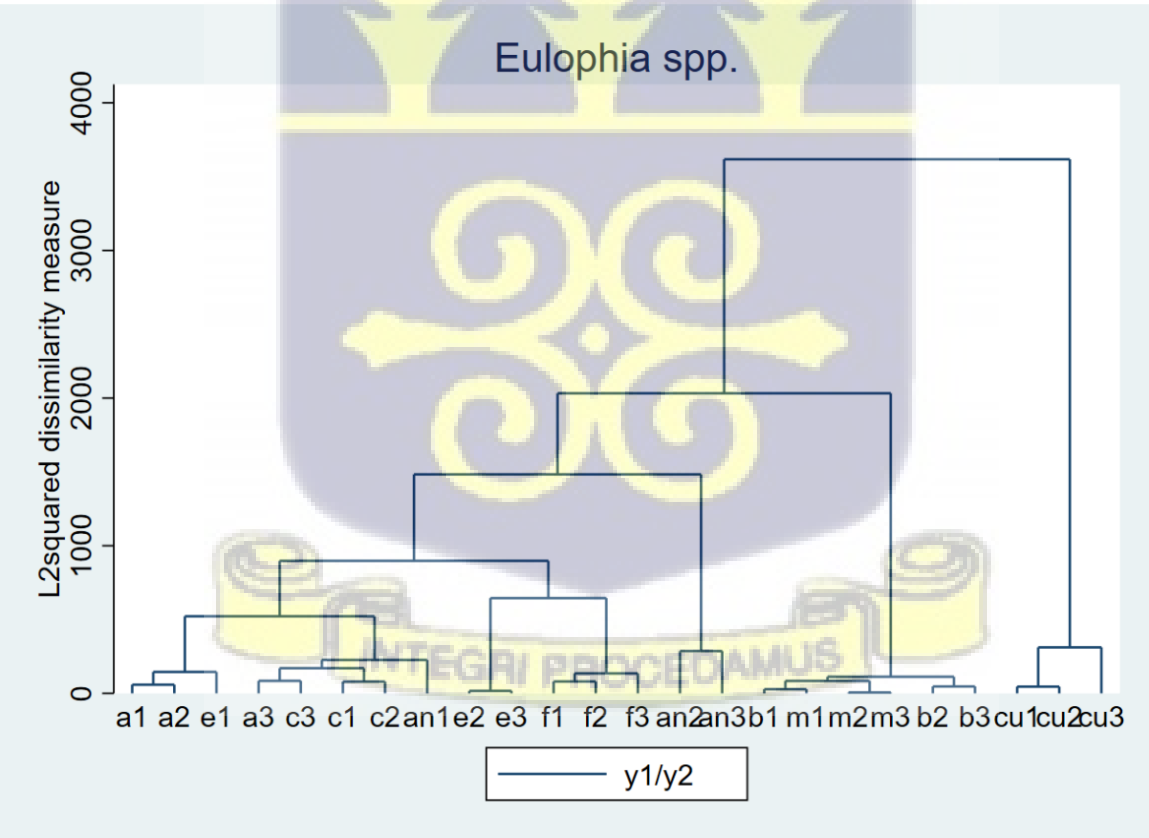
APPENDIX K: Phenology of *Eulophia* species in Ghana

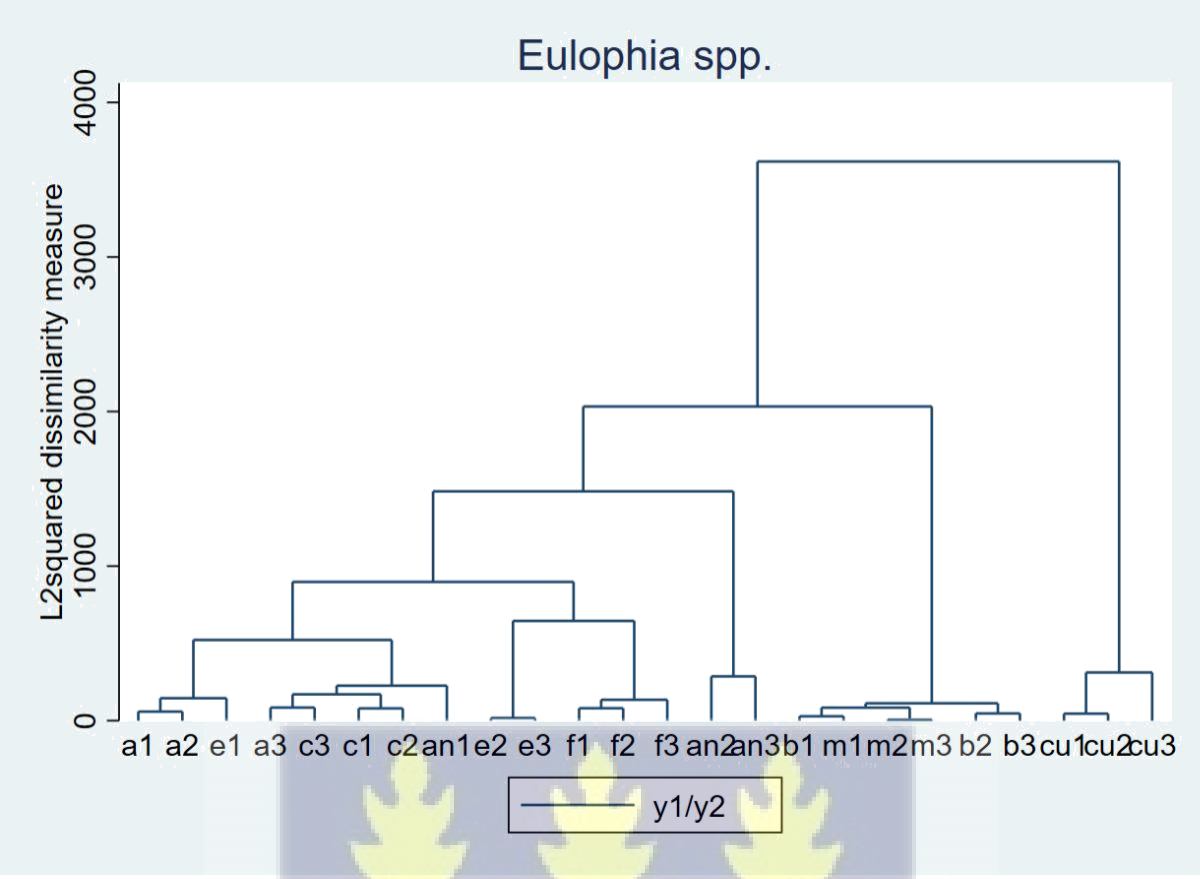


APPENDIX L: Dendrograms of the species of *Eulophia*









KEY: **a1-3=*E. alta;* ang1-3=*E. angolensis;* b1-3=*E. buettneri;* c1-3=*E. cristata;* cu1-3=*E. cucullata;* e1-3=*E. euglossa;* f1-3=*E. flavopurpurea;* m1-3=*E. milnei***

APPENDIX M: t-tests of sample means between *E. cucullata* and *E. dilecta*

Distances between bracts

	E. cucullata	*E. dilecta*
Mean	3.016667	3.333333
Variance	1.321667	0.578667
Observations	6	6
Pearson Correlation	-0.38497	
Hypothesized Mean Difference	0	
Df	5	
t Stat	-0.48351	
p (one-tail)	0.324583	
t Critical one-tail	2.015048	
p(two-tail)	0.649167	
t Critical two-tail	2.570582	

Bract length

	E. cucullata	*E. dilecta*
Mean	2.05	5.68
Variance	0.085	3.879556
Observations	10	10
Pearson Correlation	0.166401	
Hypothesized Mean Difference	0	
Df	9	
t Stat	-5.90932	
p (one-tail)	0.000113	
t Critical one-tail	1.833113	
p (two-tail)	0.000226	
t Critical two-tail	2.262157	

Petal length

	E. cucullata	*E. dilecta*
Mean	1.966667	2.066667
Variance	0.103333	0.003333
Observations	3	3
Pearson Correlation	-0.62862	
Hypothesized Mean Difference	0	
Df	2	
t Stat	-0.48038	
p (one-tail)	0.339183	
t Critical one-tail	2.919986	
p (two-tail)	0.678366	
t Critical two-tail	4.302653	

Leaf length

	E. cucullata	*E. dilecta*
Mean	18.44	47.42
Variance	2.768	35.237
Observations	5	5
Pearson Correlation	0.412514	
Hypothesized Mean Difference	0	
Df	4	
t Stat	-11.8593	
p (one-tail)	0.000145	
t Critical one-tail	2.131847	
p (two-tail)	0.000289	
t Critical two-tail	2.776445	

Stem width

	E. cucullata	*E. dilecta*
Mean	0.733333	1.133333
Variance	0.053333	0.053333
Observations	3	3
Pearson Correlation	-0.5	
Hypothesized Mean Difference	0	
Df	2	
t Stat	-1.73205	
p (one-tail)	0.112702	
t Critical one-tail	2.919986	
p (two-tail)	0.225403	
t Critical two-tail	4.302653	

Distance between leaf veins

	E. cucullata	*E. dilecta*
Mean	0.1	0.45
Variance	2.31E-34	0.011
Observations	6	6
Pearson Correlation	4.83E-16	
Hypothesized Mean Difference	0	
Df	5	
t Stat	-8.17424	
p (one-tail)	0.000223	
t Critical one-tail	2.015048	
p (two-tail)	0.000445	
t Critical two-tail	2.570582	