Review of Literature

2. Review of Literature

2.1. Morphometrics

2.1.1. Historical Context and Early Foundations

Morphometrics, the measurement (metron) of shape (morphe), is a subfield of statistics with a history going back to the very beginnings of this discipline. Statistical and morphometric analysis often go hand in hand and are used in plant systematics to quantify structural features. Frances Galton (**1889**) introduced the correlation coefficient and applied it to a variety of morphological measurements on humans. He invented a method to quantify facial shape that has later been termed two-point shape coordinates or Bookstein-shape coordinates (**Galton, 1907**). The application of multivariate statistical techniques, which were basically developed in the first half of the 20th century, led to so-called multivariate morphometrics. But in the 1980s, morphometrics experienced a major revolution through the invention of coordinate-based methods, the discovery of the statistical theory of shape, and the computational realization of deformation grids **(Adams et al., 2004; Bookstein, 1991; O'HIGGINS, 2000; Rohlf & Marcus, 1993; Slice, 2005)**.

Morphometrics has a rich history dating back to the early 20th century, with significant contributions from pioneers such as D'Arcy Thompson (**1945**), whose work "On Growth and Form" set the stage for the quantitative study of biological forms. Although Thompson's approach was primarily qualitative, it provided a conceptual framework for understanding the relationship between biological structures and their functions. The transition to quantitative morphometrics began in earnest in the mid-20th century with the advent of multivariate statistical techniques.

Fred L. Bookstein's and Leslie F. Marcus's contributions in the late 20th century were pivotal in advancing morphometric methodologies. Bookstein's (**1991**) "Morphometric Tools for Landmark Data" introduced rigorous statistical techniques for analyzing landmark data, marking a significant shift towards geometric morphometrics. Marcus (**1990**) emphasized the importance of statistical rigor in traditional morphometrics, laying the groundwork for subsequent developments in the field.

Morphological studies included quantitative data for one or more measurable traits, which were summarized as mean values and compared among groups. The development of statistical methods such as the correlation coefficient (**Pearson, 1897**), analysis of variance (**Fisher, 1954**), and principal components analysis (**Hotelling, 1933**) further advanced quantitative rigor. By the mid-twentieth century, quantitative description of morphological shape was combined with statistical analyses describing patterns of shape variation within and among groups, and the modern field of morphometrics began.

2.1.2. Traditional Morphometrics

Traditional morphometrics involves the use of linear measurements, counts, ratios, and angles to study biological forms. Blackith and Reyment's seminal work "Multivariate Morphometrics" highlighted the application of multivariate statistical techniques to biological data, providing tools for analysing morphological variations across populations. This approach, however, faced limitations due to its inability to fully capture geometric relationships and difficulties associated with size correction **(Blackith & Reyment, 1971)**.

2.1.3. Geometric Morphometrics

Geometric morphometrics emerged to address these limitations, focusing on the analysis of shape through landmark data and outline analysis. Rohlf (**1990b**) and Slice (**2005**) emphasized the importance of preserving geometric properties in morphometric analysis. Landmark-based methods, such as Procrustes analysis and Thin-Plate Spline Analysis (TPS), became central to geometric morphometrics, allowing researchers to objectively compare shapes by aligning landmark configurations and visualizing shape changes.

2.1.4. Landmark-Based Morphometrics

Landmark-based morphometrics involves the identification and digitalization of specific anatomical points on biological specimens. This method separates shape from size, enabling precise shape analysis. Marcus (**1990**) discussed the application of landmark-based techniques in evolutionary biology and taxonomy, where understanding shape variations is crucial for species differentiation and phylogenetic studies. The objective nature of landmark data makes it particularly valuable for comparative studies in evolutionary biology, anthropology, and palaeontology.

2.1.5. Outline Analysis and Elliptic Fourier Analysis (EFA)

Outline analysis techniques, such as Elliptic Fourier Analysis (EFA), are used to analyze the contours of structures by fitting digitized points along an outline with mathematical functions. EFA decomposes shapes into Fourier harmonics, providing a detailed mathematical representation of complex shapes. Rohlf (**1990b**) highlighted the utility of EFA in studying morphological adaptations and ecological interactions, where shape variations often reflect evolutionary pressures and environmental influences.

2.1.6. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a statistical technique used to reduce dimensionality in morphometric data by identifying orthogonal linear combinations of the original variables that capture the most variance. Bookstein (**1991**) and Cope et al. (**2012**) emphasized PCA's role in handling the high number of form variables present in morphometric studies, facilitating further analysis and interpretation of shape variations. PCA is crucial for identifying patterns and trends in morphological data, making it a staple in morphometric research.

2.1.7. Applications in Plant Systematics and Species Identification

Morphometric techniques have been extensively applied in plant systematics and species identification, providing valuable tools for distinguishing closely related species and understanding phylogenetic relationships. **Cope et al.** (2012) demonstrated the effectiveness of digital morphometrics in plant species identification, highlighting its potential for automated classification systems. The study utilized digital images of plant leaves and applied geometric morphometric techniques to differentiate species based on shape variations.

Sampathkumar, (**1982**) highlighted the importance of leaf characteristics in taxonomy of the family Convolvulaceae. Certain characters observed in leaves, like pattern of venation and other features offer much scope for the taxonomists, in view of their high level of constancy. Furthermore, these characters shed considerable light on the phylogenetic affinities among the taxa, since they are quite conservative by nature. According to **McLellan and Endler** (**1998**) morphometric methods are known to be effective in analysis leading to recognition and discrimination of groups and for evaluation of ontogenic and phylogenic changes in plants. **Jenson** (**2003**) has emphasized that morphometric methods of any type can be of great value at the species level and below.

Viscosi et al. (**2009**) compared traditional and geometric morphometric methods in analysing leaf morphology of four European oak species and their hybrids. Their study provided insights into the effectiveness of different morphometric approaches in resolving taxonomic challenges and identifying hybridization events.

Geometric morphometrics has also been used to study floral morphology and its role in reproductive isolation and speciation. **van der Niet et al.** (**2010**) applied three-dimensional geometric morphometrics to analyse floral shape variation in the genus *Satyrium* (Orchidaceae), revealing significant shape differences that correlated with pollinator preferences. This study underscored the importance of shape analysis in understanding evolutionary processes and ecological interactions.

In a study on the genus Eriobotrya (Rosaceae), **Idrees et al.** (**2021**) employed geometric morphometrics to analyse leaf shape variations and successfully distinguished between different species. The research highlighted the potential of morphometric methods for resolving taxonomic ambiguities and supporting species identification in complex plant groups.

Klein et al. (**2017**) used digital morphometrics to study leaf variation in two North American grapevines, *Vitis riparia* and *Vitis rupestris*. Their analysis quantified variations at the species, within-species, and individual levels, demonstrating the utility of morphometrics in plant systematics. Similarly, **Kupe et al.** (**2021**) employed elliptic Fourier descriptors to analyse the morphological characteristics of grapevine cultivars, providing detailed shape analyses that supported cultivar identification and differentiation.

Chitwood and Otoni (**2017**) explored the relationship between leaf vasculature landmarks and elliptic Fourier descriptors of the blade in Passiflora leaves, demonstrating the application of morphometric analysis in understanding plant morphology and systematics.

Migicovsky et al. (**2018**) used morphometric techniques to reveal complex and heritable apple leaf shapes, showcasing the genetic basis of morphological diversity and its implications for plant breeding and conservation.

Cáez-Ramírez et al. (**2018**) applied morphometric analysis and tissue structural continuity evaluation to study senescence progression in fresh-cut papaya, demonstrating the potential of morphometrics in postharvest biology and quality control.

Liu et al. (**2018**) conducted geometric morphometric analyses on two sympatric Chinese oaks, *Quercus dentata* and *Quercus aliena*, to study leaf shape variations. Their work highlighted the potential of morphometric techniques for distinguishing closely related species and understanding ecological adaptations.

Jumawan and Bout (2021) used elliptic Fourier analysis to evaluate leaf outlines in selected Philippine *Hoya* species, providing detailed morphological characterizations that aid in species identification and taxonomic studies.

2.1.8. Advancements and Future Prospects

In the 21st century, morphometrics research continued to evolve and expand. High-resolution imaging, three-dimensional reconstructions, and advanced statistical techniques enabled researchers to delve deeper into the complexities of plant morphology. One notable development was the utilization of geometric morphometrics, which goes beyond traditional linear measurements to capture shape information in a more holistic manner. The field of morphometrics continues to evolve with technological advancements, such as 3D scanning techniques and image processing software, enhancing the accuracy and scope of morphological studies. Integrating molecular data with morphometric analysis offers new avenues for understanding the genetic basis of morphological diversity. **Cope et al.** (2012) and **van der Niet et al.** (2010) highlighted the potential of combining morphometrics with genomic data to explore evolutionary processes and adaptive traits in greater detail. As technology progresses, morphometrics will play an increasingly vital role in exploring the complex patterns of natural forms, contributing to biodiversity conservation and scientific discovery.

2.2. Convolvulaceae

Antonii Laurentii de Jussieu (**1789**) was the first to describe Convolvulaceae in his historical work *Genera plantarum secundum ordines naturales disposita* (in latin). He placed Convolvulaceae in class- Dicotyledoneae under group- Monopetalae (Corolla hypogyna) and order- Convolvuli, Les Liserons. It was kept between order- Borragineae and Polemoniae. According to Bentham and Hooker (1885), the family Convolvulaceae belongs to the group- Gamopetalae, series- Bicarpellateae, order Polemonials. Five tribes, namely Convolvuleae, Dichondreae, Nolaneae, Creeseae, and Cuscuteae, were created from the Convolvulaceae family. While Hutchinson (**1926**), Thorne (**1992**) and Dahlgren (**1989**) assigned the family Convolvulaceae to the order Solanales. Takhtajan (**1980**) in his book *Flowering Plants* placed Convolvulaceae in Subclass- Lamiidae, superorder-Lamiianae. In that he divided the family in three sub-families i.e. Convolvulaceae, Cuscutaceae and Humbertiaceae.

Austin (**1975b**) mentioned that the family is probably more closely related to Polemoniaceae than to Solanaceae. But the presence of tropane alkaloids in Solanaceae and Convolvulaceae indicates their close association **(Griffin & Lin, 2000).** Besides this, the two families have some flavonoid profiles, caffeic acid esters and coumarins **(Gornall & Bohm, 1978; Harborne, 2000).**

Generic delimitation of this extremely natural family is a most difficult task. **(Austin, 1979; Simoes et al., 2015; Simões et al., 2022; Simões & Staples, 2017)**. According to Robert Wight (1840-1850) "difficulties have always been attended in the investigation of the species, not so much in their discrimination as in the correct limitation of the genera to which they require to be referred a point on which for a long time, no two Botanists could agree". The genus *Operculina* is separable from *Merremia* only based on fruit characteristics (**Simões et al., 2019; Staples et al., 2020**). *Ipomoea* is generally distinguished from *Merremia* based on pollen characters (**Simoes et al., 2015; Simões & Staples, 2017**). The genus *Rivea* is the most poorly defined taxon, most of the characters being shared with *Argyreia* **(Lawand, 2019; Manos et al., 2001; Staples & Traiperm, 2017)**.

2.2.1. Historical Review of the Family Convolvulaceae

One of the plants the ayurvedic physicians (*Chikitsaka* or *Vaidya*) use is *Operculina turpethum*. This vine, according to the people who use it, produces 2 types of roots: *sufed* or *sveta* or white roots that are mild, and kala or *krishna* or black roots that give drastic, often poisonous effects (**George, 1893**). In India the plant had at least 5 names in Sanskrit. These names included the most common *trivrit* or *trivrita*. Less commonly used but important were *triputa, tribhundee, puripakinee* and *nisrita*. Each of these terms contains elements making direct reference to the humors. Trivrit is composed of tri or 3 and *vir* or to cherish or *vritti* activity; hence a cherishing or action on the 3 humors. *Tribhundee* incorporates *bhundi* or to oppose, implying that it expels the 3 humors. *Nisrita* uses the strengthening prefix nis with the word for cherish and means entirely cherished humors. And *puripakinee* comes from puri or completely and *puch* or ripe; hence a complete ripener of humors.

Unlike the food plant *Ipomoea aquatica* Forsk. (**Austin, 2007**), the medicinal trivrit apparently was not widely distributed in pre-European times in eastern Asia. Chinese, Japanese, Malaysian and Micronesian names for the vines appear to be descriptive and orthographically unrelated to the names used in the Indian region. For example, the Japanese name fusen-asa-gao meaning "balloon morning face" applies part of the name given to *Ipomoea nil* (L.) Roth. This familiar Japanese morning glory is actually from the Americas and was introduced into Asia by Europeans (**Austin, 1979**). These data, and others like them, suggest that *Operculina turpethum* was taken to Japan after *Ipomoea nil.* The dried milky juice of Scammonium (*Convolvulus scammonia*) had been used as a medicine from ancient times. Theophrastus in third century B.C was familiar with its medicinal use. The drug was used in Britain in 10th and 11th centuries and appears to be one of the medicines recommended to King Alfred the Great, by Helias patriarch of Jerusalem **(Flückiger & Hanbury, 1874)**.

Linnaeus (**1753**) listed many species of this family from Asia under '*Pentandria Monogynia*'. *Convolvulaceis Orientalis*, the first specialist book on this family was by Choisy (**1833**). This work retains its significance even now and can be considered as a bible for the family. It included description of many new genera (*Aniseia, Jacquemontia* and *Rivea*) and new sections (e.g., *Ipomoea* sect.; *Erpipomoea* Choisy). German Botanist Hallier (**1893**), another expert on this family, followed Choisy and described many new taxa. Subsequently many authors (**Peter, 1891; Prain, 1906**) brought out series of publications on this group. Following these works, a large number of publications relating to individual genera or restricted areas of the family appeared in many literatures. Taxonomic treatment of Convolvulaceae in Malaysia **(van Ooststroom & Hoogland, 1953)**, East Africa (**Verdcourt, 1963**), Panama (**Austin, 1975a**), Ceylon (**Austin, 1980**), W. Pakistan **(Austin & Ghazanfar, 1979)**, and Ecuador (**Austin, 1982**), influenced further studies on this family in other parts of the world.

In 1934 van Ooststroom composed an excellent world monograph of the genus *Evolvulus.* He maintained a life-long interest in the family. His excellent works on Malaysian Convolvulaceae served as classical reference to future workers world around (**van Ooststroom, 1938; 1939; 1940**). Robertson (**1971**) revised the genus *Jacquemontia* in North and Central America and West Indies. Staples (**1990**) made a revision of *Porana* and an evaluation of the tribe. Myint and Ward (1968) published a taxonomic revision of the genus *Bonamia.* Significant contributions were made by Hoogland (**1953**) and Myint (**1966**) on the genus *Erycibe* and *Stylisma* respectively.

During the British reign in India botanical sciences, especially floristic studies flourished. Van Rheede in his monumental work, *Hortus Malabaricus* (1678 - 1703) described and illustrated 17 Convolvulaceae species from Kerala. *Hortus Malabaricus* was one of the main sources for Linnaeus to master his knowledge on the tropical flora of Asia (**Heniger, 1986**). Based on Rheede's figures in *Hortus Malabaricus,* besides Linnaeus several workers like Adanson, de Jussieu, Hamilton, de Candolle etc, described many taxa of Indian plants and adopted the vernacular names into botanical nomenclature. Roxburgh had made extensive collections in Bengal and Eastern India. His *Hortus Bengalensis* (1814) contained the names of many members of Convolvulaceae. Later in *Flora Indica* (1832) he included detailed descriptions of 100 species belonging to 10 genera of Convolvulaceae. In 1839 British Botanist Robert Wight published his well-known work *'Icons Plantarum'*, which carried 25 illustrations of Convolvulaceae members.

J.D. Hooker published his monumental seven volume work, 'Flora of British India' from 1872-1897. In the fourth volume, Convolvulaceae was treated by C. B. Clarke (1883). It summarises the results of the collections made by Roxburgh, Wallich, Wight and Amott, Griffith, Hooker, and others. In Flora of British India, the family Convolvulaceae includes the description of 152 species belonging to 15 genera. He classified the Indian species under six different subgenera viz., *Calonyction, Quamoclit, Pharbitis, Aniseia, Batatas* and *Euipomoea*. This classification is mainly based on floral characters, the size and nature of corolla, the stamens, the number of locules and ovules in the ovary. Gamble's Flora of Presidency of Madras (1915-1936) is a classical floristic account covering a major area of the Peninsular India. It includes the description of 21 genera and 79 species of Convolvulaceae. After the classical floras by Hooker and Gamble, no serious attempt had been made on this family in India except by others of the local floras.

Wood et al. recently published two monographs of genus Convolvulus (**2015**) and Ipomoea (**2020**) which includes considerable work which has been done in both the genus. Revision of genus Argyreia and Ipomoea for India was done by **Lawand (2019)** and **Kattee (2020)** respectively in their doctoral research.

Considerable work has been done on the anatomy of Convolvulaceae. **Carlquist and Hanson (1991)** made a quantitative and qualitative study of the wood and stem anatomy of 16 genera and 35 species of Convolvulaceae. Occurrence of tracheid together with fibriform vessel elements in the wood of many members suggests relationship of Convolvulaceae to Polemoniaceae and Hydrophyllaceae. Intraxylary phloem and other wood features suggest relationship between Convolvulaceae and Solanaceae. Extensive anatomical studies in the genus *Argyreia, Ipomoea, Merremia* and other genera of family Convolvulaceae were studied by Rajput coworkers (**Lawand et al., 2023; Rajput et al., 2022, 2024; Ramoliya et al., 2023**). The floral anatomy of the family has been studied by **Govil (1972). Rao and Leela (1993)** studied the seed coat morphology and epidermal patterns.

Pollen morphology plays an important role in the generic delimitation in Convolvulaceae. The genera *Ipomoea* and *Merremia* are separable only on the basis of spinulose and non-spinulose pollen grains. Hallier (**1893**) was probably the first worker to use pollen morphology as a taxonomic character in his extensive taxonomic revision of the Convolvulaceae. In Flora of Presidency of Madras, Gamble (**1923**) grouped different genera in Convolvulaceae based on pollen grains. He observed that pollen grains are spinulose in *Argyreia*, *Ipomoea*, *Rivea* and Stictocardia and non spinulose in Aniseia, Breweria, *Convolvulus*, *Cressa*, *Cuscuta*, *Erycibe*, *Evolvulus*, *Hewittia*, *Jacquemontia*, *Merremia*, *Neuropeltis*, *Operculina* and *Porana*. Sengupta (**1972**) studied 170 species from the family. Different researchers have worked on the palynology of the family which provided additional data for the identification and classification of the family **(Biju & Dhar, 2020; Buril et al., 2015; Ferguson et al., 1977; Simões et al., 2019, 2021)**

2.2.2. Classification of The Family

Pollen is a major character that divides the family into two taxonomically unranked groupings: Psiloconiae (non-spiny) and Echinoconieae (spiny) Hallier (**1893**). Ooststroom (**1953**) recognised two subfamilies (Cuscutoideae and Convolvuloideae), three tribes (Cuscuteae, Convolvuleae and Ipomoeeae) and nine sub-tribes (*Cuscutinae, Wilsoniinae, Dichondriane, Dicranostylinae, Poraninae, Erycibinae, Convolvulinae, Ipomoeinae and Argyreiinae*) in Malayasian Convolvulaceae. Austin (**1979**) divide the family Convolvulaceae into nine tribes (*Erycibeae*, *Cresseae, Convolvuleae, Merremieae*, *Ipomoea*e, *Argyreieae, Poraneae, Dichondreae* and *Cuscuteae*). The currently established classification of Convolvulaceae is based on a comprehensive molecular phylogenetic analysis of the family (**Stefanovic et al., 2002**), in which 12 tribes are recognized and morphologically characterized (*Aniseieae, Cardiochlamyeae, Convolvuleae, Cresseae, Cuscuteae, Dichondreae, Erycibeae, Humbertieae, Ipomoeeae, Jacquemontieae, Maripeae* and *'Merremieae').* The tribal rank of '*Merremia'* is abandoned by **Simoes & Staples** (**2017**), due to morphological and molecular evidence so they proposed to dissolve Merremieae and to consider the formerly included genera (**Stefanovic *et al.,* 2003**) and the genera circumscribed in their paper to be incertae sedis in terms of tribal placement in accordance with Article 3.1 of the ICN. They suggest that *Merremieae* should no longer be recognised, and they provide a generic reclassification of its members. **Simoes et al. (2022)** provided the recent classification for the family based on molecular phylogenetic data.

2.2.3. Evolution: Divergence And Distribution:

Srivastava *et al.* (2018) thought that Convolvulaceae had an east Gondwanan origin; the basal clades in Convolvulaceae are all Old World, including Madagascar but not the African mainland. The 58.7- 55.8 MY. age of the recently described *Ipomoea meghalayensis* suggests a very considerably older crown-group age for the family than several of the estimates above. Convolvulaceae are the only euasterid family in which the seeds have physical dormancy, and this is caused by the thick, hard seed coat found in nearly all members of the family, indeed, such thick and complex seed coats are unique here. The seeds normally need scarification before they take up water, but, if unscarified, water initially penetrates the seed only at particular places in the coat.

2.2.4. Current Scenario (Phylogeny and recent changes/advances):

The distinctive *Humbertia* is sister to the rest of the family (Refulio- Rodriguez & Olmstead 2014; Garcia *et al.* 2014). Within the rest of the family, part of Poraneae. *Erycibeae* in particular can look very unlike other Convolvulaceae, and herbarium specimens are often misidentified. *Ipomoea*, *Convolvulus*, and their relatives form a clade that is sister to a rather unexpected clade made up of Poraneae, Cresseae, Dichondreae (with gynobasic styles), some Erycibeae (Maripeae), etc., as well as *Jacquemontia*. Several members of this latter clade have styles divided to the base or only an at most shortly connate style with long branches (but *Jacquemontia* has a long style), and leaf blades with more or less pinnate venation.

A recent study by **Simoes et al.,** (**2022**) provided a comprehensive overview of the current classification status of the Convolvulaceae family, using nuclear genomic data to resolve phylogenetic uncertainties. The family includes around 2,000 species distributed across 60 genera, with significant economic importance due to crops like sweet potato and ornamental plants such as morning glories and bindweeds. The study confirms the monophyly of Convolvulaceae and provides a strongly supported backbone for the family. It addresses unresolved phylogenetic relationships, such as the placement of the parasitic genus Cuscuta The paper reveals that the traditional tribal classification, particularly the tribe "Merremieae," is non-monophyletic. The tribe needs revision due to the unexpected placement of some genera. The study identified six informal subfamilies: *Convolvuloideae, Dicranostyloideae, Cuscutoideae, Eryciboideae, Cardiochlamyoideae*, and *Humbertioideae.* The study supports the monophyly of some tribes like *Ipomoeeae* and *Cuscuteae* while challenging the previous circumscription of others