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Review Article

MORPHOLOGICAL EVOLUTION, CLASSIFICATION AND PHYLOGENETIC OF DIFFERENCE SPECIES OF GENUS EUPHORBIA (*EUPHORBIACEA*)-A REVIEW

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Abstract: *The present review paper focuses on the morphology, taxonomic categorization, and phylogenetic positioning of ten chosen species of Euphorbia, a large genus of the family Euphorbiaceae containing over 2000 species. The study starts with a general introduction to the genus, highlighting the importance of knowing the morphological variation and evolution in the group. A comparison of critical morphological features such as the type of leaf margining, structure of inflorescence, and presence of latex is made to understand the role of such traits in several species. The classification provides a detailed taxonomic breakdown of the ten species selected for review, pointing out the distinguishing character of each species. Evolutionary history within the genus is discussed phylogenetically using one or more molecular markers. The discussion brings together the conclusions from comparing the morphological characteristics of the studied species and the results of the analysis of their phylogenetic relationships concerning the problems of systematics and conservation. The research paper concludes by highlighting the significant findings and recommending further research on Euphorbia species employing diverse research methods.*

Keywords: *Euphorbia*, Morphological Evolution, Phylogenetic, Species Classification

Introduction

Euphorbia is a considerable genus and a subfamily Euphorbiaceae of a large and economically significant group of flowering plants with over 2,100 species. This genus is called the 'spurges'; its inflorescence is called the cyathium, which is unique to the spurges and not found in any other plant in the world ((Mavundza et al., 2022). Members of this genus can be herbaceous annuals, perennials, and subshrubs up to large succulent trees with remarkable representation in temperate zones of Africa, Madagascar, tropical Asia, and the Americas. It is worth saying that all the plants of the *Euphorbia* genus are famous for the presence of a dangerous milky latex sap, which is toxic and protects against eaters.

Therefore, it is equally essential to study the changes Euphorbia has undergone in terms of morphological, taxonomical, and phylogenetical aspects. First, this genus is enormous, and if you consider it from the perspective of the morphology of its members, it will be possible to track the organism's evolution. The changes in the cyathium and the other parts of the different species of Euphorbia prove that these plants have been subjected to variations in the environmental and ecological requirements of the floor. (Mavundza et al., 2022). Since some of these species of the genus are used in traditional medicine and have exciting pharmacological effects, identification and classification of such plants must be done systematically to harmonize their use and conservation. Moreover, it is easier to comprehend the evolutionary history of the species from those studies; it also has information on the historical distribution and diversification of the species about which the study was made.

Euphorbia, one of the most prominent families of Euphorbiaceae, has been recorded to contain over 2000 species in the subtopic, topic, and Mediterranean regions. (KURŞAT et al., 2023). This contrasts the diverse morphological characteristics, ranging from herbs to trees and shrubs and even xerophytic and succulent plants. An exciting characteristic of *Euphorbia* species is the latex that emanates from the plant body and may contain phenolic and terpenes involved in plant defense. (Kürşat, 2023). Furthermore, the reproductive organs in *Euphorbia* are peculiar: the flowers are small and often single-sexed, usually organized in a typical structure known as cyathium. This structure frequently looks like one flower but is one mature female flower surrounded by many male flowers, enclosed by a circle of leaf-like structures called bracts mimicking petals.

The characteristics of the morphological *Euphorbia* have diversified about the numerous environmental factors, proving the genus's adaptive potential. For instance, species belonging to the *Euphorbia* group, equally like other succulents, are adapted to dry conditions; the stems of most of these plants are thick and fleshy – thus storing water while also having few stomata through which water evaporates (KURŞAT et al., 2023). These adaptations are helpful when living in conditions that are similar to the desert in the absence of water. Also, some species of the

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genus have spines as a means of protection from herbivores, thus providing an example of its versatility in survival in demanding conditions (Maddhesiya et al., 2024).

Another adaptive feature is the fact that the genus has adapted to producing numerous seed types. More often than not, these morphological differences are due to reasons other than genetic differences, and in fact, they are advantageous adaptations because the species come across different ecological situations. For instance, different Euphorbia plants have seeds with a particular covered surface that can be useful in seed dispersion or protection in specific environments. (KURŞAT et al., 2023). The flexibility of the seeds coupled with the reproductive habits makes *Euphorbia* one of the plants best adapted to grow in a variety of habitats, right from the desert and to the forests of temperate climates.

Evolutionary Significance of Morphological Diversity

The variations in the form and structures that are witnessed in the specimens of the genus *Euphorbia* have essential implications for the evolution of the plant. This diversity has ensured that the genus has adapted to various ecological parameters to enable it to be widely speculated worldwide. A pattern observed in *Euphorbia* is one where several species from this family have diverged in adaptive radiation to occupy different ecological niches (Frajman & Geltman, 2021).

The most widely documented example of such evolutionary transition is the amount of morphological distinctiveness observed in *Euphorbia* populations in the Caucasus mountain systems. Specific plants like *Euphorbia normannii* found in Stavropol Heights may show how the local environment influences morphological characteristics (Frajman & Geltman, 2021). Current phylogenetic studies of *Euphorbia* confirm the existence of such species formation by means of hybridization and polyploidy, which is why the mentioned morphological differences are not revealed in the related species. (Frajman & Geltman, 2021). The awareness of these processes of evolution underscores the importance of morphological diversities toward the success and further occupancy of the genus in different habitats.

Furthermore, the changes in *Euphorbia* species' structure are not only the effect of environmental conditions from outside the plant but also contribute to the plant's ability to reproduce. For example, the cyathium has a complicated flower structure, which reduces the number of pollinators that can access it to increase pollination effectiveness and the chance of pollination success. This adaptation demonstrates the close correlation between ontogenetic change and reproduction of the genus.

Classification of *Euphorbia* Species

Taxonomic Classification Overview

The genus *Euphorbia* comes under the family of Euphorbiaceae and has approximately 6,745 species of 218 genera (Mavundza et al., 2022). The largest group is the genus *Euphorbia*, and there are between 1800 to 2250 species of plants, which can be herbaceous or woody and shrubby. Species of this group are found in the world over, especially in the temperate and tropical zones (KURŞAT et al., 2023). *Euphorbia* has an organizational structure of flowers known as cyathia, which is a group of small flowers, all of which are a reproductive unit (Kürşat et al.). The cyathium comprises a gynoecium with a single pistil and amidst several androecia- each of which has a single stamen, enclosed by bracts that provide the appearance of a petal. This structure is one factor that defines this genus and sets it apart from the rest. Also, most species of *Euphorbia* contain a milky latex, which is usually poisonous, thus acting as a deterrent to consumers of plant products (Kürşat, 2023). Some of these morphological characters are very vital in categorizing and differentiating *Euphorbia* species.

***Euphorbia* Species**

Asthma weed (*Euphorbia hirta)*

Euphorbia hirta is a small annual herb that grows in the tropic and subtropic parts of Asia, Africa, and the Americas. (Zhao et al., 2022). It is an annual aromatic plant with slender and hairy stems, which may reach a height of 40 cm, and shuttlecock-like, oblong-lanceolate, oppositely arranged leaves with a blotch of purple in the middle of the leaflet (Kumar & Kumar, 2010). It has been employed traditionally for different pharmacological actions, which comprise anti-inflammatory, anti-anaphylactic, and anti-cancer effects (Tripathi et al., 2021).

Sun spurge (*Euphorbia helioscopia)*

That plant, known by the name of Sun spurge, has the name Euphorbia helioscopia; this plant is found in Europe, Asia, and North Africa. This plant has been used in folk medicine for various purposes, especially in China and Turkey, for the treatment of malaria, scrofula, and bacillary dysentery, among other illnesses (Yang et al., 2021). It has also been confirmed for having a broad range of biological activities, including anti-tumor, anti-viral, anti-bacterial, and anti-inflammatory effects due to various diterpenoids, flavonoids, and other active components. (Chaudhary et al., 2023). The plant has also been used in modern medicine because of its anti-proliferative and modulating multi-drug resistance activities, which have been claimed to be attributed to diterpenoids present in the plant (Dou et al., 2024). One should, therefore, not undervalue the actual worth of Euphorbia helioscopia as one of the traditional divine remedies for ailments in folk medicine. However, there is a need to undertake more elaborate research regarding the safety of this compound in the process of treatment (Mohamed & Aly, 2018). This stresses the ongoing discoveries of even more possibilities that can be realized using it and the dangers associated with this element in as much as modern medicine entails heavy reliance on it. Figure 3 shows *Euphorbia helioscopia* specie.

Prostate spurge (*Euphorbia prostrata)*

Euphorbia prostrata is an annual herb with a prostrate growth habit found in various areas such as in sandy, ruderal, by roadsides and railways, and even in rocky gardens. This is the Chamaesyce species of the Euphorbiaceae family, of which there are about 600 species in the subgenus Chamaestyce, most of which are found in the New World (J. Oh et al., 2024). Although *E. prostrata is found in many parts of the world, especially the warm and tropical regions of the Americas, it has been widely naturalized in many parts of the world, including Korea,* where it is invasive to the native ecosystems. The classification of E. prostrata in the Anisophyllum section is due to the laminar base of the leaves being asymmetric and the cyathia being arranged on short lateral branches (Milan et al., 2017). Chloroplast genomes of *E. prostrata* were wholly characterized, providing considerable information about the organization of the chloroplast genome. It was found to be 162,858 base pairs long with a general quadripartite structure of LSC, SSC, and IR regions. Thus,

the GC content of the genome was said to be 35.3%, and a more significant GC proportion was determined in rRNA and tRNA genes than in other genes (H. Oh et al., 2024). The LSC region had 60 CSs and 82 genes; the SSC region had 12 CSs and 13 genes. As for the IR regions, it was identified that there are nine coding sequences, twenty genes, and four rRNA genes. Identifying this chloroplast genome of E. prostrata will benefit scholarship in future ecological and evolutionary research.

Hairy spurge (*Euphorbia villosa)*

Euphorbia villosa is a perennial herb with densely tufted, mainly inhabitant of damp and shady places in the east and south of Europe, several regions of Romania and Serbia. (Dinic & Sharma, 2020). It also occurs in France and the British Isles and has a wide-ranging habitat preference. *Euphorbia villosa* has several uses, especially in the treatment of cancer. *E. villosa* methanol extracts containing a diterpene compound have an additive anti-proliferative property when combined with epirubicin, a chemotherapy drug in human colon cancer cells (Nešović et al., 2020). The current compound has also been characterized as a probable modulator of P-glycoprotein (P-gp) that is related to the multidrug resistance aspect in cancer cells; thus, *E. villosa* could be a source of an instrument to increase the effectiveness of cancer treatments (Garcia et al., 2020).

Leafy spurge, wolf's milk (*Euphorbia virgata)*

Euphorbia virgata, or Leafy spurge, is a perennial herb that is categorized under the Euphorbiaceae family. This species is distinguished by its decumbent rooting shoot and erect culms that may reach 90 cm in height. This species is characterized by linear to linear-oblanceolate leaves and a specific cyathia pattern with crescent-shaped glands (Horn et al., 2014). *E. virgata* is found growing in several biotypes: temperate pastures, cultivated areas, waste grounds, and roadsides found at 0 to 2600 meters. The species blooms and frutescent from spring to fall, which accounts for the vigorous establishment in both the native and invaded terrains (J. W. Horn et al., 2012).

(Fig.1).

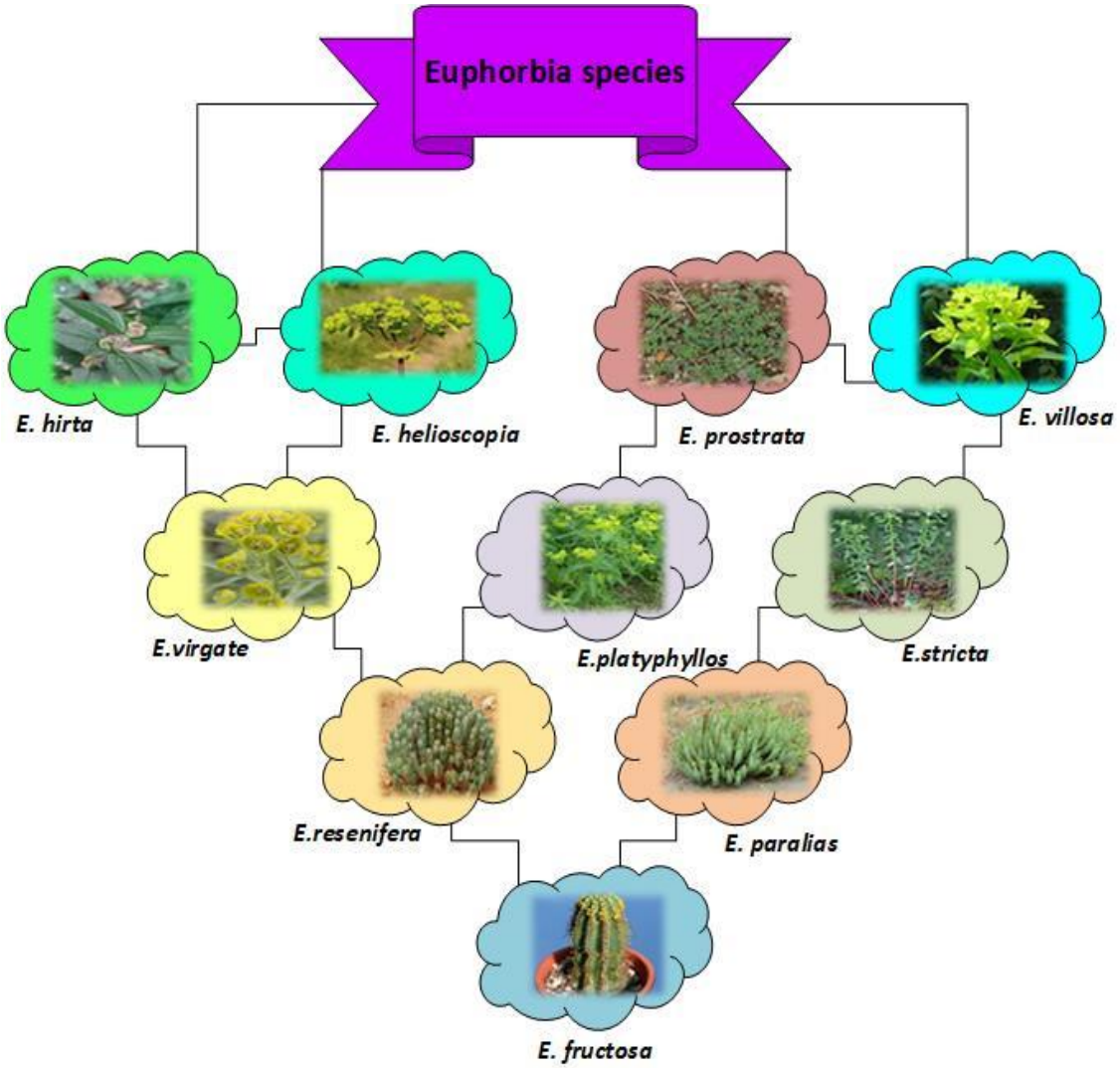

Fig.1 illustrates the different species of the genus Euphorbia and its classifications on the basis of their morphological characteristics. These are ten species of genus Euphorbia the E. hirta, E. helioscopia, E. prostrate, E.villosa, E. virgate, E. platyphyllos, E. stricta, E. resenefera, E. paralias and E. fruticosa

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Broad spurge (*Euphorbia platyphyllos)*

Euphorbia platyphyllos blooms in temperate biomes and possesses several medicinal uses; it has been known to cure skin disease and respiratory sicknesses, among many others (Abdel-Monem & Abdelrahman, 2016). Petrographically, it has been well-researched to explain its palynological characteristics. Şafak Odabaşı (2024) stated that the pollen of *Euphorbia platyphyllos* is trizonocolporate, which has a microreticulate-perforate pattern. This paper's study of pollen morphology offers insight into the taxonomy of the Euphorbia genus by specifying characteristics that are essential for the demarcation and categorization of species. Species differentiation is most apparent with reference to the dimensions of pollen grains as well as the nature of their outer surface.

Tintern spurge (*Euphorbia strict)*

Euphorbia stricta (or Upright spurge) is an annual plant that is native to southern Europe, including countries like the United Kingdom and New Zealand (Kursat et al., 2023). It is illustrated in Figure 8. *Euphorbia stricta* has a three-locular dehiscent capsule fringed with cylindrical warts or tubercles, and the seeds are non-endospermous, smooth, and reddish-brown. It is used as an ornament and can be observed growing in various locations, such as roadsides and moist grasslands. Although this plant has a nice appearance, the latex of *Euphorbia stricta* can produce a burning sensation when applied to the skin and is poisonous when taken internally; therefore, it should be handled carefully. (Kürşat, 2023).

Africa spurge (*Euphorbia resinifera)*

Resin spurge, or *Euphorbia resinifera*, is a succulent shrub plant from Morocco that is well-suited for subtropical regions (Hmidouche et al., 2023). It has a large, often unbranched stem with small, inconspicuous pale yellow flowers and is generally without leaves above the inflorescence. It is hardy in rocky, limey, and saline loams, which are ideal for growing the plant in part to full shade (*Euphorbia Resinifera*, n. d.). It is mostly grown as a decorative plant since its latex is poisonous to humans and may cause dermatitis when in contact with the skin. The low water requirements of *Euphorbia resinifera* and its ability to thrive in arid habitats make it a very hardy plant requiring little maintenance, making it suitable for dry landscapes or xeriscaping. (Hmidouche et al., 2023).

Sea spurge (*Euphorbia paralysis)*

Sea spurge or *Euphorbia paralysis* is an erect perennial plant in the family Euphorbiaceae native to the tropical, subtropical, and temperate regions of the world, such as Europe, North Africa, the Mediterranean, and parts of western (Stone, 2018). This species is primarily found in coastal areas and prefers soil that is sandy. *E. paralias* usually reaches a height of about 70 cm and has a glaucous appearance and a network of fertile branches.

Besides, *E. paralias* is known to be invasive in areas such as Australia, displacing other native plants and altering its ecosystem. Measures including the Sea Spurge Remote Area Teams in conducting the eradication also present promising ways of treating the problem (Salehi, Zakaria, et al., 2019). Sesquiterpenes and polyphenols are bioactive compounds of the plant that may be attributed to their pharmacological properties used in traditional medical systems (Salehi, Abu-Darwish, et al., 2019).

Cactus-like shrub (*Euphorbia fruticosa)*

Euphorbia fruticosa, a succulent subshrub, originates in southwestern Saudi Arabia and northern Yemen. This species is able to exist in arid climates and, therefore, is characteristic of the desert and the dry shrub vegetation zones (Bijekar & Gayatri, 2014). *E. fruticosa* does not have leaves with which to evaporate its water supply; the plant's succulence ensures it holds water well to offset its water-scarce biome.

Phylogenetics of *Euphorbia* Species

Phylogenetic Relationships within the Genus

The phylogenetic relationships within this morphologically diverse genus have been addressed in recent works to a great extent. S.-R. Lee et al. (2024) They comprehensively analyzed the chloroplast genomes of various *Euphorbia* species, revealing four major monophyletic subclades: Esula, Euphorbia, Chamaesyce, and Athymalus. Unique distribution patterns, morphology and size differences, and growth habits distinguish these subgenera. For example, subgenus Esula mainly involves herbaceous plants in temperate climates. Euphorbia, divided by tropical and subtropical climates, has many species and vegetation types. Chamaesyce, mainly distributed in the New World, is known to possess photosynthetic variations, which are C3, C4, and CAM. Athymalus, which is endemic to Africa, exhibits a range of succulent forms.

This paper by Horn et al. (2014)) employed diverse phylogenetic techniques, including maximum likelihood and the Bayesian inference of DNA sequences when arriving at its backbone phylogeny tree of *Euphorbia*. As a result, they circumscribed four huge subgeneric sections- Esula, Rhizanthium, Euphorbia, and Chamaesyce- in harmony with the four major clades of the Euphorbiaceae. The research expounded on such changes, including growth forms and reproductive attributes such as xeromorphism and composite flowers. Interestingly, an adaptation of the mentioned traits was either convergent, meaning that these adaptations evolved in different lineages of organisms belonging to the same genus but at different times, and there is thus an extensive range of adaptation of organisms in the given genus (J. W. Horn et al., 2012).

Molecular Markers Used in Phylogenetic Studies

Information on the classification source of *Euphorbia* species has been provided well by chloroplast DNA molecular markers. In the analyzed research papers, the work with several markers derived from plants' chloroplast and nuclear genomic backgrounds. In assessing the phylogenetic relationship that provided a clear picture of the evolution of the chosen genus, Yang et al. (2024)) employed chloroplast genome sequences. This method works because chloroplast DNA is not highly conserved, and as such, the big phylogeny tree is quickly reconstructed (E. Lee et al., 2024).

Subsequently, S. J. Horn et al. (2012) Considering even more molecular sequences, they included nuclear, plant, and chloroplast DNA sequences in their analyses to fine-tune the generic phylogeny of *Euphorbia*. They also contain more specific data on the phylogenetic history of the analyzed genus, which is useful for clarifying various complex interconnections and the emergence of some key morphological features. This research can thus answer both the longstanding and short-standing divergence history of

the genus by analyzing combined genomics data from these sources.

When mapping the phylogenetic origin and distribution of *Euphorbia orphanages*, a widespread plant species despite limited available space, Faltner et al. (2023) paid particular attention to nuclear ribosomal and plastid markers. These markers' application revealed the species' position within the E. sect. Patellar provides bibliographic data for the patterns of restricted distribution and notes that molecular markers could be effectively used in studying phylogenetic and ecological issues (Faltner et al., 2023).

Phylogenetic Analysis

Even though research on the genetic structure of *E. hirta* has grown, recent research has focused on the molecular characterization of the chloroplast genome for this plant to give information on the evolutionary relationship and their systematic position.

The whole chloroplast genome of *E. hirta* has been sequenced and consists of four linked molecules of 164,340 bp each. This genome contains the large single-copy (LSC) region, the small single-copy (SSC) region, and two inverted repeats (IRa and IRb), which are common for most angiosperms. It has been observed to code for 77 proteins, 4 ribosomal RNA, and 30 transfer RNA besides 111 genes. Relative to other species of *Euphorbia*, the gene content and organization look remarkably similar, suggesting remarkable similarity within the family (Ma et al., 2024)).

Using chloroplast DNA in the molecular systematic analysis, position *E. hirta* in the subgenus Chamaesyce and nested within *E. maculata.* This relationship corroborates previous classifications and implies that *E. hirta* has preserved most of its inherent characteristics and, at the same time, evolved as a result of environmental pressure. The analysis of its chloroplast genome is beneficial for the additional genetic and phylogenetic research in the genus *Euphorbia* (E. Lee et al., 2024).

Sun spurge, or Euphorbia helioscopia, is a summer perennial product in the family of Euphorbiaceae. In the past years, this plant has been applied in Chinese traditional medicine for invasive malignancy tumors and COPD, and it is comprised of asthma, bronchitis, and phlegm turbidity. (Xu et al., 2021). This plant includes various phytochemicals like terpenoids, steroids, flavones, flavonoids, and other bioactive compounds, for which the medicinal value of E. helioscopes was extended by Li et al. in 2019. This species possesses chloroplast DNA, and the sequence of this DNA is available in the database; it is a circular molecule with a size of 160 041 bp and a GC content of about 35.9 %. It is composed of a large single-copy (LSC) of 88,832 bp, a small single-copy (SSC) of 17,145 bp, and a pair of inverted repeat (IR) segments of 27,032 bp. As per the phylogenetic tree, Euphorbia helioscopia is most related to Euphorbia esula and is of the Euphorbiaceae family.

Euphorbia prostrata is an annual herb that grows in the tropical and subtropical regions of America and has naturalized in some parts of the Old World, among them Korea. The chloroplast genome of this species is 162,858 bp long, and the currently available data set has been assembled by de novo assembly methodology. It has a very typical quadripartite genome with a large single copy region (LSC) of 90580bp, a small single copy region (SSC) of 18570 bp, and two inverted repeat regions (IR) of 26854 bp each. Based on the 25 Euphorbiaceae species, a chloroplast DNA tree of clade relationships as follows: *Euphorbia prostrata* resembled *Euphorbia humifusa, Euphorbia thymifolia,* and *Euphorbia hirta. This* is supported by a high Bootstrap value (Khan et al., 2020). The outcomes generated from the current study can assist in the endeavor of decoding the phylogenetic elven and evolutionary dissociation of the Euphorbiaceae family; the current study offers present genomic data that can be utilized in a subsequent study on *Euphorbia prostrata.*

They are a particularly rare type of plant known as a narrow endemic species that can only be located in sites that have high ecological demands. The Mediterranean Basin, from which this species is described, is regarded as one of the most important hot spots of plant endemicity globally. The living and dispersal pattern of *Euphorbia villosa* and other associated species depends on factors such as the topographic, geographic, and climactic characteristics on which the vegetation of the species is mostly restricted to mountains. Most of these species have some general trans-upper requirements that define them for certain places; these factors include large rocks with steep inclination gradients, rock cover, and environmental conditions that determine the geographical distribution of the species (Vasas et al., 2004). The provision of a description of the specific features of Euphorbia villosa and the prerequisites of its environment allows us to start with the experience of the condition that could influence the future of narrow endemic species and stress the need to preserve the environment in which such species exist.

The *Euphorbia* genus has been shown to have phylogenetic relationships that could be described by molecular phylogenetic analysis of *E. virgata*. Its systematic arrangement and transformations have been facilitated by related molecular systematics reports, including chloroplast DNA and ribosomal RNA. The study of the DNA sequence analysis of *Euphorbia virgata* reveals that this plant species falls in a group of *Euphorbia* species that would exhibit various forms of adaptation to different environments.

According to the data on the phylogenetic position of *E. virgate* with the help of chloroplast DNA sequences and the position of trees, it is possible to identify it in the group of plants that can adapt and exist in arid and semi-arid climates (Augé et al., 2016). Intergenic spacers and coding regions helped to differentiate *E. virgata* within a certain group and described the evolution of *E. virgata*.

There is another species in the Euphorbiaceae family that is in the advanced phylogenetic analysis, including the broad-leaved spurge, also known as *Euphorbia platyphyllos*. This is accompanied by large and broadly developed leaves and the other reproductive organs of this species. Some of the phylogenetic analyses that have been conducted in the studies regarding the Angiosperms have been helpful in understanding their evolution as well as evolution adaptation. Finally, in the molecular phylogenetic analysis with chloroplast and nuclear DNA sequences, *Euphorbia platyphyllos* clustered in the *Euphorbia* species that reached the maximum distribution level in different biotopes.

Phylogenetic trees of other order for these markers have indicated that *E. platyphyllos* is closely related to the species with other similar leaf structures and ecological demands. These analyses have allowed the understanding of the evolutionary history of *E. platyphyllos* to show that it has

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occupied a place of diversifying the broad-leaved *Euphorbia* with specializations (Faltner et al., 2023).

The constructed phylogenetic tree is extremely useful in the analysis of the evolution of *E. platyphyllos* and facts that are available in regard to the ecology of this plant. The following is an example of these morphological adaptations: The hormonal stimulus causes changes in the forms of the leaves of the plant as well as in the reproductive part of the plant (Faltner et al., 2023). The information provided here enhances the knowledge of the evolutionary trees of this specific species as well as places under the category of Euphorbia.

Euphorbia stricta of the genus *Euphorbia* is an erect plant with particular reproductive structures of flowers. Earlier molecular phylogenies of this species have assisted in determining its phylogenesis and several things regarding the *Euphorbia* group in general. Thus, molecular studies involving chloroplast and nuclear genes appoint the right status of E. stricta in the phylogenetic tree (Murat Kürşat et al., 2023).

From the same phylogenetic tree analysis, it is well understood that *Euphorbia stricta* has many relatives in different parts of the world since its ecological distribution is rather similar. Some studies have shown that while *E. stricta* constitutes a phylogenetic clade among *Euphorbia* plants that bear certain morphological and ecological adaptations. Comparing the phylogenetic trees produced from chloroplast and nuclear DNA presents the evolutional history of the plant *E. stricta* and its successful mutualistic interactions with its environment and became effective in enhancing the diversification of Madagascar *Euphorbia* (Horn et al., 2012).

It is one of the species of plants in the Euphorbiaceae family that is characterized by the presence of resinous latex and a capacity to adapt to arid conditions. Molecular phylogenetic analysis of this species has also been applied in the study of the evolution of the species as well as the possible adaptation factors of the species. Such molecular genetics involved in the use of chloroplast DNA sequences were important in the determination of the phylogeny of *E. resinifera* at the *Euphorbia* genus level (Horn et al., 2012)

The chloroplast genome of *Euphorbia resinifera* has been informative to genetic and evolutionary variations in the genetic and evolutionarily related organisms (Lee et al., 2024). Maxim, based on the molecular phylogenetic tree of chloroplast genomes, concludes that E. resinifera is closely related to other succulent Euphorbia species, which all are part of the arid-adapted members (Horn et al., 2012). The genetic markers used in these studies are the intergenic spacers and coding regions, which enable the identification of *E. resinifera* regarding closely related species and the study of the evolutionary characteristics (Faltner et al., 2023).

Classification of *E. resinifera* in the Euphorbiaceae family can explain its involvement in the diversification of succulent *Euphorbia* species. Some of the secondary metabolites are diterpenes and triterpenes in their latex; structural colors and chemical properties are due to evolutionary adaptations to intense pressures from the environment (Salehi et al., 2019).

Euphorbia paralias, normally referred to as sea spurge, is one of the xerophyta plants that are mostly cultured in salinously and sandy areas. Most of the facts about the history of the speciation of *E. paralysis and its link with the environment have* been established by molecular phylogenetic analysis. Molecular phylogenetic analysis example of nuclear and chloroplast DNA identified *E. paralysis* as a group of related *Euphorbia* species in the coastal regions adapted to salinity in one way or another (Lee et al., 2024).

Specifically, the genetic analysis of chloroplast genomes gave a great perception of the systematics of E. paralysis. These analyses suggest that *E. paralysis is most closely related to other coastal and halophytic Euphorbia species, meaning that the plant favors high-salinity* environments (Kew Science, 2020). This morphological evolution is indicated in the phylogenetic trees, which establish the phylogenetic relationships of these sequences, the evolution of *E. paralysis* as well as its role in the diversification of *Euphorbia* species along the shores (Lee et al., 2024).

The phylogenetic placement of *E. paralysis*, therefore, equates its biology relative to the functions it performs in the coastal environment and to the extent of salinity stress. Such aspects imply that the general plant adaptation to the monodimensional but challenging coastal front around is somehow consistent with morphological and physiological traits of E. alsinoides, thus offering an informative model to study plants under extreme conditions (Faltner et al., 2023).

In an attempt to determine the phylogenetic trees of this plant, which is a perennial shrub that has developed some aspects of the environment, the phylogenetic analysis of *Euphorbia fruticosa* has been conducted. Such analyses have aided in understanding the phylogenetic affiliation of *E. fruticosa*, especially the molecular parameters thereof, inclusive of the chloroplast and the ribosomal RNA. Therefore, when considering the phylogeny data, *E. fruticosa* may be derived from one of the groups of *Euphorbia* originating from an arid zone. Interestingly, sequencing of chloroplast DNA has revealed that *E. fruticosa* is most related to other succulent *Euphorbia* species well adapted to the desert environment, especially where the species evolved particularly under such conditions (Kew Science, 2024).

Such phylogeny trees based on this data show that E. fruticosa forms part of the same phylogeny tree and, therefore, originated from relative origins as other Euphorbia species that have adapted to arid conditions (Horn et al., 2012). The position of E. fruticosa in the tree map says a lot about the role of this specific genus in the evolution of Euphorbia species that belong to arid climate environments. It has features with regard to its morphology and chemical profile, such as absorbing water from dry climes and the utilization of some parts in various traditional medical practices, which is explained by their phylogenetic tree (Murat Kürşat et al., 2023). Therefore, the findings of these phylogenetic analyses enhance the knowledge of the adaptive changes that have occurred in *E. fruticosa* and enhance the general coverage of the evolutionary history of Euphorbia.

Comparative Analysis of Morphological Traits

There is, therefore, evidence that the morphological features differ, and there is a change in the different species of the genus *Euphorbia*. The genus, which comprises a number of hundred species, differs in size, shape, and arrangement of leaves, stems, and flowers. This variation has been

considered because of differences in their habitats, ranging from desert regions to equatorial forests.

These include the following aspects of the shapes and the manner of arrangement of its leaves. In *Euphorbia*, leaves may be either simple or compound depending on the species and the complexity of the shape, which depends on the ecological station of the species. For example, *Euphorbia cacti* occurring in arid zones have mini and prickly leaves that transpire minimally. On the other hand, *Euphorbia milii, which is found in hot climates,* has large and broader leaves that cover a larger surface and capture light for the process of photosynthesis. This adaptation supports the idea that the shape and size of leaves are important in adaptation to the environment.

In the same manner, the stem structures are not very stable in most of the species of the *Euphorbia* family. Certain plants have stout and succulent stems. For instance, Euphorbia ingens are used for water storage, especially in arid regions. Some of the species, including *Euphorbia pulcherrima*, for instance, have a comparatively thin herbaceous appearance that is more appropriate in comparatively humid climates. The above differences arise from multiple evolvements, hence making the genus very strategic in handling pressure from the environment. (**Fig.2)**

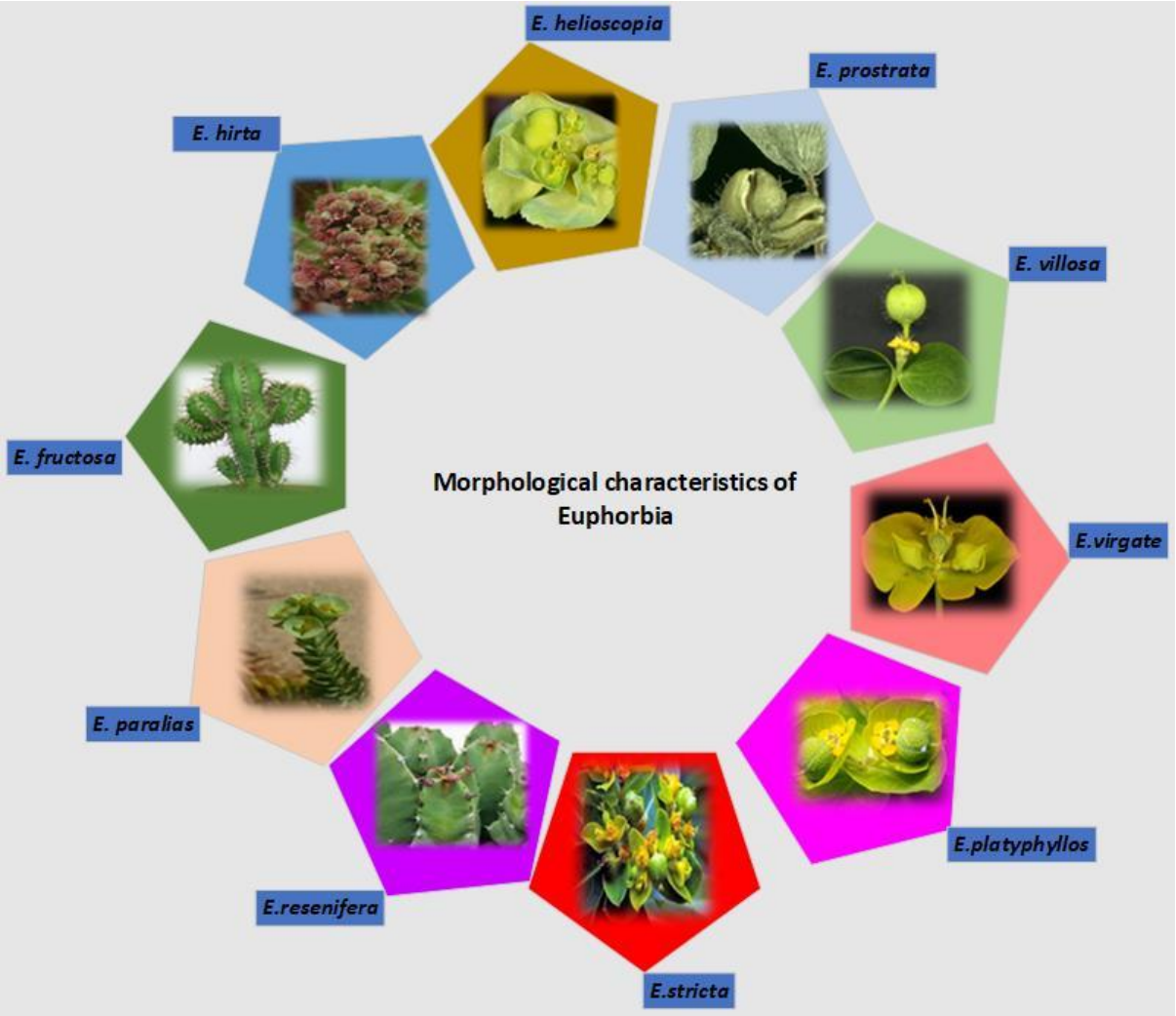

Fig.2 shows the morphological features of ten different species of the genus *Euphorbia*. These species are mainly distinguished on the basis of these morphological traits, having different flower shapes, stem orientations, plant symmetry, and its leave sizes.

Another is the position or the localization of the inflorescence, and according to the species of the plant, the inflorescence may be compound or simple. The species of *Euphorbia* have a cymose to dichasial inflorescence located in their flowers; this relationship is evidenced by the presence of inflorescence in flowers. These arrangements are connected with the reproduction processes and pollinators. For example, *Euphorbia splendens* has to build attractive secondary branches to gain a wider number of pollinators, which in turn leads to pollination and, hence, reproduction. Species with not very colorful flowers might demand complex methods of pollination or might be suitable for some other types of pollinator behavior.

Insights from Phylogenetic Studies

The taxonomic study of Euphorbia throws light on their phylogenetic analysis, which gives a clear idea of diversification and adaptedness and the history of their existence. In the further tissues, DNA analyses with the

subsequent molecular phylogenetics revealed that there are many divisions within the genetic line of the genus.

The new methodological approach was developed in the last decade when the investigators themselves disclosed large lineages linked to the specific body structures as well as the organism's capacity to obtain certain positions in the natural environment. For instance, the arrangement of the grouping of *Euphorbia* species with succulent stems and small leaves accords with the most recent phylogeny analysis on adaptations to arid environments. The correlation between gene data and morphological phenotypes substantiated the hypothesis that these phenotypes evolved as adaptations that seized on environmental factors.

Also, the phylogenetic analysis exposed that hybridization and gene flow are other important factors that have molded the genetic variation in *Euphorbia*. Situations where cases of intergeneric transfers have been observed where one species crosses another and a new forms a new morphology or a new mode of existence occurs. These hybridization events serve as an example of the fact that the processes in the evolution of the mentioned genus are not constant, which makes the genus rich in genetic variations.

Another crucial factor that has been established from the phylogenetic analyses is the temporal distribution of this diversification within the genus *Euphorbia*. Molecular clock data have enabled researchers to approximate the timing of certain divergence points in the lineage and thus generate a rough timeline for the genus's evolution. Relative to this temporal framework, evolutionary associations between environmental changes and the progression of *Euphorbia* species can be discerned.

Implications for Taxonomy and Conservation

The conclusions drawn from the proposed comparative analysis of the morphological features and molecular and phylogenetic experiments made in the study of *Euphorbia* have a broad meaning for taxonomy and the proper conservation of the species. This is due to the fact that there is a huge variation in the form and size of the genus, and therefore, cautious methods are needed to identify the different forms. The current taxonomy that has been developed from the morphological characteristics may not completely describe the real *Euphorbia* species' diversification. Molecular data incorporated into taxonomic revisions can add more refined and comprehensive classifications.

For example, the phylogeny comparisons have shown that some of the species thought to be separate were, in fact, bundled up in complicated lineages. It also raises questions concerning the general taxonomical distinction between related species and possibly even the reclassification of some taxa. Correct classification is important in order to clarify the actual biodiversity of *Euphorbia* and define its conservation strategies.

Conservation of *Euphorbia* species also requires attention to the ecological and evolutionary conditions highlighted in such molecular studies. As often occurs with many other geniuses, observing the variety of the ecological niches that are inhabited by the members of the genus, it is necessary to point out that conservation measures should be as specific rather than general. That is, the strategy for saving the animals that inhabit the areas that are characterized by the arid climate may involve the protection of the range and climate change impacts, while the species from the stable-climate areas may require other approaches.

Besides this, the knowledge about hybridization and gene flow is relevant to the study of conservation genetics. Based on the results and discussion, it can be concluded that hybridization events are capable of generating new morphological forms and may have an impact on the genetic variation of *Euphorbia*. Conservation management plans for this group of species should take into account the potential consequences of hybridization on the population's genetic backgrounds and work for the whole range of genetic variation of the genus.

Conclusion

The research through the genus Euphorbia shows a lot of variation at the species level in terms of morphological characteristics, thus emphasizing key diagnostic features like leaf shape, inflorescence composition, and latex secretion. Molecular phylogenetic analysis adds additional information to the analysis of the internal relationships within the genus and the complexity and diversity of the evolutionary history of Euphorbia. Morphological and molecular data present a stronger and more reliable approach to species phylogeny, hence underlining the significance of synergy in the taxonomy of Euphorbia. These are useful findings that allow us to improve the classification and gain insights into the evolution of such a diverse genus.

Further research in Euphorbia should be directed towards the extension of phylogenetic analyses with a large number of samples and new molecular methods to improve the resolution of the Euphorbia phylogeny and especially to solve the remaining nodes. Further research is required to explore the ecological and environmental attributes that play roles in the morphological diversities seen in Euphorbia species. Conservation initiatives should also be a focus, particularly for species within this genus that are threatened, endangered, or restricted to specific geographic locations, as knowledge of genetic variation and phylogenetics of these taxa can help guide conservation action. In conclusion, more investigation into the Euphorbia subgenus will be helpful to the disciplines of taxonomy, ecology, and conservation biology.

Declarations

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Approved by the department concerned.

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