Palyno-Anatomical and Seed Morphology of Lamiaceous Taxa from Northern Pakistan

By

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Palyno-Anatomical and Seed Morphology of Lamiaceous Taxa from Northern Pakistan

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بسم الله الرحمن الرحيم

In the name of Allah, the Most Merciful, the Most Kind

DEDICATED

To

My Beloved Parents & Family

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Table of Contents

List of Plates

	regular pentagonal to hexagonal epidermal cells;(M, N, O) *S.splendens* oblong seed with granular surface sculpturing.	

List of Figures

List of Tables

ABSTRACT

This project is the first comprehensive taxonomic information on Lamiaceous plant species from Northern Pakistan. The study is confined to pollen micromorphology, seed micromorphology, and foliar epidermal anatomy. The Lamiaceae is not previously documented regarding recent taxonomic trends (palynology, anatomy and seed morpology) from the Northern Pakistan. The present research was aimed at the documentation of significant taxonomic markers to identify the Lamiaceious species. From different parts of Northern Pakistan, 104 Lamiaceae plant species comprising 40 genera and 6 sub families were collected. Among them genus *Nepeta* species dominating the family (19 species), followed by genus *Salvia* (12 species), genus *Mentha* (8 species) and *Ocimum* (6 species) were reported. The pollen micromorphological characterization was carried out via light microscopy (LM) and scanning electron microscopy (SEM). The foliar epidermal anatomical attributes were examined via LM and SEM. Seed micromorphological features were documented through stereomicroscope and SEM. The data of quantitative measurements of the palynological and anatomical traits was collected into a matrix and analyzed statistically via SPSS (2016), Past (2021), and XLSTATE (2018). Lamiaceae species showed variation in pollen size and shape, aperture type and exine sculpturing. *Nepeta* exine sculpturing were found as reticulate, reticulate perforate, bireticulate perforate, reticulate perforate-verrucate, fine reticulate perforate and reticulate-perforate/ foveolate. The largest polar diameter was found in *Nepeta distans* (86.5µm), and smallest in *Nepeta praetervisa* (20.3 µm). The microanatomy of the stomata, epidermis, anticlinal wall pattern, and variety of trichomes were different on both surfaces of the leaves. In the current study four main types of stomata were observed: anomocytic, diacytic, anisocytic, and paracytic. The largest stomata length at the adaxial surface was observed in *Ajuga reptans* (35 µm) and the lowest in *Scutellaria prostrata* (20 µm). Variation in seed shape was observed from semi-spheroid, spherical, oblong, globose oblong, trigonous, obovate, fusiform, spheroid, oval, elliptic, rhomboid, broad elliptic and broad obovate. The Lamiaceae seeds ranged in size from (1 mm) in *Anisomeles indica* to (4 mm) in *Phlomoides vicaryi in* length and from (0.75 mm) in *Phlomoides vicaryi to* (3.5 mm) in *Vitex agnus-castus* in width. The taxa of the family were successfully divided by the Principal Component Analysis (PCA), dendrogram, correlation.

The construction of taxonomic keys also revealed micromorphological markers for accurate identification. Micromorphological characteristics that have been established serve as a foundation for the accurate identification of Lamiaceous taxa and their systematic significance.

Chapter 1
Introduction

1. Introduction

1.1 Lamiaceae: A Worldwide Overveiw

Flowering plants are the most diverse groups of land plants with 64 orders, 416 families, around "13,000 genera, and 300,000" species. The Lamiaceae (Labiatae) family was selected for the current research because it is significant to humans and is widely known for its "food, ornamental, and medicinal properties.". Lamiaceae is considered as one of the most distinctive and easily recognizable families of flowering plants. It is cosmopolitan in distribution and encompasses about 265 genera (Cantino and Sanders 1986b) and 3200 species (Liu et al., 2022). The Verbenaceae are widely regarded as the closest relatives of the Labiatae. The two families have been grouped in the Lamiales by (Bessey, 1915), (Dahlgren, 1980), (Takhtajan, 1980), (Thorne, 1992), and (Cronquist, 1981). The quadrangular stem, verticillaster inflorescence, and opposite leaves characterize this family. Herbs are generally encrusted in hairs and are aromatic, containing a high concentration of essential oil. In the cosmetic, flavor, fragrance, insecticide, and pharmaceutical industries they are utilized (Carovic-Stanko et al., 2016; Irfan et al., 2018; Zaman et al., 2022). One of Lamiaceae's distinguishing traits and a factor of commercial significance is the extraction of essential oils by glandular trichomes (Baran et al., 2010). Lamiaceae consists of twelve subfamilies, for instance, Ajugoideae, Cymarioideae, Callicarpoideae, Lamioideae, Nepetoideae, Peronematoideae, Premnoideae, Tectonoideae, Scutellarioideae, Symphorematoideae, Prostantheroideae, and Viticoideae. Various plants such as mentha, basil, oregano, thyme, lavender, and sage are highly used for their culinary purposes, as they are commonly used as culinary herbs. Additionally, certain plants, like Coleus, are cultivated primarily for their attractive foliage, while others, such as *Salvia hispanica* and *Plectanthus edulis*, are specifically grown for their edible seeds and tubers (Talebi et al., 2022).

The Lamiaceae family is commonly regarded as an advanced and highly evolved plant family. It possesses several distinctive characteristics, which are outlined below:

- Most of its members are herbaceous in nature.
- Leaves are exstipulate, arranged in either opposite or whorled patterns.

- The flowers exhibit a unique inflorescence arrangement, known as verticillaster, and are also zygomorphic in shape.
- Both the calyx and corolla are gamosepalous and bilabiate, meaning they consist of fused sepals and petals forming two distinct lips.
- The stamens, generally epipetalous, are reduced to just two in number.
- The gynoecium is bicarpellary, syncarpous, featuring axile placentation, with one ovule per locule.
- Fruits produced are simple, such as carcerulus, and seeds non-endospermic.

The Lamiaceae subfamily Nepetoideae has the highest number of species, with up to 3400 species divided into the three tribes Ocimeae, Mentheae, and Elsholtzieae. With the exception of Antarctica, all seven regions of the world have a high variety of Lamiaceae and are hosts to Nepetoideae (Harley et al., 2004a; Hedge and Miller 1990). Nepetoideae are currently thought to be one of the Lamiaceae subfamilies that are better described, and molecular studies have consistently supported this (Chen et al., 2016; Kaufmann and Wink 1994; Li et al., 2016; Wagstaff and Olmstead 1997; Zhao et al., 2021), even though it wasn't made clear until comparative pollen analysis was developed (Abu-Asab and Cantino 1994; Cantino and Sanders 1986a). Nearly every fragrant species found in the Lamiaceae family belongs to the Nepetoideae, which is distinguished by having hexacolpate, trinucleate pollen (Cantino and Sanders 1986a) an embedding embryo (Martin, 1946) and rosmarinic acid (Harley et al., 2004a). Additionally, all three tribes of the Nepetoideae family of Lamiaceae are known to include mucilaginous nutlets (Ryding, 1992). In Nepetoidea, mucilaginous nutlets could possibly be a synapomorphy.

Nepeta L. is a member of the tribe Mentheae and the subfamily Nepetoideae, it is one of the most diverse genera in that family (Harley et al., 2004b). *Nepeta* L. is one of the most diverse plant genera in the Lamiaceae family, with more than 300 species (Dirmenci et al., 2010; Kaya and Dirmenci 2008; Jamzad et al., 2003b; Sahraroo et al., 2016). *Nepeta* species are distributed throughout the world including Central and Southwest Asia, North Africa, Europe, Korea, Central America, Canary Islands, Japan and China (Celenk et al., 2008). However, most of the species are distributed in Central and Southwest Asia, as well as Transcaucasia. The species grows in a variety of habitats, from coastal areas to high-altitude alpine regions (Jamzad et al., 2003a). *Nepeta* species are typically herbaceous perennials, but they can also be annuals. Many of these species have a pleasant smell, valuable essential oil, and commercial potential. Many *Nepeta* species are used in traditional medicine for their therapeutic characteristics, which includes, used as diuretics, encouraging sweating, curing coughs, reducing spasms, alleviating asthma symptoms, lowering temperature, stimulating menstruation, and causing drowsiness (Galati et al., 2004; Rapisarda et al., 2001).

Salvia L. (Sage) is the largest Lamiaceae genus, with over 1000 species and a worldwide assemblage with a changing habit. Three geographical zones dominate the distribution of *Salvia* L. the South and North America, the western part of Asia, and the eastern portions of Asia (Walker and Sytsma 2007). Pakistan is one of the important hot spots for *Salvia* hosting 17 native species with two sub-endemics to Baluchistan province. Several species are grown for ornamentals purposes for their showy and fragrance flowers (Perveen and Qaiser 2004b). The species of the genus *Salvia* L. show a remarkable variation in growth form, secondary products, floral morphology, and pollination mode (Kahraman et al., 2010). *Salvia* differs from other Menthea tribe members in that it has only two productive stamens, each divided into two thecae by a long connective tissue. Pollen transfer is aided by these modified lever-like stamens (Walker and Sytsma 2007). Walker et al., (2004) demonstrated from the non-monophyletic lineage of the genus *Salvia* L. with the elongated connective tissue of the stamens, which is closely related to the genera of Mentha. Additionally, numerous *Salvia* species are utilized as traditional medicines throughout the world, showing diverse therapeutic attributes like antimicrobial, antioxidant, antidiabetic, antitumor, antibacterial, antimalarial, anti-inflammatory, and aphrodisiac (Kamatou et al., 2008). Aromatic essential oil is produced by the species of this genus and is utilized in herbal teas, foodstuff, cosmetics, and perfumes (Kaya et al., 2003).

1.2 Lamiaceae in Northern Pakistan

The Lamiaceae family has received limited attention in terms of systematic research in Pakistan. Previous works, such as in flora of Pakistan Khan et al., (2011) and

Kandemir (2003) this family was considered as an independent entity and identified approximately 60 genera with over 212 species. Lamiaceae is a distinctive plant family with unique features that set it apart from others. The plants of this family are known for their aromatic essence and can have smooth or hairy surfaces with sessile oil glands. The stems of Lamiaceae plants are often four-angled, and their leaves are arranged oppositely. The inflorescence forms spikes composed of variously arranged cymes, known as verticillasters, and the flowers have a bilabiate corolla structure. In Northern Pakistan, the flora comprises a diverse range of species within Lamiaceae. Lamiaceae includes a variety of herbs, shrubs, trees, and climbers. In Pakistan, there are about 60 general and 212 different taxa, which are further categorized into 12 subfamilies for instance, Ajugoideae, Cymarioideae, Callicarpoideae, Lamioideae, Nepetoideae, Peronematoideae, Premnoideae, Tectonoideae, Scutellarioideae, Symphorematoideae, Prostantheroideae, and Viticoideae (Gul et al., 2019c).

According to the Flora of Pakistan Khan et al., (2011) the Lamiaceae family also contributes to the presence of endemic plant species in the region. Several research studies have conducted ethnoecological investigations in Peshawar and neighboring areas (Fazal et al., 2010; Hussain et al., 2000; Ilyas et al., 2012; Shah et al., 2020; Khan et al., 2013; Musharaf et al., 2011; Marwat et al., 2013). Lamiaceous plants have significant applications in various industries, including items like beauty products, essences, scents, aroma compounds, insecticides, and medicinal compounds (Ayaz et al., 2020). In this framework, an investigation named "Ethnomedicinal, ecological, elemental, and phytochemical assessment of 5 plant species from the Lamiaceae in Peshawar, Pakistan" was conducted (Shah et al., 2020).

Khan et al., (2021a) conducted a study to explore the palynological features of the Lamiaceae family from the District Bannu, KPK, Pakistan. They used both scanning electron microscopy and light microscope (SEM & LM) to assess the systematic importance of these features. In another investigation Jehanzeb et al., (2020) analyzed the morphological traits of the leafstalk in 8 species of the Mint tribe originating from diverse botanical regions across Pakistan. Additionally, Bibi et al., (2021) researched the dominant plant families present in the flora of Lower Tanawal, Pakistan.

Hassan et al., (2017), conducted a comprehensive quantitative ethnobotanical research survey, focusing on the ethno botanical knowledge of 62 plant species from 38 families. The study involved semi-structured interviews and a well-organized questionnaire to gather data. In a separate study, Bano et al., (2020a) aimed to offer a comprehensive description of the pollen structure of selected species belonging to the Lamiaceae family. Ahmad et al., (2021) conducted a research project that focused on the taxonomic diversity and ethnobotanical aspects of the Lamiaceae family. Gul et al., (2019a and 2019b) conducted a study focusing on the foliar epidermal anatomy of selected taxa within the Lamiaceae family. In another research effort, Gul et al., (2019c) and Khan et al., (2021b) carried out investigation of pollen on selected species of Lamiaceae. It is worth noting that the systematic study of this family in Pakistan has been relatively limited, and further exploration is needed.

1.3 Importance of Lamiaceae family

The importance of the family is given below:

1.3 Food and Medicinal value

The plants of Lamiaceae family have been utilized for their preventive and curative properties since ancient times. For instance, "*Ajuga bracteosa* and *Leucas cephalotes*" are commonly used to alleviate fever. "*Mentha piperita* and *Thymus serphyllum*" are valued sources of menthol and thymol, respectively, and are known for their medicinal benefits. The leaves of *Ocimum tenuiflorum* are utilized to create a paste that effectively treats various skin diseases (Muthu et al., 2006; Pattanayak et al., 2010; Fatiha et al., 2015; Piras et al., 2018). Furthermore, *Anisochilus carnosus* (L.f.) Wall. is recognized for its therapeutic properties in treating skin problems, gastrointestinal disorders, respiratory diseases, and acting as a hepatoprotective agent (Kamble et al., 2008, Yasodha et al., 2018, Esquivel et al., 2017, Wani et al., 2018).

Basilicum polystachyon (L.) Moench leaves have been traditionally utilized to address urinary disorders, epilepsy, and neuralgia, as mentioned in the previous research (Rama Rao et al., 2015). *Colebrookea oppositifolia* Sm. has been acknowledged for its therapeutic properties in managing urinary infections, exhibiting antiseptic effects

(Bernstein et al., 2011; Rama Rao et al., 2015). *Plectranthus amboinicus* (Lour.) Spreng. is renowned for its medicinal benefits in alleviating respiratory problems like asthma and cough, as well as providing relief from headaches, neural disorders, and inflammation (Mishra et al., 2004).

Ocimum tenuiflorum L., commonly known as Holy Basil, holds significant ethno-medicinal importance due to its wide range of medicinal properties. Traditionally, it has been used to effectively address fever, cough, and reduce alveolar inflammation. Moreover, it is known for its therapeutic potential in treating various skin diseases and respiratory conditions such as bronchitis, asthma, and leprosy. Additionally, it is considered an immune booster, enhancing the body's natural defense mechanisms. The essential oil derived from *Ocimum tenuiflorum* possesses valuable antibacterial, antifungal, and insecticidal properties, making it beneficial in various applications. Furthermore, it has been employed to combat urino-genital diseases (Mishra et al., 2004; Nandakumar et al., 2005; Veeru et al., 2009; Bhattacharyya and Bishayee 2013; El Mokni et al., 2018; Akbar et al., 2020)

Traditionally, *Mentha piperita* L., commonly known as peppermint, has been utilized as an inhaler to reduce lung congestion, treat bronchitis, reduce cough, and combat throat infections and oral mucosa issues. Moreover, it acts as an acid neutralizer for our digestive system, promotes and maintains a healthy gut micro-flora, and provides relief from conditions such as diarrhea, flatulence, and nausea. Additionally, it aids in facilitating bowel movements and effectively treats colic disease in infants. The essential oil derived from Mentha piperita serves various medicinal purposes, including alleviating toothache, rheumatism, and muscular pain, as well as providing relief from menstrual pains. Pharmacological research has demonstrated and validated the inhibitory activity of *Mentha piperita* on respiration, along with its antitussive, antispasmodic, analgesic, coolant, anti-inflammatory, antimicrobial, radio-protective, and local anesthetic effects (Shah and Mello 2004; Dambolena et al., 2010; Balakrishnan et al., 2015; Mahendran and Rahman, 2020).

Ocimum basilicum L., commonly known as Sweet Basil, is renowned for its diverse medicinal properties. Traditionally, it has been employed to alleviate stomach pain, freshen breath, strengthen gums, and act as a carminative, helping to expel gas from the digestive system. Additionally, it is recognized for its anti-pyretic effects, reducing fever, and promoting sweating to aid in cooling the body. Moreover, it has been used to treat various heart and brain-related ailments, as well as blood disorders, and is believed to have a positive impact on the spleen's size. The infusion of its seeds is administered in cases of diarrhea, and chronic dysentery, providing therapeutic benefits for these conditions (Özcan and Chalchat 2002; Kaya and Dirmenci 2008; Zahran et al., 2020; Purushothaman et al., 2018; Mir et al., 2021). Research has also indicated the beneficial effects of *Ocimum basilicum* in addressing brain, heart, liver, and spleen disorders, further solidifying its medicinal significance (Marwat et al., 2011; Khair-ul-Bariyah et al., 2012).

Throughout history, various species belonging to the Lamiaceae family have been known for their delightful aromas, culinary uses, and flavor-enhancing qualities. Some of the prominent species within this family include *Ocimum, Origanum, Mentha, Thymus, and Lavandula* (Zahran et al., 2020; Javed et al., 2013; Venkateshappa et al., 2013; Ciocarlan, 2016). The distinctive characteristics of this family are attributed to the abundance of essential oils and aromatic compounds found in these plants. "*Mentha piperita* and *Mentha spicata* L." are highly valued as culinary herbs, adding delightful flavors to various dishes. Several *Ocimum* species, such as *O. sanctum* and *O. basilicum*, have gained popularity for their medicinal properties and are now widely cultivated for that purpose. Additionally, *O. vulgare* finds use as a spice, further contributing to the diversity of uses within the Lamiaceae family (Ignacimuthu et al., 2006; Mathew and Subramanian 2014; Piras et al., 2022; Nikolova et al., 2021).

1.4 Plant Taxonomy

Taxonomy, a crucial discipline in biological science, involves the systematic study of identifying, describing, classifying, and naming organisms, especially at the species or other taxa levels. In the field of plant taxonomy, the focus is on activities aimed at organism identification and classification. This scientific field is dynamic, continuously evolving as taxonomists gather and analyze data. To establish the relationships between organisms based on their nature and taxonomic characteristics, extensive and diverse plant data collections are essential.

For novice taxonomists, morphological features have traditionally served as the primary evidence for general taxonomy and organism identification. However, as one advances in higher education, plant taxonomy becomes more intricate, delving into the classification criteria based on morphological, anatomical, histologic, and genetic characteristics. These comprehensive approaches allow for a deeper understanding of the plant kingdom and its diverse species.

Plant taxonomy has experienced rapid and progressive transformations, closely linked to the advancements in science and technology (Jalali et al., 2016). Historically, taxonomic research was primarily driven by a sense of curiosity surrounding biodiversity and the desire to explore and understand various species. The significance of taxonomic research lies in its role as a guiding framework for prioritizing research, fulfilling the need for well-defined research strategies, communicating the value of taxonomic studies to researchers in related fields, and promoting the dissemination of taxonomic information to the public (Maulana et al., 2020).

1.5 Association of Plant Taxonomy with Leaf Anatomy

Comparative anatomical studies of angiosperms have a remarkable history, as they have effectively addressed challenging taxonomic issues with considerable success. The value of anatomical characters lies in their consistency; the more reliable and consistent a character is, the more significant its contribution (Kaikade and Ingole 2015). Within plant taxonomy, anatomical features play a crucial role, particularly in defining higher taxonomic ranks such as genera and families (Donaldson et al., 2017). Botanical control, especially in terms of anatomical characteristics, becomes essential for industries dealing with pharmaceuticals and spices (Aoyama et al., 2020).

Anatomical features of angiosperms have been extensively utilized in identifying species at various taxonomic levels and establishing their taxonomic relationships. Particularly, anatomical traits play a crucial role in accurately recognizing higher taxonomic ranks, such as genera and families. These traits have proven highly effective in elucidating relationships between orders and genera, thus becoming increasingly vital in understanding evolutionary connections. Notably, comparative anatomy of leaves, including attributes from transverse sections, has proven valuable in both identifying angiosperm species and understand their taxonomic associations (Begum et al., 2013).

Scanning Electron Microscope (SEM) has introduced a new perspective to the examination of morpho-structural traits on leaf surfaces. This advanced technique has enabled a detailed evaluation of leaf surfaces, particularly concerning trichome morphology. By utilizing the scanning visualization approach, taxonomic issues related to trichomes were effectively resolved. Through SEM analysis, it was observed that the leaf surfaces were adorned with diverse types of trichomes, and the features of the stomatal complexes held considerable importance in systematic classification (Arabameri et al., 2020). Foliar microanatomical characteristics offer valuable insights into specific plant families and their ecological adaptations. Various epidermal features, including the length and types of epidermal cells, stomatal complexes, and trichome morphotypes, have emerged as crucial factors in distinguishing dicot angiosperms (Mladenova et al., 2019). These structured variations provide substantial evidence for taxonomic delimitation and serve as essential tools in understanding the diversity and ecological adaptations of plant species.

While modern phylogenetic studies may question the systematic application of certain characters, trichome morphology has proven to be valuable in the infrageneric classification of some genera within Lamiaceae (Salmaki et al., 2009). Furthermore, at specific and subspecific levels, trichomes have been instrumental in classification (Giuliani et al., 2008; Harvey and Demissew 1994). Lamiaceae plants exhibit widespread distribution of trichomes, which can be categorized as glandular and non-glandular, found on various aerial reproductive and vegetative parts (Navarro and El Oualidi 2000). These trichome features serve as essential traits for differentiating and understanding the taxonomy and evolutionary relationships within the Lamiaceae family.

Glandular trichomes found in Lamiaceae encompass various types, such as capitate, subsessile, clavate, and branched (Navarro and El Oualidi 2000). These glandular trichomes typically consist of four distinct parts or cells: the foot, stalk, neck, and head (Bosabalidis, 1990). On the other hand, non-glandular trichomes are more prevalent in Lamiaceae compared to glandular ones. They can be categorized based on their size, thickness, surface characteristics, and mode of branching (Seyedi and Salmaki 2015). Understanding the diversity and features of these trichome types is crucial for comprehensive taxonomic and ecological studies within the Lamiaceae family.

It is widely acknowledged that essential oils are synthesized within glandular trichomes, either unicellular or multicellular (peltate and capitate types), found in certain members of the Lamiaceae family (Seyedi and Salmaki, 2015; Svidenko et al., 2018). The anatomical structure of the leaf-blade plays a crucial role in assessing infraspecific variation, while variations in anatomical traits are essential for resolving complexities in infrageneric classification at the infraspecific level (Talebi et al., 2023). Trichome micromorphology has proven to be valuable in studying the Lamiaceae family at both generic and suprageneric levels (Navarro and El Oualidi, 1999; Cantino 1990; Eyvazadeh Khosroshahi and Salmaki 2019; Eiji and Salmaki 2016; Giuliani et al., 2008; Navarro and El Oualidi 2000; Salmaki et al., 2009). Notably, certain genera within Lamiaceae exhibit wide variations in the nature and concentration of secretory trichomes, offering significant traits for distinguishing taxa (Siadati et al., 2020).

Research has demonstrated the taxonomic significance of the form and arrangement of vascular strands in petioles within Lamiaceae (Metcalfe and Chalk 1972). Furthermore, the comparative anatomy of leaves, incorporating attributes from cross-sectional leaf features in higher plants has demonstrated immense utility in differentiating between species (Atalay et al., 2016). Members of the Lamiaceae family have glandular trichomes called peltate glandular trichomes, secretory trichomes of the Lamiaceous type, which have epidermal cells, a short stalk cell, and a multicellular head (Kaul et al., 2016). The form, distribution, and number of glandular trichomes are used as distinguishing characteristics at the subfamily level in the Lamiaceae family (Nitsenko et al., 2018).

In conclusion, analyzing the form and composition of vascular bundles in leafstalks, the comparative analysis of leaf anatomy, and the observation of glandular trichome features play vital roles in the taxonomic investigation of Lamiaceae plants. These distinctive characteristics are valuable tools for differentiating and delimiting species across various taxonomic levels.

1.6 Association of Plant Taxonomy with Pollen Micromorphology

Pollen morphology, encompassing aperture type and number, symmetry, polarity, shape, and size, has generally remained stable within a plant species. Mature pollen grains are typically characterized by well-defined morphology, with variations within a species being relatively small, making them useful as taxonomic traits. Nevertheless, various studies have indicated that certain pollen parameters, particularly pollen size, can be influenced by environmental factors (El Aanachi et al., 2021). In angiosperms, significant trends at higher taxonomic levels are primarily linked to the numbers, orientation, and structure of pollen apertures, exine stratification, and occasionally, size and sculpturing (Bose et al., 2012). Pollen microscopic characteristics of studied specimens are compared by researchers to recognize plants based on the distinctions between them. For the advanced characterization of pollen morphological features in plants, scanning electron microscopy (SEM) is a valuable tool (Khan et al., 2021b). This sophisticated form of microscopy enables detailed observations of pollen structures, contributing to our understanding of plant taxonomy and evolution.

Pollen in an anther is a population of closely related male gametophytes that (appear as a result of asexual reproduction), their genetic variation is constrained by the outcomes of recombination of parent genes of the same species. It is the generation of living things that is as complete as it is theoretically conceivable to be near to the ontological entire level where there is no death (Pozhidaev and Petrova 2023). In the taxonomy of Lamiaceae, palynology holds significant importance and provides valuable data for the classification of genera and species within the family. Pollen morphology, including features like aperture number, shape, and tectum ornamentation, has been extensively studied in various members of the Lamiaceae family. These pollen characteristics have proven to be helpful in enhancing its taxonomic understanding and classification.

According to the classification of (Erdtman's 1945) the Lamiaceae family is categorized into two subfamilies according to attributes of their pollen: 1) Lamioideae, exhibiting tricolpate and binucleate pollen, and 2) Nepetoideae, characterized by hexacolpate and trinucleate pollen. This classification, depending on the number of nuclei and apertures in the pollen grains, is widely accepted and utilized in botanical studies (de Almeida et al., 2020). Numerous botanists have conducted studies on the pollen morphological characteristics of Lamiaceous species (Firdous et al., 2015). Additionally, Doaigey et al., (2018) reported that the ornamentation of sexine (the outer layer of the pollen wall) exhibits variability and could serve as a significant characteristic at the generic level. These findings have contributed to a better understanding of Lamiaceae taxonomy and provided valuable insights into the differentiation and classification of its species.

1.7 Plant Taxonomy Association with Seed Morphological Traits

Seeds play a crucial role in a plant's capacity for regeneration. Numerous plant species depend on viable and dormant seeds within the soil (seed bank) for regeneration, demonstrating their flexibility and toughness, especially in unpredictable and harsh environments like deserts (Sahoo et al., 2017). The study of seed morphology has unveiled numerous valuable insights into systematic relationships across a wide range of plant groups. Apart from the morphological features of seeds, the texture and sculpturing of the outer seed coat exhibit considerable variations among species and can serve as significant systematic markers (Lindegren et al., 2021). These aspects provide valuable information for understanding plant diversity and evolution.

Microscopic imaging using a scanning electron microscope (SEM) is a valuable approach for distinguishing between different plant species. SEM proves to be an efficient technique in seed identification, as it combines extreme magnification and deep analysis of ultrastructural aspects, revealing variations that optical microscopy cannot detect (Khan et al., 2021b; Haq et al., 2021; Rewers et al., 2021). This advanced imaging method provides essential insights into the unique characteristics and features of seeds, aiding in their accurate identification and contributing to the understanding of plant diversity and taxonomy.

The seed shape has long been considered a significant source of valuable evolutionary information due to its high intraspecific uniformity. Numerous angiosperm taxa have undergone comprehensive seed morphological studies in conjunction with phenetic or phylogenetic analysis at the genus level, contributing to a better understanding of their evolutionary relationships (Chalise et al., 2018). Seed surface properties play a crucial role in taxonomic classification, providing detailed information for accurate species identification. Parameters such as cell size, shape, periclinal and anticlinal wall sculpturing, and microrelief are all essential taxonomic and biological attributes of the seed testa cell (Tan et al., 2022). Micromorphological and ultrastructural data have proven valuable in phylogenetic analyses and seed plant classification, making them an indispensable tool in modern angiosperm systematics (Bano et al., 2020b). These microscopic techniques aid in unraveling the complexities of seed diversity and contribute significantly to the study of plant evolution and taxonomy.

Comparative information on seed micromorphology, specifically ornamentation and sculpturing on seed coats, is essential for understanding taxonomic relationships at the inter-specific level, as these traits are not sufficiently specific on their own (Sadeghi et al., 2014). Seed morphological characteristics have been acknowledged as valuable tools for species delimitation, and taxonomic investigations have revealed that many of these traits exhibit evolutionary stability with a degree of inertia in their evolution (Kahraman et al., 2012). Therefore, in-depth studies on seed micromorphology and its correlation with climate preferences are crucial to gaining insights into plant taxonomy and evolutionary relationships at a finer scale.

1.8 Justification of the Research

Lamiaceous flora is widely distributed throughout Northern Pakistan and has an essential economic and medical value. Lamiaceous taxa of the same genera or distinct genera of the family often appear identical in general appearance, necessitating appropriate identification and distinguishing these plant species from one another. As a result, extensive taxonomic study of Lamiaceous species is required i.e., anatomical, palynological, and seed features for accurate identification and delimitation. According to our information, no extensive investigation of Lamiaceous taxa in term of systematic attributes has been conducted in Northern Pakistan.

Taxonomically, the Lamiaceous flora is not being studied at the generic, or subfamily levels. Among the limited research on family, some were confined to palynological (Perveen and Qaiser 2004a) while others investigated foliar anatomy (Gul et al., 2019b). Though information on the family's systematic investigations is available, little, or no specific research has been carried out on the palynology, foliar anatomy, and seed micromorphology of the Lamiaceous species. As taxonomic differences amongst the genus and subfamily species are little recognized, the current study was conducted to identify distinct qualitative and quantitative traits that are likely to be relevant from a taxonomic perspective.

In this study, we relate taxonomic assemblages to distinct Lamiaceous flora types using an entirely new spectrum with precise seed morphological, anatomical, and palynological features, providing a strong base for correct Lamiaceous flora identification. Although investigations of localized flora, and taxonomic assessments of the Lamiaceous flora have been increasingly published in recent years, taxonomic data for many taxa are unavailable and/or reveal major gaps in knowledge.

Systematic and extensive investigations are critical for documenting the presence of plant species. Their taxonomic research should enable one to evaluate the botanical potentialities for beneficial exploration and research regarding financial usage. To conduct such a study, it is critical to be familiar with the region's flora. It is possible to evaluate the agriculture wealth of an area only until all the plants have been carefully collected and kept, correctly identified, and characterized by a classification system. Systematics is currently a well-known field in Pakistan, and many prominent angiosperms plant families have been studied to determine their taxonomic features. To precisely identify the species, many locations, such as Northern Pakistan, remain unexplored systematically. Several taxonomic investigations on different plant families have been carried out in different parts of Pakistan i.e., Gilgit Baltistan, Khyber Pakhtoon Khwa, areas of Punjab, Azad and Jammu Kashmir, Sind and Baluchistan. Whereas in Northern Pakistan, either a smaller number of studies or the Lamiaceous flora is still unexplored. In terms of systematics exploration, Lamiaceous plant species in Northern Pakistan have been neglected.

Systematic investigations are useful for determining the relationship between closely related taxa. Taxonomic techniques can be used to identify complex genera (Rodríguez-Estrella and Rivera-Rodríguez 2019). Scanning electron microscopy (SEM) of pollen ultra surface, seed morphotypes, and anatomical characteristics plays an important role in systematic investigations of various plant groups (Hussain, 2018). Characterization plays an important role in taxonomic study since the identification and system of classification provides basic information. Plant description and classification is the primary pathway for evolutionary identification of patterns (Dickison, 2000).

Field trips and identification of the wild Lamiaceous flora growing in Northern Pakistan were taken into account, as well as the vegetation types, life forms, and floristic groups of the gathered species. Voucher herbarium specimens of various plant samples were pressed and deposited in the Herbarium of Pakistan (ISL) for future reference.

This study provides access to a diverse range of Lamiaceous flora, the most important plant family. At genus and subfamily level, available information of general and systematic value is integrated. This work is particularly helpful source of reference not only for taxonomists, but for all those are interested in the various elements of plant diversity. The current effort was to examine and describe micromorphological taxonomic differences of reproductive and vegetative structures of Lamiaceous flora in Northern Pakistan, with the goal of developing a set of identifying features for Lamiaceous species. The present study used a multidisciplinary approach to offer information on the taxonomic characteristics of Lamiaceous flora by combining morphological, anatomical, palynological, and seed sculpturing data using scanning electron microscopy (SEM) approaches. Because the systematics of Lamiaceous flora in Northern Pakistan has not been examined particularly, this effort will provide foundational information that will aid in identification and classification of Lamiaceous species for future studies. The systematic position of the Lamiaceous flora remains problematic in terms of its taxonomic implications; thus, the current study will assess the systemic value of medicinally important Lamiaceous plant species using multiple parameters such as foliar anatomy (qualitative & quantitative), anatomy, palynology, and seed sculpturing (SEM) to aid in species identification. The study will also furnish comprehensive insights into taxonomy, which will assist in distinguishing and differentiating Lamiaceae plant species and genera.

1.9 Objectives of the Study

- The wild Lamiaceous species of Northern Pakistan were collected through field trips throughout the flowering season, identified by renowned taxonomists, the herbarium, and online flora. The obtained taxa were then deposited to the Herbarium of Pakistan, (ISL) QAU.
- Micromorphological investigations of Lamiaceous species are based on taxonomic methods such as palynological (SEM), seed ornamentation (SEM), and foliar anatomical characterization (SEM).
- Annotation of variances at different classification levels in accordance with anatomy, palynology and seed morphology.
- To emphasize similarities and differences among the species in the family, statistical analysis (dendrogram, correlation and loading plots, PCA) based on qualitative and quantitative palynological, anatomical and seed micromorphological features is developed.

Chapter 2

Materials And Methods

2. Materials and Methods

2.1 Research Framework

The methodology of the research project is outlined in this section. The selection of the study area, the sample method, and the experimentation techniques are briefly described. The selected study area, Northern Pakistan, was specifically targeted for the collection of Lamiaceous flora. Furthermore, this section outlines the sources from which sample data were derived, the techniques used for data collection, and the subsequent analysis methods. A series of field expeditions were conducted between March 2021 to August 2022, covering various locations across Northern Pakistan, and spanning different seasons. The principal aim of this study is to conduct a comprehensive taxonomic analysis of Lamiaceous flora. To carry out the comprehensive analysis, the plant samples were subjected to laboratory investigations at the Plant Taxonomy and Systematics lab at Quaid-i-Azam University Islamabad. The study's central focus lies in the examination of various aspects of Lamiaceous flora, particularly from palynological, seed morphological, and anatomical perspectives. Special attention is devoted to the geographic distribution patterns of the plants within the scope of the current research.

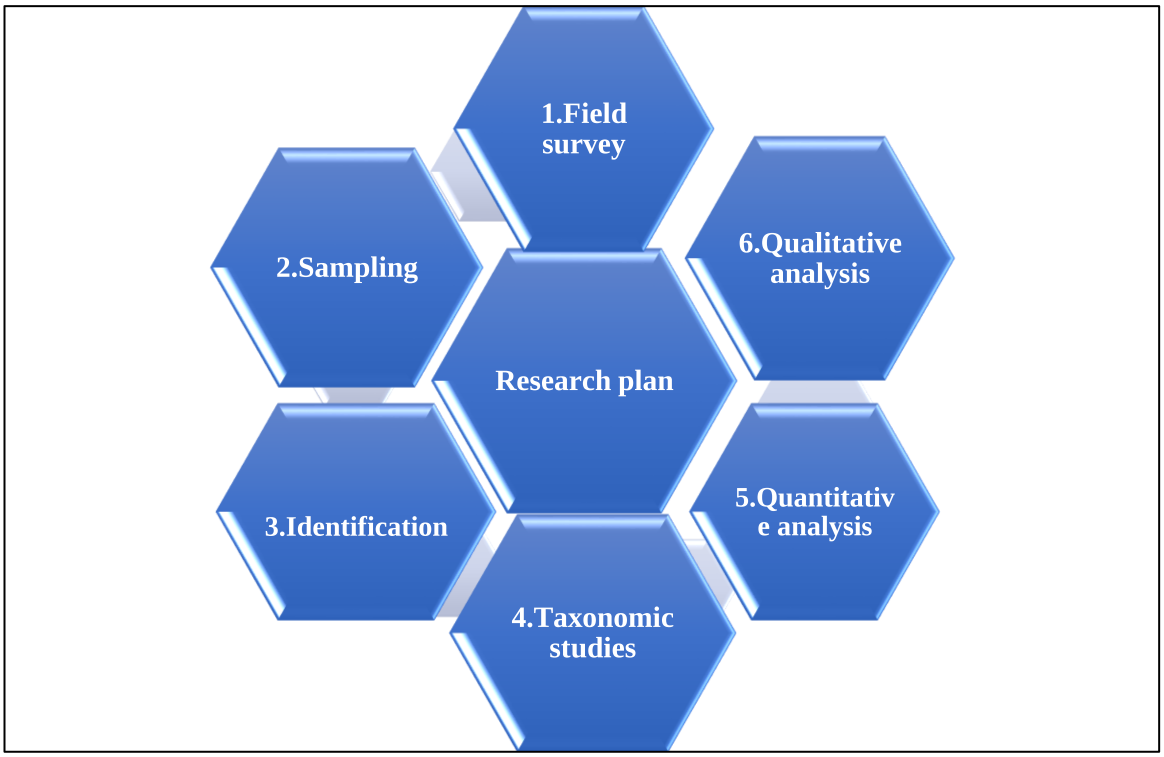

Figure 1. Flow sheet showing research plane.

2.2 Research Area: Northern Pakistan

The Northern region of Pakistan is renowned for hosting some of the world largest summits and towering mountain chains, including the Karakoram, Kunlun, Hindukush, and Tien Shan, Alai Ranges (Khan et al., 2002). Its geography varies, with rocky areas in the north to forest and green plains in the south, surrounds the lower elevations of the Himalayas, Hindukush, and Karakoram Mountain ranges (Hamayun et al., 2003). This region hosts distinct plant species that hold significance as sources of edible food, medicinal remedies, and aromatic essences (Ali and Qaiser 1986). This region covers the Hazara division, Swat valley, Mansehra, Kaghan, and specific tribal areas in the northern regions. The region positioned between 72°35' to -73°31' E longitude and 33°50' to 34°23' N latitude, the northern part of Pakistan shares borders Afghanistan to the northwest, Kashmir to the east, Punjab and Islamabad Capital Territory to the southeast, and FATA to the south (Malik et al., 2018). The annual average rainfall amounts to 1125 mm.

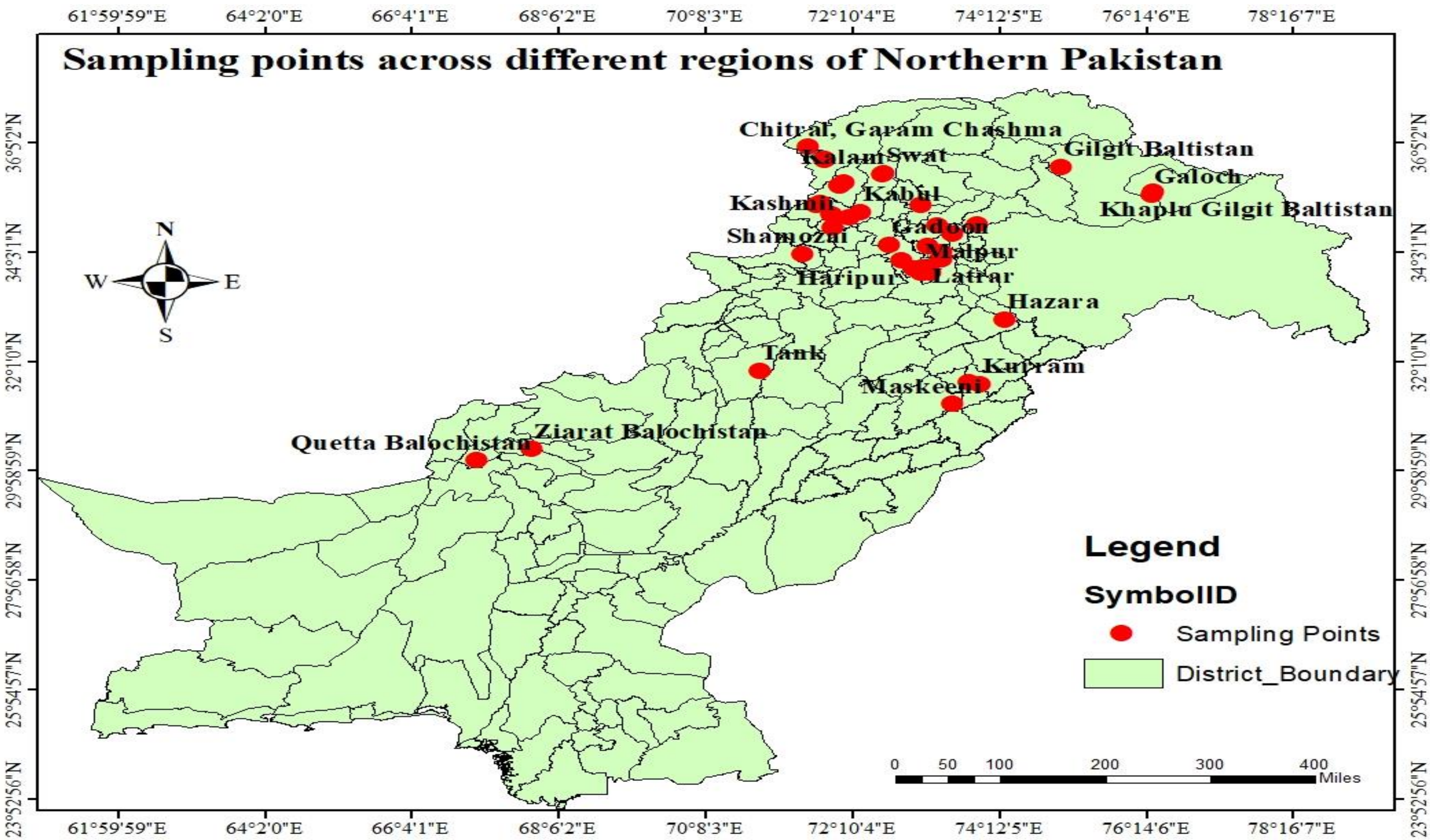

Figure 2. Map of the study Area: Northern Pakistan

Plate 1. Panoramic view of Northern areas; (A) Ayyubia (District Abbotabad), (B) Khaplu (Gilgit Baltistan).

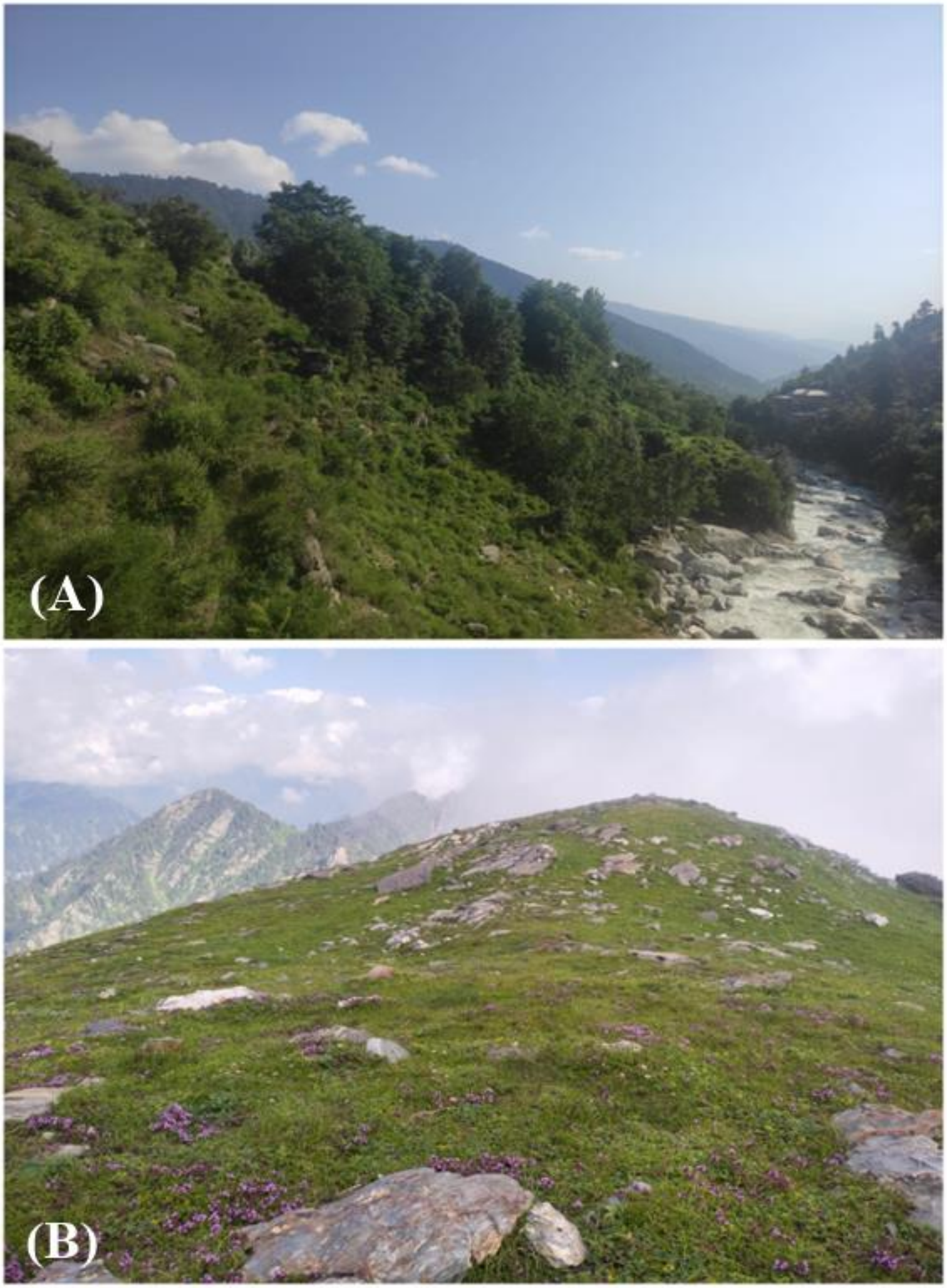

Plate 2. Panoramic view of Northern areas; (A) Shireen Gal (District Upper Dir), (B) Saritop panjkot valley (District Muzafarabad).

2.3 Collection of Lamiaceous flora

The collection, preparation, and preservation of plants is the main part of the research. To accomplish the goals, regular field trips and taxonomic knowledge are necessary. Weather updates were noticed before leaving for the field, and a reference letter is taken from the supervisor/university to avoid any unfavorable circumstances. The study area includes Upper Dir, Lower Dir, Swat, Kaghan, Chitral, Gilgit, Ayyubia, Kashmir, and Islamabad. Field trips were conducted in March 2021 to August 2022.

Using a cutter, plants were cut up and collected. They were then put in the newspaper. Ten samples were obtained from each plant, and the selection process favored fresh plants. Every individual plant was assigned a unique voucher number for identification. Unidentified Lamiaceous taxa were tagged. Upon return to the Herbarium of Pakistan at QAU Islamabad, the collected plant materials underwent a thorough cleansing process to rid them of extraneous particles. The specimens were then carefully laid out on newspapers and subjected to controlled pressure. To ensure thorough dehydration of the plants, newspapers must be replaced on a regular basis during the drying process.

2.4 Identification of the Lamiaceous flora

Plant identification stands as the foremost and crucial stage in plant taxonomy. The species were recognized by using accessible literature (http://www.efloras.org) and the Flora of Pakistan. The recognized species were subsequently cross verified by comparing them with the plant specimens stored in the Herbarium of Pakistan (ISL). The botanical nomenclature was corroborated and substantiated using Tropicos (Missouri Botanical Gardens) (http://www.tropicos.org/). The identified species were mounted on the herbarium sheet and kept in the Herbarium of Pakistan, Department of Plant Sciences, Quaid-i-Azam University, Islamabad, Pakistan, to serve as a future point of reference (Ali et al., 2000).

2.5 Preservation and Mounting of Lamiaceous Species

To protect the samples from fungal and other insects permanently, specimens had been completely dried, ready for poisoning. The standard approach was used (Nasir and Ali 1978). In a container, absolute ethanol (99.8%) poured, followed by the addition of finely crystallized mercuric chloride. Once the solution was prepared, each individual plant specimen was immersed into it. Various cautions i.e., wearing gloves, glasses, a lab coat, and a mask while poisoning was done because chemicals are flammable and can hurt the body. Subsequently, the treated specimens were placed in a shaded area to facilitate the drying process. Once completely dry, the plants were mounted onto standard-sized herbarium sheets, measuring 12x16 inches. This was achieved by applying glue to mount the specimens onto the sheets, on which necessary details, such as the specimen's name, voucher number, specific locality, collector's identity, and the date of collection are mentioned. To enhance long-term preservation, these herbarium sheets were enclosed within sealable plastic bags, thereby safeguarding spores and various plant parts for future reference, ensuring their utility across diverse research purposes. Three distinct specimens of each Lamiaceous species were deposited in the Herbarium of Pakistan, confirm their availability for scholarly research purposes.

Plate 3. Field plant collection from Northern area; (A) *Perilla frutescens* (L.) (seed collection) (B) *Phlomidoschema parviflorum* (Benth.) Vved.

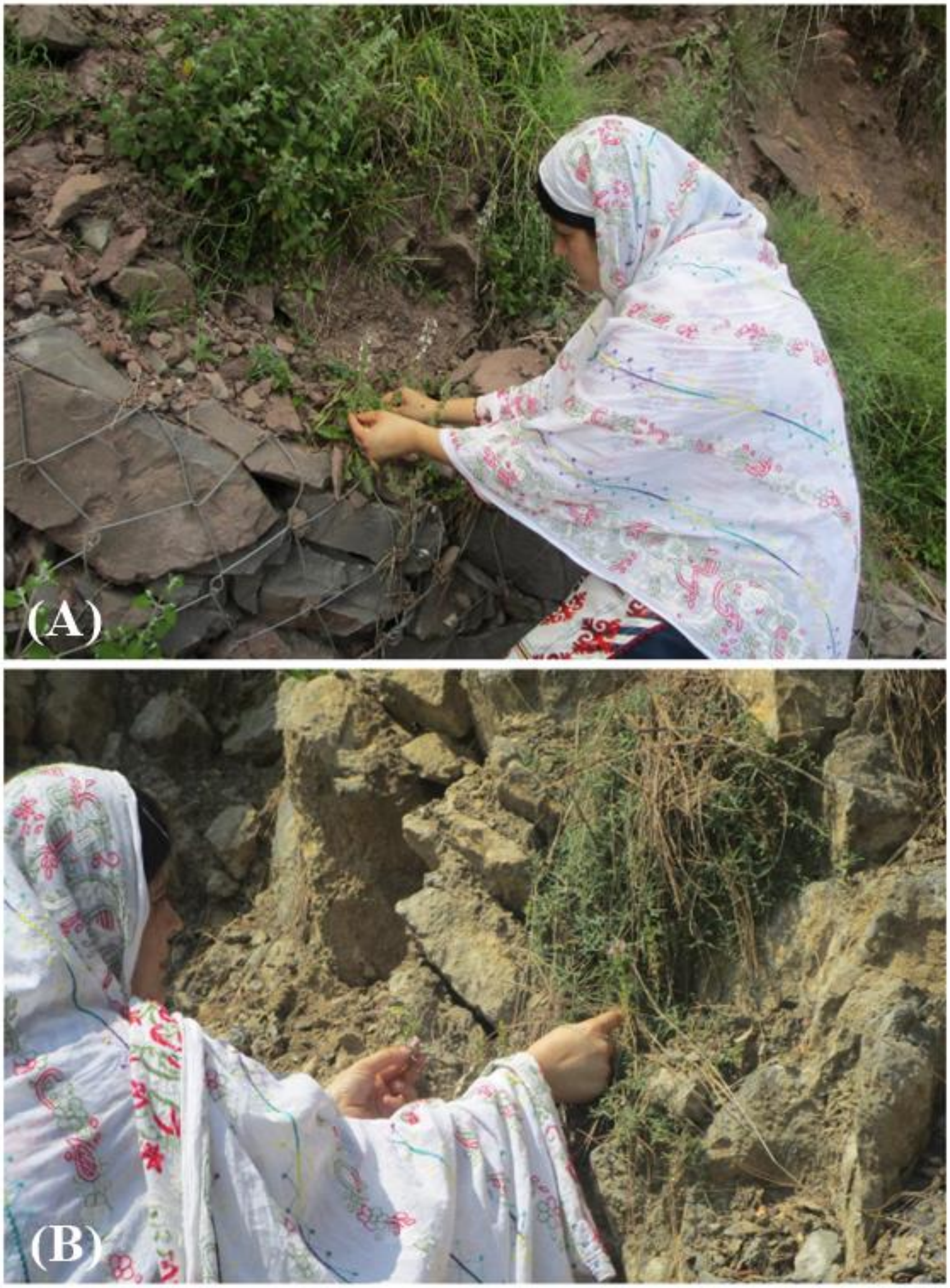

Plate 4. Field plants collection from Northern areas; (A) *Stachys palustris* L. (B) *Scutellaria linearis* Benth.

Plate 5. Lamiaceous floral Herbarium specimens (A) Preservation (B) Plant description on herbarium sheets.

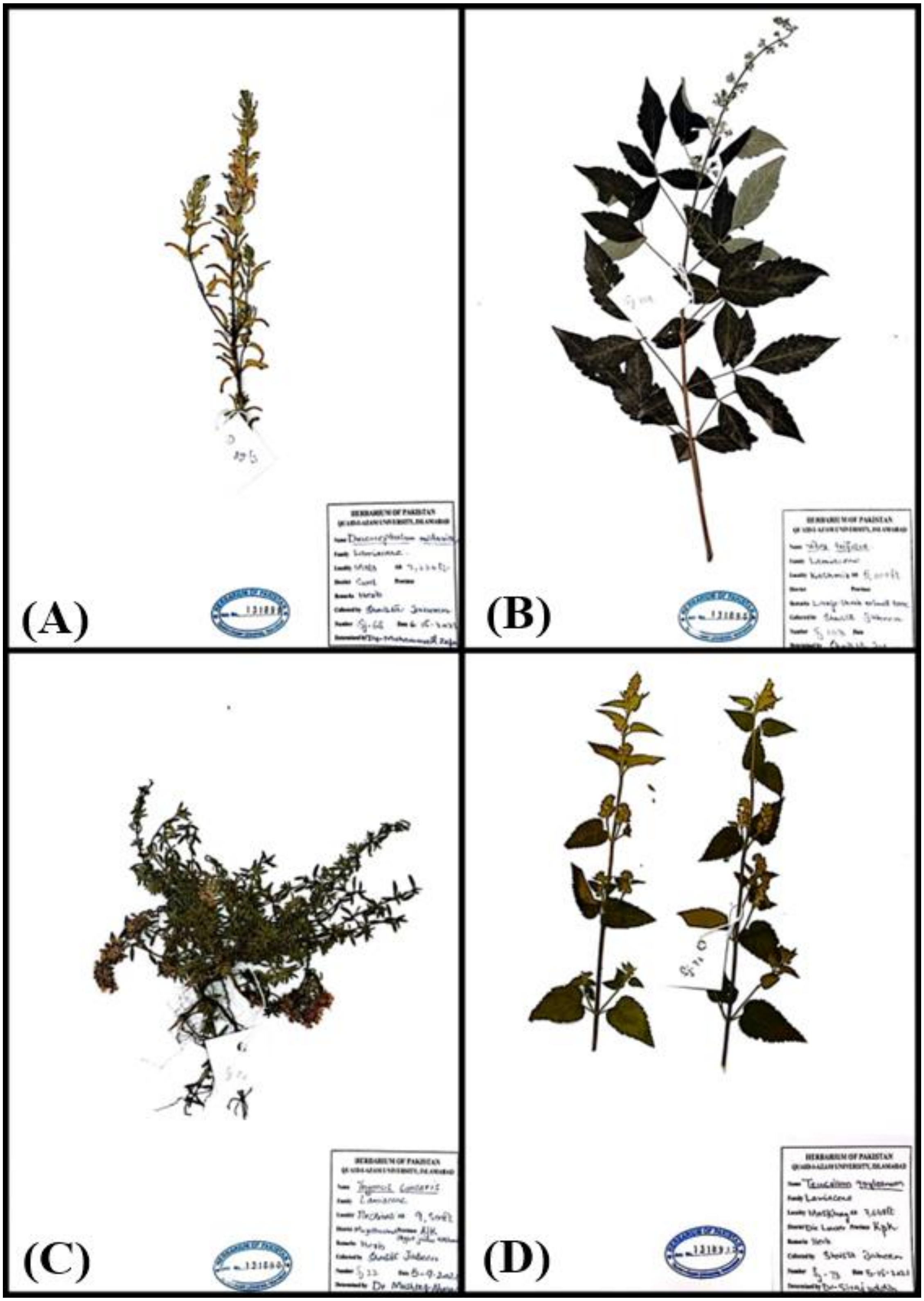

Plate 6. Mounted Herbarium Specimens: (A) *Dracocephalum moldavica* L. (B) *Vitex trifolia* L. (C) *Thymus linearis* Benth. (D) *Teucrium royleanum* Wall. ex Benth.

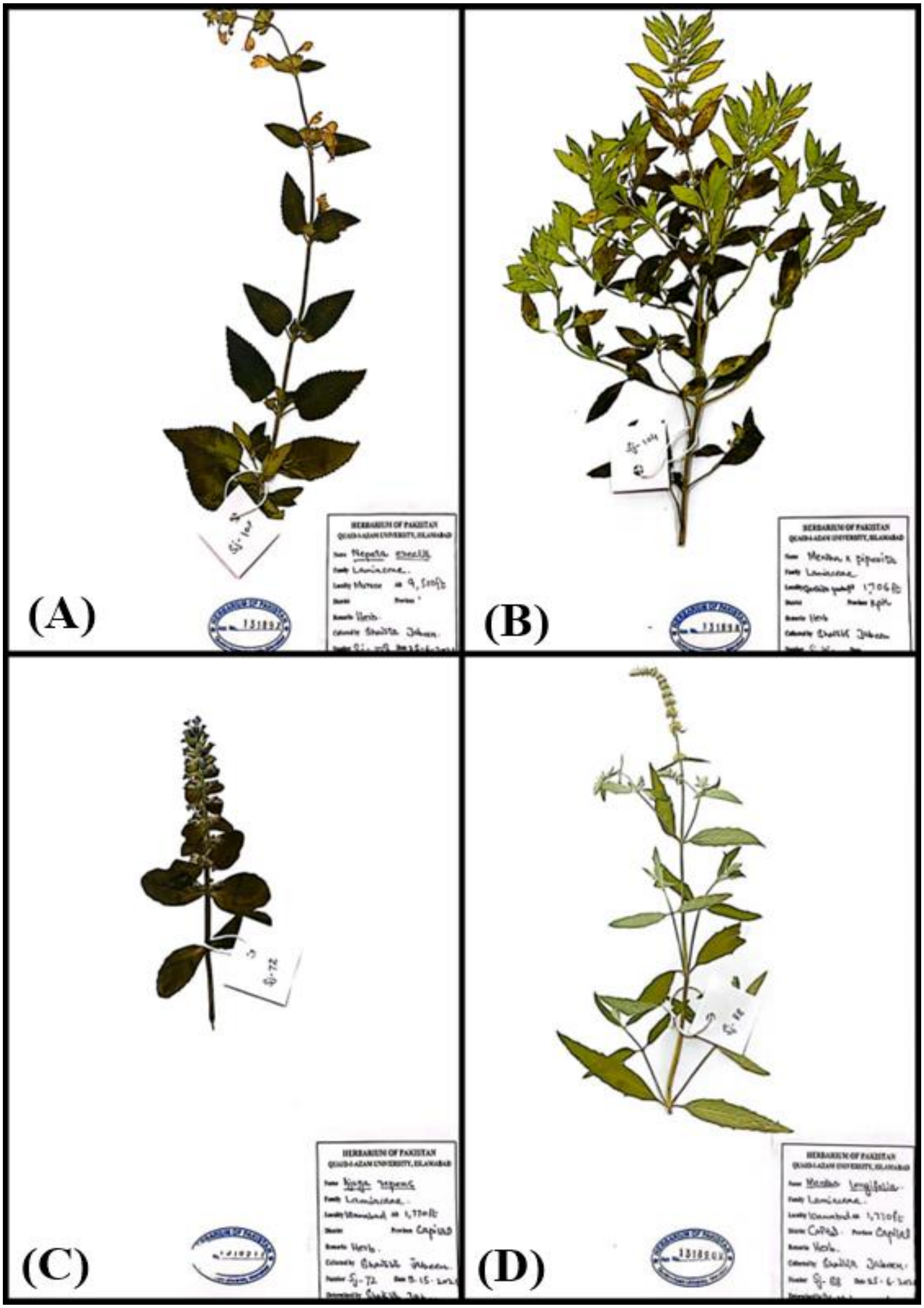

Plate 7. Mounted Herbarium Specimens: (A) *Nepeta erecta* (Royle ex Benth.) Benth. (B) *Mentha × piperita* L. (C) *Salvia splendens* Sellow ex Roem. & Schult. (D) *Mentha longifolia* (L.) L.

2.6 Microscopic Techniques for Taxonomy

2.6.1 Analysis of Pollen Structure

a) Light Microscopy (LM)

For palynological studies, a single anther, few anthers, or a complete flower were collected and put into tiny sample bags, depending on the plant material. A single to a few anthers from each sample were put into drops of acetic acid on microscopic glass slides for light microscopic slide preparations. Following (Erdtman, 1986) protocol, acetolyzed materials on slides were crushed for a short period of time to soften the anthers, release the pollen grains from the anthers, remove any extra organic material from the pollen grain surfaces. Subsequently, these pollen grains were stained, using glycerin jelly to facilitate better visualization The eyepiece (ocular; 10X) with a scale was used to measure the pollen grains, and the measurement findings were then converted into micrometers (µm) by multiplying them by 2.5. Twenty pollens were measured from each prepared slide to determine the mean value and standard error.

b) Scanning Electron Microscopy (SEM)

Pollen grains originating from Lamiaceous species underwent preparation for scanning electron microscopy (SEM), following the methodology detailed by Butt et al. (2018). The process entailed suspending the pollen within an acetolyzed solution (90% ethanol), after which the pollen was affixed onto metallic stubs. Subsequently, a delicate coating of gold palladium particles was applied to the pollen, enhancing its visual attributes under SEM. For the examination of pollen through light microscopy descriptive pollen terminology was used by (Punt et al., 2007). For the examination of pollen through scanning electron microscopy descriptive pollen terminology was used by (Halbritter et al., 2018). Regarding the categorization of pollen shapes (P/E), the definitions by (Nilsson and Praglowski 1992) were adopted. The pollen grains size was measured according to (Erdtman, 1971) classifying sizes as follows: "very small" (< 10 µm), "small" (10–25 µm), "medium" (25–50 µm), "large" (50–100 µm), "very large" (100–200 µm), and "huge" (> 200 µm).

2.6.2 Study of Leaf Epidermal Anatomy

a) Light Microscopy (LM)

Under a light microscope, mature dried foliar specimens were analyzed. The modified (Clarke, 1960), method was used to prepare each specimen. To decolorize the plant material, a very small portion of a frond was cut off and put in a culture tube with a combination of one-part lactic acid (25%) and three parts nitric acid (75%). After 5–10 minutes, this solution was heated to 100 °C. The material was then put into a petri dish and given two water washes. To make peeling easier, add lactic acid drops to the plant tissue. A frond piece was prepared, placed on a microscope slide, and then coated with a cover slip (Nazir et al., 2013). The same procedure was used for all species. For each species adaxial and abaxial surfaces, about 6–8 slides were made. Four to five leaf samples out of each species were collected, and leaf surfaces were utilized to make a minimum of five to seven slides and, in some situations, as many as 10 slides, to investigate the consistency of epidermal features.

Nail paint was used to set the cover slip on the glass slide and make glass slide permanent. To get precise data, 4-5 slides of adaxial and abaxial surfaces were made. With Nikon and Meiji light microscopes from Tokyo, Japan, the anatomical characteristics of each specimen were examined. The LEICA-DM-1000 light microscope was used to take pictures with a Meiji Unlimited DK-2000 camera (Tokyo, Japan).

b) Scanning Electron Microscopy (SEM)

Dried foliage was cleared and treated with ethanol for dirt removal prior to SEM examination. Employing dual-coated adhesive tape, both the upper and lower surfaces of the leaves were sectioned and affixed to the mounts. Subsequently, the specimens underwent gold-palladium coating via sputtering prior to investigation using a Scanning Electron Microscope (Model JEOL-5910) situated in the Central Resource Laboratory of the Department of Physics at the University of Peshawar. Photomicrographs were captured using Polaroid P/N 665 film (Benjamin et al., 2018). Using a microscope, the samples were investigated for distinct micromorphological attributes, encompassing trichomes, stomata, and epidermal cells of the leaves.

2.6.3 Examination of Seed Microscopic traits

Scanning Electron Microscopy (SEM) was employed for observing desiccated seeds. The seeds undergo 3–4-minute alcohol rinse to eliminate surface debris. Subsequently, the seed specimens were directly positioned on mounts and affixed using adhesive tape. Prior to analysis using a Scanning Electron Microscope (JEOL JSM-5910) located at the Central Resource Laboratory of the University of Peshawar, the specimens were coated with a layer of gold-palladium via sputtering. Photomicrographs were captured on Polaroid P/N 665 film. The samples were investigated to identify distinctive surface attributes of the seeds, including shape, dimensions, hue, hilum, surface patterns, cell boundaries, epidermal cells, and anticlinal walls. Seed micromorphological parameters were delineated following the terminology outlined by (Özkan et al., 2009).

2.7 Statistical Assessment

Data was examined by using statistical software (SPSS 16.00), to determine the maximum, minimum, mean, and standard error. Nearly 15 to 20 measurements of each parameter were taken for the statistical analysis of mean (minimum-maximum) ±SE. Subsequently, the averaged values were subjected to multivariate principal component analysis using XLSTAT version 2018, and cluster analysis was conducted through the utilization of Past software version 4.13. These analyses aimed to illustrate the interrelationship among the species.

2.7.1 Pollen Fertility and Sterility (%)

The fertility and sterility of pollen were measured by using the formula by (Butt et al., 2018).

$$Fertility = F/F+S \times 100$$

Where F is the number of fertile pollens on an ocular and S is the number of sterile pollens in the same ocular

$$Sterility = S / S + F \times 100$$

Where S is the number of sterile pollens in an ocular and F is the number of fertile pollens in same ocular.

2.7.2 P/E Ratio (%)

P/E ratio was calculated for each specie by using the formula (Umber et al., 2022).

$$P/E = P / E \times 100$$

Where P is the polar diameter and E is the equatorial diameter of the same pollen.

2.7.3 Estimating Stomatal and Trichome Index

Stomatal measurements were determined within a unit area to calculate the stomatal index, employing an optical microscope.

Using the (Kadiri and Olowokudejo 2008) formula, stomatal index values were determined.

$$SI = S/E+S \times 100$$

Where SI stands for stomata index, S for stomata count, and E for epidermal cell count.

Using the (Kadiri and Olowokudejo 2008) formula, trichome index values were determined.

$$TI = T/E+T \times 100$$

Where TI stands for trichomes index, T for trichome count, and E for epidermal cell count.

2.7.4 Exploratory Multivariate Analysis

Using the hierarchical grouping method (Unweighted pair group method with arithmetic mean), the Lamiaceous species' anatomical, pollen sources, and seed morphological traits were correlated based on Euclidean distance. The PAST statistical software version 4.13 was used to perform UPGMA (Kovach 2013).

One of the most significant statistical tests for analyzing a set of components is principal component analysis (PCA), which aims to represent the variation that exists among the pollen, anatomical and seed morphological quantitative attributes of the studied taxa. The observed data is represented in two-dimensional projection with axes PC (principal components) using XLSTAT version 2018.

2.8 Data Compilation Using Light Microscopy

For anatomical research, permanent microscope slides were placed beneath a light microscope to aid in the documentation process. The examinations were carried out using a magnification of 40X on the light microscope.

2.9 Capturing Microphotographs

With the aid of a mobile camera, microphotographs were captured from a light microscope at various resolutions, including 4X (25 µm) and 10X (10 µm) of the objective lenses.

Plate 8. Microscopic measurement and visualization and (A) Light microscopic slide data measurement (B) Scanning electron microscopic observation and microphotography.

Chapter 3

Results and Discussion

Section-I

Field Illustration Guide and Floristic Checklist

3. Summary

Rich floristic diversity can be observed in Northern Pakistan. Some aromatic mints, medicinal plants, and endemic plants are confined to Northern Pakistan. The present research was carried out in the selected areas of Northern Pakistan, i.e., Upper Dir, Lower Dir, Swat, Kaghan, Chitral, Gilgit, Ayyubia, Kashmir, and Islamabad. For the first time, these places were thoroughly investigated. The current research work is extensive and involves the taxonomic analysis of 104 Lamiaceous taxa, divided into six subfamilies and 40 genera. Earlier work was fragmented. Four sections are used to compile and present the results separately.

Section 1: Field illustration guide, and floristic checklist of Lamiaceous taxa of Northern Pakistan.

Section 2: Qualitative and quantitative characteristics of pollen from a micro perspective. Qualitative characteristics that is pollen size, shape, pollen outline, colpi apex, aperture number, sculpturing and orientation and exine ultrastructure. Quantitative characteristics include polar and equatorial diameter, P/E ratio, exine thickness, colpi size, mesocolpium distance, and pollen fertility and sterility.

Section 3: Qualitative and quantitative leaf epidermal and anatomical traits include length and width of epidermal cell, arrangement of the epidermal cells, the shape and size of the subsidiary cells, the anticlinal wall pattern, the size and shape of the guard cells, the size and shape of the stomata, the size and shape of the stomatal pore, the types of trichomes, and the diameter of the trichomes.

Section 4: Micromorphological seed characteristics include seed color, size, shape, cell outline, texture, form, surface texture, apex, base compression, hilum location, sculpturing, anticlinal wall, and periclinal wall pattern and epidermal cell arrangement.

3.1 Floristic Checklist of Lamiaceous Plants and Field Pictorial Guide

These findings consist of a checklist of 104 species of Lamiaceae, divided into six subfamilies. The botanical name, life form, status, date of collection, voucher specimen, accession number, localities, and geographic coordinates are all listed in Table 1 floristic checklist.

The current study investigated the taxonomic characteristics of Lamiaceous plant taxa that belongs to the 6 sub families consists of 40 genera, of which *Nepeta* was dominant (19 species), followed by *Salvia* (13 species), *Mentha* (8 species), *Ocimum* (6 species), *Stachys* (4 species) and *Ajuga*, *Clerodendrum*, *Clinopodium*, *Scutellaria* and *vitex* (3 species each). Genus *Eremostachys, Lamium, Leucas, Moluccella, Origanum, Phlomis, Plectranthus, Teucrium*, *Thymus* (2 species each). Genus *Anisochilus*, *Anisomeles*, *Callicarpa, Colebrookea, Coleus, Dracocephalum, Hyssopus, Isodon, Lallemantia, Leonurus, Lavandula, Marrubium, Melissa, Micromeria, Monarda, Perilla, Perovskia, Prunella, Pseudocaryopteris*, *Rosmarinus*, *Satureja* (1 species each). Among Lamiaceae species, the herb was the dominant life form (84 species), followed by 10 shrubby species, sub shrubs (3 species), small trees (4 species), and climbers 1 specie (Figure 4).

Using a Samsung digital camera, field photography was done during the field surveys, multiple photographs of dicot Lamiaceous species were captured. The floral pictorial guide (Plates 9 to 33) helps taxonomists identify live plants in the field for accurate identification.

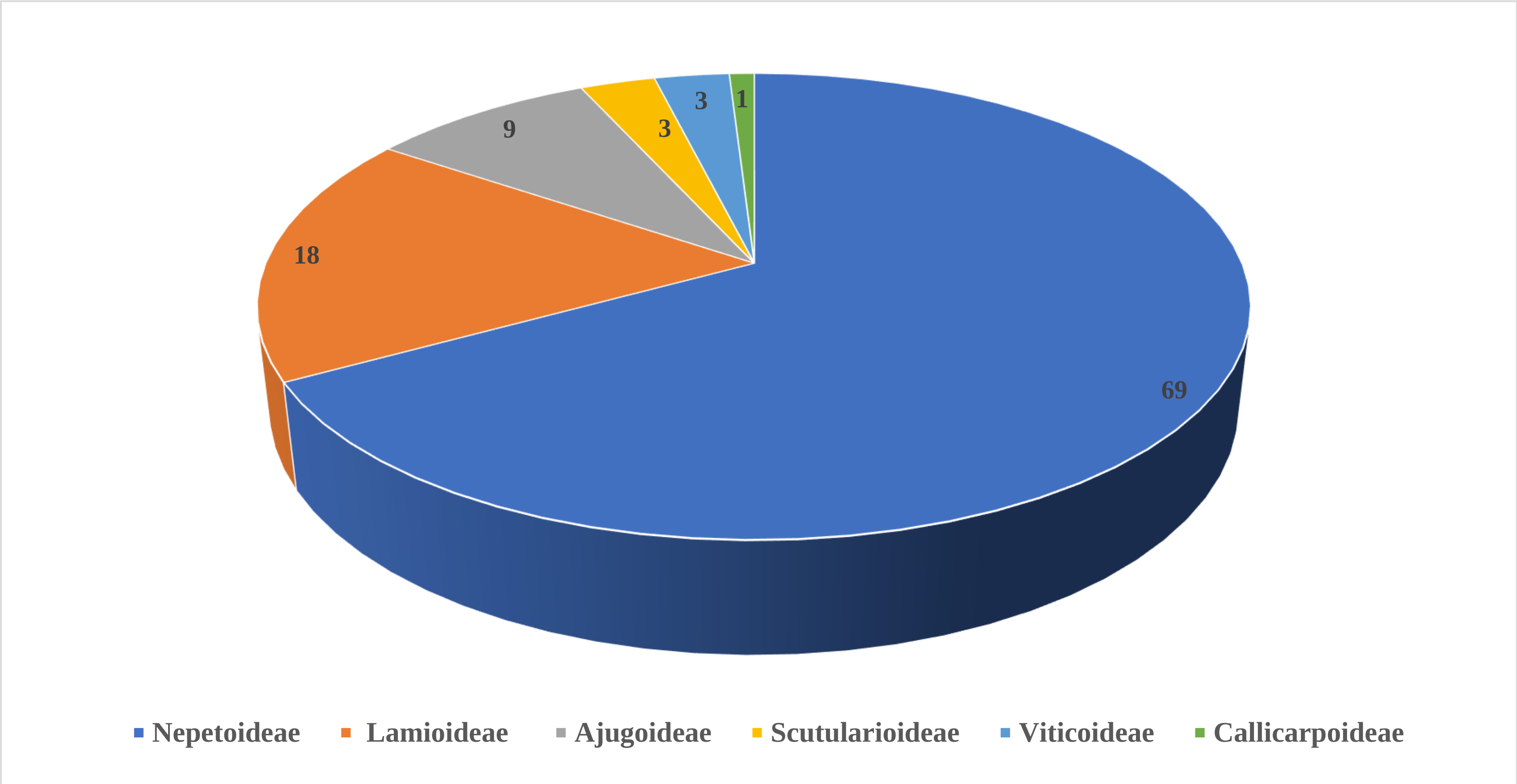

Figure 3. Graphical illustration of Lamiaceae sub families with species numbers

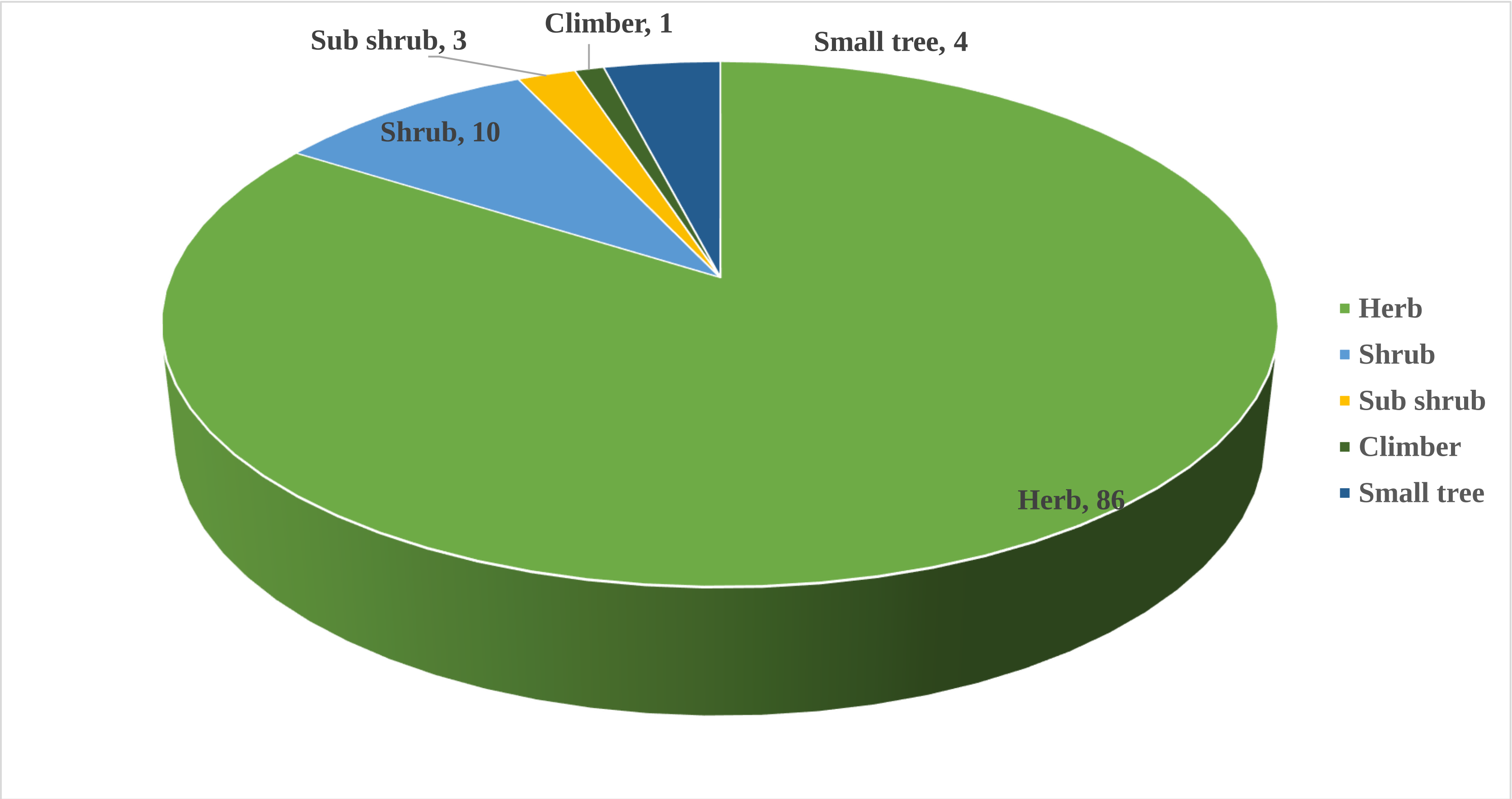

Figure 4. Life Form Classification of Lamiaceous taxa (in numbers)

Table 1. Checklist of Lamiaceous taxa with life form, status, date of collection, vouchering data, localities, and geographical coordinates.

S.no	Species	Life form	Status	Locality	Date of collection	Altitude (ft)	GPS Coordinates	Voucher specimen no/ Accession no
1.	*Ajuga integrifolia* Buch.-Ham.	Herb	Wild	Swat (KPK)	08-09-2022	7,138	34°43'08.37"N 72°29'17.68"E	SJ 5/ 133575
2.	*Ajuga parviflora* Benth.	Herb	Wild	Ayyubia national park (KPK)	20-09-2022	7,826	34°02'59.43"N 73°24'23.29"E	SJ 10/ 133576
3.	*Ajuga reptans* L.	Herb	Cultivated	*Quaid-i-Azam University* (Isl.)	08-05-2022	1,959	33°44'29.41"N 73°09'36.36"E	SJ 7/ 133577
4.	*Anisochilus carnosus* (L.f.) Wall.	Herb	Wild	Ghadoon (KPK)	06-05 2021	1,863	34°10'54.64"N 72°40'51.21"E	SJ 45/ 133578
5.	*Anisomeles indica* (L.) Kuntze	Herb	Wild	Murree (Punjab)	19-06-2021	6,290	33°54'34.12"N 73°22'58.25"E	SJ 59/ 133579
6.	*Callicarpa macrophylla* Vahl	Shrub	Wild	Neelum valley Kashmir	09-09-2021	4,589	34°34'01.23"N 73°53'36.24"E	SJ 48/ 133580

7.	*Clerodendrum inerme* (L.) Gaertn.	Shrub	Cultivated	*Quaid-i-Azam University* (Isl.)	10-10-2021	2,035	33°44'51.06"N 73°08'12.96"E	SJ 67/ 133581
8.	*Clerodendrum splendens* G. Don	Climber	Cultivated	Quaid university (Isl.)	15-10-2021	2,037	33°44'50.09"N 73°08'12.74"E	SJ 98/ 133582
9.	*Clerodendrum umbellatum* Poir.	Shrub	Cultivated	National Agriculture Research Council (Isl.)	20-15-2022	1,688	33°41'00.95"N 73°08'00.58"E	SJ 100/ 133583
10.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	Herb	Wild	Ayyubia national park (KPK)	08-09-2021	7,764	34°03´10.96"N 73°24´24.72"E	SJ 14/ 131873
11.	*Clinopodium umbrosum* (M. Bieb.) Kuntze	Herb	Wild	Talash (KPK)	09-05-2021	2,748	34°44'30.28"N 71°52'20.05"E	SJ 21/ 133585
12.	*Clinopodium vulgare* L.	Herb	Wild	Sadbar kalay (KPK)	10-06-2021	3,051	34°55'19.91"N 71°40'50.77"E	SJ 20/ 133584
13.	*Colebrookea oppositifolia* Sm.	Small tree	Wild	Latrar (Isl.)	15-06-2022	1,755	33°39'14.26"N 73°14'48.49"E	SJ 25/ 133586
14.	*Coleus forskohlii* (Willd.) Briq.	Herb	Cultivated	Chak Shahzad (Isl.)	12-08-2022	1,665	33°40'34.01"N 73°08'07.33"E	SJ 34/ 133587

15.	*Dracocephalum moldavica* L .	Herb	Wild	(Gilgit Baltistan)	15-05-2021	4,900	35°07´05"N 76°19´18"E	SJ 21/ 131899
16.	*Eremostachys superba* Royle ex Benth.	Herb	Wild	Malakand (KPK)	05-04-2021	1,478	34°30'10.92"N 71°54'16.99"E	SJ 35/ 133588
17.	*Hyssopus officinalis* L.	Shrub	Wild	Swat (KPK)	10-04-2021	6,875	35°30´40.05"N 72°36´15.80"E	SJ 34/ 131888
18.	*Isodon rugosus* (Wall. ex Benth.) Codd	Shrub	Wild	Gabeen Jaba (KPK)	04-04-2021	8,496	35°1014.65"N 72°2218.14"E	SJ 56/ 133589
19.	*Lallemantia royleana* (Benth .) Benth.	Herb	Wild	Shamozai (KPK)	04-05-2021	2,501	34°41´01.87"N 72°07´38.74"E	SJ 82/ 133404
20.	*Lamium album* L.	Herb	Wild	Ayyubia national park (KPK)	08-08-2021	8,029	34°04'50.35"N 73°24'44.69"E	SJ 78/ 133590
21.	*Lamium amplexicaule* L.	Herb	Wild	Kabal (Swat	25-04-2021	2,995	34°47'32.16"N 72°16'57.41"E	SJ 79/ 133591
22.	*Lavandula angustifolia* Mill.	Herb	Cultivated	Islamabad	30-05-2022	1,651	33°39'57.76"N 73°072'2.47"E	SJ 84/ 1335641
23.	*Leonurus cardiaca* L.	Herb	Wild	Kalam (KPK)	28-04-2021	6,823	35°29'23.92"N 72°34'43.28"E	SJ 83/ 133592

24.	*Leucas aspera* (Willd.) Link	Herb	Wild	Malpur (Isl.)	22-08-2022	1,817	33°43'38.49"N 73°09'02.00"E	SJ 86/ 133593
25.	*Leucas cephalotes* (Roth) Spreng.	Herb	Wild	Hazara (KPK)	27-05-2021	1,010	32°47'46.52"N 74°17'02.70"E	SJ 90/ 133594
26.	*Marrubium vulgare* L.	Herb	Wild	Talash (KPK)	29-08-2022	2,975	34°4359.69"N 71°5222.39"E	SJ 97/ 133595
27.	*Melissa officinalis* L.	Herb	Wild	Muzaffarabad (Kashmir)	20-07-2021	4,117	34°09´26.56"N 73°12´45.20"E	SJ 2/ 1318910
28.	*Mentha spicata* L.	Herb	Wild	Malakand (KPK)	10-08-2021	1,488	34°30´04.30"N 71°54´10.37"E	SJ 23/ 131091
29.	*Mentha x piperita citrata* - (Ehrh.) Briq.	Herb	Wild	Haripur (KPK)	15-09-2021	1,613	33°53´42.97"N 72°51´23.67"E	SJ 7/ 13187
30.	*Mentha* × *piperita* L.	Herb	Wild	Abbottabad (KPK)	20-07-2021	1,655	33°40'13.46"N 73°07'33.12"E	SJ 42/ 131898
31.	*Mentha* × *villosa* Huds.	Herb	Wild	National Agriculture Research Council (Isl.)	07-07-2022	1,656	33°40´12.67"N 73°07´35.01"E	SJ 11/ 133405
32.	*Mentha arvensis* L.	Herb	Wild	Quaid university (Isl.)	13-08-2021	2,011	33°44´44.65"N 73°07´40.07"E	SJ 19/ 131887

33.	*Mentha longifolia* (L.) L.	Herb	Wild	Sherin gal (KPK)	17-07-2021	4,744	35°16´43.18"N 72°00´08.34"E	SJ 31/ 1318909
34.	*Mentha pulegium* L.	Herb	Wild	Haripur (KPK)	05-08-2021	1,613	33°53´44.95"N 72°51´23.38"E	SJ 16/ 131890
35.	*Mentha suaveolens* Ehrh.	Herb	Wild	Haripur (KPK)	09-09-2021	1,622	33°53´47.44"N 72°51´27.47"E	SJ 28/ 131884
36.	*Micromeria biflora* (Buch. -Ham. ex D. Don) Benth.	Herb	Wild	Sheringal (KPK)	04-04 2021	2996	34°47´33.43"N 72°16´56.18"E	SJ 38 /131882
37.	*Moluccella aucheri* (Boiss.) Scheen	Shrub	Wild	Tank, Dera Ismail khan (KPK)	10-05-2022	581	31°50'15.15"N 70°53'10.25"E	SJ 69/ 133596
38.	*Monarda fistulosa* L.	Herb	Wild	Botanical garden Qarshi industries Haripur (KPK)	8-9-2021	1,614	33°53´45.02"N 72°51´23.45"E	SJ 22/ 1319813
39.	*Nepeta adenophyta* Hedge	Herb	Wild	Chitral (KPK)	6-9-2021	7764 ft	34°03´10.96"N 73°24´24.72"E	SJ 35/ 1335641
40.	*Nepeta cataria* L.	Herb	Wild	Galoch (KPK)	15-04-2021	4,900	35°07'05"N 76°19'18"E	SJ 28/ 131890
41.	*Nepeta connata* Royle ex Benth.	Herb	Wild	Panjkot vally Kashmir	10-07-2022	6,875	35°30'40.05"N 72°36'15.80"E	SJ 39/ 131480

42.	*Nepeta discolor* Royle ex Benth.	Herb	Wild	Khaplu Gilgit Baltistan	25-08-2021	4,117	34°09'26.56''N 73°12'45.20''E	SJ 1/ 131482
43.	*Nepeta distans* Royle	Herb	Wild	Sarlara (KPK)	05-05-2021	2,501	34°41'01.87''N 72°07'38.74''E	SJ 87/ 133481
44.	*Nepeta elliptica* Royle ex Benth.	Herb	Wild	Peer chanasi (Kashmiir)	03-09-2021	8,857	34°22´54.6''N 73°33'08.41''E	SJ 46/ 133597
45.	*Nepeta erecta* (Royle ex Benth.) Benth.	Herb	Wild	Ayubia national park (KPK)	08-09-2022	2,011	33°44'44.65''N 73°07'40.07''E	SJ 20/ 131898
46.	*Nepeta govaniana* (Wall. ex Benth.) Benth.	Herb	Wild	Peer chanasi (Kashmir)	08-09-2021	9,415	34°23'16.47''N 73°33'07.65''E	SJ 51/ 133598
47.	*Nepeta graciliflora* Benth.	Herb	Wild	Kashmir	07-04-2021	4,744	35°16'43.18''N 72°00'08.34''E	SJ 33/ 131483
48.	*Nepeta griffithii* Hedge	Herb	Wild	Swat (KPK)	25-04-2021	1,655	33°40'13.46''N 73°07'33.12''E	SJ 27/ 1318907
49.	*Nepeta hindostana* (B. Heyne ex Roth) Haines	Herb	Wild	Hazara (KPK)	18-04-2021	1,613	33°53'44.95''N 72°51'23.38''E	SJ 11/ 131872
50.	*Nepeta laevigata* (D. Don) Hand. -Mazz.	Herb	Wild	Murree (Punjab)	10-09-2021	1,488	34°30'04.30''N 71°54'10.37''E	SJ 50/ 1318903
51.	*Nepeta leucolaena* Benth. ex-Hook.f.	Herb	Wild	Peer Chanasi (Kashmir)	18-08-2022	6,175	34°24'00.55''N 73°31'19.90''E	SJ 24/133599

52.	*Nepeta linearis* Royle ex Benth.	Herb	Wild	Kagan valley (KPK)	06-06-2022	3,267	34°32'30.81"N 73°20'54.48"E	SJ 38/ 133600
53.	*Nepeta nervosa* Royle ex Benth.	Herb	Wild	Upper Dir (KPK)	21-05-2022	5,280	35°20'14.38"N 72°02'56.66"E	SJ 49/ 1335601
54.	*Nepeta podostachys* Benth.	Herb	Wild	Upper Chitral (KPK)	28-09-2022	4,771	35°46'13.36"N 71°46'54.63"E	SJ 87/ 1335602
55.	*Nepeta praetervisa* Rech.f.	Herb	Wild	Quetta Balochistan	05-04-2021	1,622	33°53´47.44"N 72°51´27.47"E	SJ 25/ 131891
56.	*Nepeta raphanorhiza* Benth.	Herb	Wild	Talash (KPK)	18-06-2022	2,745	34°44'27.96"N 71°52'17.08"E	SJ 94/ 1335603
57.	*Nepeta schmidii* Rech.f.	Herb	Wild	Chitral (KPK)	23-05-2022	4,822	35°45'54.95"N 71°46'53.38"E	SJ 92/ 1335604
58.	*Ocimum* × *africanum* Lour.	Herb	Wild	Quaid i Azam university residential colony (Isl.)	17-07-2022	1,976	33°44'41.58"N 73°08'18.98"E	SJ 70/ 1335605
59.	*Ocimum americanum* L.	Herb	Wild	Quaid i Azam university	18-08-2022	2,050	33°44'45.33"N 73°07'57.72"E	SJ 7/ 1335606

				residential colony (Isl.)				
60.	*Ocimum basilicum* L.	Herb	Wild	Quaid i Azam university botanical garden (Isl.)	25-08-2022	1,969	33°44'15.06"N 73°09'46.47"E	SJ 77/ 1335607
61.	*Ocimum citriodorum* Vis.	Herb	Wild	Qarshi industries (Haripur)	10-08-2022	1,652	33°53'49.63"N 72°52'43.42"E	SJ 78/ 1335608
62.	*Ocimum gratissimum* L.	Shrub	Wild	Qarshi industries (Haripur)	10-08-2022	1,648	33°53'48.57"N 72°51'43.57"E	SJ 37/ 1335609
63.	*Ocimum sanctum* L.	Herb	Wild	Chak shahzad (Isl.)	27-07-2022	1,684	33°40'08.70"N 73°08'56.12"E	SJ 52/ 1335610
64.	*Origanum majorana* L.	Herb	Cultivated	National Agriculture Research Council (Isl.)	05-05-2021	1,703	33°40´42.04"N 73°08´22.92"E	SJ 23 /131885
65.	*Origanum vulgare* L.	Herb	Wild	Nathia gali (KPK)	05-05-2021	7,182	33°54´36.23"N 73°24´10.35"E	SJ 13/ 133406
66.	*Perilla frutescens* (L.) Britton	Herb	Wild	Muzafarabad (Kashmir)	22-09-2022	2,664	33°20'54.37"N 73°28'57.32"E	SJ 14/1335642

67.	*Perovskia atriplicifolia* Benth.	Subshrub	Wild	Khaplu Gilgit Baltistan	06-06-2021	8,036 ft	33°53´20.25"N 73°55´24.47"E	SJ 6/ 133407
68.	*Phlomidoschema parviflorum* (Benth.) Vved.	Subshrub	Wild	Baragali (KPK)	28-08-2022	7,640	33°05'26.05"N 73°21'27.64"E	SJ 95/ 1335611
69.	*Phlomis bracteosa* Royle ex Benth.	Herb	Wild	(Kashmir)	15-09-2021	3,678	33°58'39.01"N 73°46'57.06"E	SJ 98/ 1335612
70.	*Phlomis stewartii* Hook.f.	Herb	Wild	Ziarat Balochistan	18-06-2022	8,054	30°23'05.25"N 67°44'12.14"E	SJ 34/ 1335 613
71.	*Phlomoides vicaryi* (Benth. ex-Hook.f.) Kamelin & Makhm.	Herb	Wild	Latrar (Isl.)	29-05-2021	1,782	33°39'13.83"N 73°14'52.49"E	SJ 38/ 1335614
72.	*Plectranthus ambonicus* (Lour.) Spreng.	Herb	Cultivated	National Agriculture Research Council (Isl.)	30-7-2022	1,677	33°4035.23"N 73°0816.85"E	SJ 48/ 1335615
73.	*Plectranthus madagascariensis* (Pers.) Benth.	Herb	Cultivated	Margalla hills (Isl.)	24-06-2022	2,174	33°45'11.57"N 73°05'08.34"E	SJ 47/ 1335616

74.	*Prunella vulgaris* L.	Herb	Wild	Murree (Punjab)	08-07-2021	5,909 ft	33°53´12.46"N 73°21´43.49"E	SJ 12/ 133408
75.	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D. Cantino	Shrub	Wild	Islamabad	04-05-2021	2,041	33°45'02.12"N 73°07'55.74"E	SJ 76/ 1335617
76.	*Rosmarinus officinalis* L.	Shrub	Wild	Malakand (KPK)	15-04- 2021	2,382	34°40´19.60"N 72°03´41.07"E	SJ 15/ 133409
77.	*Rydingia limbata* (Benth.) Scheen & V.A. Albert	Shrub	Wild	Kabal (KPK)	05-04-2021	3,063	34°48'16.03"N 72°16'57.08"E	SJ 77/ 1335 618
78.	*Salvia aegyptiaca* L.	Herb	Wild	Kurrum (KPK)	04-04-2021	1,237	31°35'33.66"N 73°56'41.65"E	SJ 79/ 1335622
79.	*Salvia cabulica* Benth.	Herb	Wild	Loralai Balochistan	15-04-2021	5,500	31°37'10.43"N 73°47'0.39"E	SJ 75/ 1335619
80.	*Salvia coccinea* Buc'hoz ex Etl.	Herb	Wild	Quaid i Azam university (Isl.)	10-04-2021	1,770	30°26'50.28"N 73°18'33.41"E	SJ 48/ 1335624
81.	*Salvia lanata* Roxb.	Herb	Wild	Swat (KPK)	02-05-2021	10,318	31°35'57.52"N 73°55'53.26"E	SJ 88/ 1335620

82.	*Salvia leucantha* Cav.	Herb	Cultivated	National Agriculture Research Council (Isl.)	15-05-2021	1,699	33°41'09.96"N 73°08'14.43"E	SJ 39/ 1335625
83.	*Salvia moorcroftiana* Wall. ex Benth.	Herb	Wild	Maskeeni (KPK)	01-09-2021	3,648	31°13'30.45"N 73°33'42.00"E	SJ 40/ 1335626
84.	*Salvia nubicola* Wall. ex Sweet	Herb	Wild	Ayyubia national park (KPK)	08-04-2021	7,815	34°03'10.12"N 73°24'23.70"E	SJ 65/ 1335627
85.	*Salvia officinalis* L.	Sub-shrub	Wild	Islamabad (Capital territory)	10-05-2021	1,770	30°260 50.28" N 73°180 33.41″ E	SJ 43/ 1335643
86.	*Salvia plebeia* R.Br.	Herb	Wild	Malakand (KPK)	10-06-2021	1,770	31° 6'29.32"N 73°24'10.95"E	SJ 67/ 1335628
87.	*Salvia reflexa* Hornem.	Herb	Wild	Kurram (KPK)	15-04-2021	5,594	31° 6'2.91"N 73°16'21.92"E	SJ 94/ 1335629
88.	*Salvia rhytidea* Benth.	Herb	Wild	Chitral, Garam Chashma (KPK)	15.04.2021	2,550 m	35° 19' 9.89" N 75° 33' 24.74" E	SJ102/ 1335642

89.	*Salvia santolinifolia* Boiss.	Herb	Wild	Momand agency (KPK)	30-04-2021	2,667	31°35'43.35"N 73°56'29.14"E	SJ 71/ 1335621
90.	*Salvia splendens* Sellow ex Schult.	Herb	Wild	Chak Shahzad (Isl.)	11-04-2021	1,770	31° 2'14.01"N 73° 4'32.18"E	SJ 95/ 1335630
91.	*Satureja hortensis* L.	Herb	Wild	Hazara (KPK)	01-05-2021	1,633	34°01'41.18"N 72°55'32.80"E	SJ 33/ 1334010
92.	*Scutellaria grossa* Wall.	Herb	Wild	Kaghan valley (KPK)	27-07-2022	3,241	34°32'29.37"N 73°21'02.25"E	SJ 46/ 1335631
93.	*Scutellaria linearis* Benth.	Herb	Wild	Peer Chanasi (Kashmir)	05-08-2021	8,001	34°22'56.01"N 73°33'31.96"E	SJ 47/ 1335632
94	*Scutellaria prostrata* Jacquem. ex Benth.	Herb	Wild	Upper Dir (KPK)	26-07-2022	6,586	35°21'54.00"N 72°08'54.65"E	SJ 39/ 1335633
95.	*Stachys emodi* Hedge	Herb	Wild	Nathia gali (KPK)	28-09-2022	7,958	34°04'22.48"N 73°22'54.40"E	SJ 27/ 1335634
96.	*Stachys floccosa* Benth.	Herb	Wild	Talash (KPK)	07-05-2022	2,728	34°44'35.12"N 71°52'08.98"E	SJ 30/ 1335635
97.	*Stachys palustris* L.	Herb	Wild	Peer chansai (Kashmir)	08-08-2021	5,655	34°23'23.06"N 73°43'52.81"E	SJ 31/ 1335636

98.	*Teucrium royleanum* Wall. ex Benth.	Herb	Wild	Maskeni (KPK)	18-05-201	3,311	34°55'41.51"N 71°37'08.99"E	SJ 36/ 1335637
99.	*Teucrium stocksianum* Boiss.	Herb	Wild	Shamozai (KPK)	19-05-2021	2,512	34°41'10.41"N 72°08'51.29"E	SJ 38/ 1335638
100.	*Thymus linearis* Benth.	Herb	Wild	Peer chansai (Kashmir)	08-09-2021	9,255 ft	34°23´09.00"N 73°32´49.37"E	SJ 59/ 131889
101.	*Thymus vulgaris* L.	Herb	Cultivated	National Agriculture Research Council (Isl.)	06-06-2021	1,637 ft	33°39´38.98"N 73°08´23.69"E	SJ 62/ 1334011
102.	*Vitex agnus-castus* L.	Small tree	Wild	University of Peshawar (KPK)	15-06-2022	1,090	34°00´19.23"N 71°29´15.20"E	SJ 55/ 1335638
103.	*Vitex negundo* L.	Small tree	Wild	Neelum valley (Kashmir)	08-09-2021	6,133	34°43'07.39"N 74°08'04.72"E	SJ 66/ 1335639
104.	*Vitex trifolia* L.	Small tree	Wild	Neelum valley (Kashmir)	08-09-2021	6,220	34°42'47.35"N 74°07'47.23"E	SJ 74/ 1335640

Keywords: KPK= Khyber Pakhtoon Khwa, Isl= Islamabad, ft= feet

Plate 9. Field pictorial view of (A) *Ajuga integrifolia*; erect or ascending stem, (B) *Ajuga parviflora*; leaves rosette-forming, (C) *Ajuga reptans*; whorls of blue flowers, (D) *Anisochilus carnosus*; spike-like head.

Plate 10. Field pictorial view of (A) *Anisomeles indica*; corolla, white with purplish markings, (B) *Callicarpa macrophylla*; leaves ovate-lanceolate, (C) *Clerodendrum inerme*; Flowers axillary, white, (D) *Clerodendrum splendens*; lush green leaves with red flowers.

Plate 11. Field pictorial view of (A) *Clerodendrum umbellatum*; red or pink flower, (B) *Clinopodium hydaspidis*; Inflorescence of distant few-to many-flowered, (C) *Clinopodium umbrosum*; leaves broadly ovate, (D) *Clinopodium vulgare*; Stem erect or ascending.

Plate 12. Field pictorial view of (A) *Colebrookea oppositifolia*; flowers slender spikes, (B) *Coleus forskohlii*; purple blue flowers, (C) *Dracocephalum moldavica*; bright blue violet flowers, (D) *Eremostachys superba*; Verticillasters 7-14 or 8-18 yellow flowers.

Plate 13. Field pictorial view of (A) *Hyssopus officinalis*; lineae-oblong leaves, (B) Isodon *rugosus* ; white tingled or spotted pink flower, (C) *Lallemantia royleana*; inflorescence from stem, (D) *Lamium album*; Leaves ovate, flower white.

Plate 14. Field pictorial view of (A) *Lamium amplexicaule*; broadly ovate reniform leaves, (B) *Lavandula angustifolia*; leaves narrow linear, (C) *Leonurus cardiaca*; white-pink flowers in whorl, (D) *Leucas aspera*; leaves linear lanceolate flower

Plate 15. Field pictorial view of (A) *Leucas cephalotes*; Leaves narrow oblong-elliptic, (B) *Marrubium vulgare*; undivided leaves with prominent veination, (C) *Melissa officinalis*; flower white, (D) *Mentha spicata*; leaves ovate-oblong.

Plate 16. Field pictorial view of (A) *Mentha x piperita citrata*; leaves ovat-elliptic, (B) *Mentha × piperita*; flower in whorls, (C) *Mentha × villosa*; obovate dentate leaves, (D) *Mentha arvensis*; flower white axillary.

Plate 17. Field pictorial view of (A) *Mentha longifolia*; white flower (B) *Mentha pulegium*; stem prostrate, (C) *Mentha suaveolens*; leaves circular to oblong-ovate, (D) *Micromeria biflora*; leaves narrow ovate.

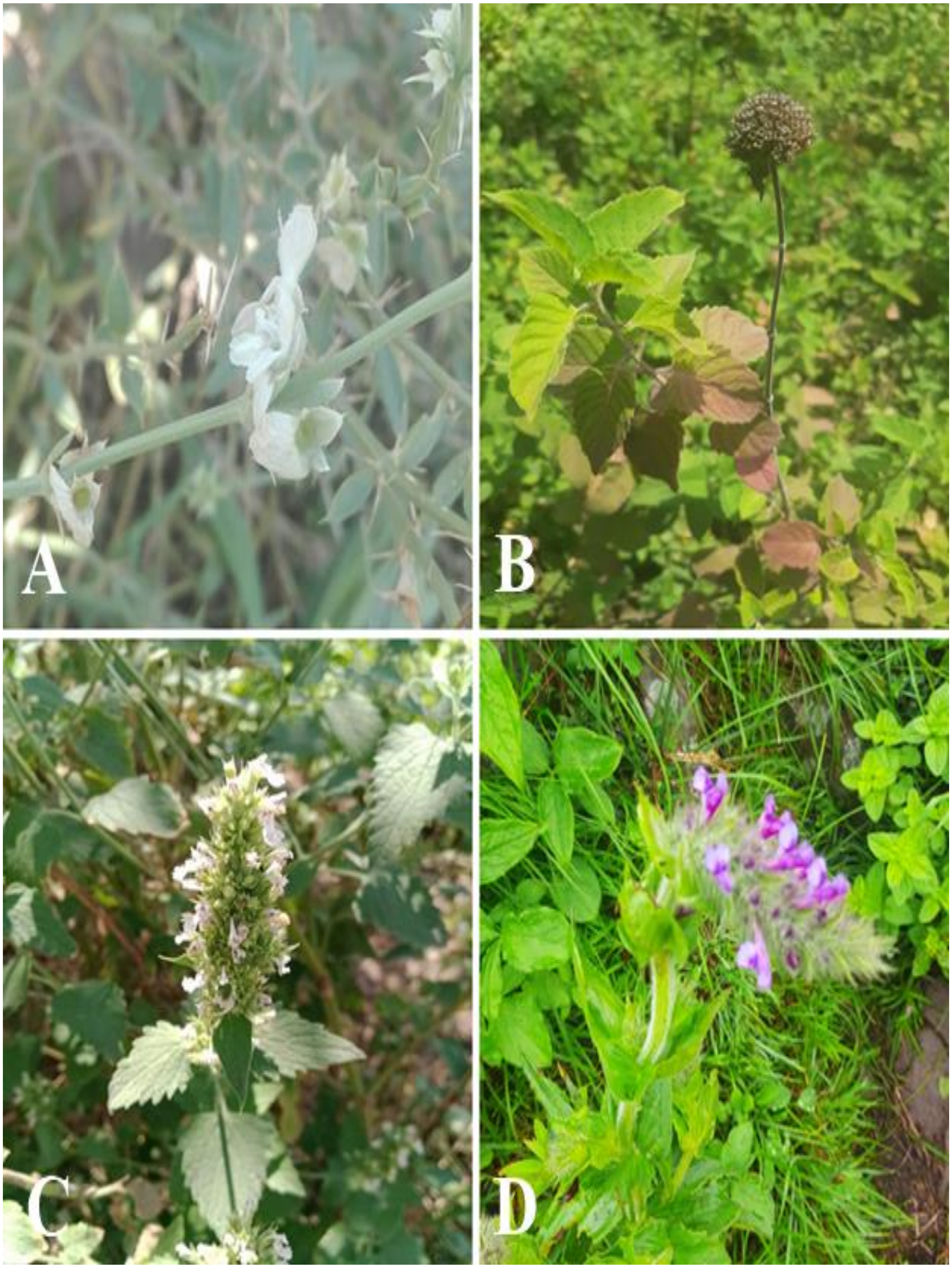

Plate 18. Field pictorial view of (A) *Moluccella aucheri*; spines present in all leaf axils, (B) *Monarda fistulosa*; greenish red elliptic leaves, (C) *Nepeta cataria*; leaves triangular-ovate, (D) *Nepeta connata*; leaves without petiole.

Plate 19. Field pictorial view of (A) *Nepeta discolor*; white flower spike is hairy, (B) *Nepeta distans*; axillary spike white flowers, (C) *Nepeta elliptica*; leaves narrow or broadly elliptic, (D) *Nepeta erecta*; flowers deep violet blue.

Plate 20. Field pictorial view of (A) *Nepeta govaniana*; Tall erect herb with yellow flowers, (B) *Nepeta graciliflora*; cordate dentate leaves, (C) *Nepeta griffithii*; light purple flowers, (D) *Nepeta hindostana*; Leaves broad ovate or triangular-ovate.

Plate 21. Field pictorial view of (A) *Nepeta laevigata*; elongated spike with purple, pink flower, (B) *Nepeta leucolaena*; clump-forming, (C) *Nepeta linearis*; linear leaves (D) *Nepeta nervosa*; deep blue flowers.

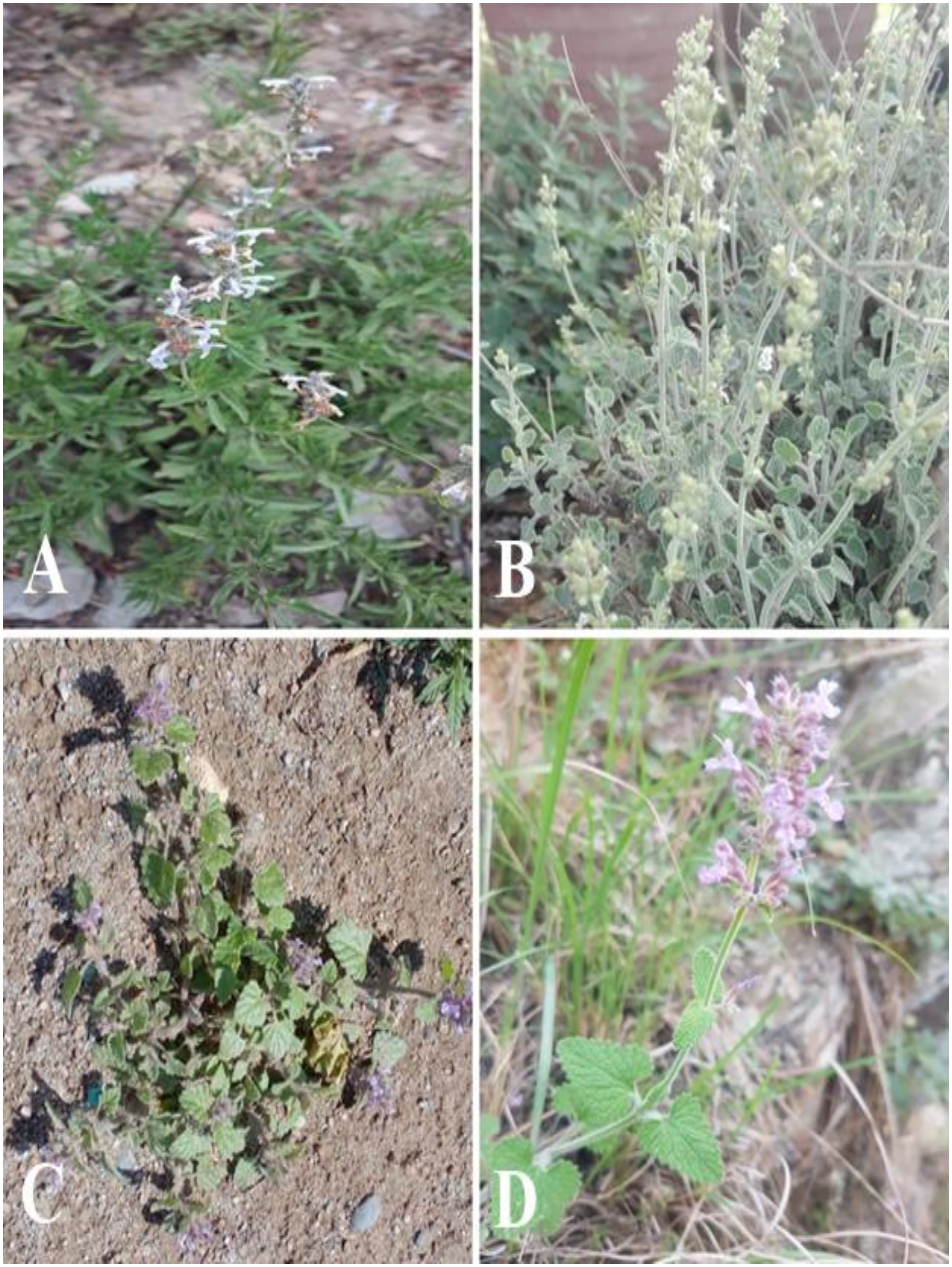

Plate 22. Field pictorial view of (A) *Nepeta podostachys*; leaves concolorous, (B) *Nepeta praetervisa*; many stems thick whitish leaves, (C) *Nepeta raphanorhiza*; Stems several, prostrate, (D) *Nepeta schmidii*; leaves raniform with pinnate venation.

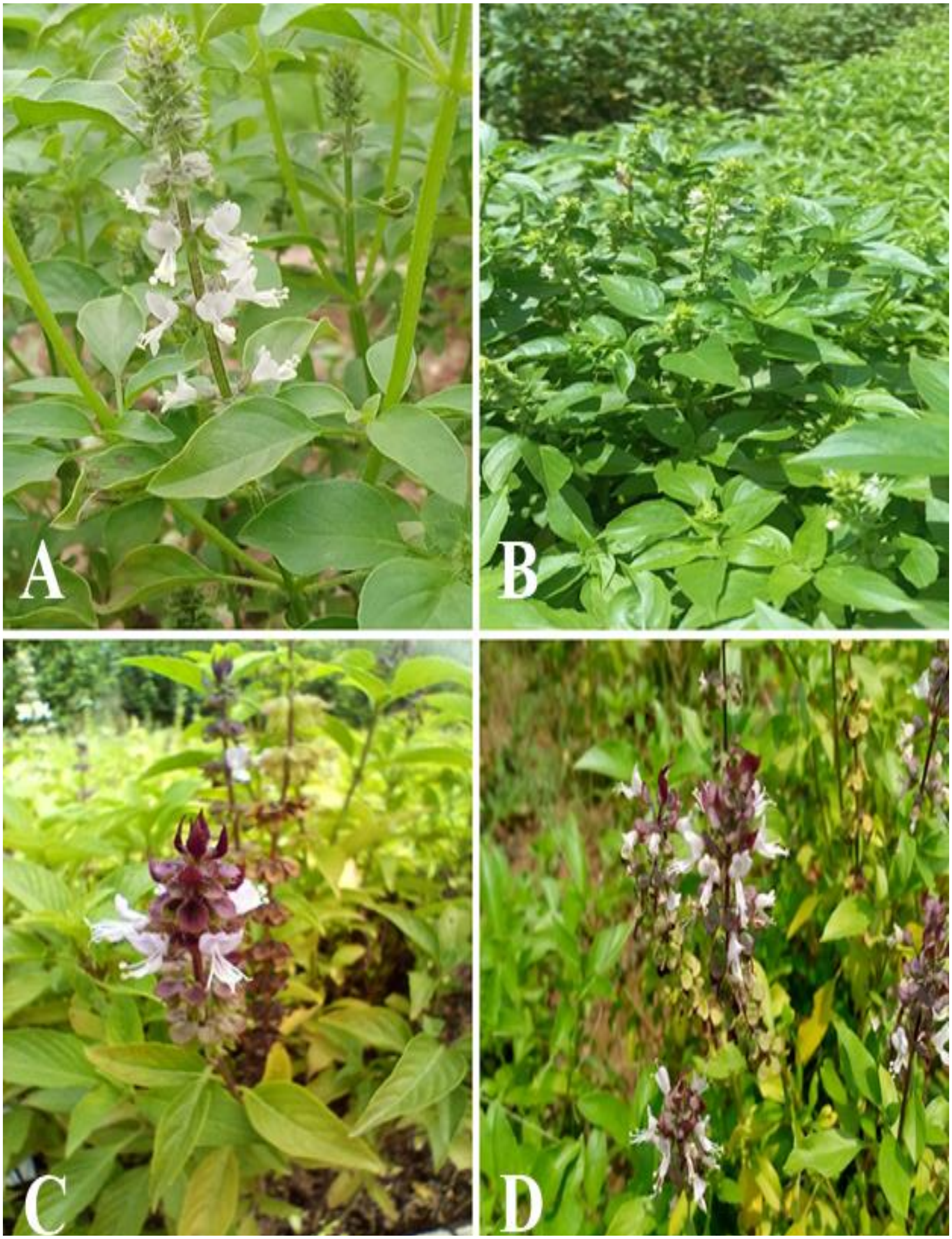

Plate 23. Field pictorial view of (A) *Ocimum* × *africanum*; leaves entire, white flowers, (B) *Ocimum americanum*; leaves elliptic to ovate, (C) *Ocimum basilicum*; inflorescence often condensed and purplish, (D) *Ocimum citriodorum*; inflorescence less condensed, ovate leaves.

Plate 24. Field pictorial view of (A) *Ocimum gratissimum*; erect and terminal verticillasters inflorescence (B) *Ocimum sanctum*; white flowers sinuate leaves, (C) *Origanum majorana*; minute white flowers, (D) *Origanum vulgare*; stems several, leaf entire and white flowers.

Plate 25. Field pictorial view of (A) *Perilla frutescens*; axillary spike with pink flower, (B) *Perovskia atriplicifoli*; violet blue flowers, (C) *Phlomidoschema parviflorum*; light green entire leaves with white stem (D) *Phlomis bracteosa*; Leaves ovate, flower pinkish purple.

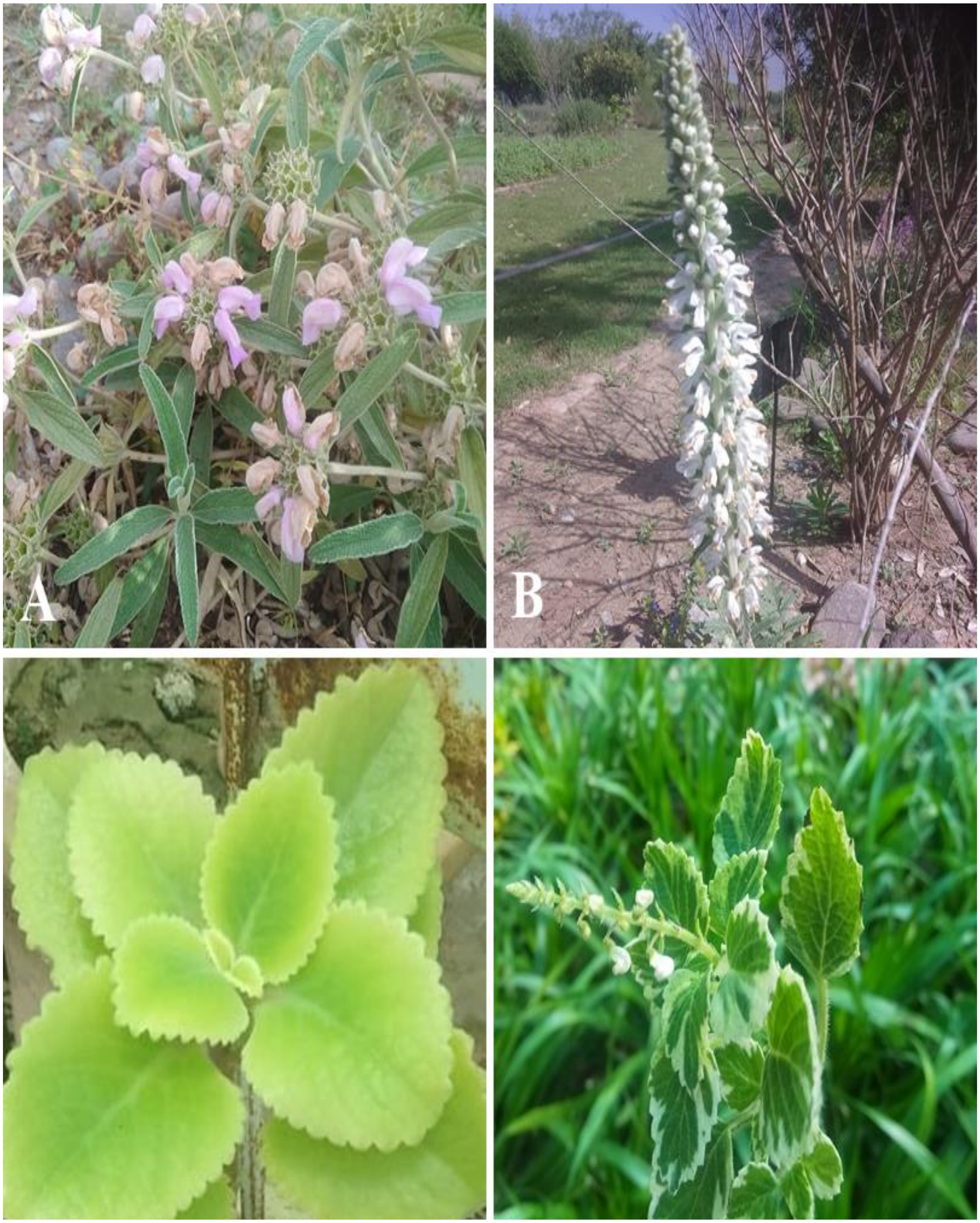

Plate 26. Field pictorial view of (A) *Phlomis stewartii*; thick texture narrowly oblong leaves, (B) *Phlomoides vicaryi*; stems solitary, white flower with purple markings, (C) *Plectranthus ambonicus*; leaves succulent, broadly ovate with lobed margins, (D) *Plectranthus madagascariensis*; broadly ovate variegated leaves with lobed margins.

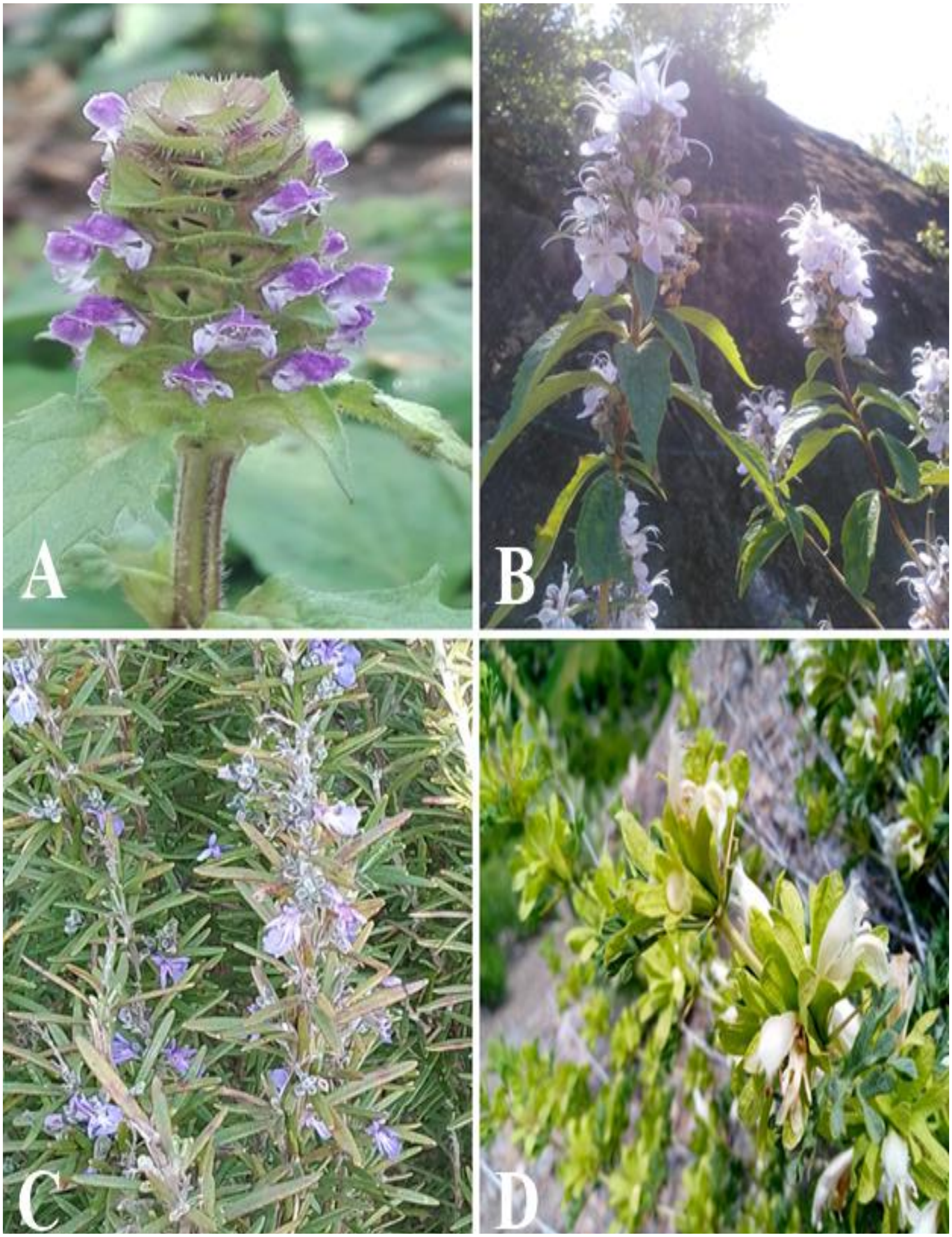

Plate 27. Field pictorial view of (A) *Prunella vulgaris*; calyx narrowly tubular with eglandular hairs, (B) *Pseudocaryopteris bicolor*; leaves opposite ovate, flower purple, white, (C) *Rosmarinus officinalis*; leaves linear, flower pale purple (D) *Rydingia limbata*; Leaves clustered, oblong.

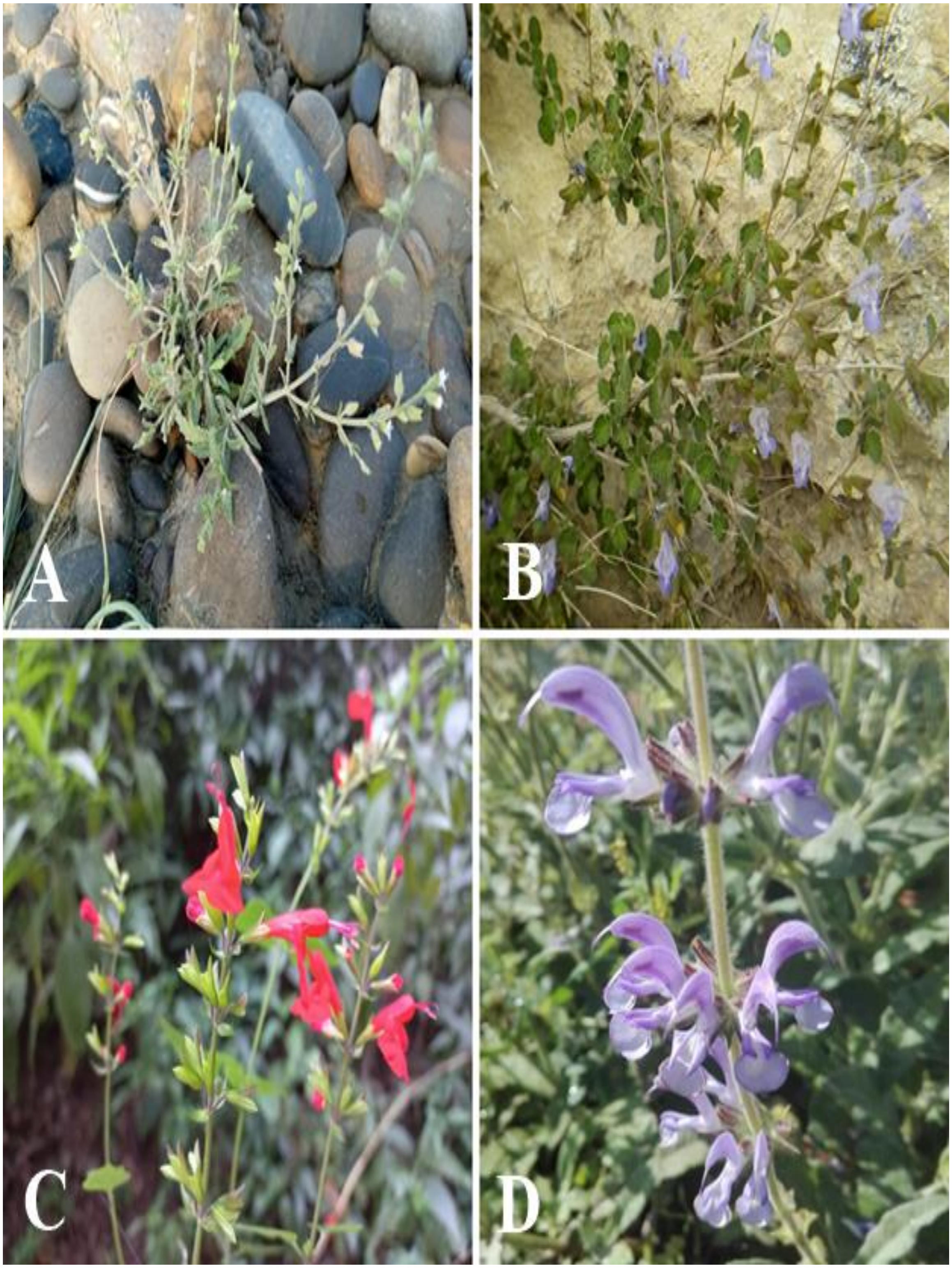

Plate 28. Field pictorial view of (A) *Salvia aegyptiaca*; leaves linear oblong, flower white (B) *Salvia cabulica*; leaves broadly ovate, (C) *Salvia coccinea*; flower scarlet, (D) *Salvia lanata*; flower dark violet or clear blue.

Plate 29. Field pictorial view of (A) *Salvia leucantha*; flower purple, white, (B) *Salvia moorcroftiana;* leaves mostly basal, thick-textured, (C) *Salvia nubicola*; flower pale yellow with prominent brownish markings, (D) *Salvia plebeia*; Stem erect, several, flower pale pink.

Plate 30. Field pictorial view of (A) *Salvia reflexa*; leaves broadly oblong, flower white, (B) *Salvia santolinifolia*; leaves linear in outline with a sinuate margin, (C) *Salvia splendens*; Leaves regularly ovate with serrate margins, (D) *Satureja hortensis*; Leaves linear-lanceolate spread over stem.

Plate 31. Field pictorial view of (A) *Scutellaria grossa*; leaves triangular with lobed margins, (B *Scutellaria linearis;* flower pinkish mauve, (C) *Scutellaria prostrata*; Stems prostrate, leaves broadly ovate (D) *Stachys emodi*; flower in axils of upper leaves.

Plate 32. Field pictorial view of (A) *Stachys floccosa*; white floccose on stem and leaves, (B *Stachys palustris*; stem erect with white flowers, (C) *Teucrium royleanum*; leaves ovate, flower white, (D) *Teucrium stocksianum*; leaves greyish-white, narrow elliptic.

Plate 33. Field pictorial view of (A) *Thymus linearis*; Much branched dwarf, creeping mat-forming herb, (B) *Thymus vulgaris*; stems erect with white flower, (C) *Vitex agnus-castus*; leaves palmately 5-7, Flowers deep violet, (D) *Vitex negundo*; leaves 3-5, flowers small usually blue.

Section-II

Pollen Micromorphology of Lamiaceous Taxa

3.2 Pollen Micromorphology of Lamiaceous taxa

In the recent study we describe the detailed pollen micromorphology of Lamiaceous taxa from Northern Pakistan. A total of 97 Lamiaceae species are selected for pollen micromorphological studies using LM (light microscopy) and SEM (scanning electron microscopy). Among them genus *Nepeta* species dominating the family (18 species), followed by genus *Salvia* (12 species), genus *Mentha* and Ocimum (6 species each), genus *Stachys* (4 species), genus *Ajuga*, *Clerodendrum*, *Clinopodium*, *Scutellaria* and *vitex* (3 species each), genus *Eremostachys*, *Lamium*, *Leucas*, *Moluccella*, *Origanum*, *Phlomis*, *Teucrium*, *Thymus* (2 species each). Genus *Anisochilus*, *Anisomeles*, *Callicarpa*, *Colebrookea*, *Coleus*, *Dracocephalum*, *Hyssopus*, *Isodon*, *Lallemantia*, *Leonurus*, *Marrubium*, *Melissa*, *Micromeria*, *Perilla*, *Perovskia*, *Prunella*, *Pseudocaryopteris*, *Plectranthus*, *Rosmarinus*, *Satureja*, (1 species each).

Pollen analyzed micromorphological characteristics of the current study includes quantitative traits i.e., polar diameter, equatorial diameter, polar to equatorial diameter ratio (P/E ratio), colpi length and width, mesocolpium exine thickness, fertility, and sterility determination. The qualitative studied characteristics includes pollen size, pollen shape, shape of pollen in polar view, shape of pollen in equatorial view, pollen outline, colpi apex, symmetry, polarity, aperture type, aperture orientation, lumina shape, no of secondary lumina per primary lumen, aperture sculpturing, exine sculpturing.

3.2.1 Pollen Micromorphological Structure of Lamiaceous Taxa

A total of 34 Lamiaceous taxa were studied with the help of LM (light microscopy) and scanning electron microscope (SEM). Five sub families i.e., Ajugoideae, Callicarpoideae, Lamioidea, Scutularioideae and Viticoideae consisting of 17 genera in this palynological study were investigated. The most prominent pollen type determination based on pollen traits, particularly the aperture type and exine structure may provide more precise environmental information of Lamiaceous pollen, among the most prominent components of pollen assemblages in moist regions. The maximum, minimum, standard error and means of the studied pollen characters are presented in Table 3. Pollen micromorphological characteristics based on scanning electron micrographs of each sub family are also presented in Table 4. The pollen ultra structures were presented in Plate. 34-44. Pollen characteristics serve as an accurate representation of taxonomic features; therefore, they exhibit relatively little infraspecific variation. However, the sculpturing patterns of various taxa frequently differ significantly from one another. The palynological analysis of the subfamily Ajugoideae, Callicarpoideae, Lamioidea, Scutularioideae and Viticoideae which was observed via SEM, was found to be helpful to examine and to evaluate the Lamiaceae phylogenetic relationship.

3.2.2 Variations in Pollen Size

The pollens are mostly tricolpate, pollen grains shed as monad, and are not frequently isopolar. The pollen size ranges from small to large. The largest polar diameter was found in *Pseudocaryopteris bicolor* (50 µm), and smallest in *Moluccella aucheri* (10 µm). The largest equatorial diameter was found in *Clerodendrum inerme* (81 µm), and smallest in *Ajuga integrifolia* (11 µm), presented in Figure 5. The highest P/E ratio was found in *Marrubium vulgare* (2 %), and lowest the remaining species (1 %), presented in Figure 6. The pollen size and shape of *Stachys palustris* in the investigation of Myoung and Yuon (2012) are similar with our results of *Stachys palustris* except in exine surface sculpturing. It has been proved that pollen morphology is helpful in the systematics of the Lamiaceae (Abu-Asab and Cantino, 1994). The pollinic traits seen with the help of SEM are useful to distinguish and establish the association within the species (dos Santos Amorim et al., 2014) because they are determined genetically, extremely constant, and unique to each species (e.g., aperture number and type and exine sculpturing) and have a crucial taxonomic value (Mert, 2010; Soares et al., 2017). There is enough published literature about the pollen size that it was greatly influenced by different preparation techniques, and it was researched that point-dried pollen typically being smaller than acetalized pollen through SEM analysis (Harley, 1992; Janssens et al., 2005; Moon et al., 2008; Schols et al., 2004).

3.2.3 Variations in Pollen Out line

Four types of pollen outlines were observed in the current research: psilate, scabrate, rough and echinate. The dominant pollen outline was psilate and the least common was echinate or we will say that echinate pollen outline was the unique one, (Plate 35 G, Plate 36 A and D).

3.2.4 Variations in Shape

Eight types of pollen shapes were observed in the present research i.e., prolate, sub prolate, prolate spheroidal, oblate, sub oblate, oblate-spheroidal and spherical. The dominant pollen shape is sub prolate (10 species). Six types of pollen shapes in polar view were studied: trigonal, circular, wide obovate, spherical, sub spherical and oval. The dominant pollen shape in polar view was trigonal followed by circular and the least observed shape was oval and spherical observed in (Plate 43 B, Plate 44 E). Pollen shapes in equatorial view are broad elliptic, elliptic, circular, broad ovate, trigonal, spherical, and oval. The dominant pollen shape in equatorial view was circular followed by broad elliptic and the least observed shape was oval and trigonal observed in (Plate 34 C, Plate 44 K). The pollen shape of *Lamium purpureum*, *Scutellaria albida*, *Teucrium chamaedrys* subsp. *syspirense* and *Stachys cretica* in the research of Ozaltan and Koçyigit (2022) were not coincides with our observed pollen shapes in *Teucrium and Scutellaria* specie but coincides in pollen shapes of *Lamium* and *Stachys* specie.

3.2.5 Variations in Symmetry, Colpi Apex and Apertures

The pollens are tricolpate, pollen grains shed as monad, are radially symmetrical and isopolar in nineteen species and bilateral and heteropolar in fifteen species. Four types of colpi apex were observed: acute, slightly acute, round, and linear. The dominant colpi apex was acute and the least common was linear.

3.2.6 Variations in Aperture Orientation and Aperture Sculpturing

In the current research the five types of aperture orientation were observed: raised, sunken, bulged, concave and convex were studied. The dominant aperture orientation was concave and the least common was bulged one.

3.2.7 Variations in Aperture Sculpturing

Eight types of aperture sculpturing were observed: verrucate, foveolate, micro-echinate, colliculate, psilate, rugulate, rough and scabrate. The dominant aperture sculpturing was verrucate and and the least common was regulate and scabrate. Length of colpi ranges from (22 µm), highest in *Pseudocaryopteris bicolor to* smallest (2 µm), in *Teucrium royleanum*. Width of colpi ranges fom (15 µm,) highest in *Leonuru sibiricus to* smallest (4 µm), in *Scutellaria grossa*. presented in Figure 7. Mesocolpium area ranges (38 µm), maximum in *Clerodendrum inerme* and minimum (10 µm), *Stachys emodi* and *Scutellaria grossa* presented in Figure 9.

3.2.8 Variations in Exine sculpturing

From SEM observations nine types of exine sculpturing were observed i.e., fine reticulate, coarsely reticulate, reticulate, reticulate perforate, micro-echinate, micro-echinate papillate, micro reticulate, foveolate, pitted-roughly reticulate perforate. The dominant exine sculpturing was reticulate perforate and least dominant was gemmate. Thickness of exine varies from (7 µm), maximum in *Stachys palustris* to (2 µm), minimum in *Stachys emodi* presented in Figure 8. Previous studies of Gul et al., (2021) observed Prolate-spheroidal and oblate-spheroidal pollen shape with bireticulate exine sculpturing in *phlomoides vicaryi* and *Phlomoides superba* which is not in accordance to our studied *Phlomoides* species, but in accordance in exine sculpturing of *Anisomeles indica*, *Leucas aspera* and *Rydingia limbate*. The exine sculpturing of *Teucrium royleanum* and *Teucrium stocksianum* are fine reticulate to pitted-roughly reticulate perforate which is not in accordance to Marzouk et al., (2017) but in accordance in pollen shape. The exine sculpturing and shape pollen of *Callicarpa macrophylla* is oblate and regulate perforate respectively which are not corroborated with the results of Ma et al., (2016). The pollen size and shape of *Otostegia fruticosa* is medium and spheriodal shape with perforate exine sculpturing in the research of Al-Watban et al., (2015) which is not similar with our studied *Otostegia* species in exine sculpturing, pollen size and shape. The pollen shape and exine sculpturing of the *Ajuga arabica, Scutellaria arabica, Stachys aegyptiaca*, *Marrubium vulgare*, *Leucas* species and *Teucrium oliverianum* in the studies of Doaigey et al., (2018) are not similar with our studied taxa except in fine reticulate exine sculpturing in *Ajuga integrifolia* and *Scutellaria linearis* species. The exine sculpturing and pollen shape of *Ajuga integrifolia, Ajuga parviflora*, *Scutellaria grossa, Scutellaria linearis, Scutellaria prostrata*, *Phlomidoschema parviflorum*, *Stachys floccosa, Moluccella aucheri* and *Teucrium royleanum* in the research of Perveen and Qaiser (2004) are not coincides with our results in pollen shape except in *Teucrium royleanum and Scutellaria prostrata,* and in exine sculpturing except in *Ajuga integrifolia* and *Scutellaria linearis.* Only *Anisomeles indica* had bireticulate exine sculpturing in our observation, however other Lamiaceae species were also known for bireticulate exine sculpturing (Abu-Asab and Cantino 1994; Jamzad et al., 2000; Wagstaff et al., 1995). Myoung and Yuon (2012) observed bireticulate exine sculpturing in their studied *Lamium* species which is not corroborated with our results. Most Lamioideae taxa exhibited supratectal sculpture (Abu-Asab and Cantino, 1994). The earlier study of Qureshi et al., (2019) only referenced reticulate exine ornamentation in *Rydingia limbata*, which was found similar to our findings. Azizian and Moore (1982) observed reticulate exine sculpturing in the *Eremostachys* species is similar to our findings. In addition, Myoung and Yuon (2012) observed bireticulate exine ornamentation in *Phlomoides* species found dissimilar to our results. By using light microscopy, Ghosh and Mandal (2016) investigated reticulate exine in *Anisomeles indica* which is not inconsistent to our results. Aluri (1992) documented the macromorphology of *Anisomeles indica* while ignoring the pollen micromorphology. Previous research of Prabhakar and Ramakrishna, (2014) contradicts pollen micromorphology of *Leucas* and reported the coarse reticulate exine sculpturing and proposed that pollen features may aid in species identification. According to Abu-Asab and Cantino (1994) exine ornamentation of *Leucas aspera* is suprareticulate and scorobiculate that is not coincides with our results.

3.2.9 Pollen Fertility and Sterility

Pollen fertility is crucial in determining the variety of plants and where they are found in different ecosystems. The highest and the lowest percentage of fertility confirms their stability. The highest pollen fertility was found in *Colebrookea oppositifolia* (90.2%) and lowest in *Teucrium stocksianum* (69.1%) while, the highest sterility was observed in *Teucrium stocksianum* (30.9%) and lowest in *Colebrookea oppositifolia* (9.8%).

3.2.10 Cluster Analysis and Principal Component Analysis (PCA) of Lamiaceous Pollen as a Statistical Tool

The dendrogram depicting the similarity index based on investigated quantitative character (Hu et al., 2010). The Lamiaceous taxa pollen quantitative data divides the dendrogram into two major clusters (Fig. 10). The first cluster consists of *Callicarpa macrophylla* which is entirely varied from the other studied taxa of the family in terms of quantitative measurements. The second cluster is further divided into two subclusters i.e., subcluster 1 and subcluster 2 which were further divided. In sub cluster 1 greater similarity was observed between *Ajuga reptans* and *Colebrookea oppositifolia*. In sub cluster 2 greater similarity was observed between *Ajuga parviflora* and *Phlomidoschema parviflorum*.

One of the most significant statistical tests for analyzing a set of components is principal component analysis (PCA), which aims to represent the correlation that exists among the pollen quantitative traits (Nazish and Althobaiti, 2022). The observed data is represented in two-dimensional projection with axes PC (principal components). In the present study, the pollen size, (polar diameter, equatorial diameter), colpi size, (colpi length, colpi width), exine thickness and mesocolpium, of 34 Lamiaceae species were used to explore pollen variability. Principal component analysis variable loadings for first seven components illustrated in Table 2. Figure 12 illustrates the correlation between the seven principal component variables of pollen. The PCA analysis shows that the eigenvalues of PC1 and PC2 were more than 1, and as a result, they are thought to be the most important elements. Data analysis revealed that PCI accounts for (47.95 %) of the data's overall variance. Polar diameter was the most significant component followed by P/E ratio in first axes PC1. *Eremostachys superba, Clerodendrum umbellatum, Pseudocaryopteris bicolor*, *Scutellaria linearis*, *Lamium amplexicaule*, and *Phlomis stewartia* were found on the positive side of first axes. Whereas *Leonurus sibiricus, Leucas cephalotes*, *Vitex trifolia*, *Vitex agnus-castus*, *Teucrium royleanum*, *Ajuga integrifolia*, *Ajuga parviflora*, *Ajuga reptans* and *Scutellaria prostrata* were found on the negative side of first axes (Figure. 12). PC 2 accounts for (20.38 %) of the total variance. *Clerodendrum inerme*, *Callicarpa macrophylla* and *Phlomoides vicaryi*, *Clerodendrum splendens*, *Phlomidoschema parviflorum*, *Lamium album*, *Teucrium stocksianum* and *Anisomeles indica* were found on the positive side of the second axes. Whereas *Stachys floccose*, *Leucas aspera*, *Marrubium vulgare* and *Scutellaria grossa*, *Phlomis bracteosa*, *Moluccella aucheri*, *Vitex negundo*, *Colebrookea oppositifolia*, *Stachys palustris,* Stachys emodi and *Rydingia limbate* were found on the negative side of the second axes. Additionally, the semantic differential chart and active variables of the PCA biplot were displayed in Figures 11 and 13 respectively to better visualize and assess the relationships between these three factors.

3.2.11 Taxonomic keys based on Pollen qualitative features of the studied Lamiaceous species:

1	a	Pollen shape oblate……………………………	*Callicarpa macrophylla*
	b	Pollen shape sub oblate………………………….	*Stachys emodi*
2	a	Pollen shape per oblate………………………….	4
	b	Pollen shape other than per oblate……………	3
3	a	Pollen outline echinate………………………….	*Clerodendrum inerme*
	b	Pollen outline psilate………………………………	*Marrubium vulgare*
4	a	Pollen shape oblate spheroidal……………………	9
	b	Pollen shape other than oblate spheroidal………..	5
5	a	Exine sculpturing micro-echinate, papillate………	*Clerodendrum splendens*

	b	Exine sculpturing other than micro-echinate, papillate	6
6	a	Colpi apex round…………………………………	*Colebrookea oppositifolia*
	b	Colpi apex other than round………………………	7
7	a	Aperture sculpturing scabrate…………………	*Lamium album*
	b	Aperture sculpturing not visible…………………	*Leucas aspera*
8	a	Aperture sculpturing verrucate……………………	*Stachys floccosa*
	b	Aperture sculpturing other than verrucate……	9
9	a	Pollen shape spherical…………………………	12
	b	Pollen shape other than spherical…………………	10
10	a	Aperture orientation sunken………………………	*Phlomidoschema parviflorum*
	b	Aperture orientation other than sunken……………	11
11	a	Pollen shape in polar view circular………………	*Phlomoides vicaryi*
	b	Pollen shape in polar view sub spherical………..	*Teucrium stocksianum*
12	a	Pollen shape prolate spheroidal…………………	15
	b	Pollen shape other than prolate spheroidal………	13
13	a	Pollen shape in equatorial view broad elliptic……	*Ajuga integrifolia*
	b	Pollen shape in equatorial view other than broad elliptic...	14
14	a	Pollen outline rough……………………………	*Moluccella aucheri*
	b	Pollen outline other than rough……………………	15
15	a	Aperture sculpturing foveolate……………………	*Anisomeles indica*
	b	Aperture sculpturing other than foveolate……	14
14	a	Exine sculpturing reticulate………………………	*Ajuga reptans*
	b	Exine sculpturing reticulate perforate……………	*Scutellaria prostrata*
15	a	Pollen shape prolate……………………………	23
	b	Pollen shape other than prolate……………………	16
16	a	Pollen shape in polar view sub spherical………..	*Phlomis bracteosa*
	b	Pollen shape in polar view other than sub spherical.	17

17	a	Pollen outline echinate…………………………	*Clerodendrum umbellatum*
	b	Pollen outline other than echinate………………	18
18	a	Aperture sculpturing regulate……………………	*Pseudocaryopteris bicolor*
	b	Aperture sculpturing other than regulate………..	19
19	a	Exine sculpturing micro reticulate……………	*Leucas cephalotes*
	b	Exine sculpturing other than micro reticulate……	20
21	a	Pollen size medium………………………………	*Eremostachys superba*
	b	Pollen size other than medium……………………	22
22	a	Pollen shape in polar view circular………………	*Leonurus cardiaca*
	b	Pollen shape in polar view trigonal………………	*Scutellaria grossa*
23	a	Pollen shape sub prolate…………………………	32
	b	Pollen shape other than sub prolate………………	24
24	a	Exine sculpturing coarsely reticulate……………	*Ajuga parviflora*
	b	Exine sculpturing other than coarsely reticulate…	25
25	a	Pollen shape in polar view oval…………………	*Vitex agnus-castus*
	b	Pollen shape in polar view other than oval………	26
26	a	Aperture sculpturing colliculate………………	*Lamium amplexicaule*
	b	Aperture sculpturing other than colliculate………	27
27	a	Aperture orientation raised……………………	*Teucrium royleanum*
	b	Aperture orientation other than raised……………	28
28	a	Colpi apex round………………………………	*Scutellaria linearis*
	b	Colpi apex other than round………………………	29
29	a	Pollen shape in equatorial view oval……………	*Vitex trifolia*
	b	Pollen shape in equatorial view other than oval…	30
30	a	Exine sculpturing reticulate………………………	*Rydingia limbata*
	b	Exine sculpturing other than reticulate……………	31
31	a	Pollen outline psilate………………………………	*Scutellaria linearis*
	b	Pollen outline other than psilate…………………	32
32	a	Pollen isopolar…………………………………	*Stachys palustris*
	b	Pollen heteropolar………………………………	*Vitex negundo*

Table. 2: Factor loading of PCA **(**principal component analysis) using quantitative pollen characters.

Variables/ Factors	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**	**PC 7**
PD	0.894	0.232	0.082	-0.196	0.116	-0.226	0.193
ED	0.720	-0.580	-0.026	-0.289	0.063	-0.151	-0.185
P/E	0.037	0.923	0.198	-0.246	-0.170	-0.047	-0.129
CL	0.764	0.059	-0.214	0.499	-0.314	-0.131	-0.033
CW	0.674	0.400	-0.450	0.122	0.375	0.156	-0.059
ET	0.501	-0.029	0.799	0.276	0.161	0.080	-0.036
MC	0.865	-0.143	0.006	-0.242	-0.273	0.309	0.056
Eigenvalue	3.356	1.427	0.934	0.581	0.386	0.219	0.097
Variability (%)	47.949	20.383	13.340	8.299	5.510	3.135	1.384
Cumulative %	47.949	68.332	81.672	89.971	95.480	98.616	100.000

Keywords: PD=Polar diameter, ED=Equatorial diameter, P/E=Polar diameter divided by equatorial diameter, Cl= Colpi length, Cw=Colpi width ET=Exine

Table. 3: Quantitative pollen micromorphological findings of Lamiaceous taxa.

S. no	Taxon	**Polar diameter** Min-Max = Mean±SE (µm)	**Equatorial diameter** Min-Max = Mean±SE (µm)	**P/E ratio (µm)**	**Length of colpi** Min-Max = Mean±SE (µm)	**Width of colpi** Min-Max = Mean±SE (µm)	**Exine thickness** Min-Max = Mean±SE (µm)	**Mesocolpium** Min-Max = Mean±SE (µm)	**Fertility (%)**	**Sterility (%)**
1.	*Ajuga integrifolia* Buch. -Ham.	11.4-12.6=12.0±.25	10.5-11.2=10.9±.12	1.1	12.2-13.7=12.9±.26	8.7-10.5=9.7±.30	2.2-4.0=3.3±.31	12.0-13.5=12.8±.28	89.2	10.2
2.	*Ajuga parviflora* Benth.	22.2-24.0=23.1±.32	14.5-21.2=17.6±1.2	1.3	7.2-8.7=8.1±.26	5.0-6.2=5.6±.23	2.2-4.0=3.3±.30	12.0-13.2=12.6±.23	78.3	21.7
3.	*Ajuga reptans* L.	20.5-26.2=23.4±1.1	16.2-23.0=19.8±1.2	1.1	9.2-11.5=10.3±.43	7.7-8.7=8.4±.20	3.0-3.5=3.2±.11	15.2-18.7=16.9±.60	84.6	15.6
4.	*Anisomeles indica* (L.) Kuntze	28.7-33.7=31.4±.87	26.2-33.7=29.9±1.2	1.0	11.2-13.0=12.1±.36	8.0-10.5=9.3±.47	3.0-5.5=4.4±.45	17.7-20.5=19.2±.50	88.5	11.5
5.	*Callicarpa macrophylla* Vahl	22.2-23.5=22.9±.21	29.7-31.2=30.6±.26	0.7	19.5-20.7=20.1±.23	9.5-10.5=10.0±.17	5.0-5.7=5.3±.12	21.7-23.0=22.4±.23	79.4	20.6
6.	*Clerodendrum inerme* (L.) Gaertn.	38.7-43.7=42.0±.86	76.2-84.2=81.1±1.36	0.5	14.7-16.2=15.5±.28	57.5-8.7=8.1±.21	5.0-6.2=5.5±.21	36.2-40.2=38.1±.71	82.3	17.7
7.	*Clerodendrum splendens* G.Don	29.0-31.2=29.9±.365	14.0-37.5=32.0±4.52	0.9	10.0-11.2=10.7±.215	9.2-10.5=9.8±.215	3.7-4.7=4.2±.176	19.7-22.0=21.0±.413	86.4	13.6
8.	*Clerodendrum umbellatum* Poir.	46.7-52.7=49.5±1.17	27.2-31.2=29.1±.820	1.7	16.2-17.7=17.0±.266	11.2-12.7=12.0±.289	4.7-5.7=5.2±.176	27.5-34.0=30.4±1.14	80.2	19.8
9.	*Colebrookea oppositifolia* Sm.	15.9-18.5=16.6±.40	12.5-18.0=16.8±1.2	1.11	7.0-8.0=7.5±.17	6.5-5.5=5.9±.16	3.9-5.7=4.9±.39	12.5-13.5=12.0±.17	90.2	9.8
10.	*Eremostachys superba* Royle ex Benth.	36.2-38.2=47.3±.43	23.7-27.0=25.8±.56	1.8	13.5-15.0=14.2±.28	13.0-15.5=14.1±.51	4.7-6.2=5.5±.25	25.0-28.0=26.3±.57	89.9	10.1
11.	*Lamium album* L.	29.5-21.2=30.3±.32	29.7-32.2=31.1±.48	0.9	12.0-10.2=12.6±.23	7.2-8.7=8.0±.25	3.7-5.0=4.4±.21	24.5-25.5=25.0±.18	87.7	12.3
12.	*Lamium amplexicaule* L.	30.2-36.2=33.5±1.1	27.0-28.7=27.7±.31	1.2	15.0-15.7=15.3±.12	15.2-15.7=15.4±.10	3.0-3.5=3.2±.07	22.2-24.0=23.2±.32	88.9	11.1
13.	*Leonurus cardiaca* L.	24.5-25.5=24.9±.18	13.5-15.7=14.9±.39	1.6	9.5-10.2=9.9±.15	7.2-7.7=7.6±.10	2.5-3.0=2.8±.09	14.5-15.5=15.0±.17	89.9	10.1
14.	*Leucas aspera* (Willd.) Link	24.5-27.0=25.4±.44	27.0-28.7=27.6±.32	0.9	11.2-13.2=12.3±.35	9.5-10.2=9.8±.16	3.2-4.2=3.8±.18	14.7-16.2=15.5±.26	82.3	17.7
15.	*Leucas cephalotes*	24.5-	13.7-	1.6	8.7-	7.0-	3.7-	17.2-	83.5	16.5

	(Roth) Spreng.	25.5=25.0±.17	16.2=14.9±.42		10.5=9.7±.28	8.7=7.8±.32	5.0=4.4±.21	18.7=17.9±.26		
16.	*Marrubium vulgare* L.	9.5-10.7=10.1±.23	21.2-25.2=23.2±.65	0.4	7.7-11.2=10.3±.72	5.2-7.7=6.4±.41	3.2-3.7=3.6±.10	23.0-26.2=24.7±.53	80.2	19.8
17.	*Moluccella aucheri* (Boiss.) Scheen	21.2-25.5=23.4±.76	18.7-23.7=21.0±.81	1.1	8.0-9.0=8.5±.17	7.0-8.0=7.5±.18	2.2-3.0=2.6±.16	15.2-18.7=16.9±.67	84.6	15.4
18.	*Phlomidoschema parviflorum* (Benth.) Vved.	26.2-28.7=27.4±.53	21.2-30.5=26.6±1.9	1.0	14.5-16.2=15.3±.32	7.2-8.7=8.0±.24	4.7-5.5=5.0±.14	17.0-18.7=17.7±.30	78.3	21.7
19.	*Phlomis bracteosa* Royle ex Benth.	30.7-33.7=32.2±.55	22.0-23.7=22.9±.34	1.4	19.7-21.2=20.4±.26	10.7-13.7=12.2±.53	1.7-5.0=3.9±.58	23.7-25.7=24.7±.35	75.3	24.7
20.	*Phlomis stewartii* Hook.f.	24.7-27.7=26.0±.51	15.2-22.7=20.1±1.2	1.2	10.2-15.5=14.0±.96	1.2-8.7=7.0±1.4	3.5-4.5=3.9±.16	14.2-15.7=15.1±.26	78.2	21.8
21.	*Phlomoides vicaryi* (Benth. ex-Hook.f.) Kamelin & Makhm.	36.2-40.2=37.9±.71	33.7-36.0=35.1±.40	1.0	9.5-11.2=10.2±.31	7.0-8.0=7.5±.17	4.7-6.0=5.4±.21	26.7-28.5=27.5±.32	85.4	14.6
22.	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D.Cantino	47.7-51.2=49.7±.63	31.2-33.7=32.0±.44	1.5	21.2-23.0=22.3±.30	11.2-13.0=12.2±.30	4.4-6.2=5.1±.30	32.0-33.7=32.9±.34	85.1	14.9
23.	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	25.7-27.7=26.4±.37	20.7-22.7=21.8±.37	1.2	8.2-10.2=9.2±.33	5.7-6.7=6.3±.16	3.5-5.5=4.7±.55	10.7-13.0=12.1±.39	79.9	20.1
24.	*Scutellaria grossa* Wall.	13.7-15.2=14.6±.257	11.2-13.7=12.7±.470	1.1	7.0-8.0=7.5±.176	3.7-5.0=4.4±.231	2.7-3.5=3.15±.127	9.5-10.5=10.0±.176	75.3	24.7
25.	*Scutellaria linearis* Benth.	45.7-48.0=46.8±.45	33.7-35.7=34.8±.33	1.3	17.7-19.5=18.6±.29	10.2-11.2=10.7±.17	5.2-6.2=5.7V.17	18.7-21.2=20.2±.47	78.9	21.1 `
26.	*Scutellaria prostrata* Jacquem. ex Benth.	22.2-24.5=23.7±.38	19.7-21.2=20.7±.27	1.1	12.2-13.2=12.7±.17	7.2-8.7=8.1±.24	3.0-3.5=3.2±.09	14.7-16.2=15.6±.25	73.7	26.3
27.	*Stachys emodi* Hedge	22.2-23.2=22.8±.16	28.7-30.5=29.7±.30	0.7	8.2-10.2=9.2±.39	6.2-8.7=7.2±.42	2.7-3.0=2.0±.06	9.7-11.2=10.2±.24	83.7	16.3
28.	*Stachys floccosa* Benth.	21.7-24.2=23.2±.55	23.7-26.2=24.8±±.489	0.9	11.2-13.2=12.3±.358	8.0-9.2=8.4±.242	3.5-4.2=3.8±.127	14.7-16.5=15.8±.310	89.1	10.9
29.	*Stachys palustris* L.	23.7-28.7=26.5±.95	17.7-23.0=20.5±.99	1.2	8.7-11.2=10.0±.47	6.2-7.0=6.2±.12	6.2-8.7=7.4±.41	13.7-16.2=15.0±.44	78.4	21.6
30.	*Teucrium royleanum* Wall.	23.7-27.7=25.7±.68	18.7-23.2=20.9±.84	1.2	10.2-13.0=1.6±.45	10.5-11.5=10.9±.20	3.5-4.7=4.2±.23	11.2-14.5=13.4±.57	77.3	22.7

	ex Benth.									
31.	*Teucrium stocksianum* Boiss.	36.2-38.2=37.3±.358	33.0-36.2=34.7±.66	1.0	13.7-15.5=14.7±.306	12.0-13.25=12.6±.231	2.2-3.2=2.7±.20	17.0-18.2=17.6±.23	69.1	30.9
32.	*Vitex agnus-castus* L.	18.7-22.0=20.3±.57	14.7-15.7=15.2±.17	1.3	9.5-10.7=10.9±.23	5.7-7.2=6.4±.26	4.7-6.0=5.3±.21	12.0-13.7=12.5±.32	78.3	21.7
33.	*Vitex negundo* L.	26.2-33.0=29.1±1.3	22.2-24.7=23.6±.44	1.2	6.2-8.7=7.8±.46	6.2-7.0=6.6±.15	4.2-5.2=4.7±.16	25.2-27.5=26.0±.41	69.9	30.1
34.	*Vitex trifolia* L.	19.5-20.7=20.1±.23	14.7-16.0=15.4±.21	1.3	9.5-10.5=10.0±.17	5.0-6.2=5.5±.21	4.7-6.2=5.6±.21	11.2-13.2=12.2±.35	73.2	26.8

Keywords: Min= Minimum, Max= Maximum, SE= Standard Error, P= Polar Diameter, E= Equatorial Diameter, µm= Measurement in Micrometer

Table. 4: Qualitative pollen morphological findings of Lamiaceous taxa.

S. no	**Taxon**	**Pollen size**	**Pollen shape**	**Shape of pollen in polar view/ Amb**	**Shape of pollen in equatorial view**	**Pollen outline**	**Colpi apex**	**Symmetry**	**Polarity**	**Aperture type**	**Aperture orientation**	**Aperture sculpturing**	**Exine sculpturing**
1.	*Ajuga integrifolia* Buch. -Ham.	Small	Prolate spheroidal	Circular	Broad elliptic	Psilate-scabrate	Rounded	Radial	Isopolar	Tricolpate	Slightly raised	Verrucate	Fine reticulate
2.	*Ajuga parviflora* Benth.	Small	Subprolate	Trigonal	Elliptic	Psilate	Acute	Radial	Isopolar	Tricolpate	Sunken	Slightly scabrate	Coarsely reticulate
3.	*Ajuga reptans* L.	Medium	Prolate spheroidal	Circular	Circular	Psilate	Slightly acute	Radial	Isopolar	Tricolpate	Bulged	Verrucate	Reticulate
4.	*Anisomeles indica* (L.) Kuntze	Medium	Prolate sphe	Circular	Circular	Psilate	Acute-slig	Radial	Isopolar	Tricolpate	Raised	Foveolate	Bireticulate

			roidal				htly rounded						
5.	*Callicarpa macrophylla* Vahl	Small-Medium	Oblate	Circular	Broad eliptic	Scabrate	Acute	Radial	Isopolar	Tricolpate	Concave	Verrucate	Rugulate perforate
6.	*Clerodendrum inerme* (L.) Gaertn.	Medium	Peroblate	Widely obovate, irregular	Broad ovate	Echinate	Slightly acute	Bilateral	Heteropolar	Tricolpate	Sunken	Micro-echinate	Micro-echinate
7.	*Clerodendrum splendens* G.Don	Medium	Oblate spheroidal	Circular	Circular	Echinate	Slightly acute	Radial	Isopolar	Tricolpate	Slightly raised	Micro-echinate	Micro-echinate, papillate
8.	*Clerodendrum umbellatum* Poir.	Large	Prolate	Trigonal	Elliptic	Echinate	Slightly acute	Bilateral	Heteropolar	Tricolpate	Sunken	Micro-echinate	Micro-echinate
9.	*Colebrookea oppositifolia* Sm.	Small	Oblate spheroidal	Circular	Circular	Psilate	Rounded	Radial	Isopolar	Tricolpate	Convax	Psilate-verrucate	Reticulate perforate
10.	*Eremostachys superba* Royle ex Benth.	Medium	Prolate	Trigonal	Broad elliptic	Psilate	Acute	Bilateral	Heteropolar	Tricolpate	Concave	verrucate	Reticulate
11.	*Lamium album* L.	Small-Medium	Oblate-sphereoidal	Trigonal	Broad elliptic	Psilate	Acute	Radial	Isopolar	Tricolpate	Slightly convex	Scabrate	Fine reticulate
12.	*Lamium ample*	Medi	Sub	Trigo	Trigo	Ro	Acu	Radia	Isop	Trico		Collic	Reticul

	xicaule L.	um	prolate	nal-Circular	nal	ugh	te	l	olar	lpate	Bulged	ulate	ate perforate
13.	*Leonurus cardiaca* L.	Small-Medium	Prolate	Circular	Broad elliptic	Psilate	Acute	Radial	Isopolar	Tricolpate	Bulged	Colliculate	Reticulate
14.	*Leucas aspera* (Willd.) Link	Medium	Oblate-spheroidal	Circular	Circular	Psilate	Acute	Radial	Isopolar	Tricolpate	Slightly convex	Not visible	Fine reticulate
15.	*Leucas cephalotes* (Roth) Spreng.	Small-Medium	Prolate	Circular	Circular	Psilate	Acute	Radial	Isopolar	Tricolpate	Bulged	Colliculate	Micro reticulate
16.	*Marrubium vulgare* L.	Small-Medium	Peroblate	Trigonal	Circular	Psilate	Acute	Bilateral	Heteropolar	Tricolpate	Sunken	Verrucate	Foveolate
17.	*Moluccella aucheri* (Boiss.) Scheen	Small-Medium	Prolate spheroidal	Very widely obovate	Circular	Rough	Slightly acute	Bilateral	Heteropolar	Tricolpate	Raised	Colliculate	Fine reticulate
18.	*Phlomidoschema parviflorum* (Benth.) Vved.	Medium	Spherical	Spherical	Broad elliptic	Slightly rough	Acute	Radial	Isopolar	Tricolpate	Sunken	Psilate	Reticulate perforate
19.	*Phlomis bracteosa* Royle ex Benth.	Small-Medium	Prolate	Sub spherical	Spherical	Scabrate	Rounded	Radial	Isopolar	Tricolpate	Concave	Colliculate	Fine reticulate
20.	*Phlomis stewartii* Hook. f.	Small-Medium	Sub prolate	Circular	Broad elliptic	Psilate	Acute	Bilateral	Heteropolar	Tricolp	Concave	Verrucate	Fine reticulate

21.	*Phlomoides vicaryi* (Benth. ex-Hook.f.) Kamelin & Makhm.	Medium	Spherical	Circular	Circular	Scabrate	Acute	Radial	Isopolar	Tricolpate	Slightly convex	Verrucate	Fine reticulate perforate
22.	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D.Cantino	Large	Prolate	Trigonal-Widely obovate	Wide oval	Scabrate	Rounded	Bilateral	Heteropolar	Tricolpate	Raised	Rugulate	Gemmate
23.	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	Small-Medium	Subprolate	Trigonal	Spherical	Psilate	Rounded	Heteropolar	Bilateral	Tricolpate	Concave	Verrucate	Reticulate
24.	*Scutellaria grossa* Wall.	Small	Prolate	Trigonal	Spherical-Broad elliptic	Psilate	Acute	Bilateral	Heteropolar	Tricolpate	Concave	Rough	Reticulate
25.	*Scutellaria linearis* Benth.	Medium	Subprolate	Very widely obovate	Spherical	Psilate	Round	Bilateral	Heteropolar	Tricolpate	Sunken	Verrucate	Fine reticulate
26.	*Scutellaria prostrata* Jacquem. ex Benth.	Small	Prolate-spheroidal	Trigonal	Spherical	Psilate	Acute	Bilateral	Heteropolar	Tricolpate	Concave	Verrucate	Reticulate perforare
27.	*Stachys emodi* Hedge	Small-Medium	Suboblate	Trigonal	Spherical	Scabrate	Slightly round	Bilateral	Heteropolar	Tricolpate	Sunken	Rough	Foveolate
28.	*Stachys floccosa* Benth.	Small-Medium	Oblate-spheroidal	Spherical	Spherical	Scabrate	Acute	Radial	Isopolar	Tricolpate	Raised	Verrucate	Reticulate perforate
29.	*Stachys palustris* L.	Small-Medium	Subprolate	Trigonal-Subspherical	Spherical	Scabrate	Acute	Radial	Isopolar	Tricolpate	Sunken	Verrucate	Reticulate perforate

30.	*Teucrium royleanum* Wall. ex Benth.	Small-medium	Subprolate	Widely obovate	Slightly circular	Scabrate	Rounded	Radial	Isopolar	Tricolpate	Raised	Rough	Fine reticulate
31.	*Teucrium stocksianum* Boiss.	Medium size	Spherical	Subspherical	Broad elliptic	Scabrate	Acute	Radial	Isopolar	Tricolpate	Slightly raised	Slightly rough	Pitted-roughly reticulate perforate
32.	*Vitex agnus-castus* L.	Small	Subprolate	Oval	Oval	Scabrate	Linear	Bilateral	Heteropolar	Tricolpate	Concave	Psilate	Fine reticulate
33.	*Vitex negundo* L.	Medium	Subprolate	Subspherical	Broad eliptic	Scabrate	Acute	Bilateral	Heteropolar	Tricolpate	Concave	Verrucate	Reticulate perforare
34.	*Vitex trifolia* L.	Small	Subprolate	Trigonal	Oval	Scabrate	Acute	Bilateral	Heteropolar	Tricolpate	Concave	Psilate	Reticulate perforare

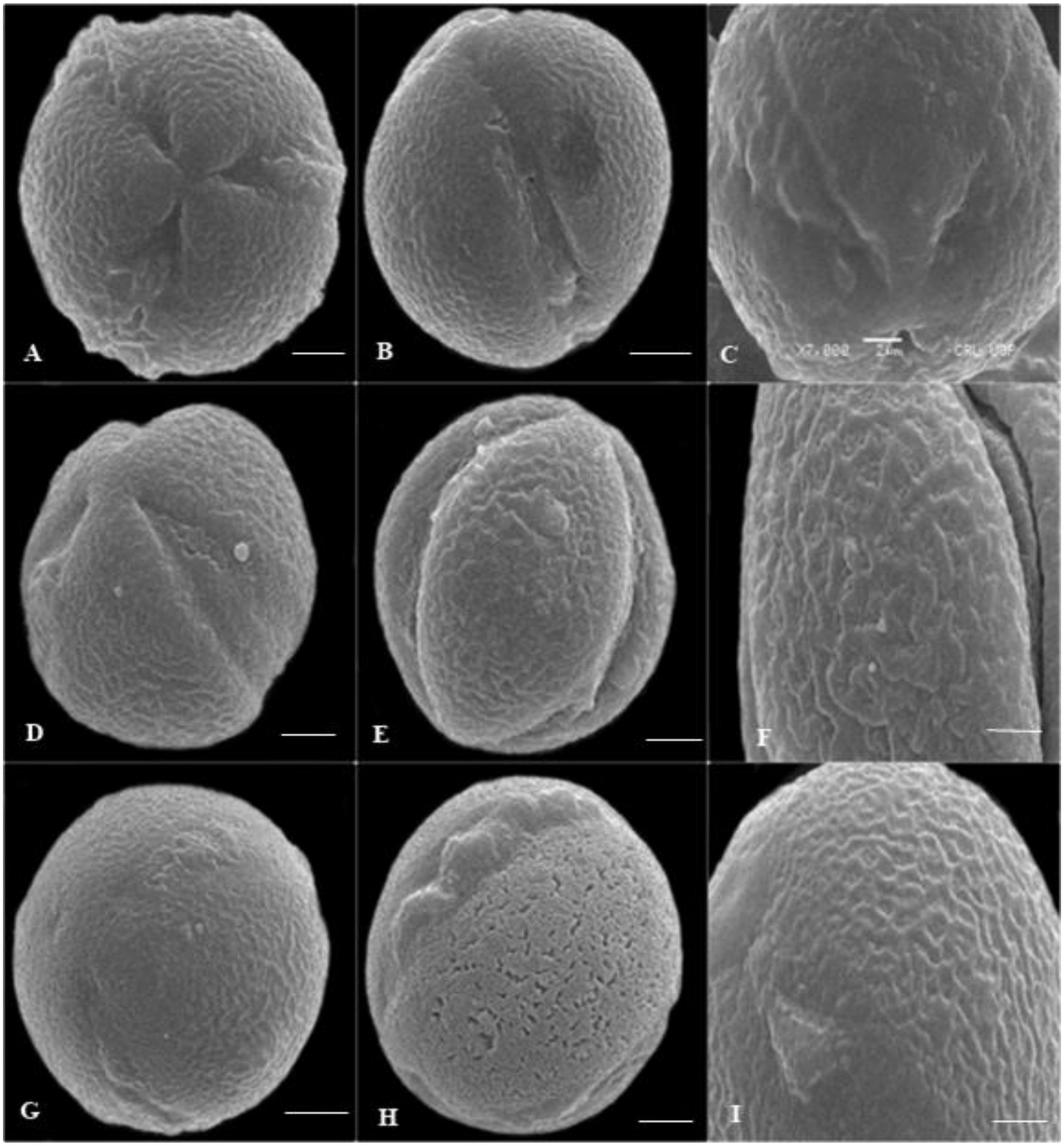

Plate. 34: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Ajuga integrifolia* (A-C), A) polar view, B) equatorial view, C) close view of the exine filled with verrucate structures. *Ajuga parviflora* (D-F). D) polar view, E) equatorial view, F) close view of exine. *Ajuga reptans* (G-I). G) polar view, H) equatorial view aperture filled with verrucate structures, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial

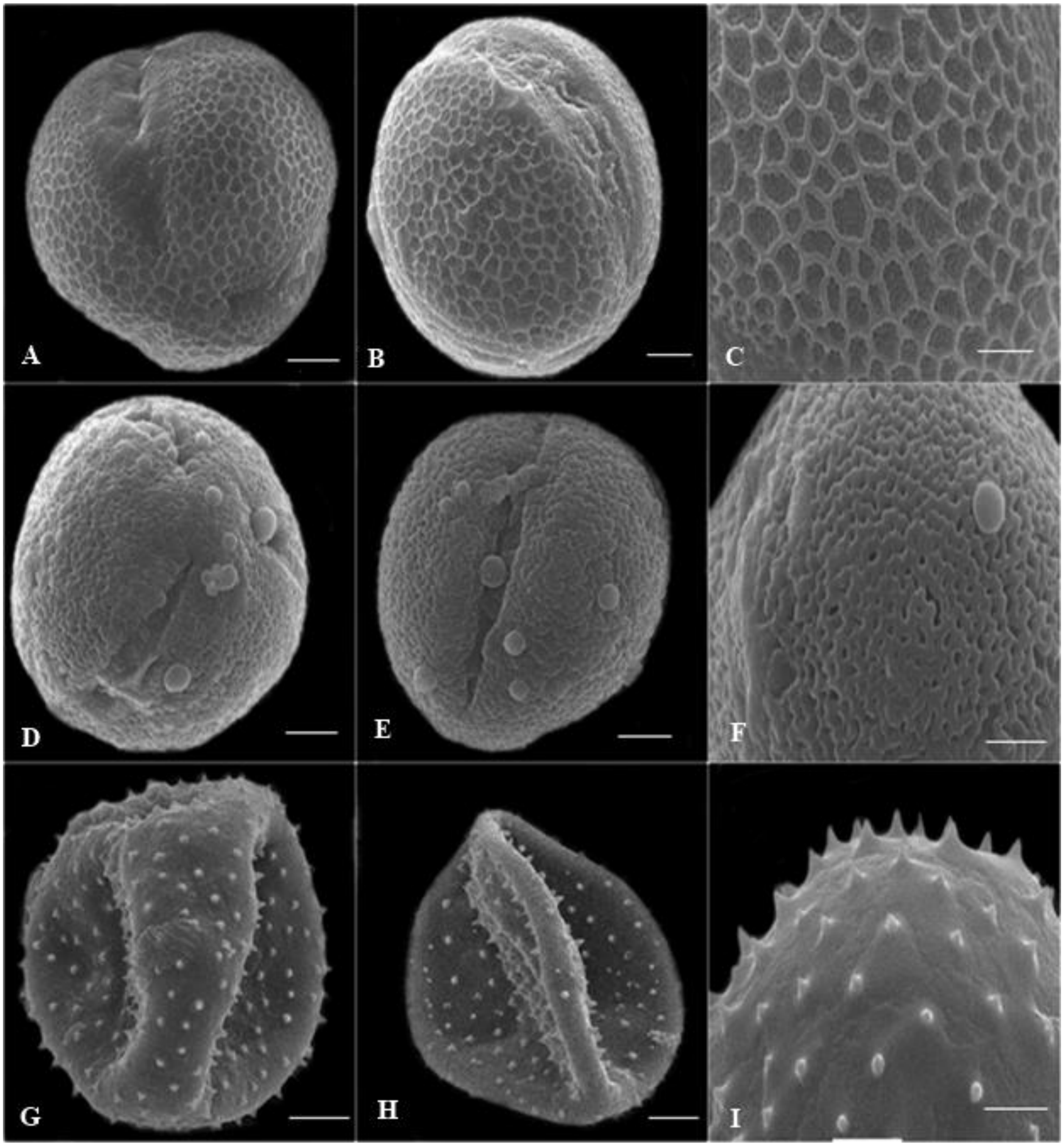

Plate. 35: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Anisomeles indica* (A-C), A) polar view, B) equatorial view, C) reticulate exine surface. *Callicarpa macrophylla* (D-F). D) polar view, E) equatorial view, F) close view of exine. *Clerodendrum inerme* (G-I). G) polar view, H) oblique equatorial view, I) micro-echinate exine surface. Scale bars: 5μm for polar and equatorial micrographs, scale bar 2μm for exine sculpturing.

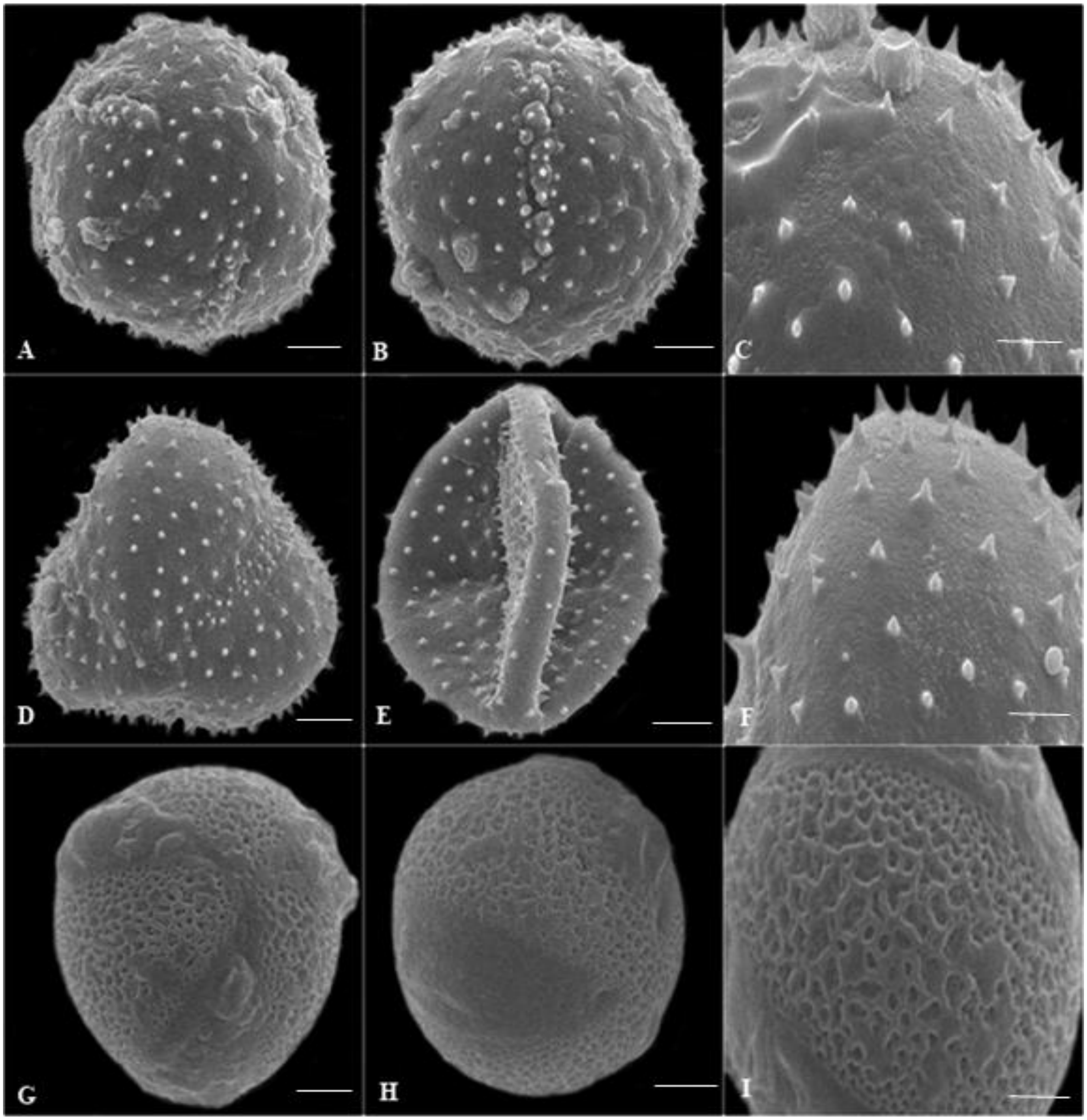

Plate. 36: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Clerodendrum splendens* (A-C), A) trigonal polar view, B) equatorial view, C) close view of the exine aperture filled with verrucate structures. *Clerodendrum umbellatum* (D-F). D) polar view, E) equatorial view, F) reticulate perforate exine surface. *Colebrookea oppositifolia* (G-I). G) polar view aperture filled with verrucate structures, H) equatorial view, I) fine reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs except in A and B (10 µm), scale bar 2µm for exine sculpturing except in F (5 µm).

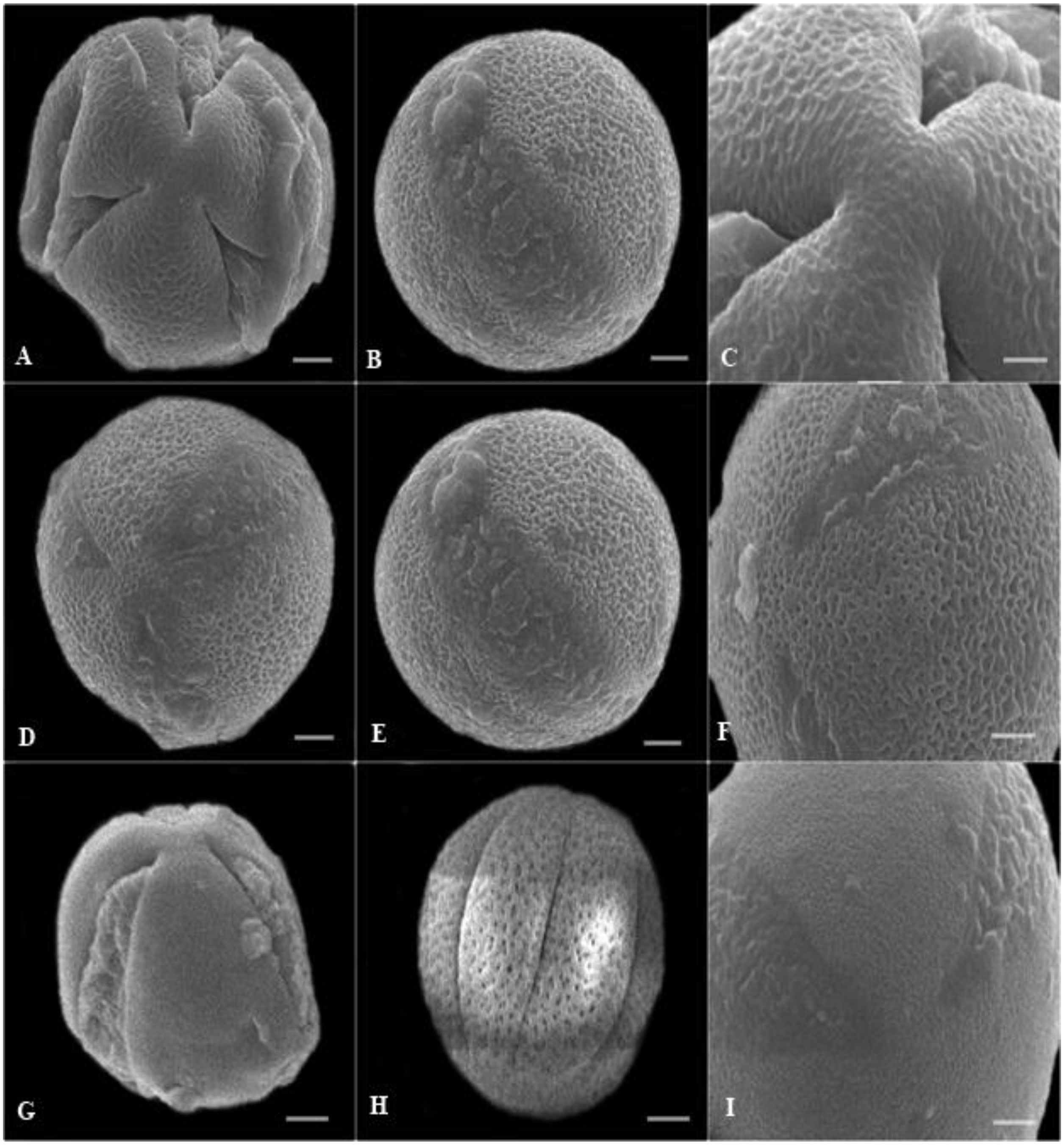

Plate. 37: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Eremostachys superba* (A-C), A) trigonal polar view, B) equatorial view, C) close view of the exine aperture filled with verrucate structures. *Lamium album* (D-F). D) polar view, E) equatorial view, F) reticulate perforate exine surface. *Lamium amplexicaule* (G-I). G) polar view aperture filled with verrucate structures, H) equatorial view, I) fine reticulate exine surface. Scale bars: 5μm for polar and equatorial micrographs except in A and B (10 μm), scale bar 2μm for exine sculpturing except in F (5 μm).

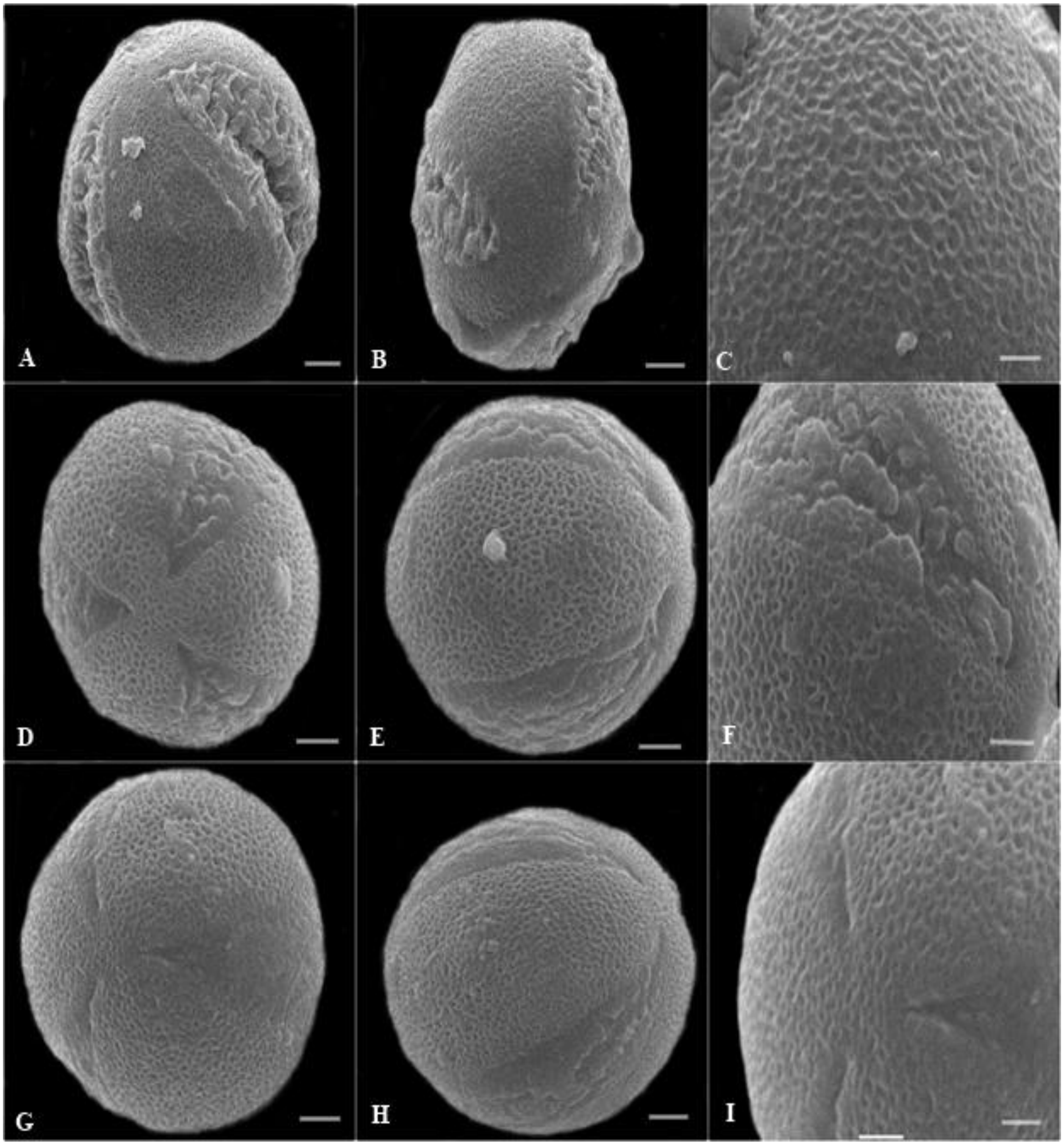

Plate. 38: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Leonurus cardiaca* (A-C), A) polar view with Colliculate aperture, B) equatorial view, C) reticulate exine surface. *Leucas aspera* (D-F). D) polar view, E) broad elliptic equatorial view, F) close view of exine. *Leucas cephalotes* (G-I). G) polar view, H) equatorial view I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing except in C (1 µm).

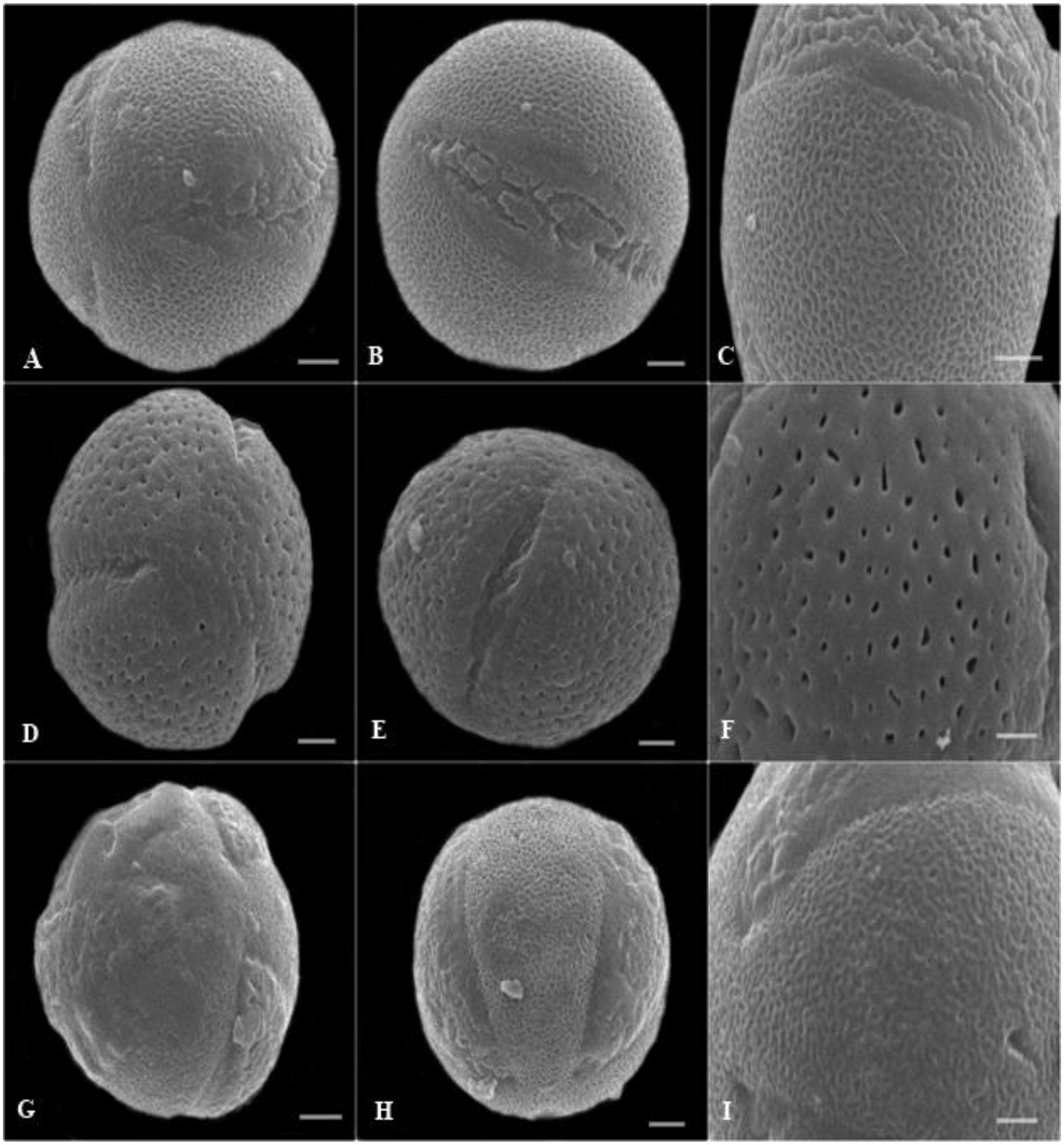

Plate. 39: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Marrubium vulgare* (A-C), A) polar view, B) circular equatorial view, C) close view of the exine. *Moluccella aucheri* (D-F). D) polar view, E) equatorial view, F) Foveolate exine surface. *Phlomidoschema parviflorum* (G-I). G) polar view, H) equatorial view, I) fine reticulate exine surface. Scale bars: 5μm for polar and equatorial micrographs, scale bar 2μm for exine sculpturing.

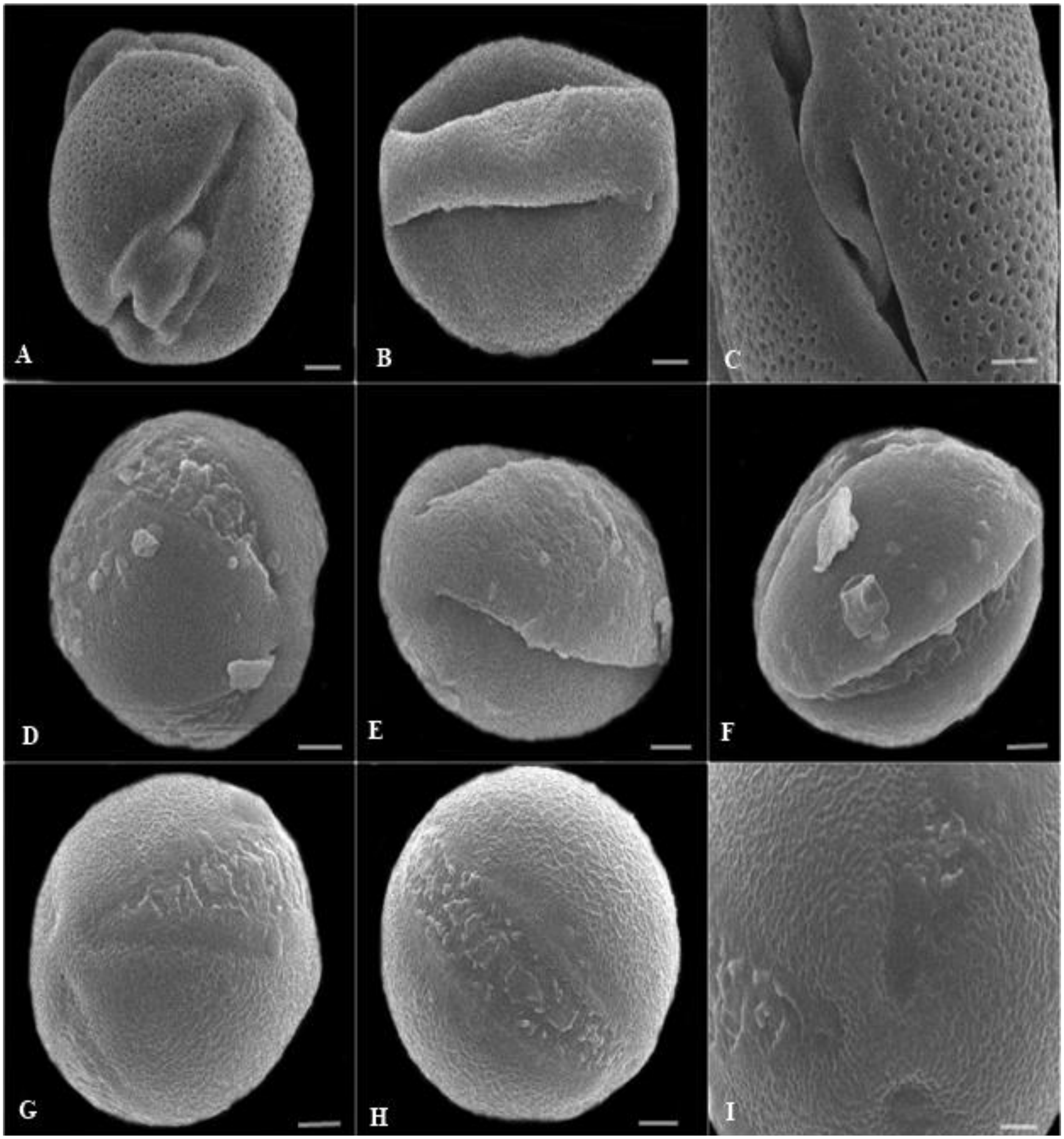

Plate. 40: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Phlomis bracteosa* (A-C), A) polar view, B) equatorial view with sunken colpi, C) reticulate exine surface. *Phlomis stewartii* (D-F). D) polar view, E) equatorial view, F) colliculate exine. *Phlomoides vicaryi* (G-I). G) polar view, H) equatorial view aperture filled with verrucate structures, I) fine reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

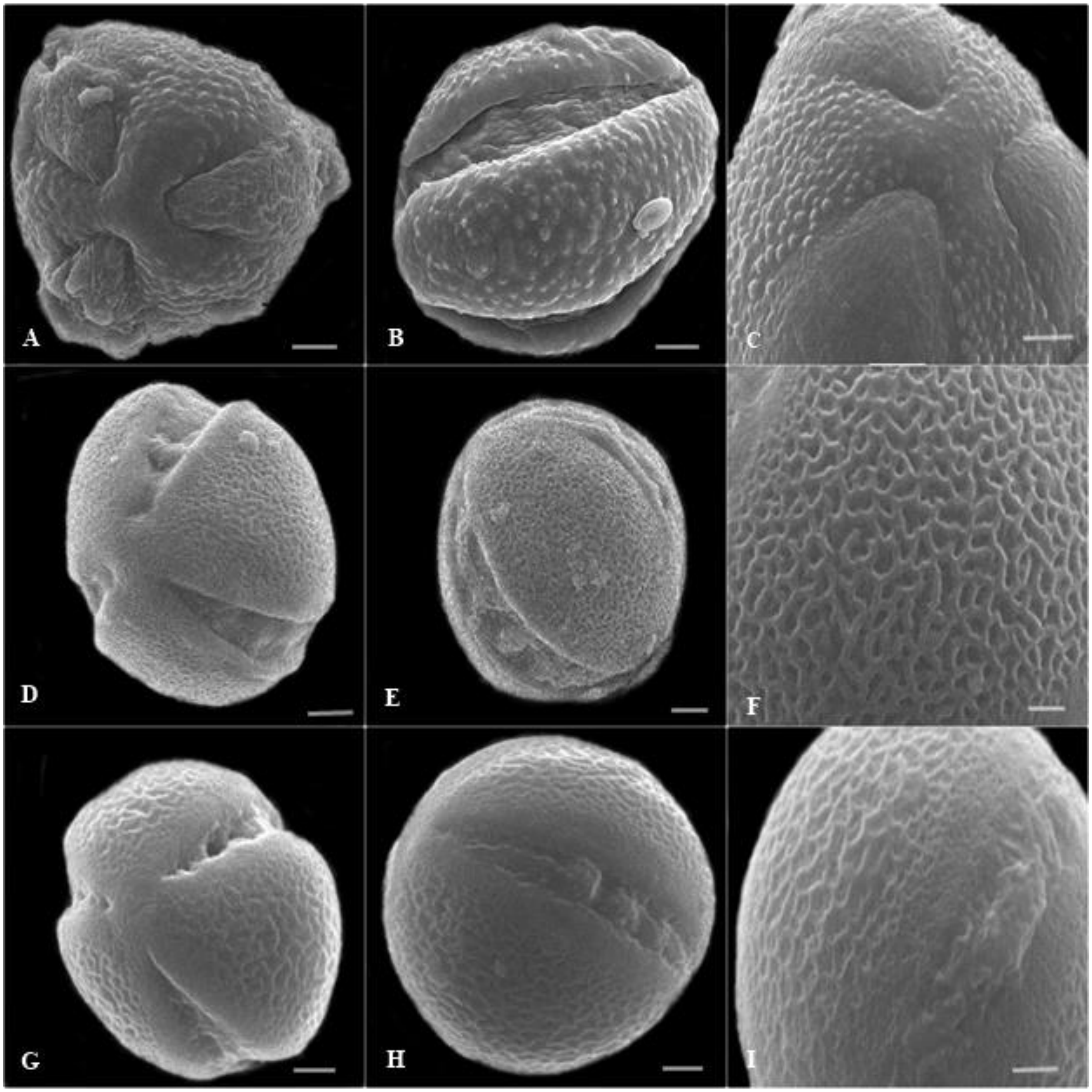

Plate. 41: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Pseudocaryopteris bicolor* (A-C), A) polar view, B) equatorial view with sunken colpi, C) reticulate exine surface. *Rydingia limbata* (D-F). D) polar view, E) equatorial view, F) colliculate exine. *Scutellaria grossa* (G-I). G) polar view, H) equatorial view aperture filled with verrucate structures, I) fine reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

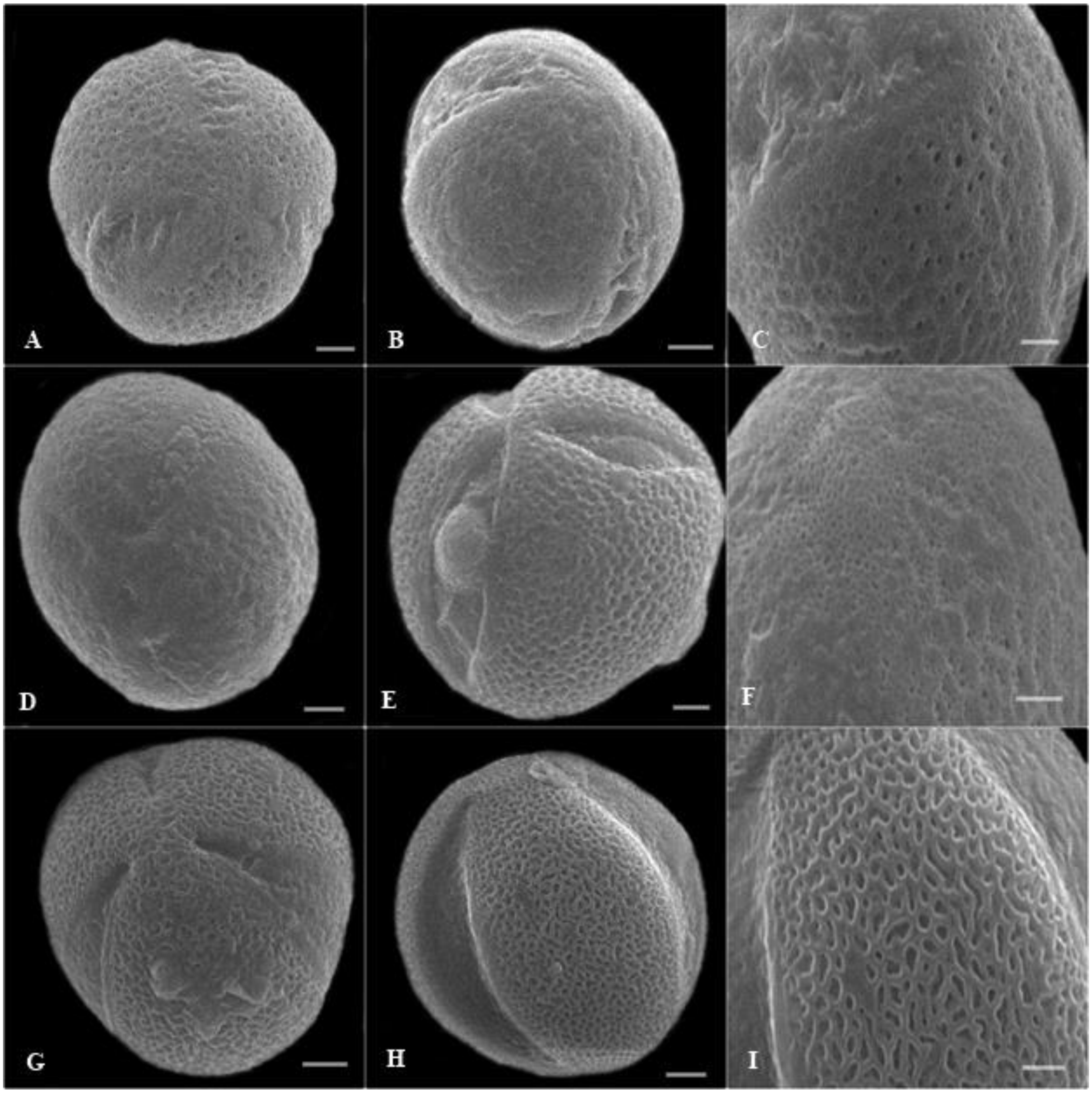

Plate. 42: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Scutellaria linearis* (A-C), A) polar view, B) equatorial view, C) reticulate perforate exine surface. *Scutellaria prostrata* (D-F). D) psilate polar view, E) equatorial view, F) reticulate perforate exine surface. *Stachys emodi* (G-I). G) polar view, H) equatorial view, I) foveolate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing except in Fand I (1 µm).

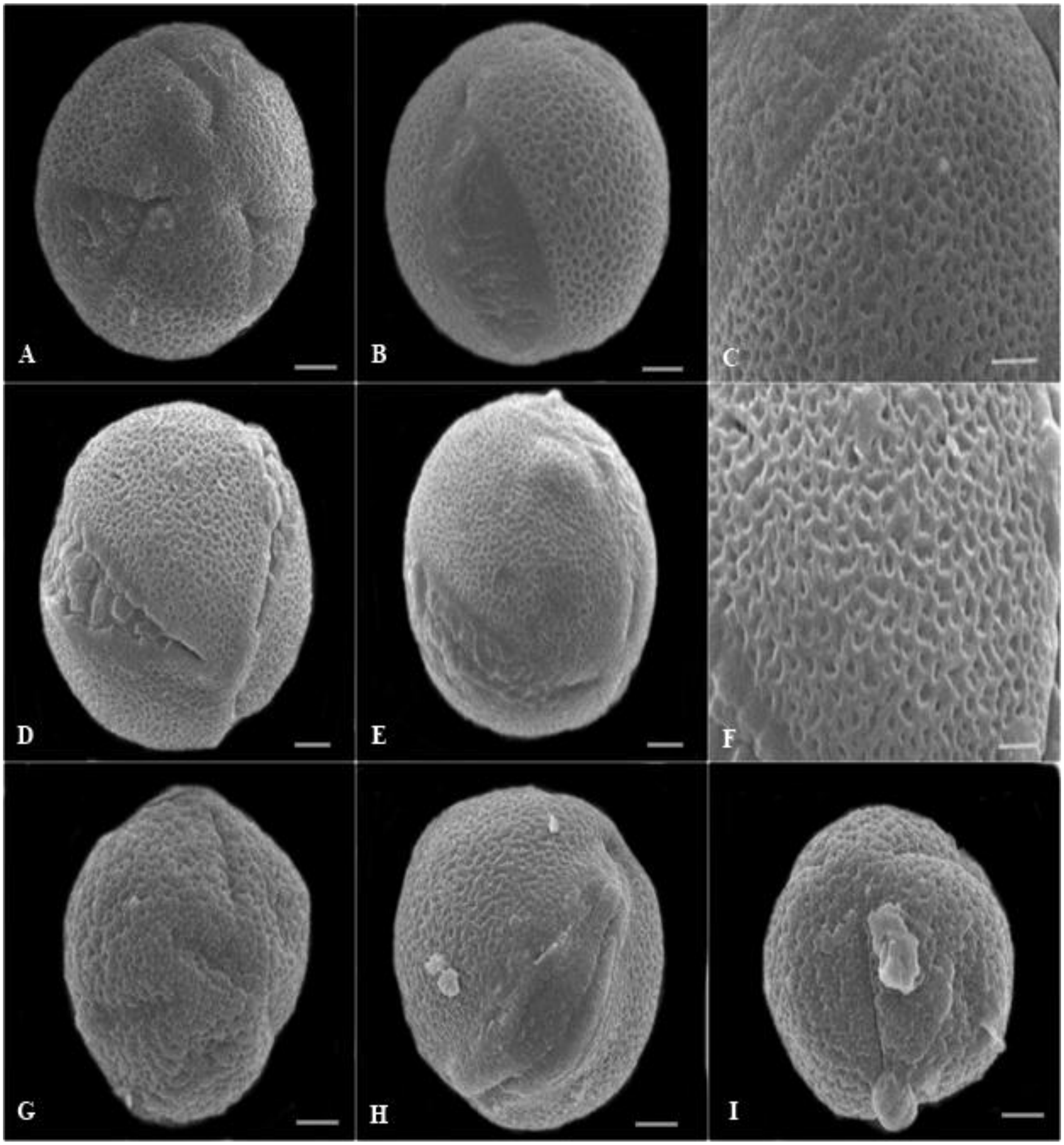

Plate. 43: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Stachys floccosa* (A-C), A) psilate polar view, B) equatorial view, C) reticulate perforate exine surface. *Stachys palustris* (D-F). D) polar view aperture filled with verrucate structures, E) equatorial view, F) close view of exine. *Teucrium royleanum* (G-I). G) polar view, H) equatorial view with raised colpi, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing except in F (1 µm) and I (5 µm).

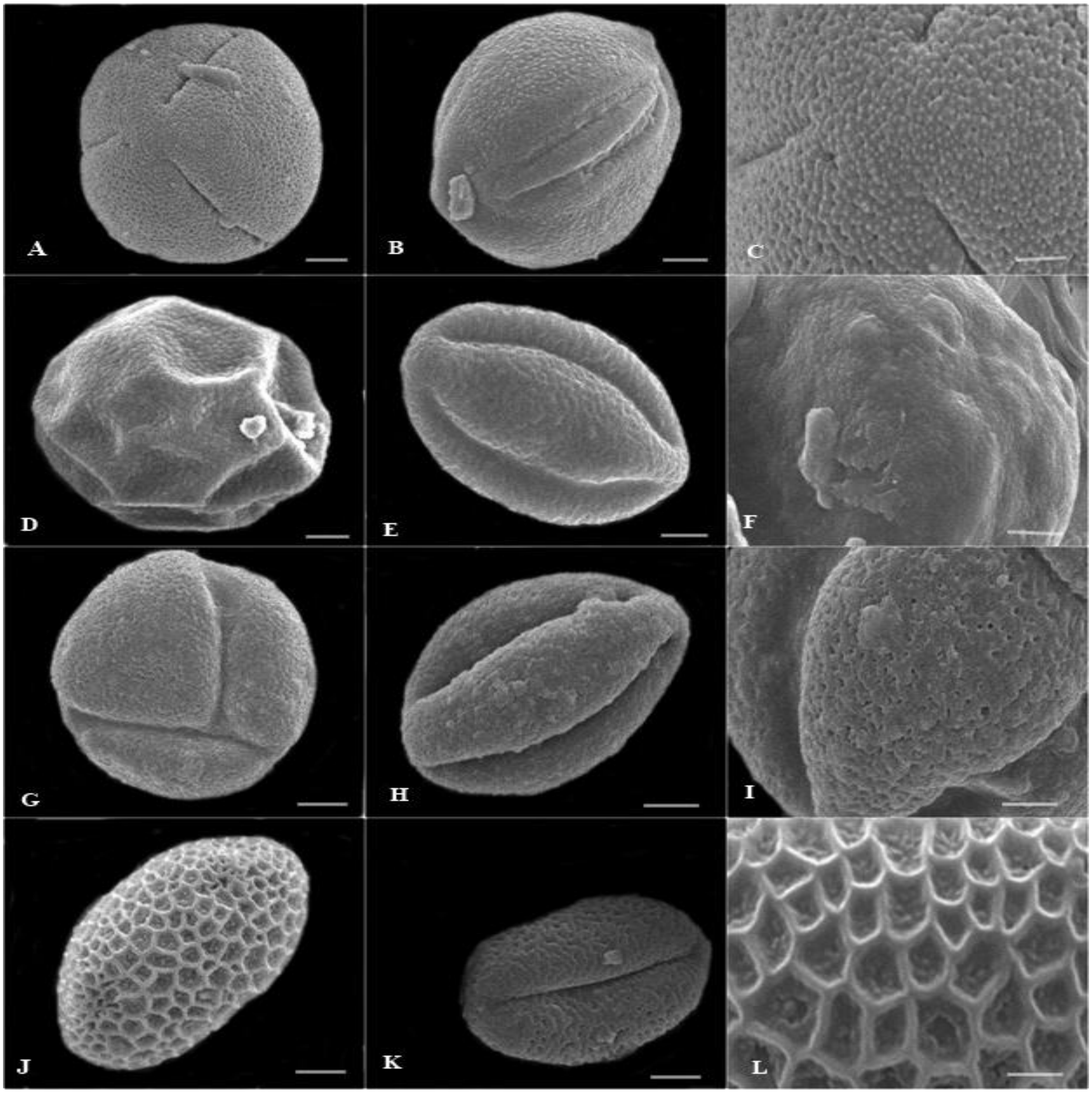

Plate. 44: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Lamiaceous taxa. *Teucrium stocksianum* (A-C), A) polar view, B) equatorial view, C) pitted-roughly reticulate perfortate exine surface. *Vitex agnus-castus* (D-F). D) polar view, E) equatorial view with concave aperture, F) close view of exine. *Vitex negundo* (G-I). G) polar view, H) equatorial view, I) reticulate exine surface. *Vitex trifolia* (J-L), J) polar view, K) equatorial view, L) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs except in D and G (10 µm), scale bar 2µm for exine sculpturing except in L (1 µm) and F (5 µm).

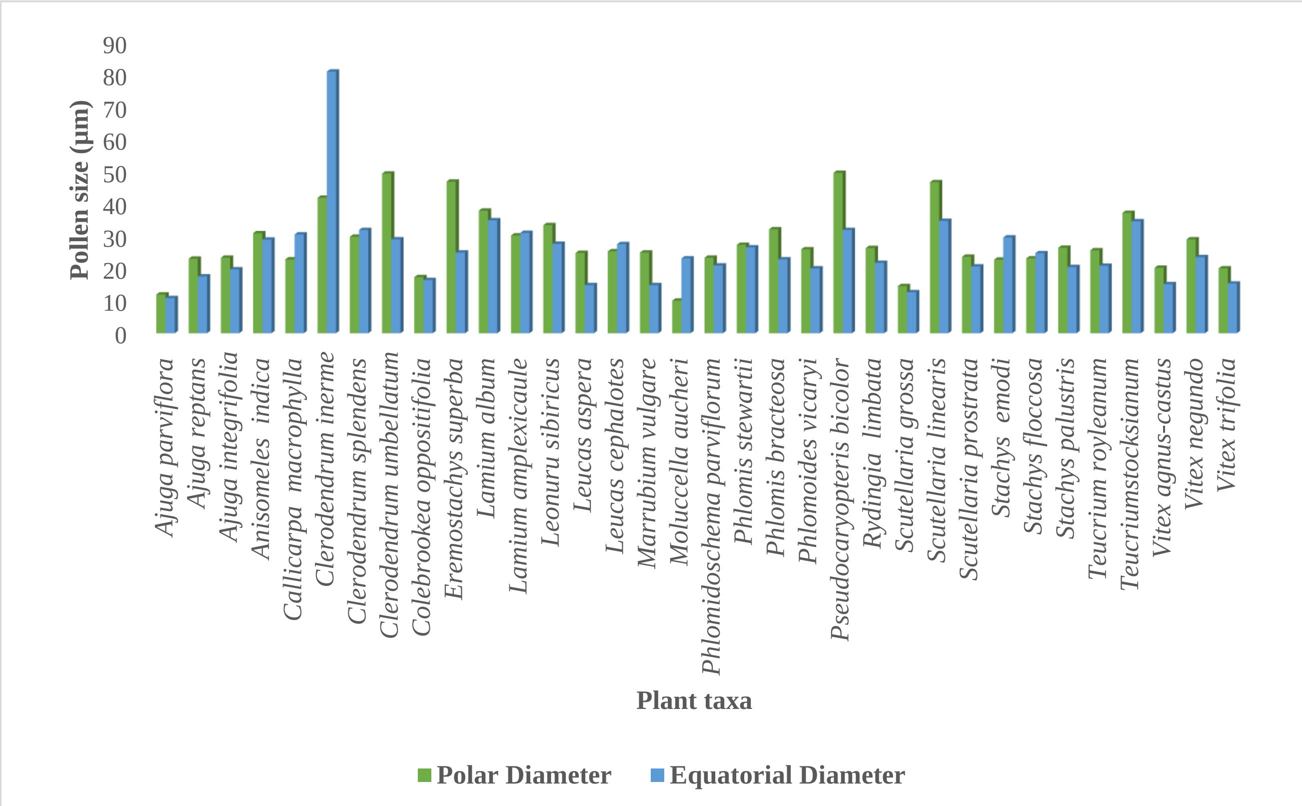

Figure. 5: Variation among polar and equatorial diameter in Lamiaceous taxa

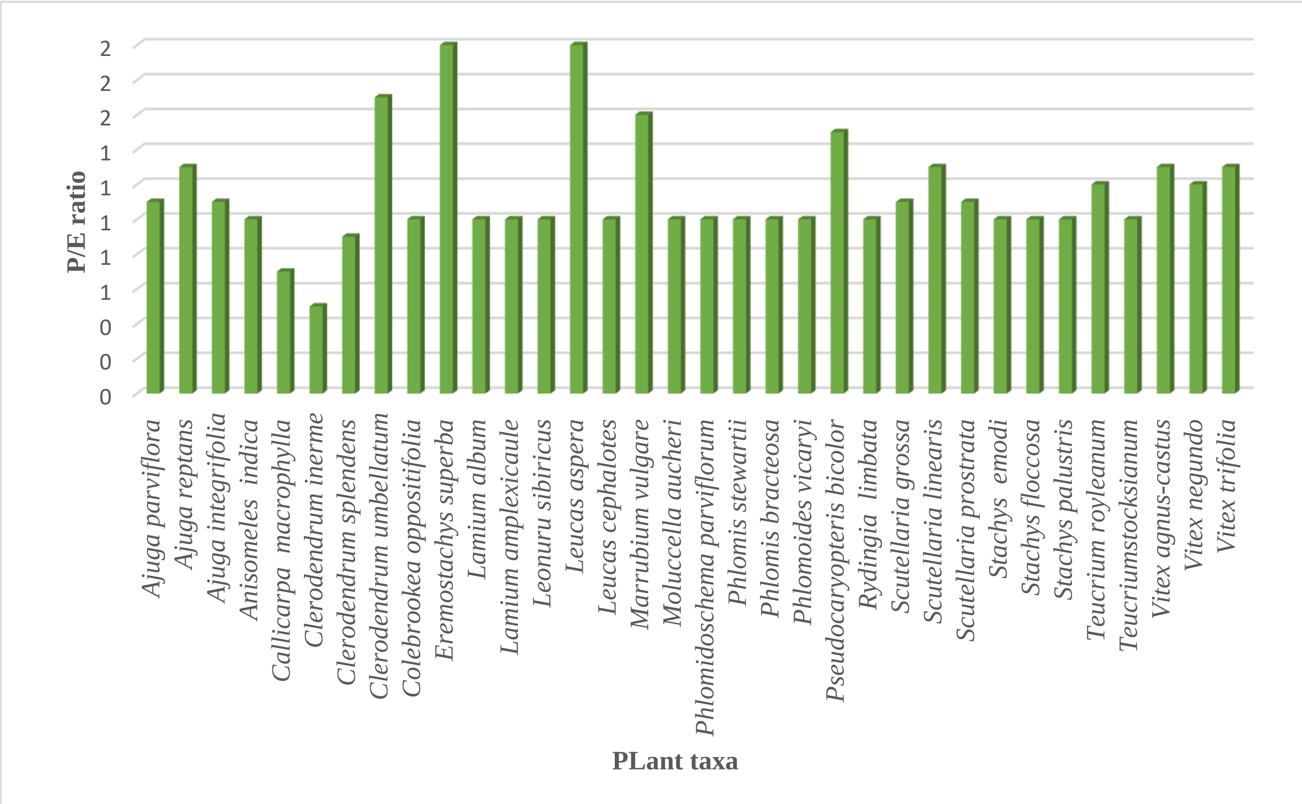

Figure. 6: Showing variation among polar to equatorial diameter (P/E ratio) in Lamiaceous taxa

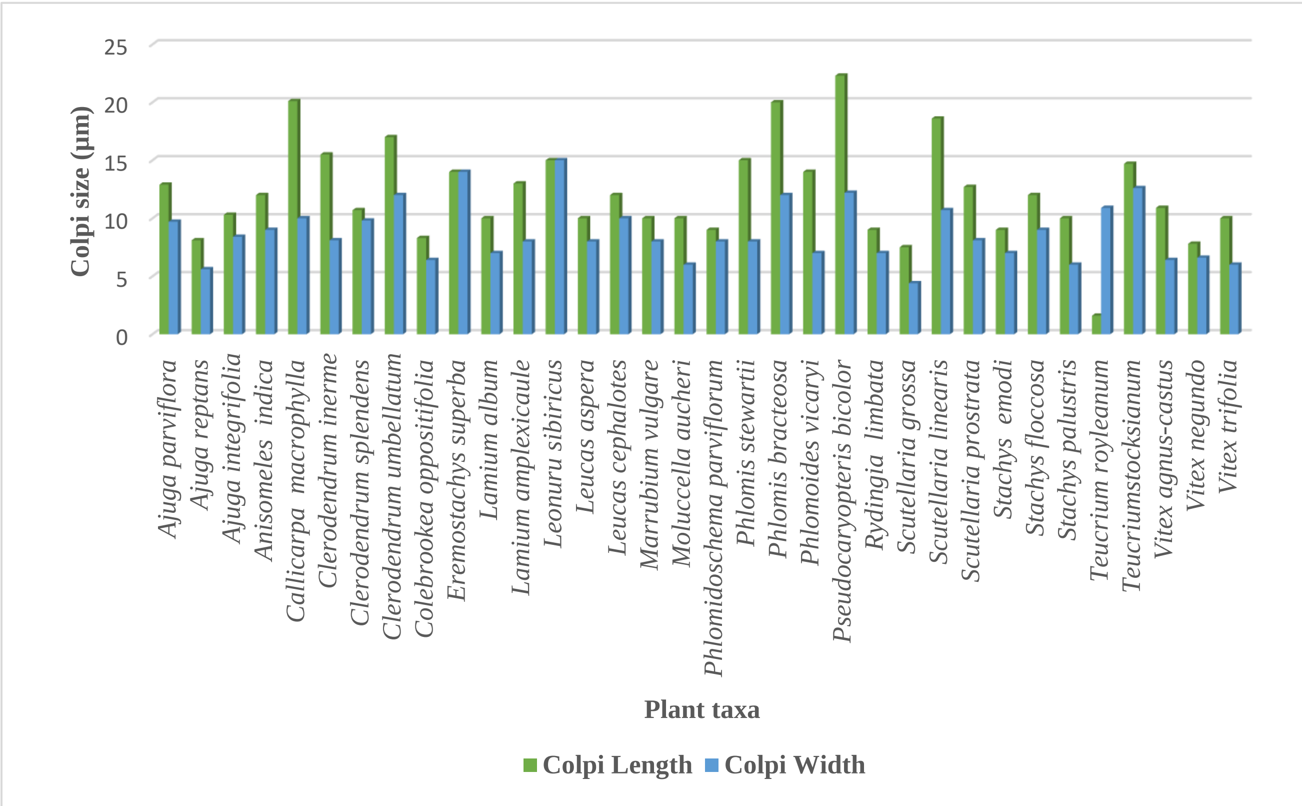

Figure. 7: Variation among colpi length and width in Lamiaceous taxa

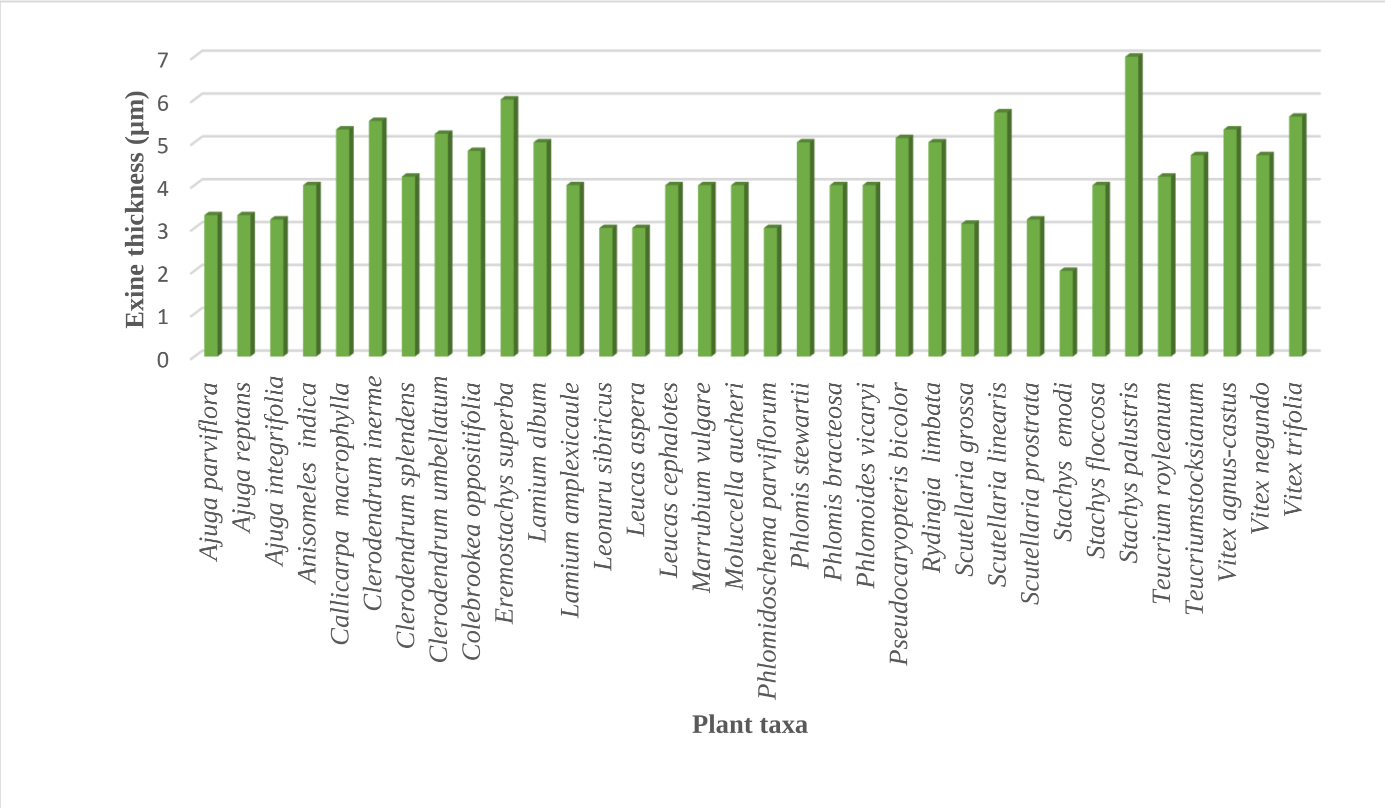

Figure. 8: Showing variation of exine thickness among the Lamiaceous taxa

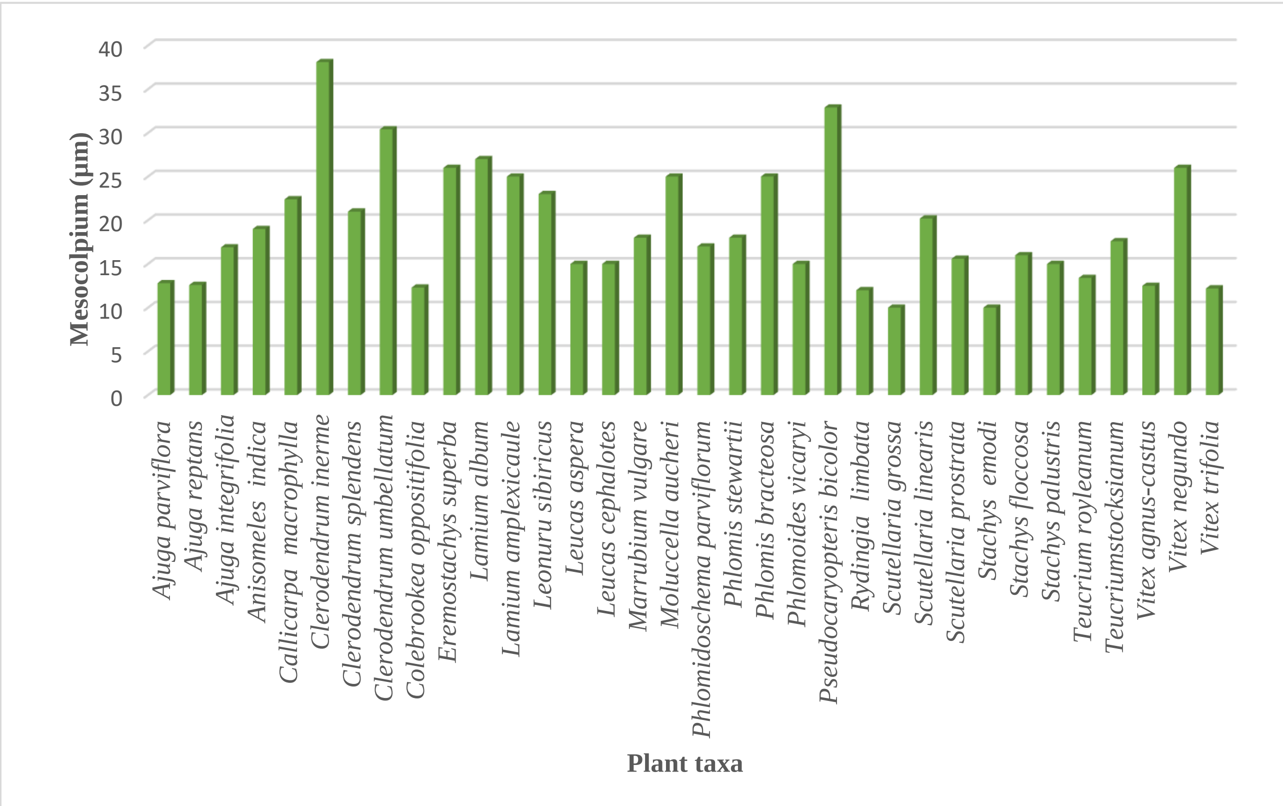

Figure. 9: Showing variation of mesocolpium among the Lamiaceous taxa

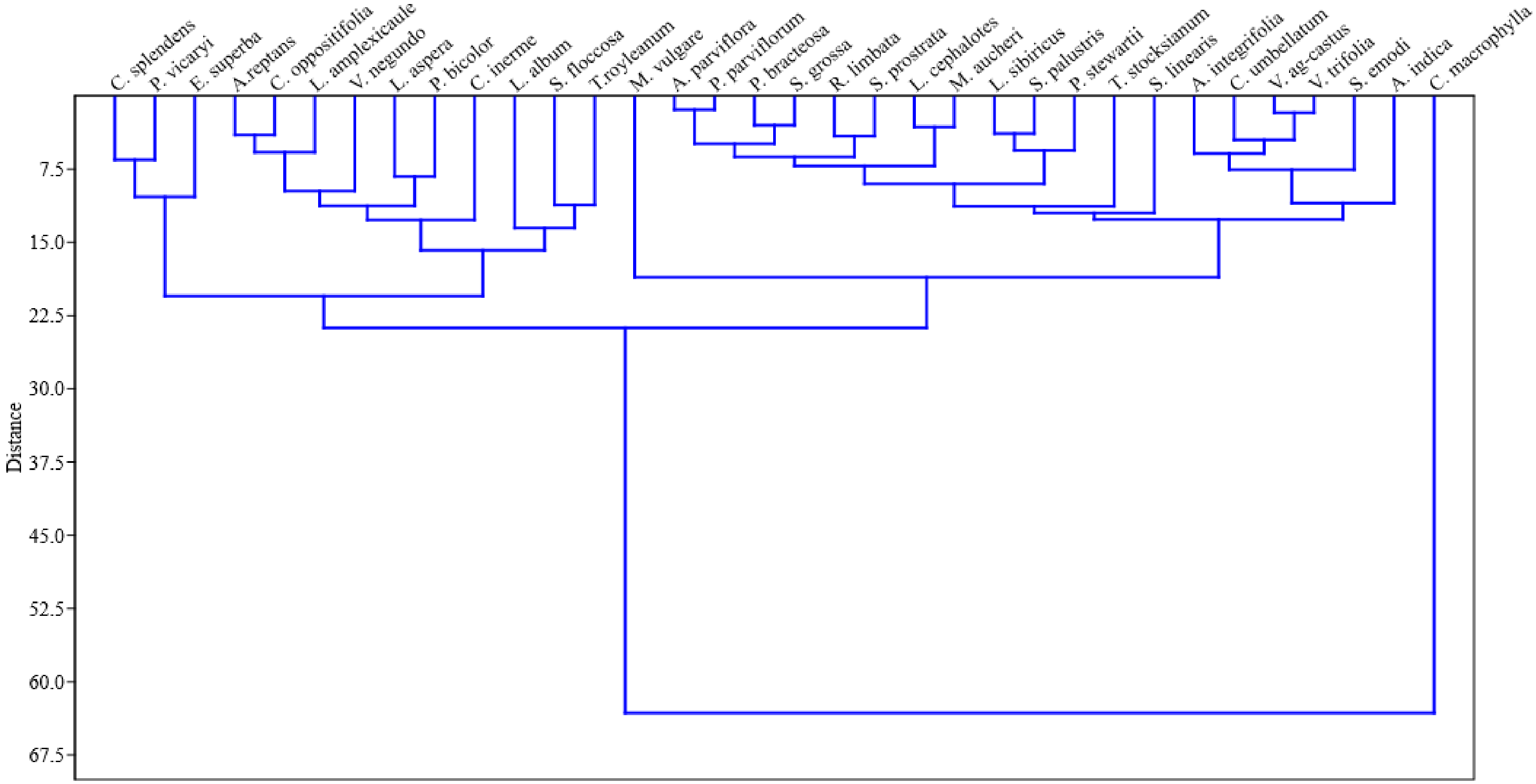

Figure. 10: UPGMA dendogram for 34 species of Lamiaceae based on quantitative pollen characters

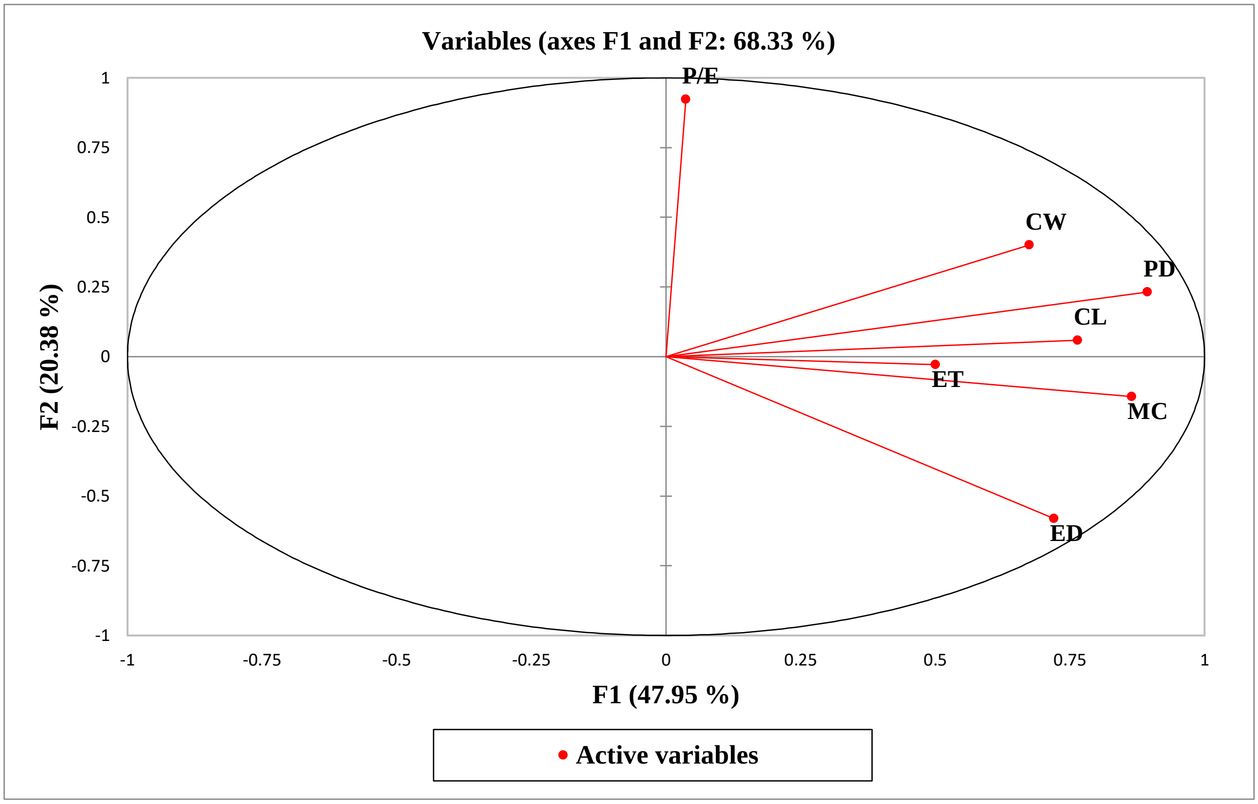

Figure. 11: Active variables of pollen of the principal component analysis biplot

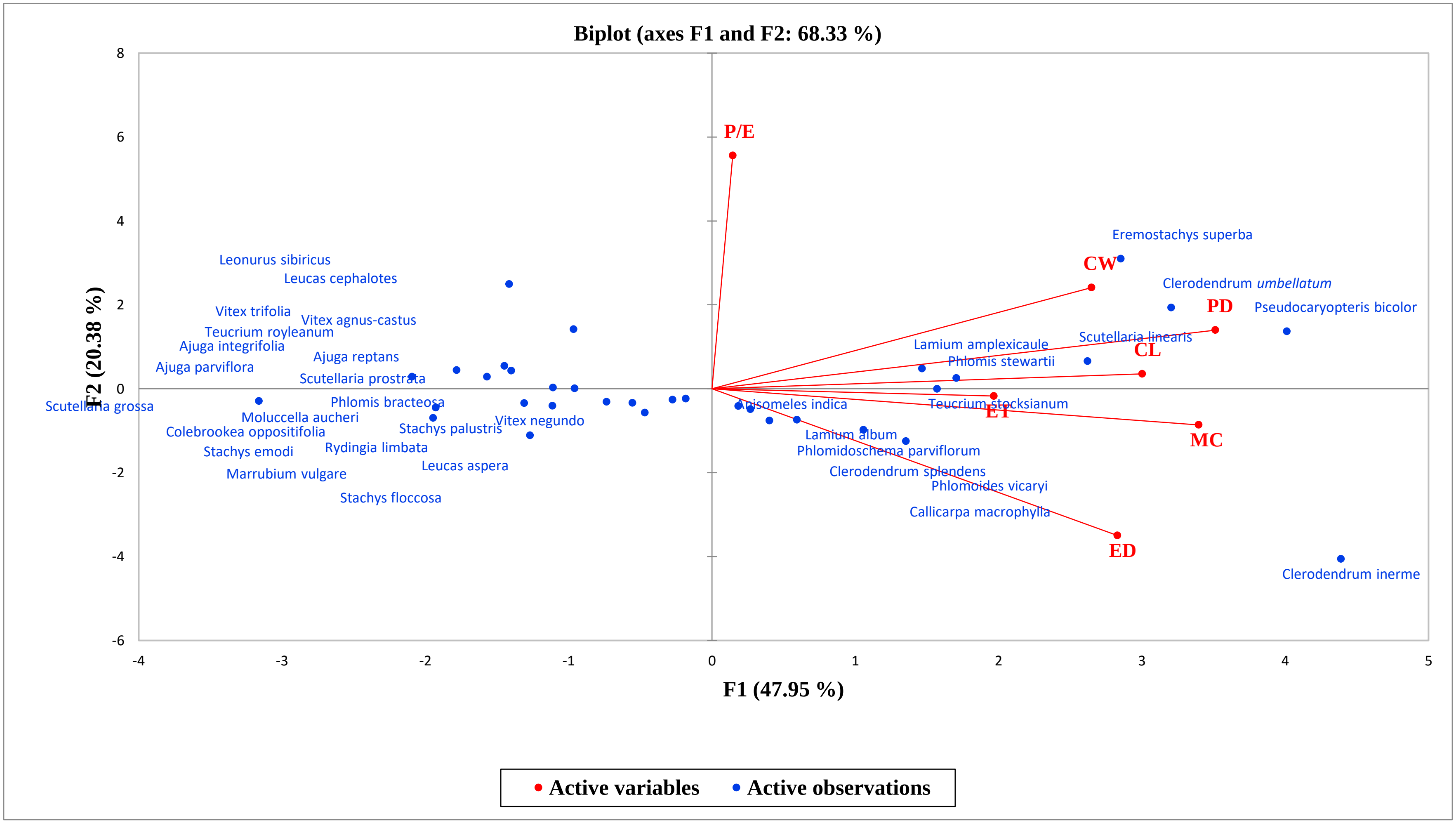

Figure. 12: Principal component analysis (PCA) based on the seven pollen traits that is PD: Polar area diameter, ED: Equatorial diameter, P/E: Polar to equatorial ratio. CL: Colpus length, CW: Colpus width, ET: Exine thickness, MC: Mesocolpium of Lamiaceous taxa

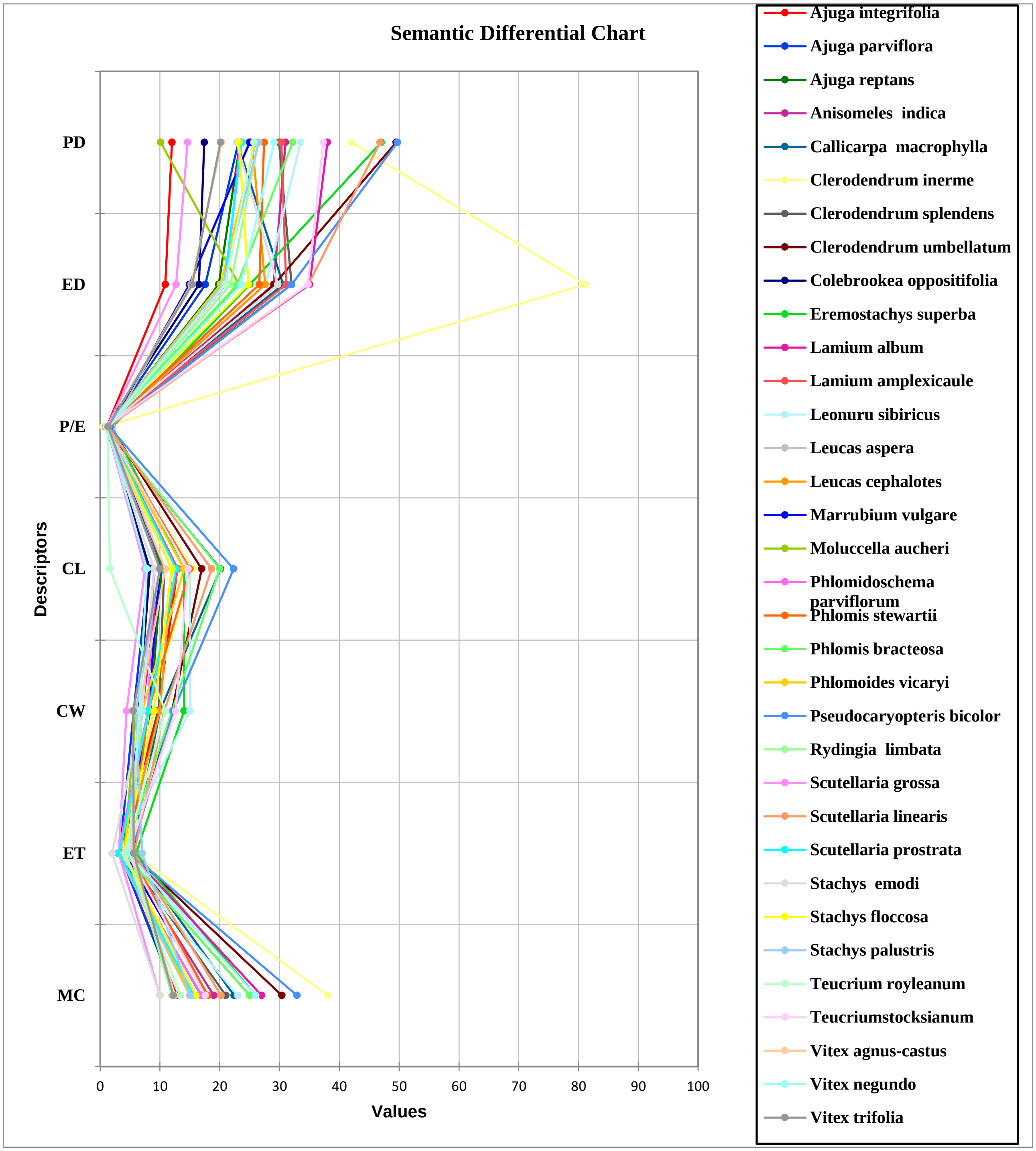

Figure. 13: Semantic Differential Chart of seven pollen variables i.e., polar diameter, equatorial dimeter, polar to equatorial diameter, colpi length, colpi width, exine thickness and mesocolpium of Lamiaceous taxa

3.3 Pollen Micromorphological Structure of Sub Family Nepetoideae

A total of 34 Nepetoideae taxa were studied with the help of light microscopy (LM) and scanning electron microscope (SEM). Nepetoideae sub family was studied for the first time for palynological studies. In the current research Nepetoideae sub family consists of 18 genera. The most prominent pollen type determination based on pollen traits, particularly the aperture type and exine structure may provide more precise environmental information of Nepetoideae pollen, among the most prominent components of pollen assemblages in moist regions. The maximum, minimum, standard error and means of the studied pollen characters are presented in Table 6. Pollen micromorphological characteristics based on scanning electron micrographs of Nepetoideae sub family are also presented in Table 7. The pollen SEM micrographs were presented in Plate. 45-55.

3.3.1 Variations in Pollen Size

The pollens are mostly hexacolpate or hexazonocolpate, pollen grains shed as monad, and are frequently isopolar. The pollen size ranges from small to large. The largest polar diameter was observed in *Thymus linearis* (77 µm), and smallest in *Mentha arvensis* (18 µm). The largest equatorial diameter was found in *Ocimum citriodorum* (72 µm), and smallest in *Origanum vulgare* (14 µm) presented in Figure 14. The highest P/E ratio was found in *Isodon rugosus* (4.32 %), and lowest in *Origanum vulgare* (0.50 %) presented in Figure 15. There is enough published literature about the pollen size that it was greatly influenced by different preparation techniques, and it was researched that point-dried pollen typically being smaller than acetalized pollen in SEM analysis (Harley, 1992; Janssens et al., 2005; Moon et al., 2008b; Schols et al., 2004). The pollen size might differ among Nepetoideae taxa, and it was determined that size variations were stable among species belonging to the same genus. The size, shape and exine surface sculpturing of *Origanum vulgare* in the investigation of Myoung and Yuon (2012) were found disagreed with our results.

3.3.2 Variations in Shape

Eight types of pollen shapes were observed in the present research i.e., prolate, prolate spheroidal, sub prolate, per prolate, oblate, sub oblate, oblate-spheroidal and spherical. The dominant pollen shape is prolate spheroidal (10 species). Three types of pollen shapes in polar view were studied: slightly circular, spherical and sub spherical. The dominant pollen shape in polar view was sub spherical followed by spherical and the least observed shape was slightly circular observed in (Plate 46 D). Pollen shapes in equatorial view are widely elliptic, very wide obovate-oblong elliptic, ellipsoid, widely oval, broadly elliptic, spherical and sub spherical. The dominant pollen shape in equatorial view was spherical followed by sub spherical and the least observed shape was widely oval observed pollen are mostly oblate-spheroidal similar in shape to our studied species *Mentha pulegium* but different in size. Our studies coincides with the research of Al-Taie (2019) in exine sculpturing of the their studies species but not coincides with the pollen shape. Earlier investigation of Moon et al., (2008b) observed oblate spheroidal shape in *Rosmarinus officinalis* with circular polar view which is similar to our studies. The pollen shape of *Ocimum basilicum* and *Prunella vulgaris* in the research of Ozaltan and Koçyiğit (2022) that was found dissimilar with our observed pollen shapes in both species. The pollen shape class and shape in polar and equatorial view of *Mentha longifolia*, *Mentha spicata*, *Ocimum basillicium* and *Thymus vulgaris* in the research of Azzazy (2016) were found inconsistent with our result in pollen shapes of above mentioned species.

3.3.3 Variations in Pollen Out line

Five types of pollen outlines were observed in the current research: psilate, scabrate, rough, sinuate, and irregular wavy. The dominant pollen outline was rough followed by psilate and the least common was sinuate or we will say that sinuate pollen outline was the unique one, observed in (Plate 50 H, Plate 52 A).

3.3.4 Variations in Symmetry, Colpi Apex and Apertures

The pollens are mostly hexazonocolpate (26 species) or hexacolpate (6 species) pollen grains shed as monad, are frequently radially symmetrical and isopolar in 31 species and bilateral and heteropolar in 1 species. Four types of colpi apex were observed: acute, slightly round, round, and broad round. The dominant colpi apex was acute and the least common was broad round found in (Plate 52 D-F). Colpi apex is not clear in *Mentha suaveolens*. In the current research we found tricolpate pollen in *Thymus vulgaris*, a member of the Nepetoideae. The tribe Mentheae had an aperture heteromorphism, which was composed of hexazonocolpate pollen combined with 4-colpate, 5-colpate, or 8-colpate pollen (Moon et al., 2008a; Moon et al., 2008b; Claude et al., 1992). Aperture heteromorphism can also be caused by normal ecological conditions because it is common in cultivated species. Our research revealed that all species primarily produce hexacolpate pollen, supporting its designation as a synmorphy for the Nepetoideae subfamily (Abu-Asab and Cantino, 1994).

3.3.5 Variations in Aperture Orientation

In the current research the four types of aperture orientation were observed: raised, sunken, bulged, and slightly raised. The dominant aperture orientation is sunken and the least common was bulged and slightly raised (Plate 45 g, Plate 48 E). These apertural characteristics have been found helpful in the classification of additional Lamiaceae taxa as well as in the definition of the Nepetoideae species (Doaigey et al., 2018; Perveen and Qaiser 2004).

3.3.6 Aperture Sculpturing

Eight types of aperture sculpturing were observed: verrucate, baculate, granulate, slightly gemmate colliculate, psilate, slightly verrucate, slightly granulate and scabrate. The dominant aperture sculpturing was verrucate and and the least common was baculate and psilate. Length of colpi ranges from (29 µm), highest in *Thymus linearis* to smallest (2 µm), in *Mentha arvensis* and *Mentha longifolia.* Width of colpi ranges fom (10 µm,) highest in *Ocimum citriodorum* to smallest (3µm), in *Mentha spicata* presented in Figure 16. Mesocolpium area ranges (3s µm), maximum in *Thymus linearis* and minimum (6 µm), *Ocimum* × *africanum* presented in Figure 18. Earlier studies of Kahraman et al., (2010) reported birticulate perforate exine sculpturing and angular shape of primary lumina and 5-8 number of secondary reticulum of *Salvia chrysophylla* similar with our studied specie i.e., *Ocimum americanum* but different in number of secondary reticulum.

3.3.7 Variations in Exine sculpturing

From SEM observations ten types of exine sculpturing were observed i.e., reticulate, reticulate perforate, verrucate, reticulate granulate, fine reticulate, foveolate, mega reticulate granulate, mega bireticulate perforate, rugulate and scabrate. The dominant exine sculpturing was reticulate perforate and least dominant were rugulate and scabrate. Thickness of exine varies from (9 µm), maximum in *Ocimum* × *africanum to* (2 µm), minimum in *Origanum vulgare presented* in Figure 17. According to Gul et al., (2019) the exine sculpturing of *Thymus linearis, Origanum vulgare* and *Ocimum americanum* are in accordance to our results but not in pollen polar view. The pollinic traits seen with the help of SEM are useful to distinguish and establish the association within the species (dos Santos Amorim et al., 2014), because they are determined genetically, extremely constant, and unique to each species (e.g., aperture number and type and exine sculpturing). and have a crucial taxonomic value (Mert 2010; Soares et al., 2017). Reticulate perforate to reticulate perforate- foveolate exine sculpturing were observed in *Mentha longifolia* and *Mentha spicata* which were not consistent with the research of Azzazy (2016) he observed bireticulate and reticulate exines in *M. spicata* and *M. longifolia* respectively. The bireticulate and mega reticulate may be distinguishing characteristics of *Ocimum* species in the current research similar with Gul et al., (2019). Harley (1992) also observed bireticulate perforate tectum in *ocimum* species and recommended to revise in their categorization. The Nepetoideae was thought to be monophyletic, the relation between genera, tribe and subtribe in a family were poorly understood since complex and closely related morphological traits make taxa challenging to delineate (Bräuchler et al., 2010). The pollen size and shape of *Mentha microphylla* is small-medium and sub-spheroidal pollen shape with reticulate perforate exine sculpturing in the research of Al-Watban et al., (2015) were corroborated with our *Mentha* species in exine sculpturing and pollen size but not in pollen shape. The pollen shape and exine sculpturing of the *ocimum* species, *Mentha longifolia, Thymus decussatus, Lallemantia royleana, Plectranthus asirensis, Origanum syriacum* and *Micromeria imbricata* in the studies of Doaigey et al., (2018) were not similar with our observed taxa except in mega reticulate exine sculpturing in *ocimum* species. The exine sculpturing and pollen shape of *Isodon rugosus* in the research of Hameed et al., (2020) shows dissimilarity with our results. The exine sculpturing and pollen shape of *Clinopodium hydaspidis, Clinopodium umbrosum, Clinopodium vulgare, Isodon rugosus, Melissa officinalis, Mentha longifolia, Mentha spicata, Micromeria biflora Ocimum americanum, Prunella vulgaris, Origanum vulgare* and *Thymus linearis* in the research of Perveen and Qaiser (2004) were not coincides with our results in pollen shape except in *Melissa officinalis* and *Micromeria biflora,* and also shows similarity in exine sculpturing except in *Clinopodium vulgare.*

3.3.8 Pollen Fertility and Sterility

Pollen fertility is crucial in determining the variety of plants and where they are found in different ecosystems. The highest and the lowest percentage of fertility confirms their stability. The highest pollen fertility was found in *Perilla frutescens* (85.4%) and lowest in *Thymus vulgaris* (40.2%) while, the highest sterility was observed in *Thymus vulgaris* (59.8%) and lowest in *Perilla frutescens* (14.6%).

3.3.9 Cluster Analysis and Principal Component Analysis (PCA) of Nepetoideae pollen as a Statistical Tool

The dendrogram distributed the Nepetoideae taxa into two major clusters (Figure 18). Cluster 1 is divided into two clades in which similarity was observed among *Ocimum* × *africanum* and *Ocimum sanctum* (clade 1). Similarity was also observed in *Thymus linearis* and *Thymus vulgaris* (clade 2), which are more similar than clade 1. *Ocimum citriodorum* is more distinct from the two clades that is (clade 1 and 2). Cluster 2 divided the remaining Nepetoideae taxa into two sub clusters (subcluster 2A and 2B) which were further divided into smaller clades. The greatest similarity was observed among sub cluster 2A clades i.e., *Clinopodium umbrosum* and *Mentha suaveolens*, similarity was also observed among *Hyssopus officinalis* and *Mentha* × *villosa*. *Isodon rugosus* is more distinct from the above-mentioned similar clades. Greater similarity was observed among sub cluster 2B clades i.e., *Ocimum gratissimum* and *Perilla frutescens*. *Clinopodium hydaspidis* is more dissimilar from the above-mentioned clade presented in Figure 19.

Principal Component Analysis is one of the important statistical analyses for examining variance among a group of factors (Nabila et al., 2022). Seven quantitative variables that is polar diameter (PD), equatorial diameter (ED), polar to equatorial diameter ratio (P/E ratio), colpi length and width (CL and CW), exine thickness (ET), and mesocolpium (MC) of sub family Nepetoideae were used to better understand the similarities and differences among them through multivariate principal component analysis (PCA). To improve the accuracy of the mathematical classification and to enable a visual analysis of the data set in the form of two-dimensional plots, a limited number of essential variables were chosen for PCA. Principal component analysis variable loadings for first seven components illustrated in Table 5. The results of the PCA analysis showed that PC1 and PC 2 had an eigenvalue greater than 1 and was the most important element. Data analysis revealed that PCI accounts for (56.39%) of the data's overall variance. Polar diameter was the most significant component followed by exine thickness and equatorial diameter in first axes PC1. *Ocimum × africanum*, *Plectranthus madagascariensis*, *Ocimum gratissimum*, *Ocimum americanum Perilla frutescens*, *Anisochilus carnosus*, *Clinopodium hydaspidis* and *Micromeria biflora* in Figure 21 were positioned on the positive side of first axes. Whereas *Ocimum citriodorum*, *Thymus vulgaris, Thymus linearis, Prunella vulgaris, Dracocephalum nutans, Ocimum sanctum, Melissa officinalis, Clinopodium vulgare* and *Ocimum basilicum*. on the negative side of the first axes. Data analysis revealed that PC2 accounts for (17.15 %) of the data's overall variance. Polar to equatorial diameter ratio (P/E ratio) was the most significant component in second axes PC2. *Isodon rugosus*, *Mentha longifolia* and *Coleus forskolin* positioned on the positive side of the second axes. Whereas *Hyssopus officinalis*, *Satureja hortensis*, *Mentha arvensis*, *Lallemantia royleana*, *Origanum vulgare Mentha pulegium, Mentha spicata*, *Mentha arvensis*, *Mentha suaveolens*, *Rosmarinus officinalis*, *Mentha × villosa*, *Origanum majorana* and *Clinopodium umbrosum* positioned on the negative side of second axes. Additionally, the semantic differential chart and active variables of the PCA biplot were displayed in Figures 20 and 22 respectively to better visualize and assess the relationships between these three factors.

3.3.10 Taxonomic keys based on pollen qualitative features of Nepetoideae species:

1	a	Exine sculpturing fine reticulate perforate…………	*Clinopodium vulgare*
	b	Exine sculpturing other than fine reticulate perforate	2
2	a	Exine sculpturing verrucate………………………	*Coleus forskohlii*
	b	Exine sculpturing other than verrucate…………	3
3	a	Exine sculpturing reticulate granulate……………	*Isodon rugosus*
	b	Exine sculpturing other than reticulate granulate…	4

4	a	Exine sculpturing mega reticulate granulate………	*Ocimum × africanum*
	b	Exine sculpturing other than mega reticulate granulate	5
5	a	Exine sculpturing mega reticulate perforate………	*Ocimum citriodorum*
	b	Exine sculpturing other than mega reticulate perforate	6
6	a	Exine sculpturing mega reticulate scabrate………..	*Ocimum gratissimum*
	b	Exine sculpturing other than mega reticulate scabrate	7
7	a	Exine sculpturing fine reticulate-verrucate………..	*Perilla frutescens*
	b	Exine sculpturing other than fine reticulate-verrucate	8
8	a	Exine sculpturing rugulate-reticulate………………	*Prunella vulgaris*
	b	Exine sculpturing other than rugulate-reticulate……	9
9	a	Exine sculpturing scabrate…………………………	*Rosmarinus officinalis*
	b	Exine sculpturing other than scabrate………………	10
10	a	Exine sculpturing reticulate perforate- foveolate…	12
	b	Exine sculpturing other than reticulate perforate-foveolate	11
11	a	Aperture sculpturing granulate…………………	*Mentha arvensis*
	b	Aperture sculpturing slightly verrucate…………..	*Mentha spicata*
12	a	Exine sculpturing mega bireticulate perforate……	15
	b	Exine sculpturing other than mega bireticulate perforate	13
13	a	Aperture orientation bulged……………………	*Ocimum sanctum*
	b	Aperture orientation bulged……………………	14
14	a	Pollen in equatorial view sub spherical…………..	*Ocimum americanum*
	b	Pollen in equatorial view very wide obovate………	*Ocimum basilicum*
15	a	Exine sculpturing foveolate……………………	19
	b	Exine sculpturing other than foveolate…………..	16
16	a	Aperture orientation raised…………………………	*Origanum majorana*
	b	Aperture orientation other than raised………………	17
17	a	Pollen out line scabrate…………………………	*Thymus vulgaris*

	b	Pollen out line other than scabrate…………………	18
18	a	Aperture sculpturing colliculate………………	*Mentha × villosa*
	b	Aperture sculpturing granulate…………………	*Origanum vulgare*
19	a	Exine sculpturing reticulate……………………	23
	b	Exine sculpturing other than reticulate…………..	20
20	a	Pollen out line scabrate…………………………	*Hyssopus officinalis*
	b	Pollen out line other than scabrate…………………	21
21	a	Pollen in equatorial view ellipsoid…………………	*Satureja hortensis*
	b	Pollen in equatorial view spherical…………………	*Clinopodium umbrosum*
22	a	Aperture orientation sunken………………………	*Anisochilus carnosus*
	b	Aperture orientation raised…………………………	*Plectranthus madagascariensis*
23	a	Exine sculpturing reticulate perforate………………	30
	b	Exine sculpturing other than reticulate perforate……	24
24	a	Pollen size large…………………………………	*Thymus linearis*
	b	Pollen size other than large………………………	25
25	a	Aperture sculpturing not visible……………………	*Mentha suaveolens*
	b	Aperture sculpturing other than not visible………..	26
26	a	Pollen in equatorial view ellipsoid………………	*Mentha longifolia*
	b	Pollen in equatorial view other than ellipsoid……..	27
27	a	Aperture sculpturing gemmate…………………	*Lallemantia royleana*
	b	Pollen outline other than gemmate…………………	28
28	a	Aperture sculpturing baculite……………………….	*Clinopodium hydaspidis*
	b	Aperture sculpturing other than baculite…………..	29
29	a	Pollen size small……………………………………	*Mentha pulegium*
	b	Pollen size other than small……………………	30
30	a	Pollen outline scabrate…………………………	*Micromeria biflora*
	b	Pollen outline other than scabrate…………………	31
31	a	Aperture orientation sunken……………………	*Melissa officinalis*
	b	Aperture orientation raised…………………………	*Dracocephalum nutans*

Table. 5: Factor loading of PCA **(**principal component analysis) using quantitative pollen characters**.**

Variables/ Factors	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**	**PC 7**
PD	0.943	0.102	-0.110	-0.193	-0.189	0.008	-0.125
ED	0.933	-0.064	-0.191	-0.100	-0.218	-0.152	0.097
P/E	-0.137	0.779	0.588	-0.142	-0.076	-0.054	0.013
CL	0.918	-0.078	0.218	-0.183	0.047	0.254	0.052
CW	0.683	0.091	0.184	0.698	-0.059	0.017	-0.008
ET	0.354	0.723	-0.556	0.042	0.201	0.026	0.013
MC	0.857	-0.206	0.273	-0.080	0.346	-0.149	-0.020
Eigenvalue	3.947	1.200	0.860	0.596	0.255	0.114	0.028
Variability (%)	56.388	17.147	12.279	8.518	3.637	1.627	0.405
Cumulative %	56.388	73.535	85.814	94.332	97.968	99.595	100.000

Keywords: PD=Polar diameter, ED=Equatorial diameter, P/E=Polar diameter divided by equatorial diameter, Cl= Colpi length, Cw=Colpi width ET=Exine thickness, MC=Mesocolpium

Table. 6: Quantitative pollen micromorphological findings of subfamily Nepetoideae.

S.no	Taxon	**Polar diameter** Min-Max = Mean±SE (µm)	**Equatorial diameter** Min-Max = Mean±SE (µm)	**P/E ratio (µm)**	**Length of colpi** Min-Max = Mean±SE (µm)	**Width of colpi** Min-Max = Mean±SE (µm)	**Exine thickness** Min-Max = Mean±SE (µm)	**Mesocolpium** Min-Max = Mean±SE (µm)	**Fertility (%)**	**Sterility (%)**
1.	*Anisochilus carnosus* (L.f.) Wall.	30.7-36.7=34.6±1.0	31.0-36.2=33.2±1.1	1.04	13.7-15.5=14.6±.32	7.5-9.0=8.4±.21	4.2-5.5=4.8±.23	11.0-12.0=11.5±.17	70.5	29.5
2.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	37.0-38.2=37.6±.23	23.0-27.7=25.1±.85	1.49	18.7-20.5=19.7±.30	7.7-8.7=8.2±.17	3.5-4.2=3.9±.12	14.5-16.0=15.2±.26	67.1	33,9
3.	*Clinopodium umbrosum* (M. Bieb.) Kuntze	23.7-33.7=26.6±1.8	24.7-28.0=25.7±.57	1.03	11.7-13.2=12.6±.26	7.0-8.0=7.5±.18	3.2-3.7=3.5±.11	12.0-13.0=12.5±.17	65.8	34.2
4.	*Clinopodium vulgare* L.	31.2-42.2=36.9±1.7	33.7-44.5=38.0±1.84	0.97	13.5-17.2=15.1±.61	4.5-5.5=5.0±.18	3.2-5.2=4.0±.46	17.2-19.2=18.7±.37	70.8	29.2
5.	*Coleus forskohlii* (Willd.) Briq.	29.5-31.7=30.7±.46	23.7-26.2=24.8±.43	1.03	12.0-13.2=12.6±.23	6.5-7.0=6.7±.09	4.5-6.2=5.3±.34	12.7-13.5=13.1±.12	75.4	24.6
6.	*Dracocephalum nutans* L.	31.2-36.2=34.2±.86	38.2-48.0=41.8±1.7	0.81	12.2-16.2=13.7±.68	5.2-8.7=7.2±.57	4.7-5.7=5.4±.18	17.0-18.7=17.8±.32	80.4	19.6

7.	*Hyssopus officinalis* L.	23.0-28.7=25.7±1.1	18.7-22.0=20.4±.64	1.25	11.0-12.0=11.5±.17	5.7-6.7=6.2±.17	3.7-5.0=4.3±.21	12.0-13.7=12.8±.32	69.2	30.8
8.	*Isodon rugosus* (Wall. ex Benth.) Codd	28.0-30.5=29.4±.465	15.2-18.0=16.8±.520	4.32	10.7-13.0=11.5±.398	6.0-7.0=6.35±.187	4.75-5.75=5.2±.176	9.7-10.7=10.3±.165	84.4	11.6
9.	*Lallemantia royleana* (Benth.) Benth.	26.2-42.7=30.9±3.0	25.5-40.2=34.7±2.5	0.89	11.2-14.5=12.6±.58	7.0-8.2=7.6±.23	2.2-3.0=2.6±.16	14.5-17.7=15.9±.63	67.6	32.4
10.	*Melissa officinalis* L.	38.7-35.2=42.1±1.0	37.7-47.2=44.8±1.7	0.93	14.5-15.7=15.1±.21	5.0-6.2=5.6±.23	3.2-4.7=3.9±.28	12.7-16.2=14.4±.60	65.4	34.6
11.	*Mentha arvensis* L.	16.2-18.7=17.6±.40	11.2-18.0=15.8±1.2	1.11	7.0-8.0=7.5±.17	4.5-5.5=4.9±.16	2.5-4.7=3.9±.39	7.5-8.5=8.0±.17	63.2	36.8
12.	*Mentha longifolia* (L.) L.	19.5-18.2=20.2±.30	13.7-15.5=14.7±.30	1.39	7.7-8.7=8.1±.18	4.7-5.7=5.3±.16	2.7-32.5=9.1±5.8	9.5-10.5=10.0±.18	68.9	31.1
13.	*Mentha pulegium* L.	17.7-20.5=19.5±.48	20.2-20.7=20.4±.09	0.95	8.7-10.2=9.4±.29	5.2-5.2=5.2±.00	2.5-3.2=2.9±.1	11.7-13.0=12.3±.231	60.5	39.5
14.	*Mentha spicata* L.	20.2-21.2=20.7±.17	18.7-22.5=20.0±.71	1.0	8.7-10.2=9.1±.28	2.7-4.0=3.4±.23	2.5-3.5=3.0±.17	7.2-8.2=7.8±.16	58.8	41.2

15.	*Mentha suaveolens* Ehrh.	26.2-28.7=27.4±.44	25.5-28.7=26.5±.57	1.03	11.2-13.0=12.0±.34	5.2-6.2=5.6±.18	3.7-4.7=4.3±.16	12.2-13.2=12.7±.17	61.5	38.5
16.	*Mentha* × *villosa* Huds.	23.7-25.7=24.7±.33	10.4-26.2=22.3±2.9	1.10	11.2-13.2=12.4±.36	5.7-6.5=6.0±.14	3.2-4.0=3.6±.12	11.2-13.2=12.4±.35	64.8	35.2
17.	*Micromeria biflora* (Buch. - Ham. ex D.Don) Benth.	32.2-45.2=39.7±2.1	31.2-37.0=33.2±1.0	1.19	11.2-17.7=13.5±1.1	7.0-8.0=7.5±.18	3.7-5.2=4.7±.27	11.7-13.7=12.7±.37	79.9	20.1
18.	*Ocimum* × *africanum* Lour.	64.7-74.5=67.3±1.8	54.7-58.0=56.2±.57	1.19	14.5-15.7=15.1±.23	4.7-5.7=5.2±.17	6.2-10.7=8.7±.97	5.2-6.2=5.7±.17	58.3	41.7
19.	*Ocimum americanum* L.	43.7-53.7=50.2±1.7	37.5-45.2=42.1±1.32	1.19	12.7-15.5=14.5±.54	6.25-8.25-7.25±.35	3.75-5.25=4.65±.257	15.7-17.5=16.35±.302	62.5	37.5
20.	*Ocimum basilicum* L.	52.0-55.2=43.4±.62	41.2-48.0=44.7±1.1	0.97	14.2-15.5=14.8±.23	7.2-8.5=7.9±.21	4.7-5.7=5.2±.17	19.5-20.7=20.1±.23	73.4	26.6
21	*Ocimum citriodorum* Vis.	64.7-73.7=68.9±1.6	56.2-93.7=71.6±6.2	0.96	21.2-26.2=23.0±.91	8.0-10.5=9.5±.46	3.7-6.2=5.3±.46	22.0-23.7=22.8±.34	64.4	35.6
22.	*Ocimum gratissimum* L.	34.7-37.0=36.0±.43	29.7-33.7=31.9±.72	1.12	10.7-12.0=11.3±.23	8.0-9.2=8.6±.23	4.7-6.2=5.5±.26	12.0-13.,7=12.8±.32	67.7	32.3

23.	*Ocimum sanctum* L.	43.0-57.7=50.6±2.4	43.0-57.7=52.6±2.5	0.96	12.0-13.7=12.7±.30	6.2-8.0=7.1±.32	4.7-5.5=5.1±.12	17.7-20.5=18.9±.49	69.9	30.1
24.	*Origanum majorana* L.	25.7-31.2=28.7±1.0	17.2-24.7=20.5±1.22	1.4	9.7-15.2=12.6±.88	4.7-7.2=5.9±.41	2.5-3.2=2.9±.12	13.2-15.2=14.2±.35	70.4	29.6
25.	*Origanum vulgare* L.	18.7-21.0=20.2±.38	13.2-15.7=14.3±.28	0.50	8.2-9.5=8.7±.20	3.5-4.5=3.9±.16	2.0-2.5=2.2±.11	7.2-8.7=7.8±.25	70.1	29.9
26.	*Perilla frutescens* (L.) Britton	37.0-38.7=37.7±.30	27.7-31.0=29.6±.66	1.27	12.0-13.2=12.6±.23	7.2-8.2=7.7±.17	5.0-6.0=5.5±.17	14.7-16.0=15.4±.21	85.4	14.6
27.	*Plectranthus madagascariensis* (Pers.) Benth.	32.2-37.5=34.7±1.0	27.2-30.2=28.7±.59	1.20	9.7-11.7=10.9±.38	6.2-9.0=8.2±.50	4.7-6.2=5.6±.26	16.2-17.7=17.1±.29	56.4	43.6
28.	*Prunella vulgaris* L.	34.7-37.5=36.4±.47	43.7-45.7=44.7±.33	0.81	12.0-13.7=12.8±.31	7.0-13.5=8.8±.19	4.7-5.7=5.2±.17	11.2-12.7=11.9±.31	83.2	16.8
29.	*Rosmarinus officinalis* L.	32.0-3.7=32.8±.31	28.7-38.7=34.0±1.9	0.96	9.7-12.7=11.1±.58	6.5-7.7=7.0±.21	3.5-5.0=4.1±.28	11.2-15.5=13.4±.78	76.8	23.2
30.	*Satureja hortensis* L.	22.0-23.7=22.7±.30	13.7-17.0=16.0±.58	1.41	11.2-13.0=12.2±.30	5.7-6.5=6.1±.12	3.2-4.0=3.6±.12	12.0-13.0=12.5±.18	78.8	21.2

31.	*Thymus linearis* Benth.	73.7-78.7=76.5±.85	63.7-73.7=67.4±1.8	1.13	86.2-31.2=28.9±.98	7.2-8.2=7.7±.17	4.7-5.7=5.2±.20	33.2-36.2=34.6±.53	75.5	24.5
32.	*Thymus vulgaris* L.	61.5-74.5=68.7±2.2	59.0-70.2=64.2±2.0	1.07	26.0-29.3=27.4±.61	8.0-9.2=8.6±.23	4.5-6.0=5.2±.28	31.2-35.0=33.1±.70	40.2	59.8

Keywords: Min= Minimum, Max= Maximum, SE= Standard Error, P= Polar Diameter, E= Equatorial Diameter, μm= Measurement in Micrometer

Table. 7: Qualitative pollen morphological findings of subfamily Nepetoideae.

S.no	Taxon	Pollen size	Pollen shape	Shape of pollen in polar view (Amb)	Shape of pollen in equatorial view	Pollen outline	Colpi apex	Symmetry	Polarity	Aperture type	Aperture orientation	Aperture sculpturing	Exine sculpturing
1.	*Anisochilus carnosus* (L.f.) Wall.	Medium	Prolate-spheroidal	Spherical	Sub Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate	Reticulate
2.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	Medium	Prolate	Sub Spherical	Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Baculate	Reticulate perforate
3.	*Clinopodium umbrosum* (M.Bieb.) Kuntze	Medium	Prolate-spheroidal	Spherical	Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Slightly raised	Granulate	Reticulate perforate
4.	*Clinopodium vulgare* L.	Medium	Oblate-spheroidal	Spherical	Widely elliptic	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate	Fine reticulate perforate
5.	*Coleus forskohlii* (Willd.) Briq.	Medium	Prolate-spheroidal	Slightly circular	Very wide obovate-oblong elliptic	Rough	Acute	Bilateral	Heteropolar	Hexacolpate	Sunken	Slightly gemmate	Verrucate

6.	*Dracocephalum nutans* L.	Medium	Sub oblate	Spherical	Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Verrucate	Reticulate perforate
7.	*Hyssopus officinalis* L.	Small-Medium	Sub prolate	Spherical	Spherical	Scabater	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Gemmate	Reticulate
8.	*Isodon rugosus* (Wall. ex Benth.) Codd	Small-Medium	Per prolate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate-gammate	Reticulate granulate
9.	*Lallemantia royleana* (Benth.) Benth.	Medium	Oblate-spheroidal	Sub spherical	Spherical	Scabater	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Gemmate	Reticulate perforate
10.	*Melissa officinalis* L.	Medium	Oblate-spheroidal	Sub spherical	Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate	Reticulate perforate
11.	*Mentha arvensis* L.	Small	Prolate-spheroidal	Spherical	Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Bulged	Granulate	Reticulate perforate-foveolate
12.	*Mentha longifolia* (L.) L.	Small	Sub prolate	Spherical	Ellipsoid	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate	Reticulate perforate

13.	*Mentha pulegium* L.	Small	Oblate-spheroidal	Sub spherical	Spheric al	Psilate	Acute	Radial	Isopolar	Hexazono colpate	Raised	Verrucate - granulate	Reticulat e perforate
14.	*Mentha spicata* L.	Small	Spheric al	Sub spherical	Spheric al	Psilate	Acute	Radial	Isopolar	Hexazono colpate	Raised	Slightly verrucate	Reticulat e perforate - foveolat e
15.	*Mentha suaveolens* Ehrh.	Mediu m	Prolate-spheroidal	Sub spherical	Ellipsoi d	Rough	Acute	_	Apolar	Hexacolp ate	Sunken	Not visible	Reticulat e perforate
16.	*Mentha* × *villosa* Huds.	Mediu m	Prolate-spheroidal	Spheri cal	Spheric al	Rough	Acute	Radial	Isopolar	Hexacolp ate	Sunken	Colliculat e	Foveolat e
17.	*Micromeria biflora* (Buch. -Ham. ex D.Don) Benth.	Mediu m	Sub prolate	Spheri cal	Spheric al	Scabra te	Acute	Radial	Isopolar	Hexazono colpate	Sunken	Verrucate	Reticulat e perforate
18.	*Ocimum* × *africanum* Lour.	Mediu m-Large	Sub prolate	Spheri cal	Spheric al	Sinuat e	Roun d	Radial	Isopolar	Hexazono colpate	Sunken	Gemmate - verrucate	Mega reticulat e granulat e
19.	*Ocimum americanum* L.	Mediu m	Sub prolate	Sub spherical	Sub spheric al	Irregul ar-wavy,	Slight ly round	Radial	Isopolar	Hexazono colpate	Raised	Scabrate	Mega bireticul

													ate perforate
20.	*Ocimum basilicum* L.	Medium	Oblate-spheroidal	Spherical	Very wide obovate	Irregular-wavy,	Acut-e round	Radial	Isopolar	Hexacolpate	Raised	Scabrate	Mega bireticulate perforate
21.	*Ocimum citriodorum* Vis.	Large	Oblate-spheroidal	Spherical	Very wide obovate	Irregular-wavy,	Round	Radial	Isopolar	Hexacolpate	Sunken	Scabrate-granulate	Mega reticulate perforate
22.	*Ocimum gratissimum* L.	Medium	Prolate-spheroidal	Spherical	Widely oval	Sinuate	Round	Radial	Isopolar	Hexacolpate	Sunken	Granulate	Mega reticulate scabrate
23.	*Ocimum sanctum* L.	Medium	Oblate-spheroidal	Spherical	Sub spherical	Scabrate	Broad round	Radial	Isopolar	Hexazonocolpate	Bulged	Granulate	Mega bireticulate perforate
24.	*Origanum majorana* L.	Small-Medium	Prolate-spheroidal	Spherical	Broadly elliptic	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Colliculate	Foveolate
25.	*Origanum vulgare* L.	Small	Oblate	Spherical	Spherical	Rough	Slightly acute	Radial	Isopolar	Hexazonocolpate	Sunken	Granulate	Reticulate perforate

26.	*Perilla frutescens* (L.) Britton	Medium	Sub prolate	Spherical	Sub Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Scabrate	Fine reticulate-verrucate
27.	*Plectranthus madagascariensis* (Pers.) Benth.	Medium	Sub prolate	Sub Spherical	Sub Spherical	Psilate	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Verrucate	Reticulate
28.	*Prunella vulgaris* L.	Medium	Sub oblate	Sub Spherical	Ellipsoid	Scabrate	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Granulate	Rugulate-reticulate
29.	*Rosmarinus officinalis* L.	Medium	Oblate-spheroidal	Spherical	Sub Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Verrucate	Scabrate
30.	*Satureja hortensis* L.	Small	Prolate	Sub Spherical	Ellipsoid	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Verrucate	Reticulate
31.	*Thymus linearis* Benth.	Large	Prolate spheroidal	Spherical	Widely elliptic	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Slightly granulate	Bieticulate perforate
32.	*Thymus vulgaris* L.	Large	Prolate spheroidal	_	Widely elliptic	Scabrate	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Psilate	Foveolate

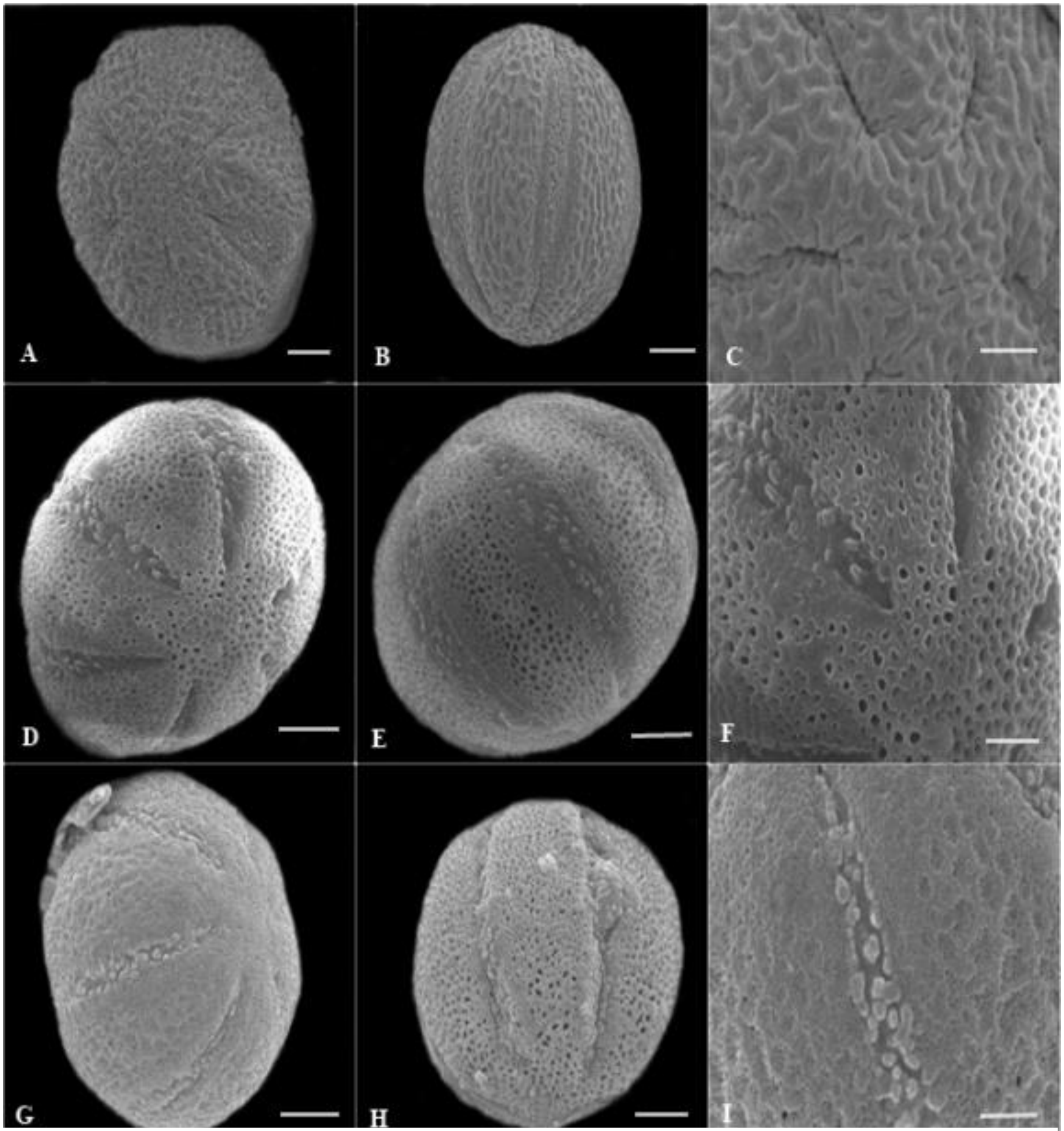

Plate. 45: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Anisochilus carnosus* (A-C), A) polar view, B) equatorial view, C) reticulate exine surface. *Clinopodium hydaspidis* (D-F). D) polar view showing sunken aperture, E) equatorial view, F) reticulate perforate exine surface. *Clinopodium umbrosum* (G-I). G) polar view aperture filled with granulate structures, H) equatorial view, I) fine reticulate exine surface. Scale bars: 10 µm for polar and equatorial micrographs except in H (5µm), scale bar 2µm for exine sculpturing.

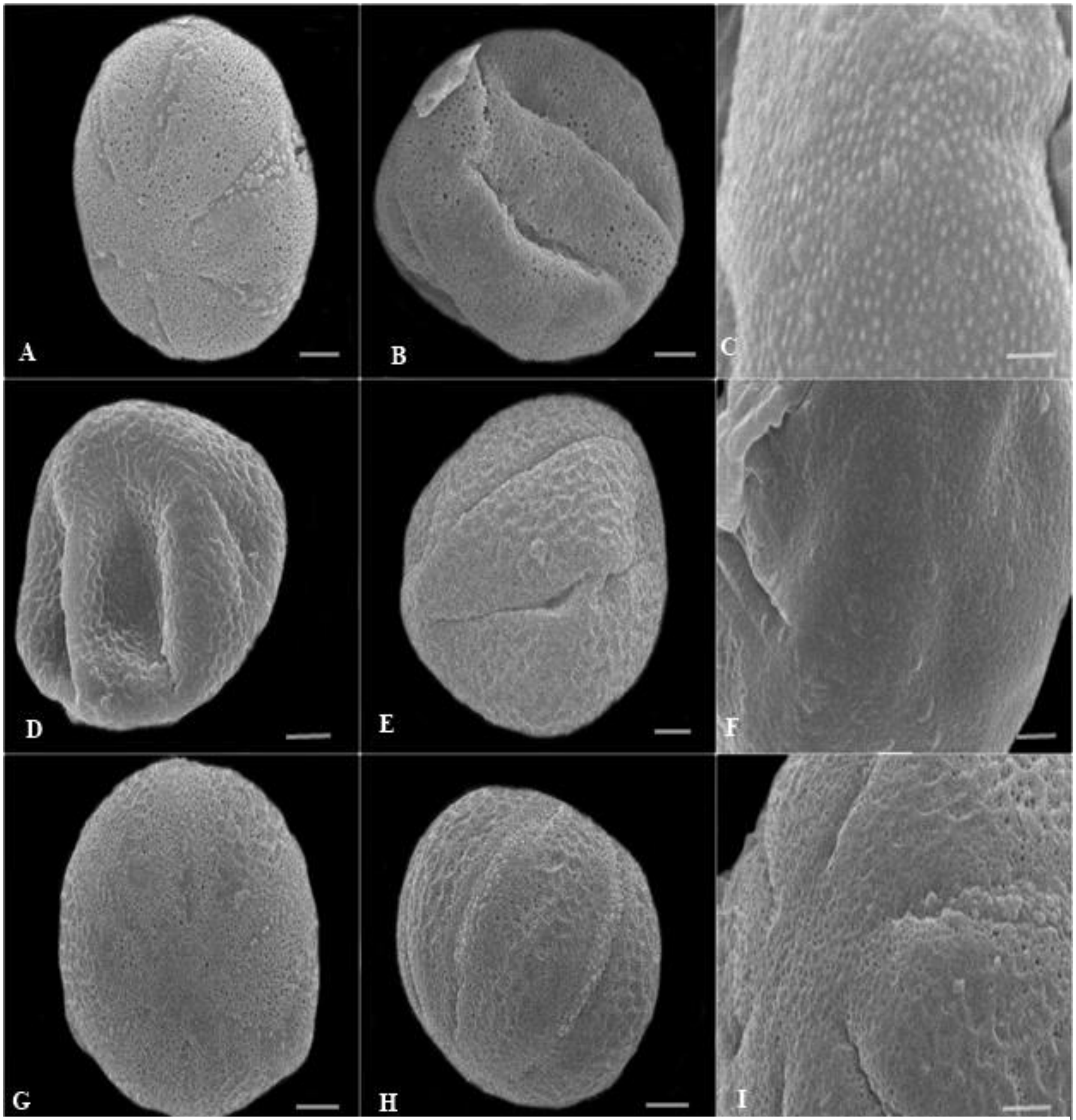

Plate. 46: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Clinopodium vulgare* (A-C), A) polar view, B) equatorial view, C) close view of the exine. *Coleus forskohlii* (D-F), D) polar view showing sunken aperture, E) equatorial view, F) close view of the exine surface. *Dracocephalum nutans* (G-I). G) polar view, H) equatorial view, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing except in C (1 µm).

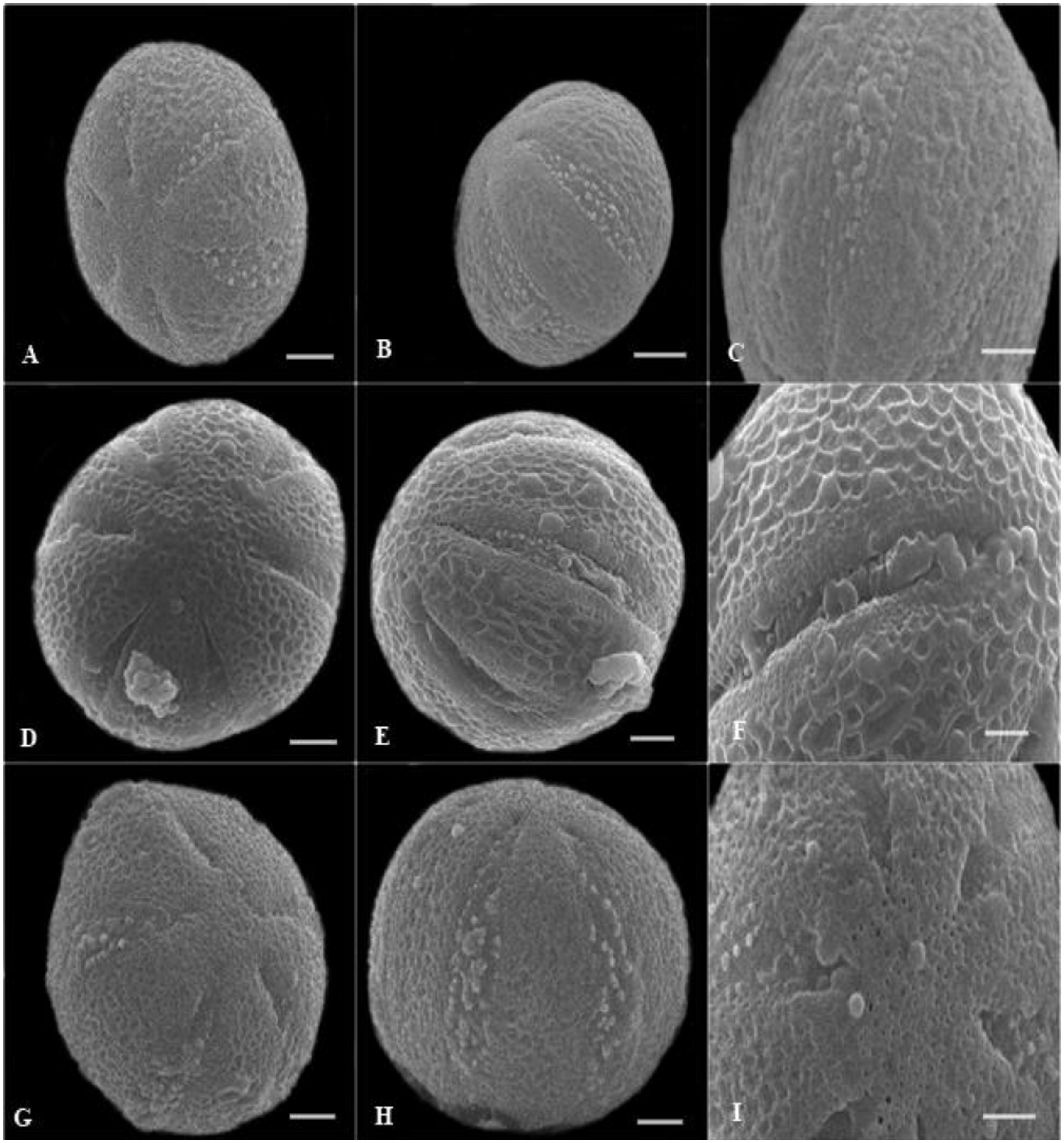

Plate. 47: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Hyssopus officinalis* (A-C), A) polar view, B) equatorial view showing gemmate aperture surface, C) close view of exine surface. *Isodon rugosus* (D-F). D) polar view, E) equatorial view, F) reticulate perforate exine surface. *Lallemantia royleana* (G-I). G) polar view, H) equatorial view showing aperture filled with verrucate structures, I) reticulate perforate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

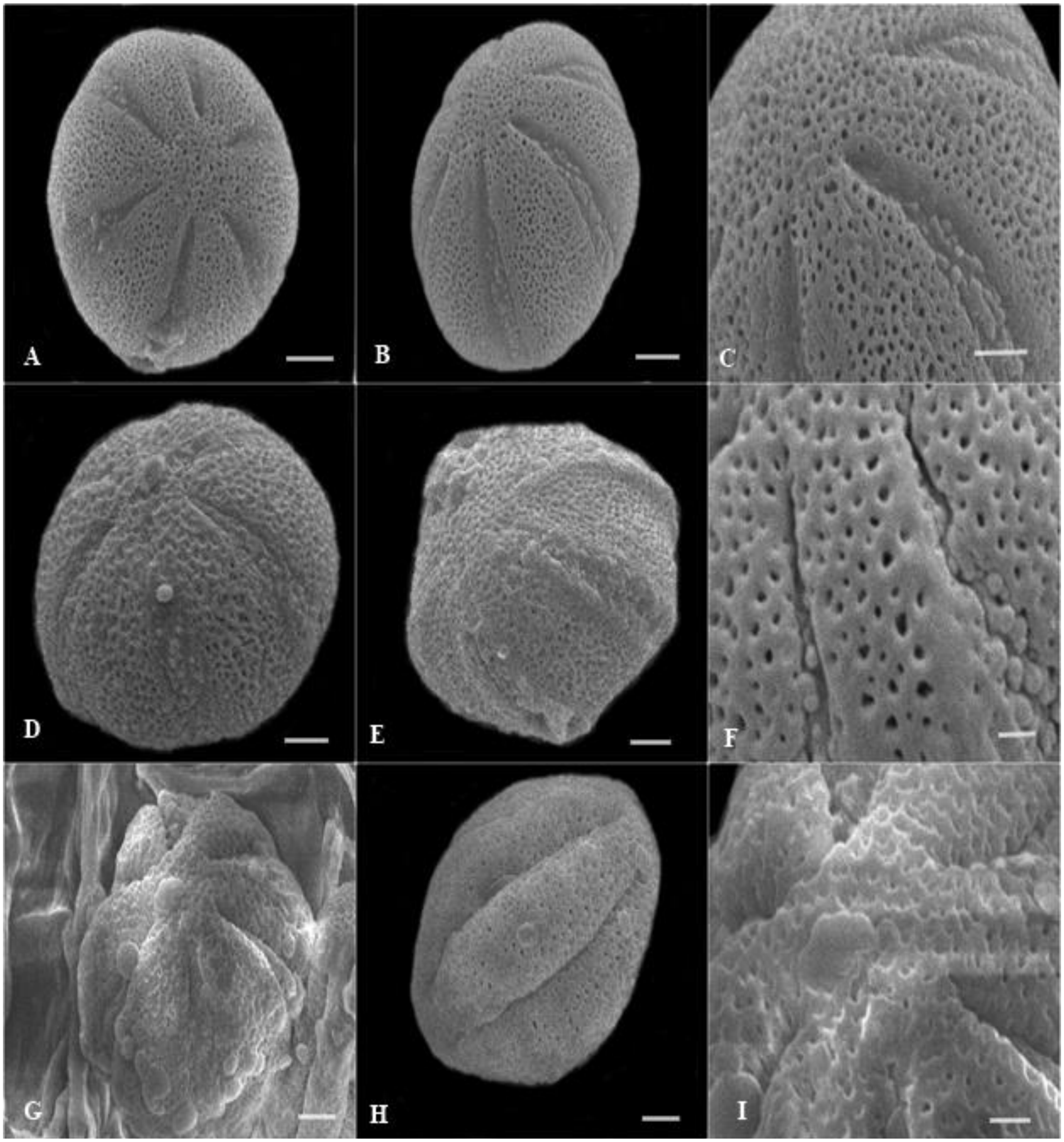

Plate. 48: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Melissa officinalis* (A-C), A) polar view, B) equatorial view showing psilate outline, C) reticulate perforate exine surface. *Mentha arvensis* (D-F). D) polar view, E) equatorial view with raised colpi, F) Reticulate perforate- foveolate exine surface. *Mentha longifolia* (G-I). G) polar view, H) equatorial view, I) close view of exine surface. Scale bars: 5μm for polar and equatorial micrographs, scale bar 2μm for exine sculpturing except in F and I (1 μm).

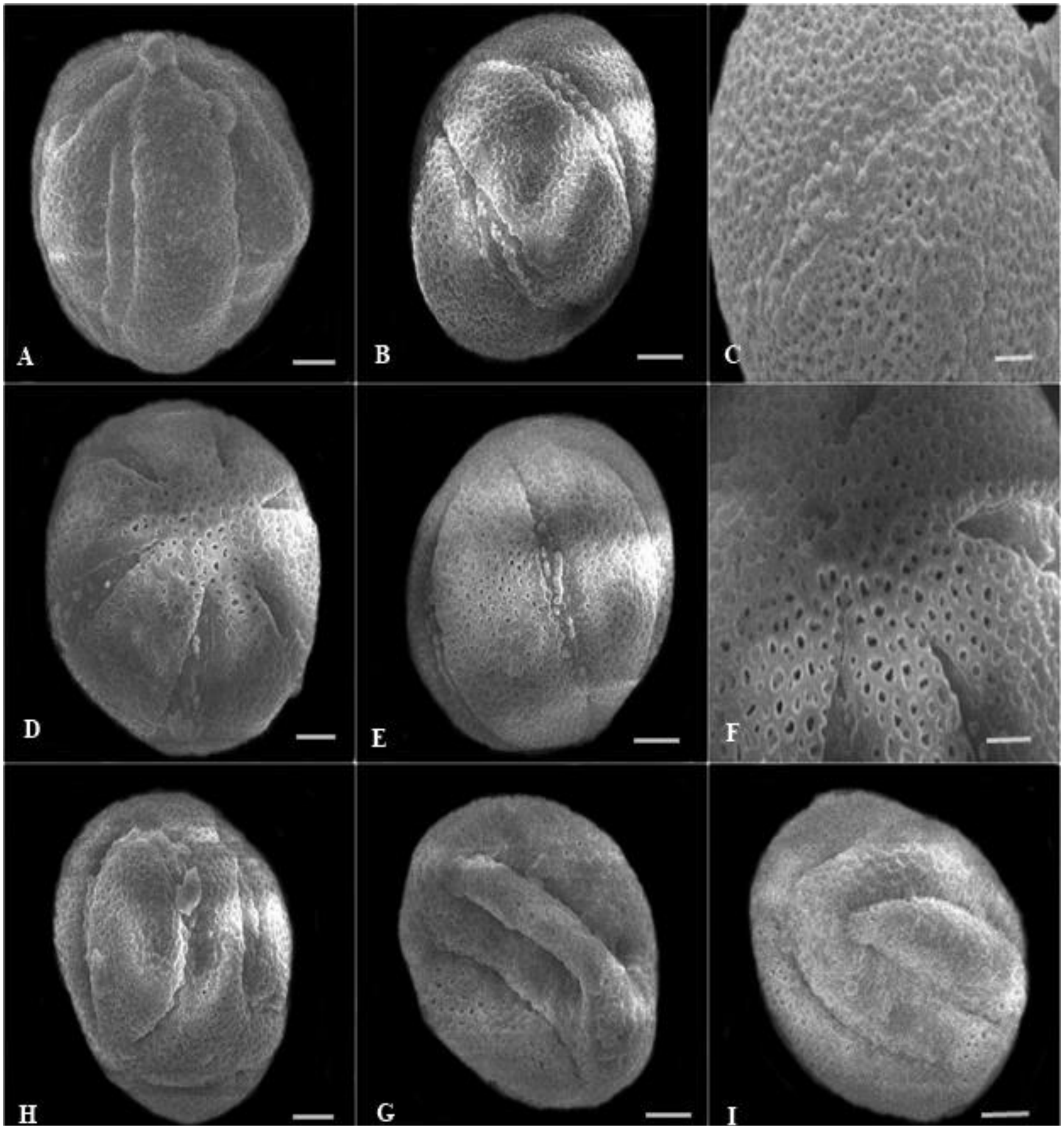

Plate. 49: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Mentha pulegium* (A-C), A) polar view, B) spherical equatorial view, C) coarsely reticulate perforate. *Mentha spicata* (D-F). D) polar view, E) equatorial view, F) reticulate perforate- foveolate exine surface. *Mentha suaveolens* (G-I). G) polar view, H) Oblige equatorial view, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing except in 1 (5 µm).

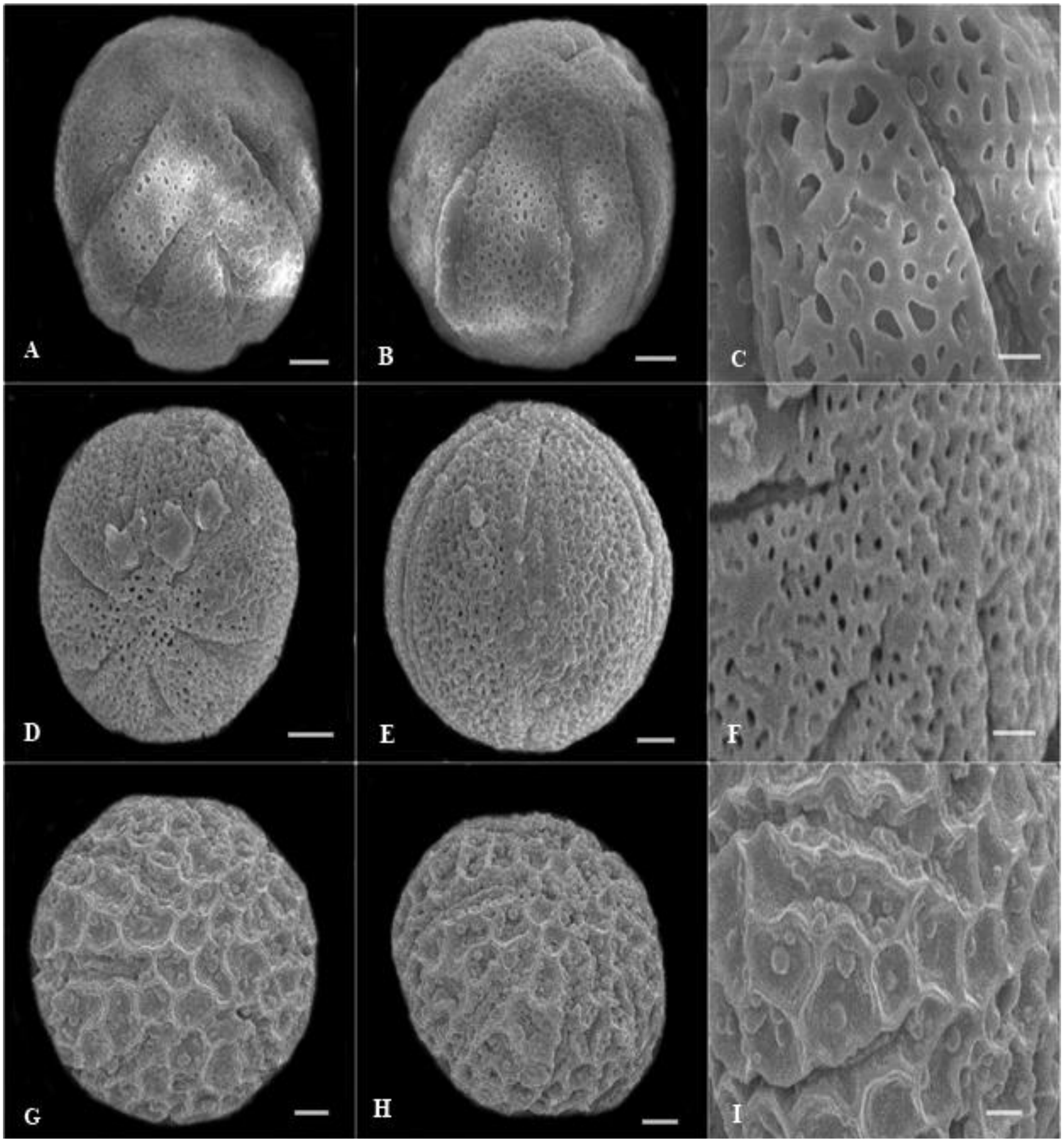

Plate. 50: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Mentha* × *villosa* (A-C), A) polar view, B) equatorial view, C) Foveolate exine surface. *Micromeria biflora* (D-F). D) polar view, E) equatorial view, F) reticulate perforate exine surface. *Ocimum* × *africanum* (G-I). G) polar view reticula filled with filled with gemmate structures, H) equatorial view, I) coarsely reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs except in G and H (10 µm), scale bar 2µm for exine sculpturing except in F and I (1 µm).

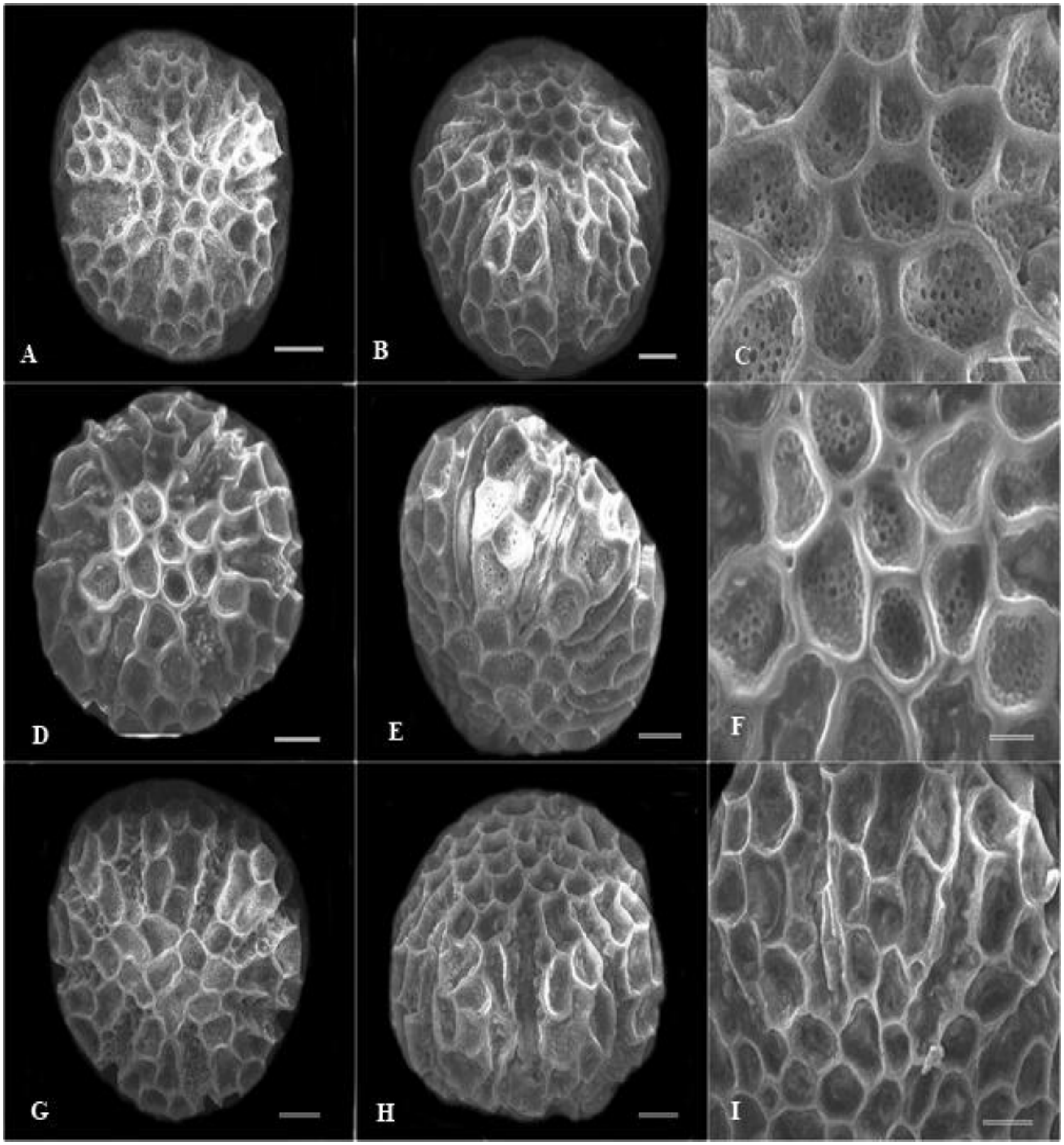

Plate. 51: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Ocimum americanum* (A-C), A) polar view, B) equatorial view, C) mega bireticulate perforate exine surface. *Ocimum basilicum* (D-F). D) polar view, E) equatorial view irregular-wavy, (F) mega bireticulate perforate exine surface. *Ocimum citriodorum* (G-I). G) polar view, H) equatorial view, I) mega reticulate exine surface. Scale bars: 10 µm for polar and equatorial micrographs, scale bar 5 µm for

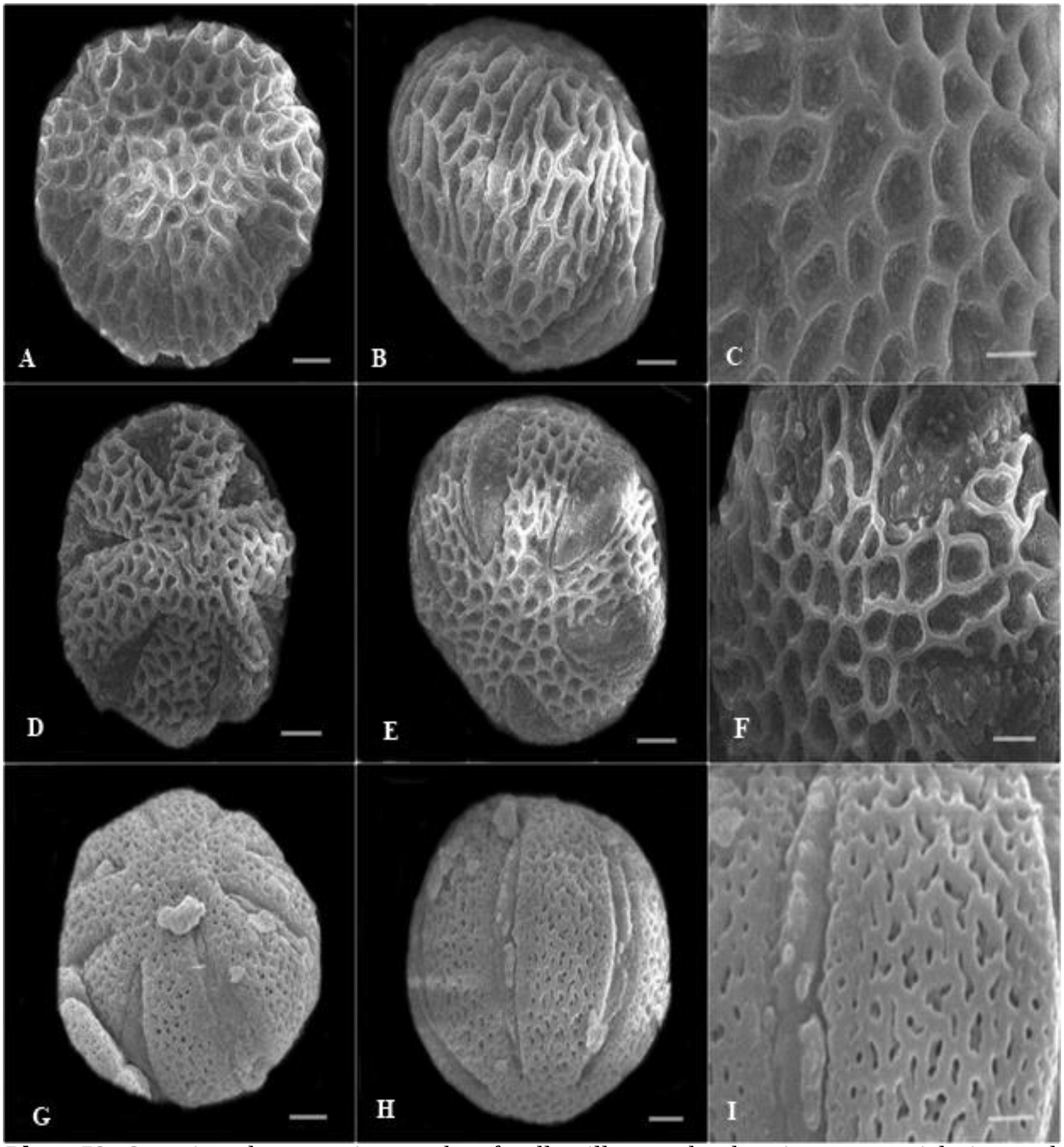

Plate. 52: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Ocimum gratissimum* (A-C), A) widely oval polar view, B) equatorial view, C) close view of the exine. *Ocimum sanctum* (D-F). D) polar view, E) equatorial view showing bulged aperture, F) mega reticulate exine surface. *Origanum majorana* (G-I). G) polar view, (H) equatorial view aperture filled with colliculate structures, I) foveolate exine surface. Scale bars: 10µm for polar and equatorial micrographs except in D (5µm), scale bar 2µm for exine sculpturing except in F (5 µm)

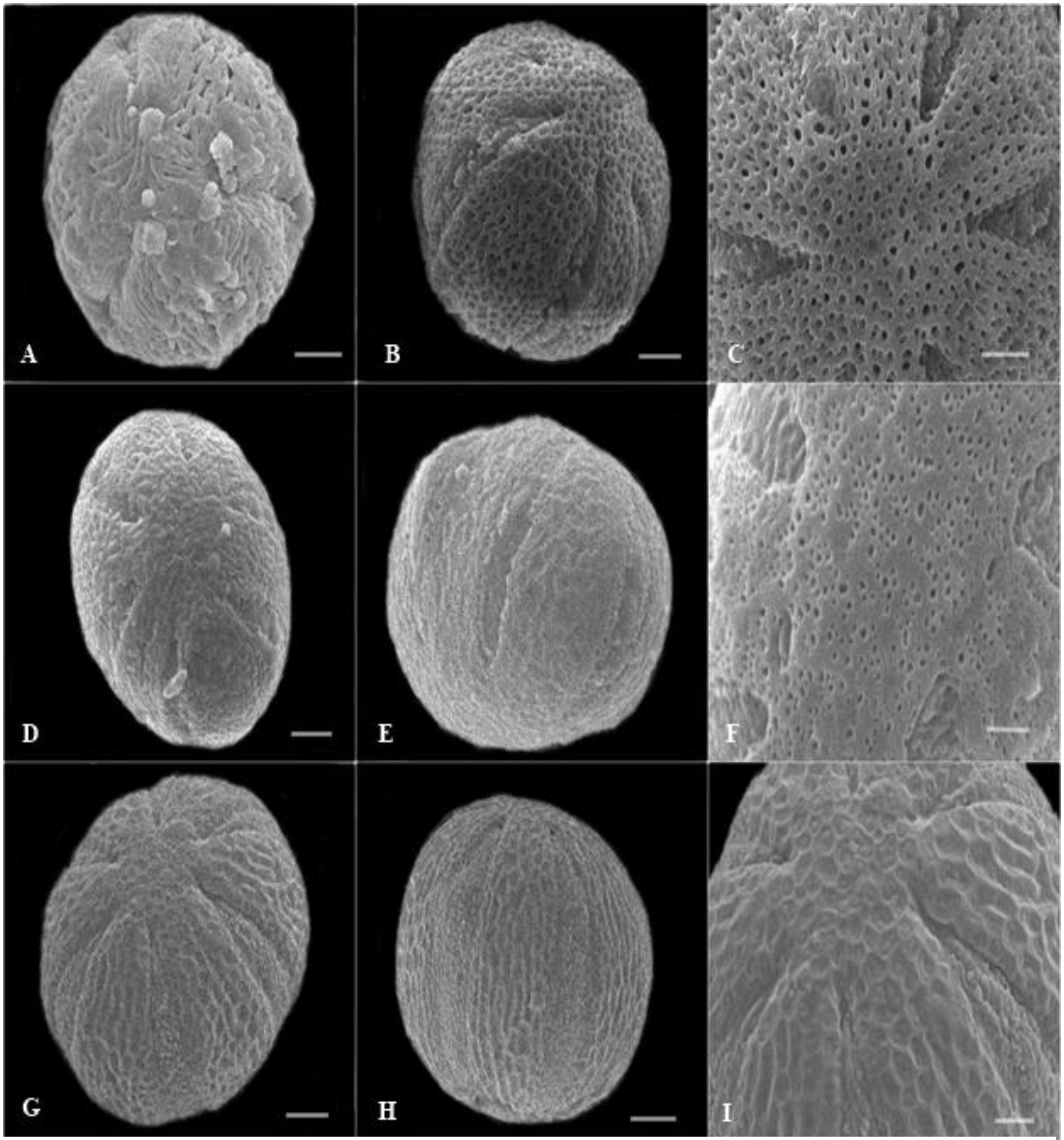

Plate. 53: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Origanum vulgare* (A-C), A) polar view rough outline, B) equatorial view, C) reticulate perforate exine surface. *Perilla frutescens* (D-F). D) polar view, E) equatorial view, F) reticulate perforate exine surface. *Plectranthus madagascariensis* (G-I). G) polar view with regular reticula, H) equatorial view, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs except in G and H (10 µm), scale bar 2µm for exine sculpturing except in F (5 µm).

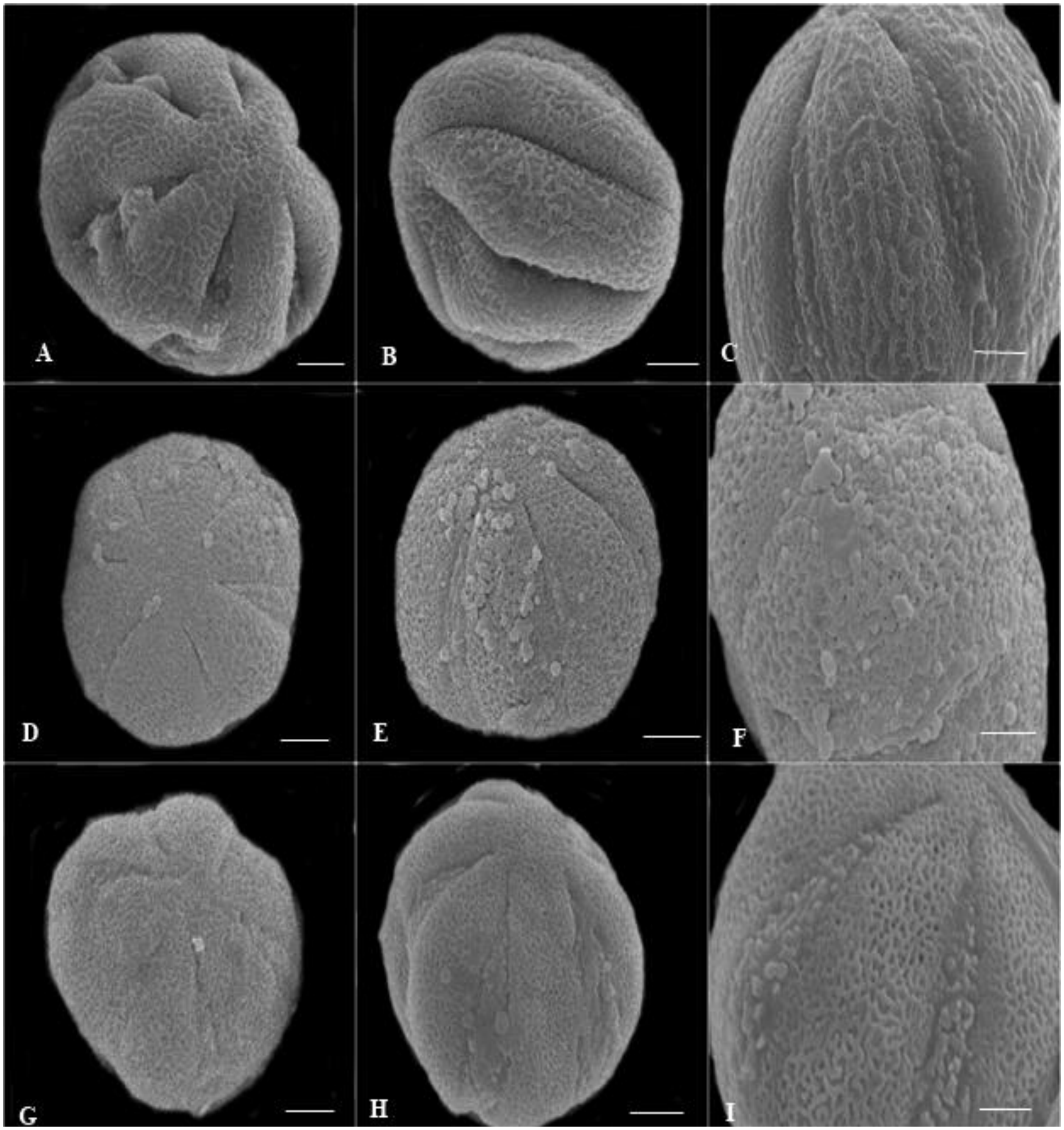

Plate. 54: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Prunella vulgaris* (A-C), A) polar view, B) ellipsoid equatorial view, C) close view of the exine with rugulate reticula. *Rosmarinus officinalis* (D-F). D) polar view with outline, E) equatorial view, F) Scabrate exine surface. *Satureja hortensis* (G-I). G) polar view, H) equatorial view with acute colpi apex, I) reticulate exine surface. Scale bars: 5µm for polar and equatorial micrographs except in A (10 µm), scale bar 2µm for exine sculpturing.

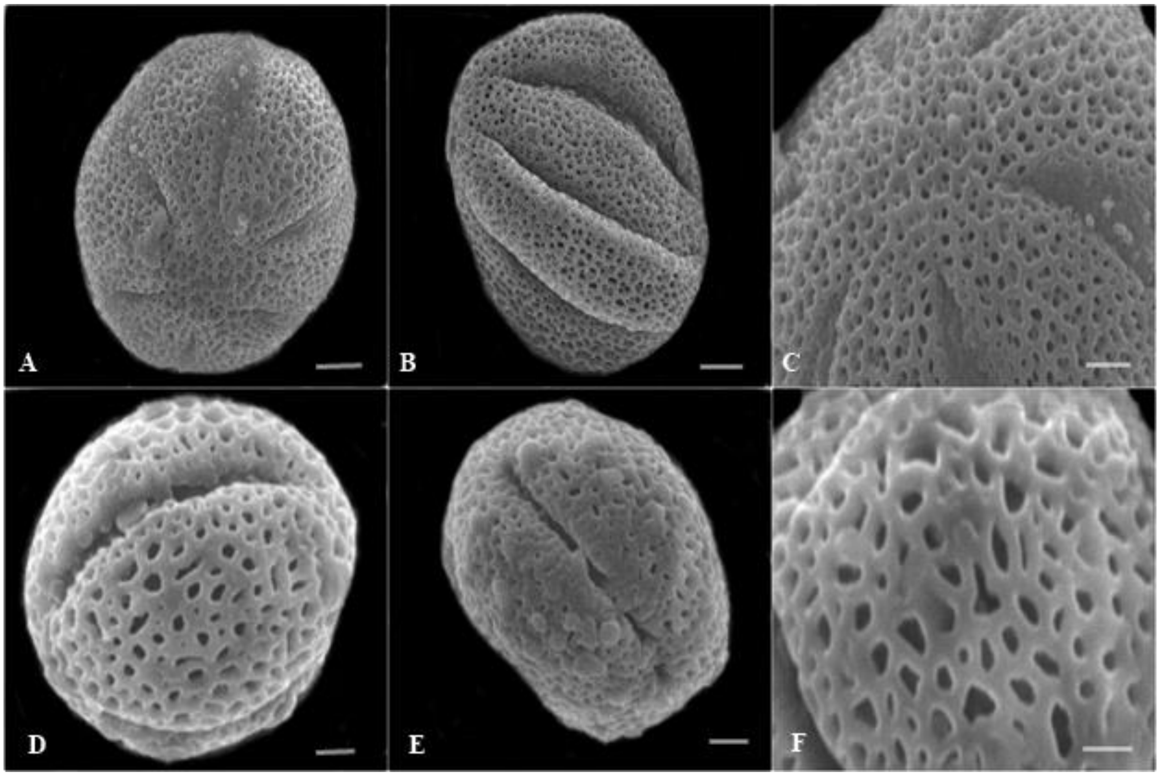

Plate. 55: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Nepetoideae taxa. *Thymus linearis* (A-C), A) polar view, B) equatorial view, C) reticulate perforate exine surface. *Thymus vulgaris* (D-F). D) polar view with sunken aperture, E) equatorial view, F) foveolate exine surface. Scale bars: 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

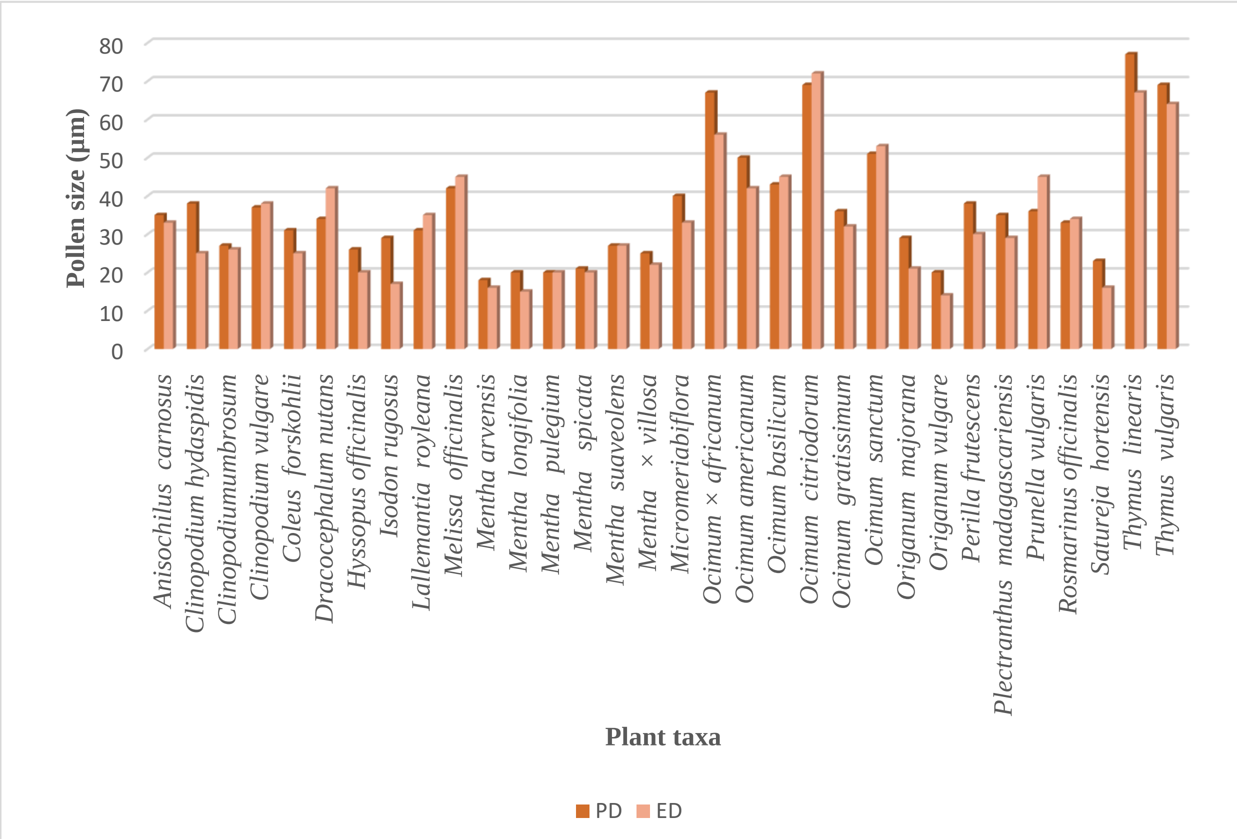

Figure. 14: Variation among polar and equatorial diameter in Nepetoideae taxa

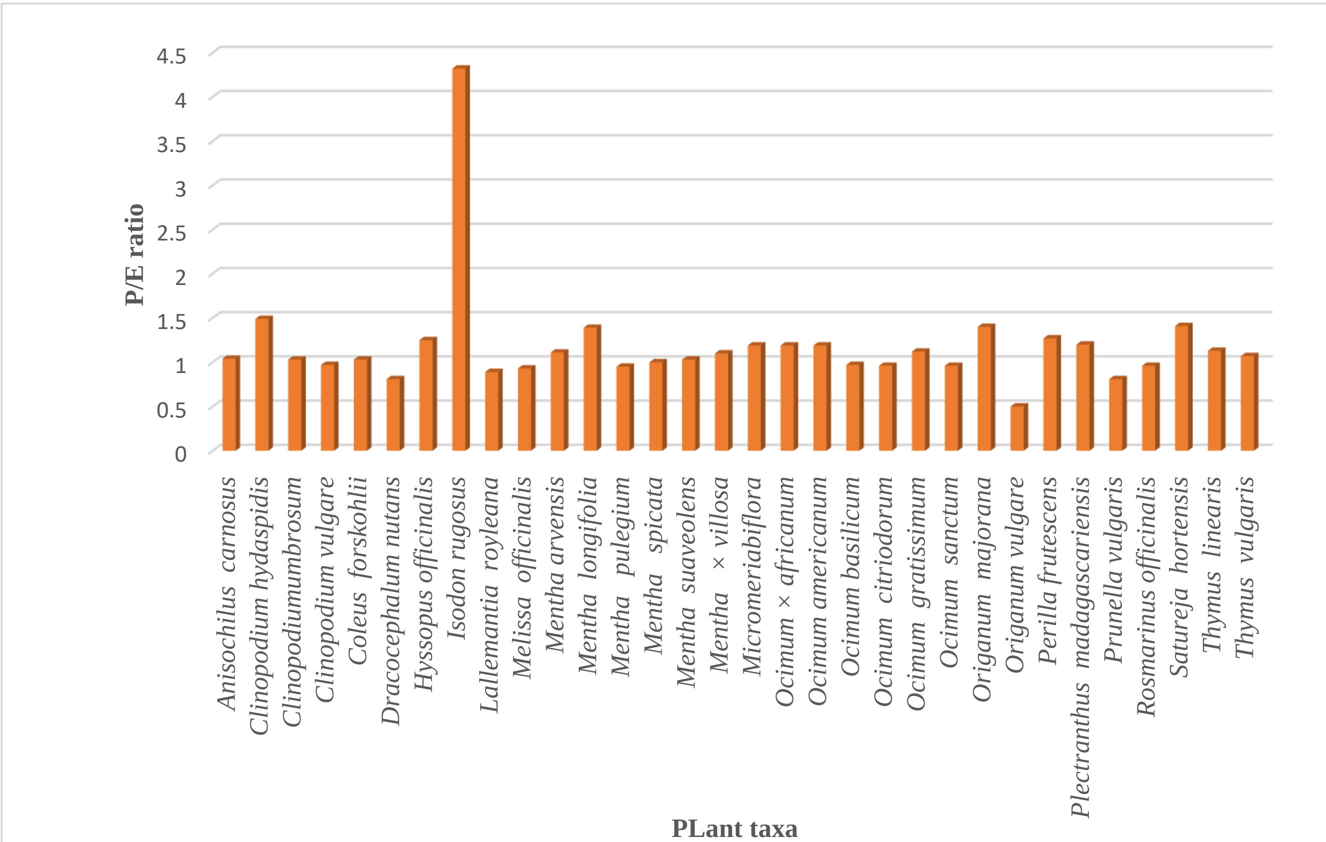

Figure. 15: Showing variation among polar to equatorial diameter ratio (P/E ratio) in subfamily Nepetoideae

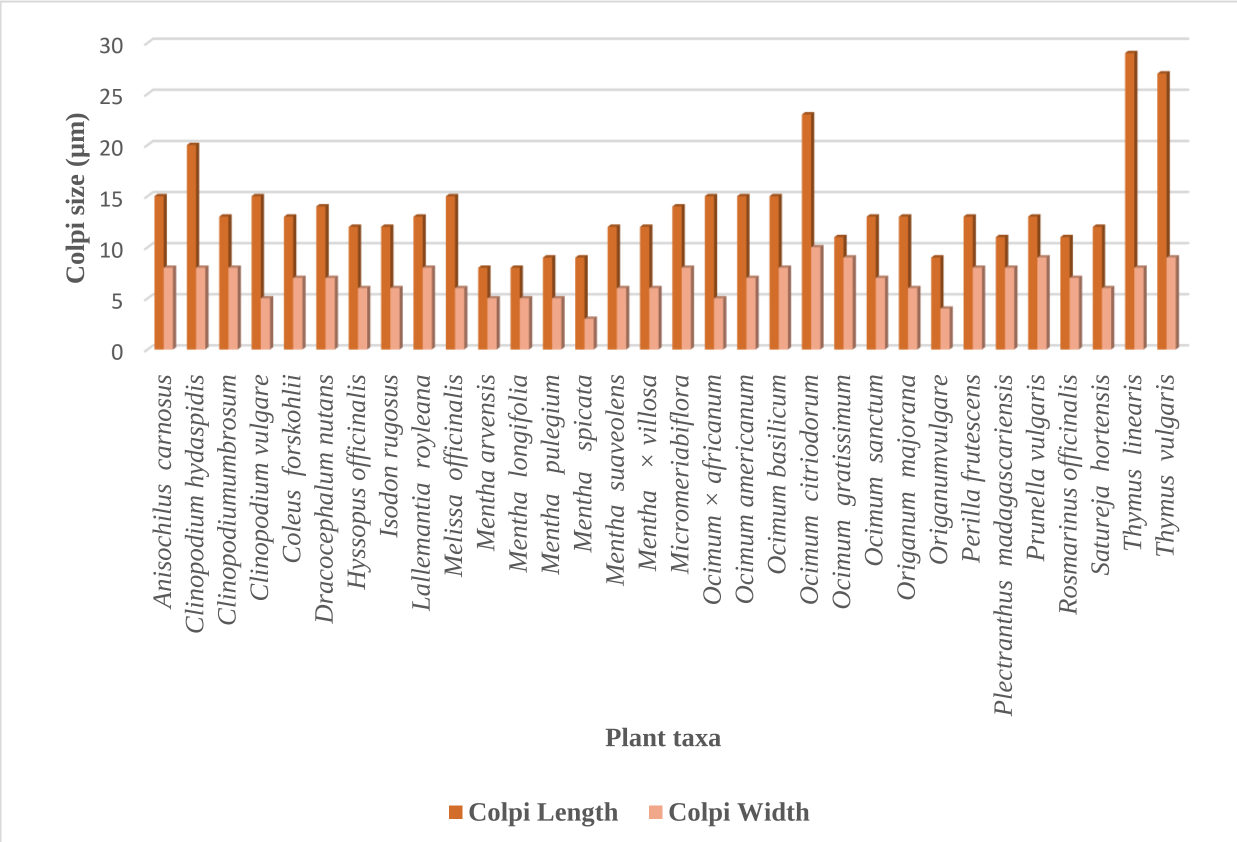

Figure. 16: Variation among colpi length and width in subfamily Nepetoideae

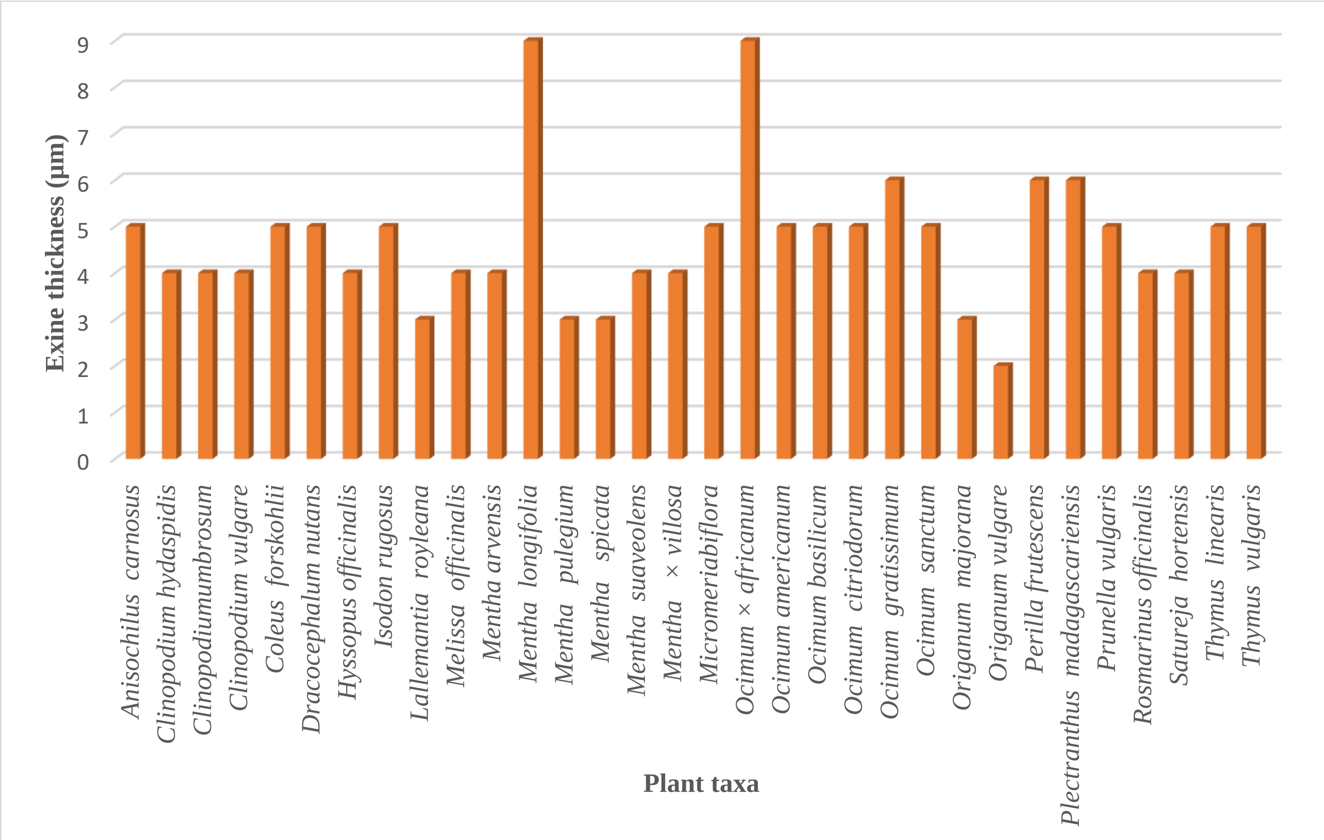

Figure. 17: Showing variation of exine thickness among the subfamily Nepetoideae species

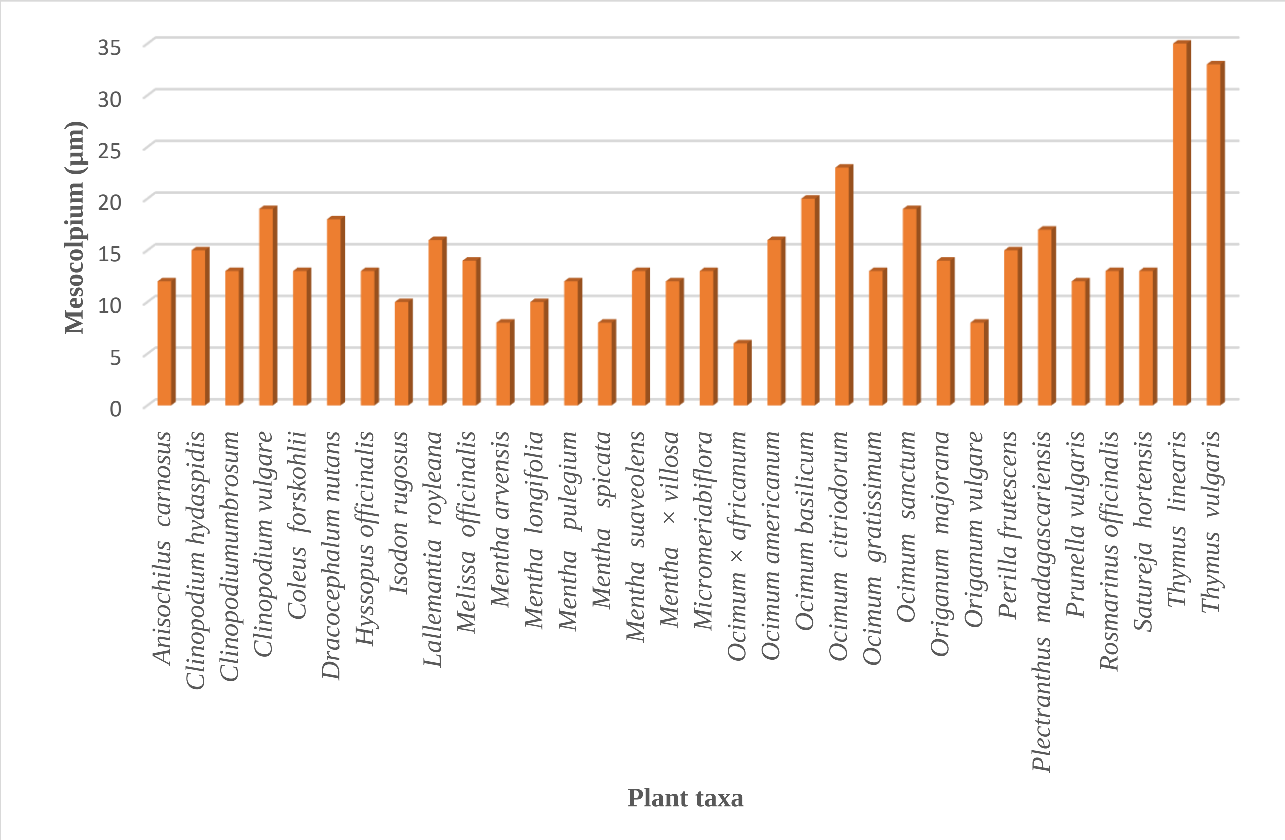

Figure. 18: Showing variation of mesocolpium among the selected subfamily Nepetoideae taxa

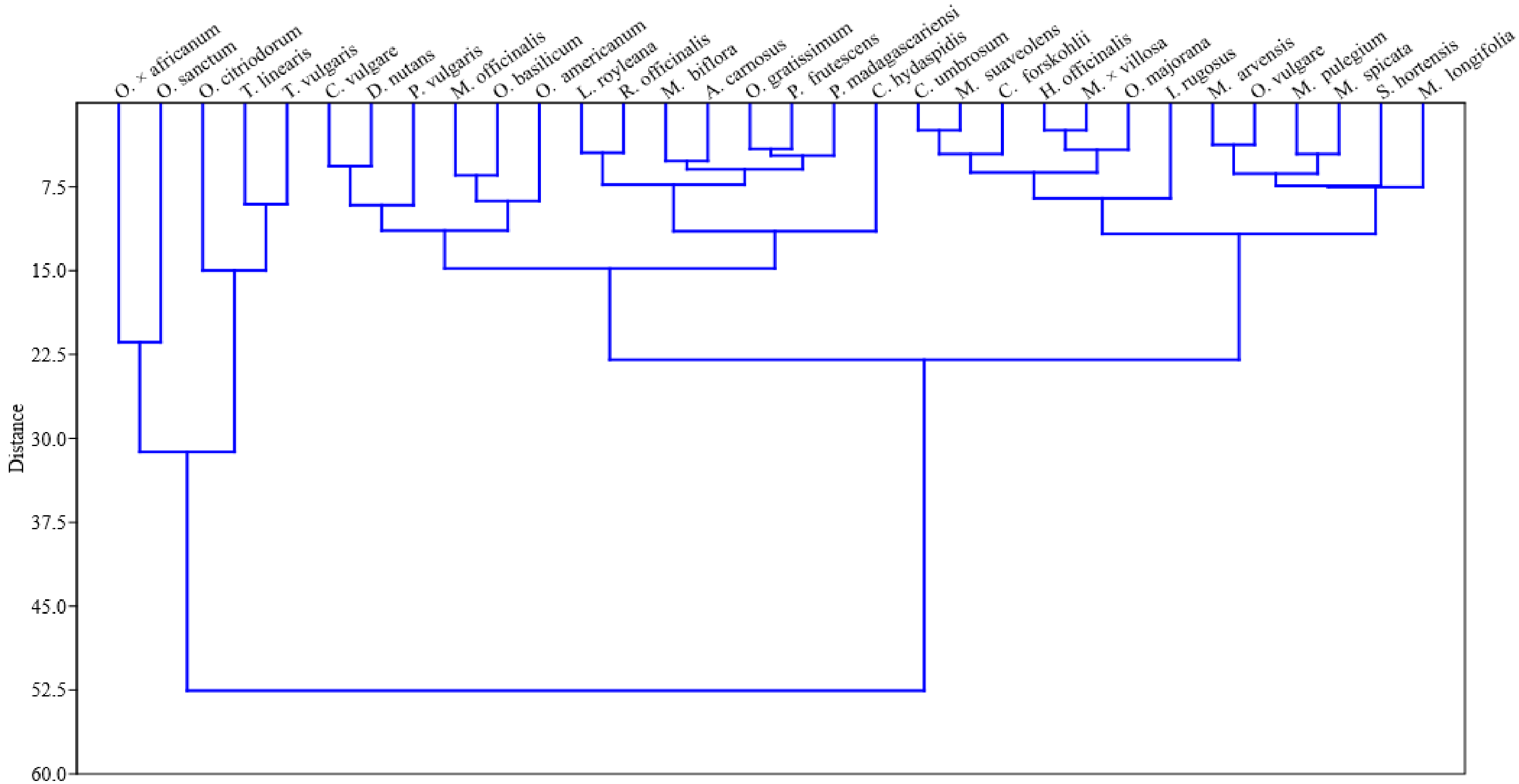

Figure. 19: UPGMA dendogram of 32 species of subfamily Nepetoideae based on quantitative pollen characters

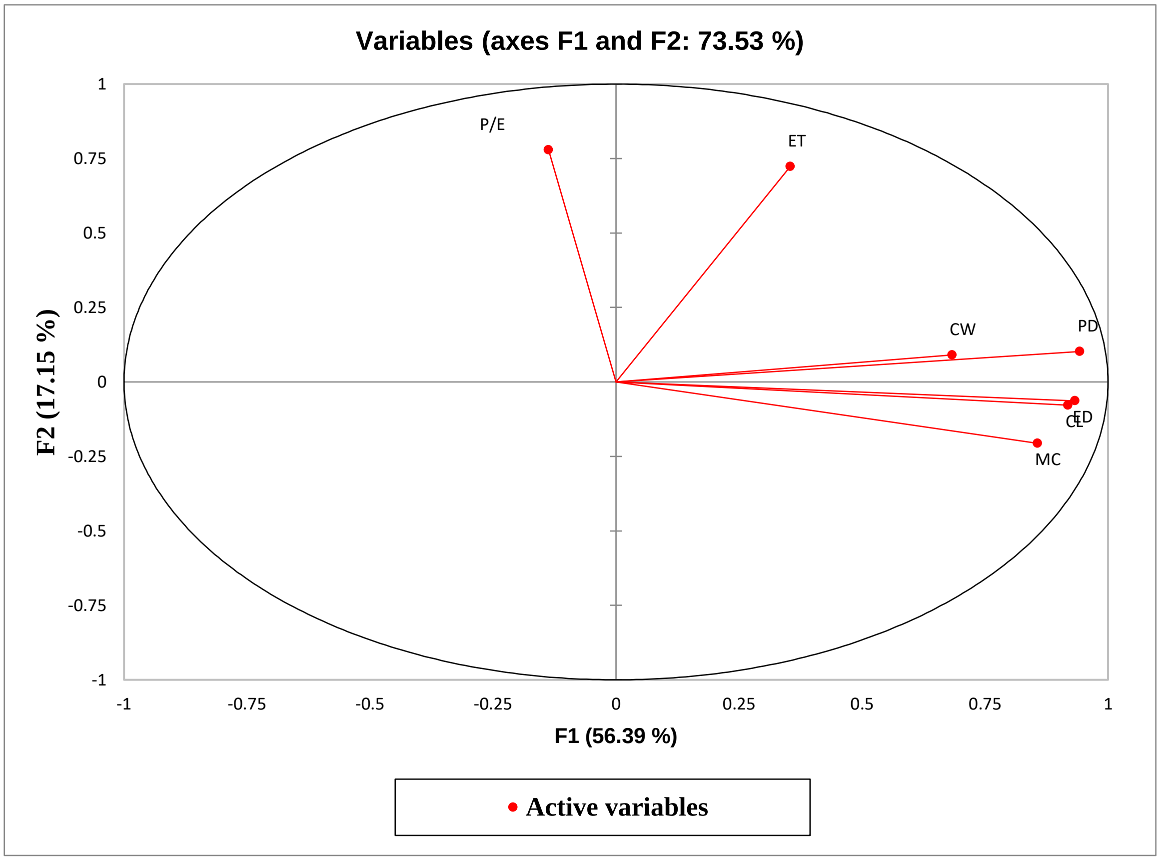

Figure. 20: Active variables of pollen of the principal component analysis biplot

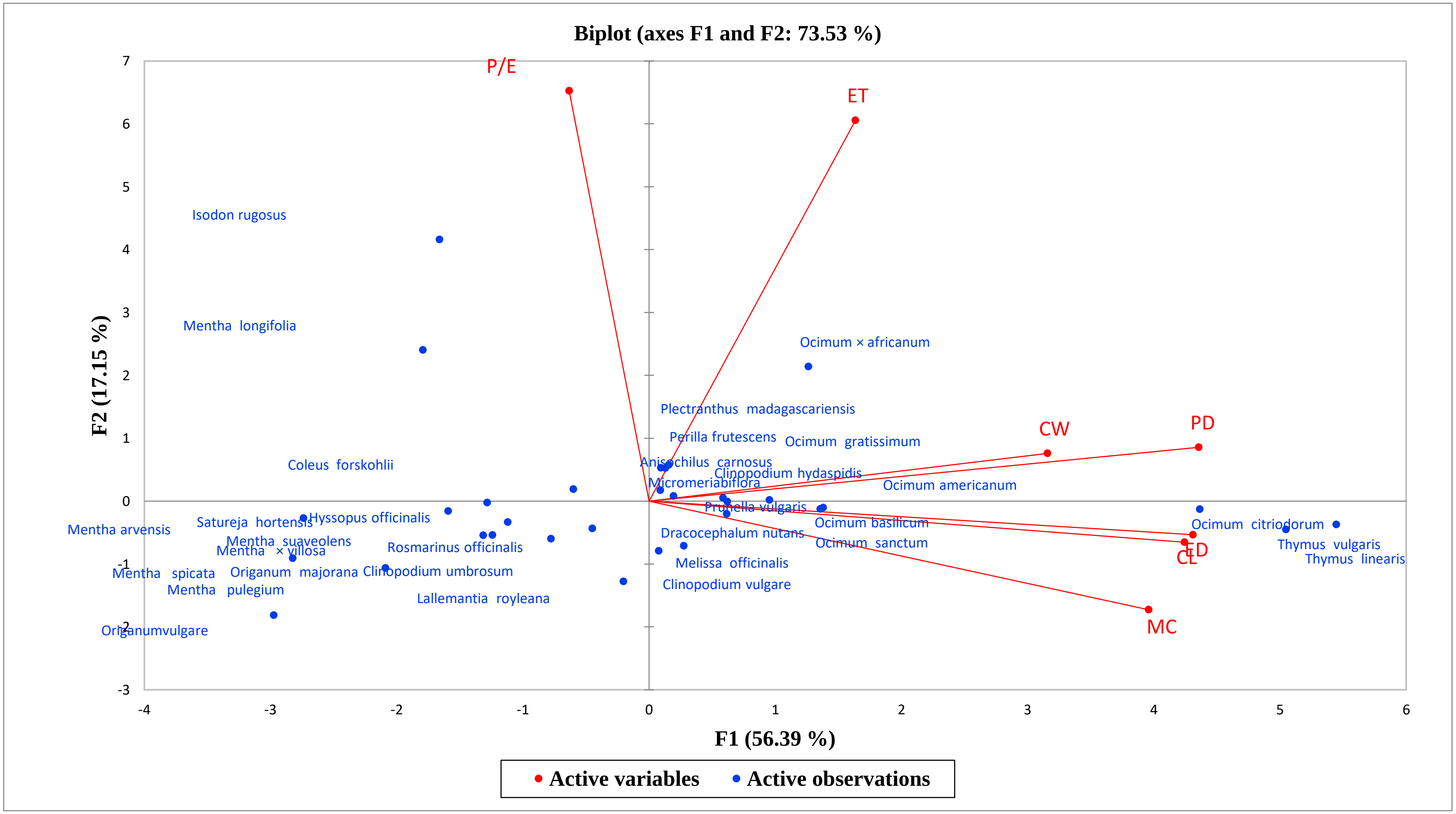

Figure. 21: Principal component analysis (PCA) based on the seven pollen traits that is PD: Polar area diameter, ED: Equatorial diameter, P/E: Polar to equatorial ratio. CL: colpus length, CW: colpus width, ET: Exine thickness, MC: Mesocolpium of Nepetoideae taxa

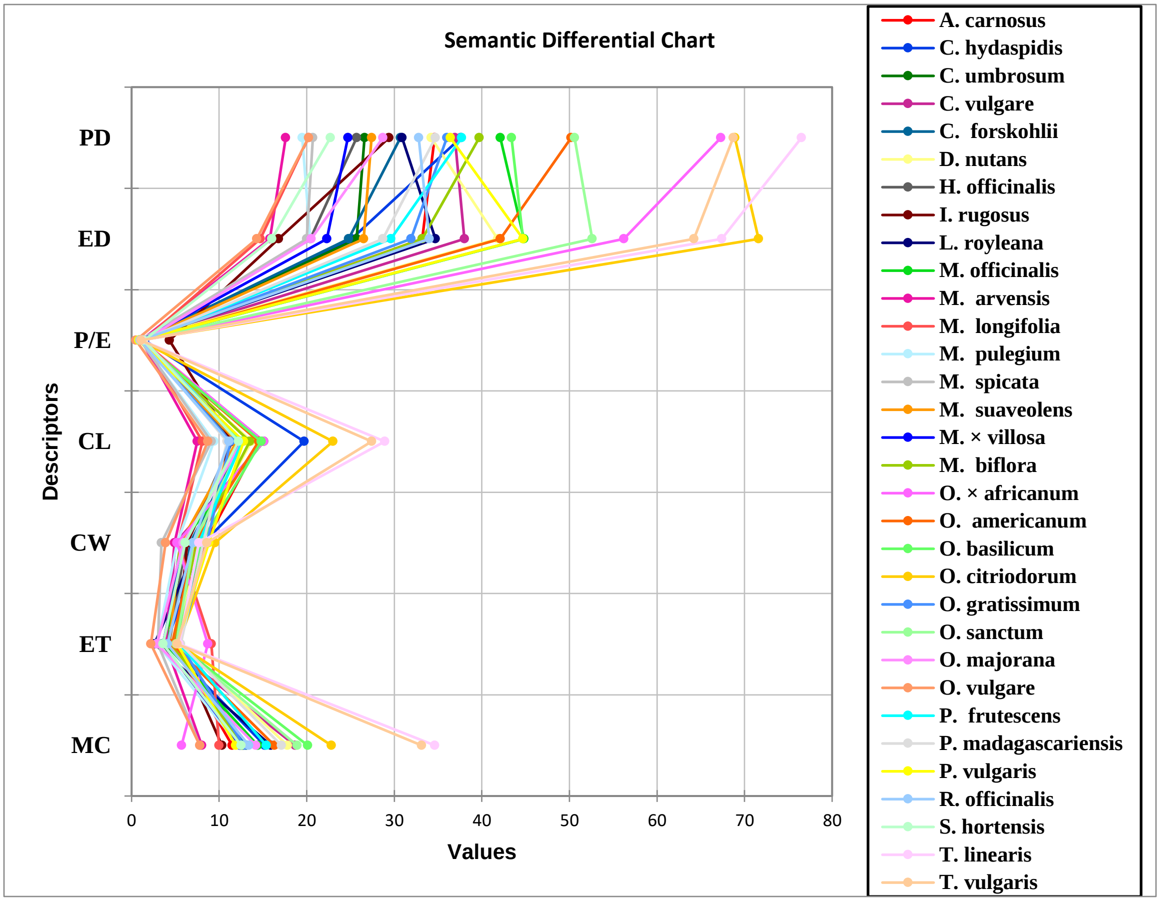

Figure. 22: Semantic Differential Chart of seven pollen variables i.e., polar diameter, equatorial dimeter, polar to equatorial diameter, colpi length, colpi width, exine thickness and mesocolpium of Nepetoideae species

3.4 Pollen Micromorphological Structure of Genus *Nepeta*

A total of 18 species of Nepeta genus were studied with the help of light microscopy (LM) and scanning electron microscope (SEM). Scanning electron micrographs were presented on plates 56-61. Micromorphological variations were observed within pollens of genus *Nepeta* for example, size and shape of pollens, pollen outline, colpi apex, Symmetry, polarity, aperture orientation, lumina shape, lumina number per reticula, aperture sculpturing, exine sculpturing. Pollen quantitative measurements and qualitative characteristics were illustrated in table 9 and 10.

The pollens are mostly 6-colpate or 6-zonocolpate, pollen grains shed as monad, and are frequently isopolar. The pollen size ranges from small to large. The largest polar diameter was found in *Nepeta distans* (83.7-88.0=86.5±.75 µm), and smallest in *N. praetervisa* (19.5-21.2=20.3±.34 µm). The largest equatorial diameter was found in *N. distans* (55.7-76.2=66.0±3.6 µm), and smallest in *N. griffithii* (13.0-18.7=15.3±1.2 µm) presented in Figure 23. Six types of pollen shapes were observed in the present research i.e., oblate-spheroidal, sub oblate, prolate, spherical, per prolate and sub prolate. The highest P/E ratio was found in *N. linearis* (2.05%), and lowest in *N. elliptica* (0.72%), presented in Figure 24. Pollen shapes in polar and equatorial view are spherical and subspherical except in *N. govaniana* in which polar view is sub spherical and equatorial view is irregular (Plate. 58 A and B), in *N. laevigata* the polar view is broad shape and equatorial view is rhomboid (Plate. 59 D and E), and in *Nepeta linearis the* polar view is hexagonal and equatorial view is ellipsoid (Plate. 60 A and B).

In the current research the aperture sculpturing is mostly granulated in 13 species followed by verrucate 5 species. Length of colpi ranges fom (32.5-36.2=34.1±.700 µm), highest in *N. distans* to smallest (8.7-9.7=9.2±.17 µm), in *N. nervosa* and *Nepeta praetervisa*. Width of colpi ranges from (8.0-13.7=10.7±1.1 µm,) highest in *N. distans* to smallest (4.5-5.5=5.0±.176 µm), in *N. graciliflora* presented in Figure 25. Mesocolpium area ranges (31.2-34.2=32.8±.53 µm), maximum in *N. distans* and minimum (8.0-9.0=8.5±.17 µm), in *N. praetervisa* presented in Figure 27. From SEM observations three types of exine sculpturing were observed i.e., reticulate perforate, bireticulate perforate and only reticulate in two species. Thickness of exine varies from

(6.2-8.0=7.1±.32 µm), maximum in *N. distans* to (2.2-3.0=2.7±.13 µm), minimum in *Nepeta raphanorhiza* (Table 9) presented in Figure 26.

3.4.1 *Nepeta cataria*

Pollen is found as monad and are mostly hexacolpate, isopolar. Pollen size is medium, pollen shape oblate spheroidal. The shape of pollen in polar and equatorial view is sub-spherical and spherical respectively. The pollen outline is rough, pollen apex acute. Aperture ornamentation and aperture sculpturing is concave and verrucate respectively. Lumina shape is elongated, number of secondary lumina per primary lumen is not clear and exine sculpturing is reticulate perforate not coincide with the results of Celenk et al., (2008). Lumina shape and exine sculpturing of the present study shows inconsistent with the observation of Talebi et al., (2020). According to Perveen and Qaiser (2004) the exine sculpturing is coarsely reticulate and the pollen shape of *N. cataria is* prolate-spheroidal which is different from our results (Plate. 56 C), but our results shows similarity in pollen shape and exine sculpturing with the findings of Moon et al., (2008).

3.4.2 *Nepeta connata*

Type of pollen hexazonocolpate and are isopolar. Pollen size is medium, pollen shape sub oblate. The shape of pollen in polar and equatorial view is spherical. Pollen outline is scabrate, pollen apex acute (Plate. 56 D-F). Aperture ornamentation and aperture sculpturing is concave and granulate respectively. Lumina shape and number of secondary lumina per primary lumen is not clear and exine sculpturing is bireticulate perforate found inconsistent with the results of Perveen and Qaiser (2004).

3.4.3 *Nepeta discolor*

Pollen size is small- medium, pollen shape prolate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is slightly rough, pollen apex round (Plate. 56 G-I). Pollen is radially symmetrical and isopolar. Type of aperture and ornamentation is hexazonocolpate and slightly convex. Lumina shape is elongated were found similar with the findings of Azizian et al., (2001). The number of secondary lumina per primary lumen is 10-20. Aperture sculpturing is granulated and exine sculpturing is bireticulate perforate. Previous studies of Moon et al., (2008) observed pollen shape, exine sculpturing, and lumine number of *N. eremophila* and *N. pungens* similar with our examined *Nepeta discolor* but disagreed with the shape of lumine.

3.4.4 *Nepeta distans*

Pollen size is large, pollen shape prolate. According to Moon et al., (2008) the pollen shape of *N. longibracteata* and *N. sibirica* similar with our observed *Nepeta distans* but dissimilar in size. The shape of pollen in polar and equatorial view is sub-spherical and spherical respectively. The pollen outline is rough, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and concave. Lumina shape is circular-oval and number of secondary lumina per primary lumen is 10-13 (Plate. 57 A-C). Aperture sculpturing is gammate and exine sculpturing is reticulate perforate were found inconsistent with the results of Perveen and Qaiser (2004) in pollen shape and exine sculpturing. Yet they neglected the remaining characteristics for intense, lumin shape, aperture sculpturing.

3.4.5 *Nepeta elliptica*

Pollen is found as monad. Pollen size is medium, pollen shape suboblate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and convex. Lumina shape is Irregular and number of secondary lumina per primary lumen is 10-14 (Plate. 57 E-F). Aperture sculpturing is gammate and exine sculpturing is bireticulate perforate. The present study showed similarity with Celenk et al., (2008) in pollen and lumina shape of *N. stenantha.*

3.4.6 *Nepeta erecta*

Pollen is found as monade. Pollen size is medium, pollen shape spherical. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and slightly convex. Lumina shape is circular and lumina number per reticula is not clear (Plate. 57 H-I). Aperture sculpturing is gammate and exine sculpturing is reticulate perforate. According to Perveen and Qaiser (2004) pollen shape and exine ornamentation of *N. erect* is sub spheroidal and coarsely reticulate not agreed with our results.

3.4.7 *Nepeta govaniana*

Monad, pollen size is medium, pollen shape oblate spheroidal coincides with the findings of Ozaltan and Koçyigit (2022). The shape of pollen in polar and equatorial view is sub-spherical and irregular respectively. The pollen outline is sinuate, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and Sunken. Lumina shape is Oval and lumina number per reticula is 12-17 (Plate. 58 A-C). Aperture sculpturing is verrucate and exine sculpturing is reticulate perforate-verrucate. According to Perveen and Qaiser (2004) the pollen shape and exine ornamentation of *N. govaniana* is prolate spheroidal and rough rugulate not coincides with our results.

3.4.8 *Nepeta graciliflora*

Pollen size is medium, pollen shape Suboblate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and convex. Lumina shape is irregular in *Nepeta graciliflora* coincides with the results of Jamzad et al., (2003) in *N. gloeocephala* and *N. Ispahani*. Lumina number per reticula is 6-9 (Plate. 58 D-F). Aperture sculpturing is granulated and exine sculpturing is reticulate perforate.

3.4.9 *Nepeta griffithii*

Pollen is found as monad. Pollen size is small- medium, pollen shape prolate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen is radially symmetrical and isopolar. The type of aperture and ornamentation is hexacolpate and slightly convex. Lumina shape is circular-oval and number of secondary lumina per primary lumen is 5-9 (Plate. 58 H-I). Aperture sculpturing is granulated and exine sculpturing is reticulate perforate-sparsely gammate.

According to Perveen and Qaiser (2004) the pollen shape and exine ornamentation of *N. griffithii* is prolate spheroidal and coarsely reticulate not coincides with our results.

3.4.10 *Nepeta hindostana*

Pollen is found as monade. Pollen size is small, pollen shape prolate. The shape of pollen in polar and equatorial view is oblong and widely oval respectively. The pollen outline is psilate, pollen apex acute. Pollen symmetry was found to be bilateral and heteropolar. The polar region was observed as small and smooth. The type of aperture and ornamentation is hexacolpate and sunken. Lumina shape is irregular number of secondary lumina per primary lumen is 6-10 (Plate. 59 A-C). Aperture sculpturing is Verrucate and exine sculpturing is bireticulate perforate. According to Perveen and Qaiser (2004) the pollen shape and exine ornamentation of *N. hindostana* is prolate spheroidal and coarsely reticulate not coincides with our results.

3.4.11 *Nepeta laevigata*

Pollen is found as monade. Pollen size is small- medium, pollen shape prolate. The shape of pollen in polar and equatorial view is broad and Rhomboid. The pollen outline is psilate, pollen apex acute. Pollen symmetry was found to be bilateral and heteropolar. The polar region was observed as medium and smooth. The type of aperture and ornamentation is hexazonocolpate and bulged. Lumina shape and number of secondary lumina per primary lumen is absent (Plate. 59 D-F). Aperture sculpturing is granulated and exine sculpturing is reticulate. Previous studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. laevigata* was prolate spheroidal and coarsely reticulate not similar with our results.

3.4.12 *Nepeta leucolaena*

Monad, pollen size medium, shape spherical. The shape of pollen in polar and equatorial view was spherical and sub-spherical. The pollen outline is scabrate, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and slightly raised. Lumina shape circular and number of secondary lumina per primary lumen is 10-15 (Plate. 59 G-I). Aperture sculpturing is granulated and exine sculpturing is reticulate perforate. Previous studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. leucolaena* was prolate spheroidal and coarsely reticulate not agreed with our results. Our research explores extra characteristics that may serve to differentiate between these closely linked taxa.

3.4.13 *Nepeta linearis*

Monad, pollen size small-medium, shape per prolate. The shape of pollen in polar and equatorial view is Hexagonal and Ellipsoid (Plate. 60 A-C). The pollen outline is scabrate, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and Sunken respectively. Lumina shape Irregular and number of secondary lumina per primary lumen was not clear. Aperture sculpturing is granulated and exine sculpturing is fine reticulate perforate. Previous studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. linearis was* prolate spheroidal and coarsely reticulate not similar with our results.

3.4.14 *Nepeta nervosa*

Monad, pollen size small-medium, shape sub prolate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and sunken respectively. Lumina shape elongated and number of secondary lumina per primary lumen is 14-19 (Plate. 60 D-F). Aperture sculpturing is granulated and exine sculpturing is reticulate perforate. Earlier studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. nervosa was* prolate spheroidal and coarsely reticulate not consistent with our results.

3.4.15 *Nepeta podostachys*

Monad, pollen size medium, shape sub prolate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and bulged respectively (Plate. 60 G-H). Lumina shape irregular and number of secondary lumina per primary lumen is 15-18Aperture sculpturing is verrucate and exine sculpturing is reticulate perforate. Earlier studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. podostachys* was oblate spheroidal and coarsely reticulate found dissimilar with our results.

3.4.16 *Nepeta praetervisa*

Monad, pollen size small, shape sub prolate. The shape of pollen in polar and equatorial view is spherical. The pollen outline is rough, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and sunken respectively. Lumina shape circular-elongated and number of secondary lumina per primary lumen is 4-9 (Plate. 61 A-C). Aperture sculpturing is granulated and exine sculpturing is reticulate perforate.

3.4.17 *Nepeta raphanorhiza*

Monad, pollen size medium, shape prolate. The shape of pollen in polar and equatorial view is hexagonal-spherical and spherical respectively (Plate. 61 D-F). The pollen outline is scabrate, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and raised respectively. Lumina shape circular-oval and number of secondary lumina per primary lumen was not clear. Aperture sculpturing is granulated and exine sculpturing is reticulate- perforate/foveolate. Earlier studies of Perveen and Qaiser (2004) observed pollen shape and exine ornamentation of *N. raphanorhiza* was prolate spheroidal and coarsely reticulate found dissimilar with our results.

3.4.18 *Nepeta schmidii*

Monad, pollen size small-medium, shape prolate. The shape of pollen in polar and equatorial view is subspherical and spherical respectively. The pollen outline is rough, pollen apex acute. Pollen symmetry was found to be radial and isopolar. The type of aperture and ornamentation is hexazonocolpate and sunken respectively. Lumina shape and number of secondry lumina per primary lumen not clear (Plate. 61 G-I). Aperture sculpturing is verrucate and exine sculpturing is reticulate. Previous studies of Al-Watban et al., (2015) observed prolate pollen shape and reticulate perforate exine sculpturing of *N. deflersiana* shows similarity with our results in pollen shape but shows dissimilarity in exine sculpturing.

3.4.19 Pollen Fertility and Sterility

Pollen fertility is crucial in determining the variety of plants and where they are found in different ecosystems. The highest and the lowest percentage of fertility confirms their stability. The highest pollen fertility was found in *N. laevigata* (90.9%) and lowest in *N. hindostana* (64.2%) while, the highest sterility was observed in *N. hindostana* (35.8%) and lowest in *N. laevigata* (9.7%).

3.4.20 Principal Component Analysis (PCA) and Cluster Analysis of Nepeta Pollen as a Statistical Tool

The similarity index among the studied Nepeta Genus taxa was analyzed using UPGMA cluster analysis. The pollen quantitative data divides the dendrogram into three major clusters (Figure. 27). The first cluster consists of *N. distans* which is entirely varied from the other studied taxa of the genus in terms of quantitative measurements. The second cluster is divided into four subclusters i.e., subcluster1, subcluster 2, subcluster 3 and subcluster 4. The subcluster 4 is again divided into two cluster, in which *N. laevigata* and *N. schmidii* were the most similar as compared to the other studied taxa. The third cluster is divided into one subcluster which is again divided into two clusters. The third subdivided cluster showed similarity between *N. connata* and *N. graciliflora* but less similar than *N. laevigata* and *N. schmidii*.

One of the most significant statistical tests for analyzing a set of components is principal component analysis (PCA), which aims to represent the variation that exists among them. The observed data is represented in two-dimensional projection with axes principal components (Ashfaq et al., 2019). In the present study, the pollen size, (polar diameter, equatorial diameter), colpi size, (colpi length, colpi width), exine thickness and mesocolpium, of 18 *Nepeta* species were used to explore pollen variability. Principal component analysis variable loadings for first seven components illustrated in Table 8.

Total accumulative variance of (85.05 %) was presented in the current study in (Figure. 30). PC1 and PC2 are regarded as the most significant because the eigen value is higher than one both PCs. Additionally, PC1 showed a variability of (66.51 %) and PC2 showed a variability of (18.54 %), with a large positive loading element of the pollen quantitative traits. Polar diameter followed by colpi length, mesocolpium and colpi width are the most valuable variables in PC1. On the first axes positive side, *N. distans* were found with the largest polar diameter followed by colpi length, colpi width and mesocolpium. *N. linearis* is also found on the positive side of first axes with high value of P/E ratio. Whereas *N. cataria*, *N. connata*, *N. erecta*, *N govaniana* and *N podostachys* were observed on negative side of first axes. Equatorial diameter followed by exine thickness are the significant components in PC2. On the second axes positive side, *N. raphanorhiza*, *N. hindostana*, *N. griffithii*, *N. nervosa*, *N. laevigata*, *N. discolor* and *N. schmidii* were observed while, *N. praetervisa*, *N. leucolaena*, *N. elliptica* and *N. graciliflora* were observed on negative side of second axes. Additionally, the active variables and semantic differential chart of the PCA biplot were displayed in Figures 29 and 31 respectively to better visualize and assess the relationships between these factors.

3.4.21 Dichotomous key of Genus *Nepeta* species based on pollen qualitative traits.

1	a	Pollen shape per prolate……………………………	*Nepeta linearis*
	b	Pollen shape other than per prolate…………………	2
2	a	Pollen oblate spheroidal……………………………	3
	b	Pollen oblate other than oblate spheroidal…………	4
3	a	Equatorial view spherical………………………….	*Nepeta cataria*
	b	Equatorial view irregular………………………….	*Nepeta govaniana*
4	a	Pollen shape spherical……………………………...	5
	b	Pollen shape other than spherical………………….	6
5	a	Lumina shape circular…………………………….	*Nepeta leucolaena*
	b	Lumina shape not clear…………………………….	*Nepeta erecta*
6	a	Pollen shape sub oblate…………………………….	7

	b	Pollen shape other than sub oblate………………….	9
7	a	Exine sculpturing reticulate perforate…………….	*Nepeta graciliflora*
	b	Exine sculpturing bireticulate perforate……………	8
8	a	Aperture orientation concave………………………	*Nepeta connata*
	b	Aperture orientation convex……………………….	*Nepeta elliptica*
9	a	Pollen sub prolate………………………………….	10
	b	Pollen prolate……………………………………….	12
10	a	Aperture sculpturing verrucate……………………...	*Nepeta podostachys*
	b	Aperture sculpturing granulate…………………….	11
11	a	Number of secondary lumina per primary lumen 14-19	*Nepeta nervosa*
	b	Number of secondary lumina per primary lumen 4-9	*Nepeta praetervisa*
12	a	Pollen in equatorial view rhomboid…………………	*Nepeta laevigata*
	b	Pollen in equatorial view other than rhomboid……...	13
13	a	Pollen apex round…………………………………...	*Nepeta discolor*
	b	Pollen apex other than round……………………….	14
14	a	Lumina absent………………………………………	*Nepeta schmidii*
	b	Lumina present…………………………………….	15
15	a	Exine sculpturing reticulate-perforate/ foveolate….	*Nepeta raphanorhiza*
	b	Exine sculpturing other than reticulate-perforate/ foveolate	16
16	a	Aperture orientation Concave………………………	*Nepeta distans*
	b	Aperture orientation Slightly convex………………	*Nepeta griffithii*
17	a	Aperture orientation sunken………………………...	*Nepeta hindostana*

Table. 8: Principal component analysis variable loadings for first seven pollen components

Variables/ Factors	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Polar diameter	0.979	0.128	-0.024	-0.091	-0.072	-0.097	-0.047
Equatorial diameter	0.880	-0.451	-0.073	-0.047	-0.108	-0.025	0.057
Polar/equatorial ratio	-0.097	0.982	0.145	-0.032	-0.043	-0.026	0.034
Colpi length	0.960	0.086	-0.130	-0.098	0.207	-0.027	0.017
Colpi width	0.817	0.228	-0.295	0.438	-0.017	0.033	-0.005
Exine thickness	0.666	-0.127	0.718	0.157	0.025	0.010	-0.002
Mesocolpium	0.939	0.195	-0.012	-0.257	-0.042	0.115	-0.014
Eigenvalue	4.655	1.298	0.646	0.303	0.064	0.026	0.007
Variability (%)	66.506	18.541	9.233	4.335	0.917	0.367	0.101
Cumulative %	66.506	85.047	94.280	98.615	99.531	99.899	100.000

Keywords: PD=Polar diameter, ED=Equatorial diameter, P/E=Polar diameter divided by equatorial diameter, Cl= Colpi length, Cw=Colpi width ET=Exine thickness, MC=Mesocolpium

Table. 9: Quantitative pollen micromorphological findings of Genus Nepeta

S.no	Taxon	Polar diameter Min-Max = Mean±SE (µm)	Equatorial diameter Min-Max = Mean±SE (µm)	P/E ratio	Length of colpi Min-Max = Mean±SE (µm)	Width of colpi Min-Max = Mean±SE (µm)	Exine thickness Min-Max = Mean±SE (µm)	Mesocolpium Min-Max = Mean±SE (µm)	Fertility (%)	Sterility (%)
1.	*Nepeta cataria* L.	36.2-41.2=38.7±.85	41.2-46.2=43.2±.85	0.89	12.5-13.7=13.0±.21	5.7-7.0=6.3±.23	4.7-5.7=5.2±.17	13.7-16.2=15.2±.45	78.3	21.7
2.	*Nepeta connata* Royle ex Benth.	26.2-30.7=28.5±.880	31.0-35.5=33.1±.860	0.86	12.2-13.7=13.0±.289	5.7-6.7=6.2±.176	5.5-6.5=6.0±.176	11.7-12.7=12.2±.176	69.5	30.5
3.	*Nepeta discolor* Royle ex Benth.	29.5-31.2=30.3±.320	19.2-21.2=20.4±.384	1.48	8.7-10.0=9.35±.231	5.7-6.5=6.1±.127	3.2-4.0=3.6±.127	11.2-13.2=12.4±.331	75.4	24.6
4.	*Nepeta distans Royle*	83.7-88.0=86.5±.75	55.7-76.2=66.0±3.6	1.3	32.5-36.2=34.1±.700	8.0-13.7=10.7±1.1	6.2-8.0=7.1±.32	31.2-34.2=32.8±.53	80.3	19.7
5.	*Nepeta elliptica* Royle ex Benth.	19.7-28.7=24.0±1.5	32.0-34.5=33.0±.47	0.72	12.0-13.7=13.0±.29	7.2-8.7=8.0±.28	3.0-4.0=3.5±.17	9.2-1s0.5=9.8±.23	85.5	14.5
6.	*Nepeta erecta* (Royle ex Benth.) Benth.	41.2-43.7=42.4±.42	40.5-43.7=42.1±.56	1.0	13.7-15.2=14.5±.25	7.2-9.0=8.1±.32	3.7-4.7=4.2±.17	16.2-18.5=17.6±.40	89.9	10.1
7.	*Nepeta govaniana* (Wall. ex Benth.) Benth.	34.2-38.2=36.6±.69	37.7-42.7=40.8±.82	0.89	12.0-13.5=12.7±.26	6.2-7.2=6.9±.18	5.5-6.7=6.2±.21	12.0-13.5=12.9±.25	75.2	24.8
8.	*Nepeta graciliflora* Benth.	26.2-28.7=27.6±.45	31.2-34.7=32.7±.59	0.84	10.7-13.7=11.9±.54	4.5-5.5=5.0±.176	2.2-3.7=3.1±.26	12.2-14.0=13.3±.30	65.4	34.6
9.	*Nepeta griffithii*	25.5-	13.0-	1.75	9.7-12.7=11.0±.52	5.0-6.2=5.6±.23	4.2-	12.0-	68.9	31.1

	Hedge	28.2=26.9±.49	18.7=15.3±1.2				5.5=4.8±.23	13.2=12.6±.23		
10.	*Nepeta hindostana* (B. Heyne ex Roth) Haines	29.2-30.7=30.1±.26	19.5-23.7=20.9±.77	1.46	12.0-13.7=12.8±.32	7.0-8.2=7.6±.23	3.7-5.2=4.3±.25	12.0-13.2=12.6±.23	64.2	35.8
11.	*Nepeta laevigata* (D. Don) Hand. -Mazz.	23.7-25.2=24.4±.26	15.0-18.2=16.6±.52	1.46	10.2-11.7=11.1±.26	4.5-5.5=5.0±.17	3.2-4.2=3.7±.17	12.0-13.2=12.6±.23	90.3	9.7
12.	*Nepeta leucolaena* Benth. ex Hook.f.	24.7-26.2=25.4±.24	23.7-28.2=25.4±.76	1	9.5-11.2=10.3±.32	5.7-6.7=6.2±.17	2.2-3.5=3.0±.20	9.7-11.2=10.4±.26	72.4	27.6
13.	*Nepeta linearis* Royle ex Benth.	34.0-38.0=35.9±.70	15.7-19.2=17.5±.591	2.05	11.2-13.2=12.3±.358	7.7-8.7=8.2±.176	3.7-5.0=4.4±.231	14.7-17.0=16.0±.382	80.5	19.5
14.	*Nepeta nervosa* Royle ex Benth.	23.7-27.2=25.7±.67	16.2-21.2=19.2±.84	1.33	8.7-9.7=9.2±.17	5.5-6.2=5.9±.12	3.7-5.2=4.5±.25	10.7-12.7=11.7±.33	86.1	13.9
15.	*Nepeta podostachys* Benth.	34.0-41.5=38.7±1.3	22.2-26.2=31.7±2.5	1.22	10.7-13.5=12.1±.49	6.5-8.0=7.2±.25	5.2-6.7=6.0±.25	9.5-11.2=10.2±.31	89.9	10.1
16.	*Nepeta praetervisa* Rech.f.	19.5-21.2=20.3±.34	17.0-18.5=17.7±.26	1.16	8.7-9.7=9.2±.17	5.7-6.5=6.1±.12	3.7-4.5=4.2±.14	8.0-9.0=8.5±.17	70.3	29.7
17.	*Nepeta raphanorhiza* Benth.	31.2-45.2=35.3±2.5	17.7-25.2=21.0±1.38	1.6	13.7-15.7=14.6±.33	7.5-8.7=7.9±.21	2.2-3.0=2.7±.13	10.0-13.7=12.0±.64	78.4	21.6
18.	*Nepeta schmidii* Rech .f.	24.2-25.7=24.9±.26	15.0-16.7=16.0±.31	1.5	8.7-10.7=9.8±.35	5.5-6.2=5.8±.12	4.2-5.5=4.8±.21	12.0-13.0=12.5±.17	82.4	17.6

Key words: Min= Minimum, Max= Maximum, SE= Standard Error, P= Polar Diameter, E= Equatorial Diameter, % = percentage, μm= Measurement in Micrometer

Table. 10: Qualitative pollen morphological findings of Genus Nepeta

S.no	Taxon	Pollen size	Pollen shape	Shape of pollen in polar view	Shape of pollen in equatorial view	Pollen outline	Colpi apex	Symmetry	Polarity	Aperture type	Aperture orientation	Lumina shape	No of secondry lumina per primay lumen	Aperture sculpturing	Exine sculpturing
1.	*Nepeta cataria* L.	Medium	Oblate-spheriodal	Sub spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Concave	Slightly elongated	Not clear	Verrucate	Reticulate perforate
2.	*Nepeta connata* Royle ex Benth.	Medium	Sub oblate	Spherical	Spherical	Scabrate	Acute	Radial	Isopolar	Hexazonocolpate	Concave	Elongated	Not clear	Granulate	Reticulate
3.	*Nepeta discolor* Royle ex Benth.	Small-Medium	Prolate	Spherical	Spherical	Slightly rough	Round	Radial	Isopolar	Hexazonocolpate	Slightly convex	Elongated	10-20	Granulate	Bireticulate perforate
4.	*Nepeta distans Royle*	Large	Prolate	Sub spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Concave	Circular-Oval	10-13	Gammate	Bireticulate perforate
5.	*Nepeta elliptica* Royle ex Benth.	Medium	Sub oblate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Convex	Irregular	10-14	Gammate	Reticulate perforate

6.	*Nepeta erecta* (Royle ex Benth.) Benth.	Medium	Spherical	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Slightly convex	Circular	Not clear	Gemmate	Reticulate perforate
7.	*Nepeta govaniana* (Wall. ex Benth.) Benth.	Medium	Oblate-spheroidal	Sub Spherical	Irregular	Sinuate	Acute	Radial	Isopolar	Hexacolpate	Sunken	Oval	12-17	Verrucate	Reticulate perforate-verrucate
8.	*Nepeta graciliflora* Benth.	Medium	Sub oblate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Convex	Irregular	6-9	Granulate	Bireticulate perforate
9.	*Nepeta griffithii* Hedge	Small-Medium	Prolate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexacolpate	Slightly convex	Circular-Oval	5-8	Granulate	Reticulate perforate
10.	*Nepeta hindostana* (B. Heyne ex Roth) Haines	Small-Medium	Prolate	Spherical	Spherical	Psilate	Acute	Bilateral	Heteropolar	Hexacolpate	Sunken	Irregular	6-10	Verrucate	Bireticulate perforate
11.	*Nepeta laevigata* (D. Don) Hand. -Mazz.	Small-Medium	Prolate	Broad shape	Rhomboid	Psilate	Round	Bilateral	Heteropolar	Hexazonocolpate	Bulged	_	_	Granulate	Reticulate
12.	*Nepeta leucolaena* Benth. ex	Medium	Spherical	Spherical	Sub Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Slightly raised	Circular	10-15	Granulate	Reticulate perforate

	Hook.f.														
13.	Nepeta linearis Royle ex Benth.	Small-Medium	Per prolate	Hexagonal	Ellipsoid	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Irregular	Not clear	Granulate	Fine reticulate
14.	*Nepeta nervosa* Royle ex Benth.	Small-Medium	Sub prolate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Elongated	14-19	Granulate	Reticulate perforate
15.	*Nepeta podostachys* Benth.	Medium	Sub prolate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Bulged	Irregular	15-18	Verrucate	Reticulate perforate
16.	*Nepeta praetervisa* Rech.f.	Small	Sub prolate	Spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	Circular-elongated	4-9	Granulate	Reticulate perforate
17.	*Nepeta raphanorhiza* Benth.	Medium	Prolate	Hexagonal-spherical	Spherical	Scabrate	Acute	Radial	Isopolar	Hexazonocolpate	Raised	Circular-Oval	Not clear	Granulate	Reticulate-perforate/foveolate
18.	*Nepeta schmidii* Rech.f.	Small-Medium	Prolate	Sub spherical	Spherical	Rough	Acute	Radial	Isopolar	Hexazonocolpate	Sunken	_	_	Verrucate	Reticulate

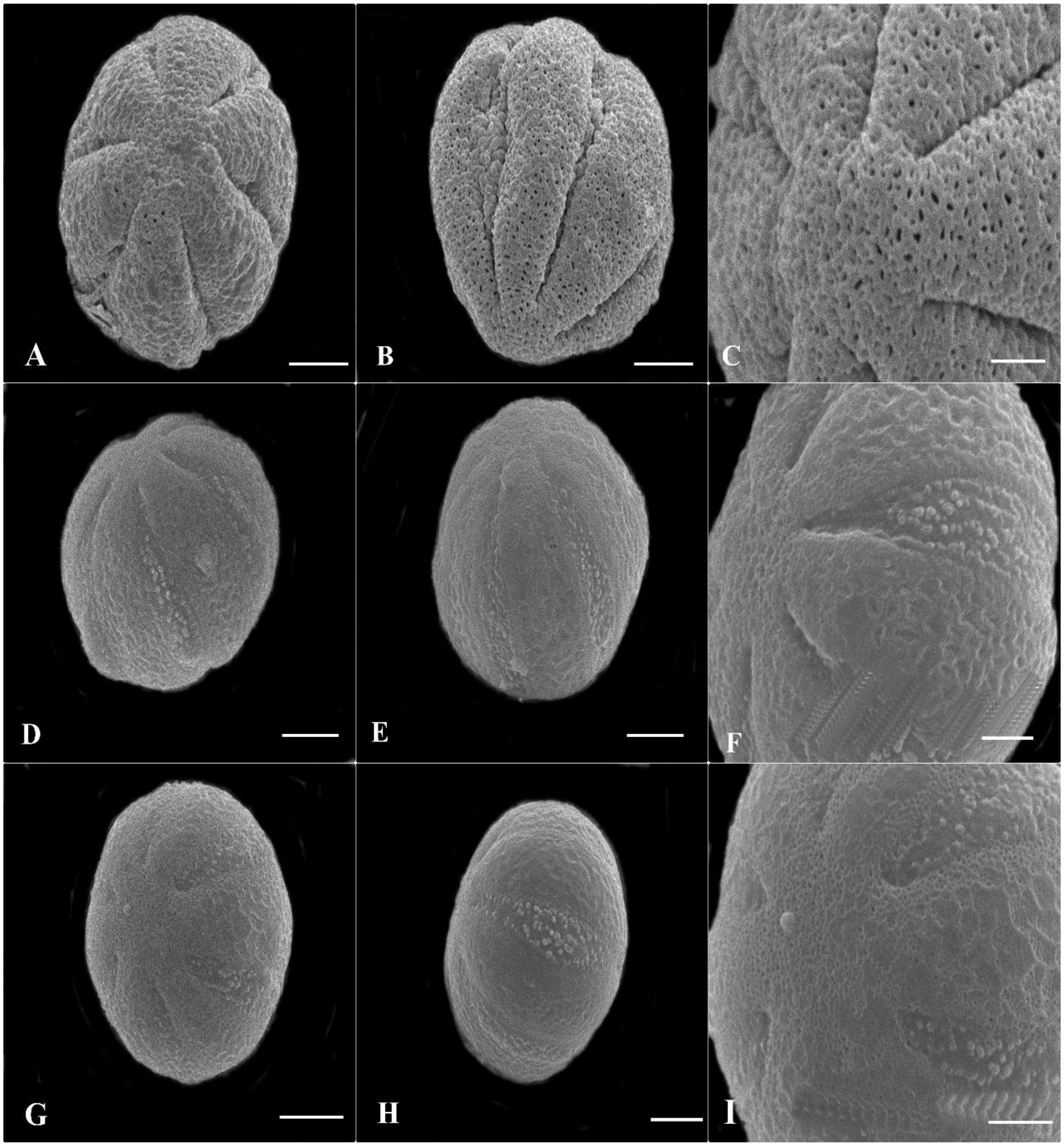

Plate. 56: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *Nepeta cataria* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. connata* (D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. discolor* (G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

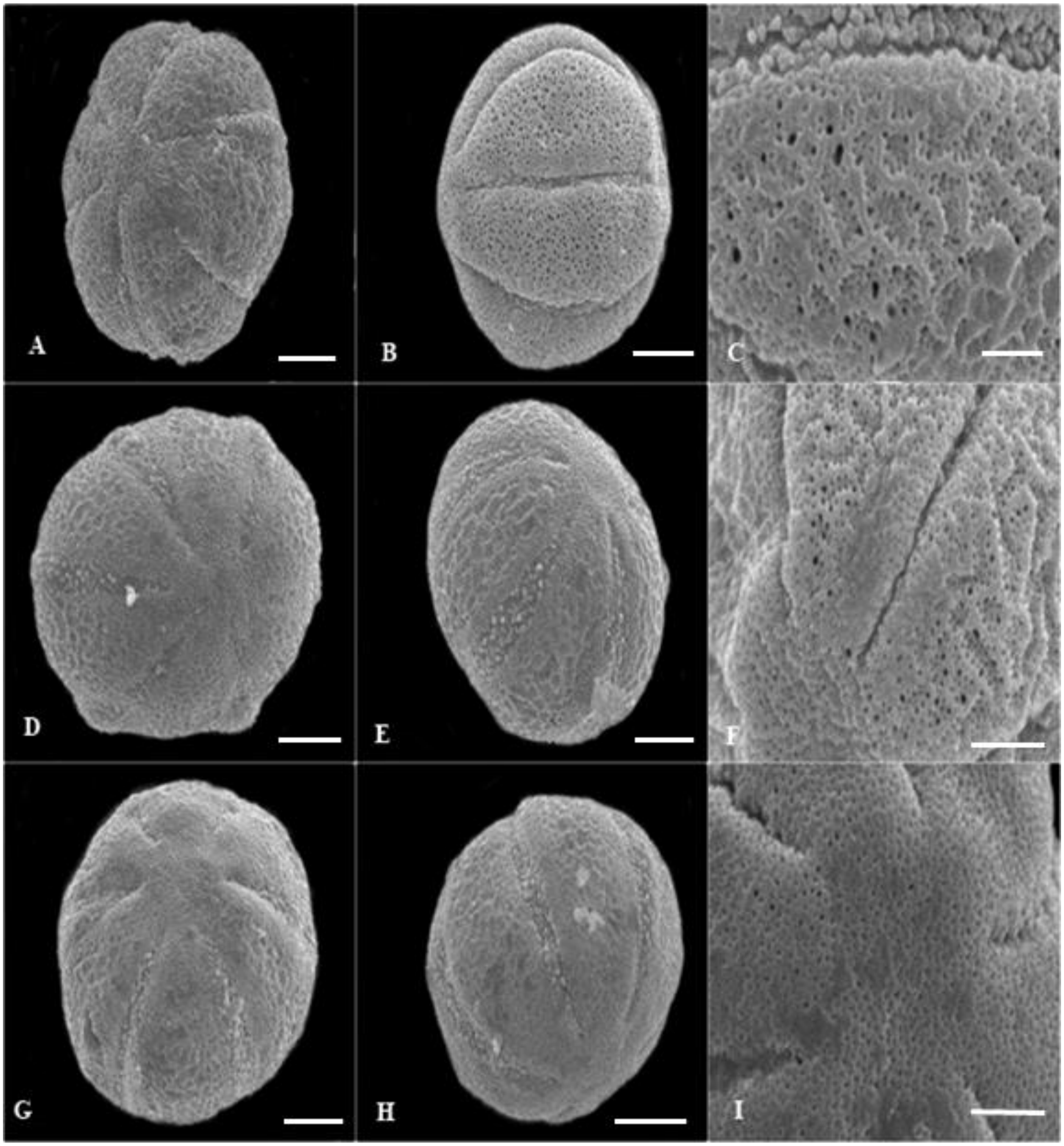

Plate. 57: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *N. distans* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. elliptica* (D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. erecta* (G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, for (G, H) 10 µm, scale bar 2µm for exine sculpturing, for (C) 1µm.

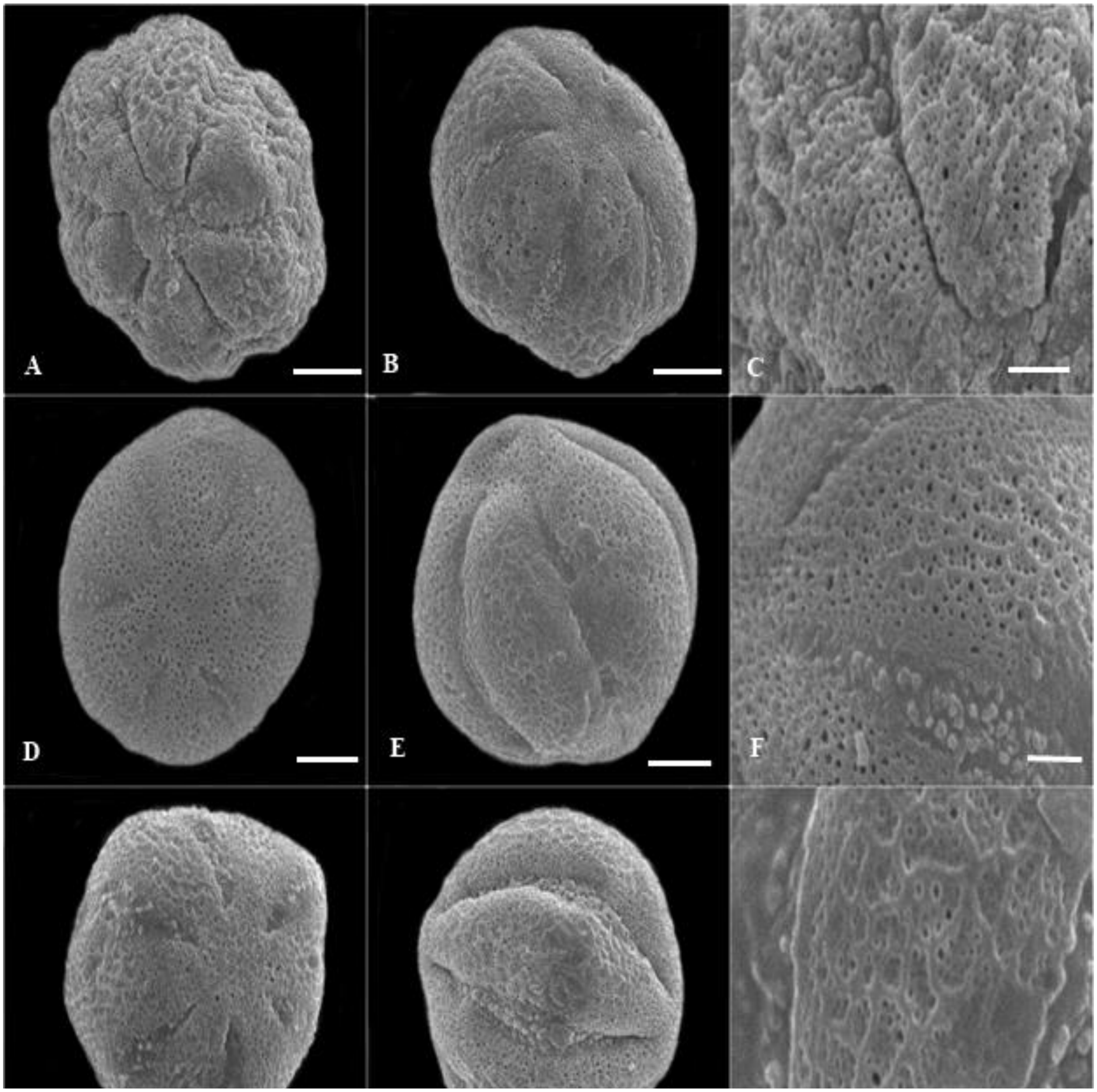

Plate. 58: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *N. govaniana* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. graciliflora* (D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. griffithii* (G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, for (A, B) 10 µm, Scale bar 2µm for exine sculpturing.

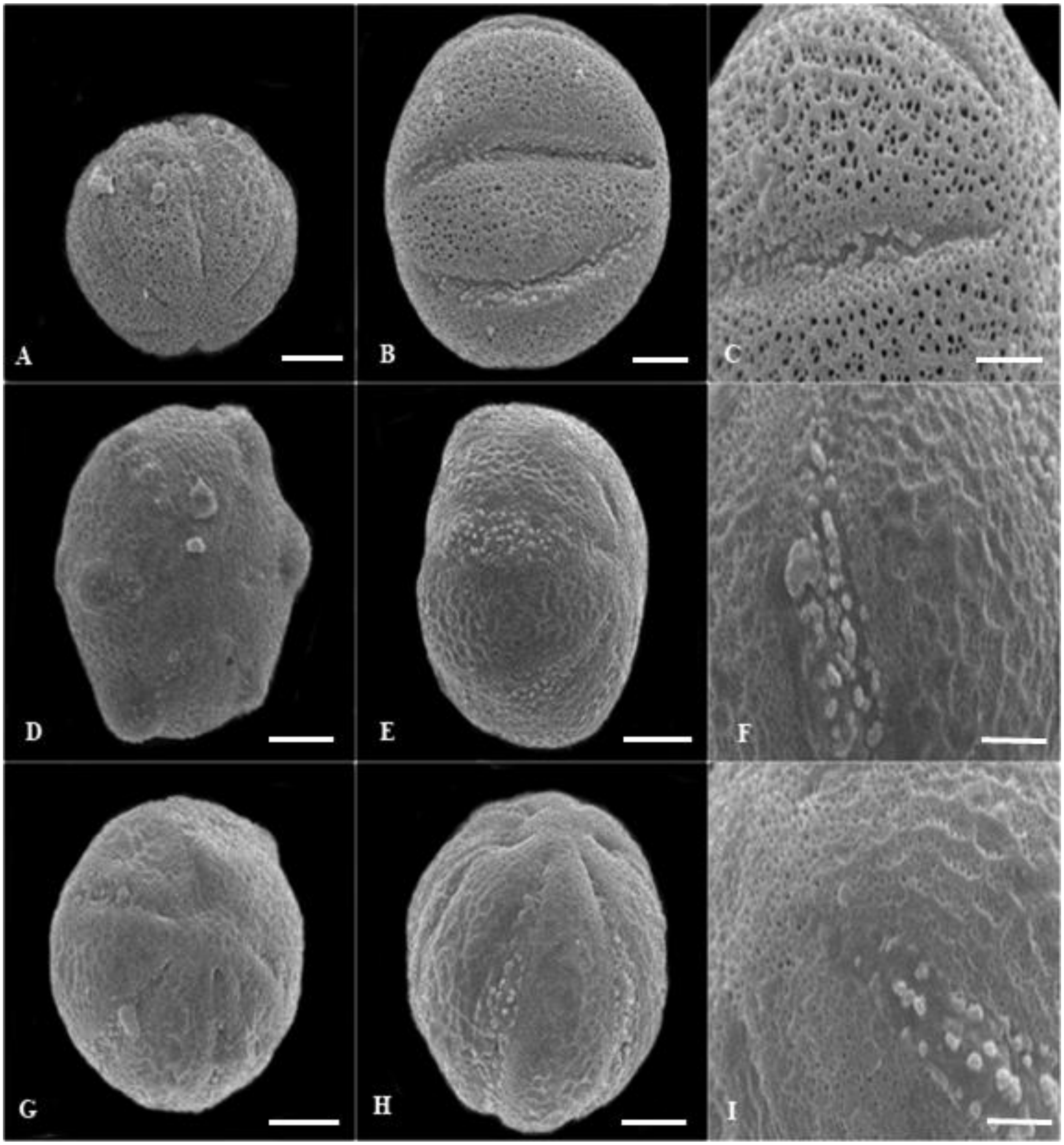

Plate. 59: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *N. hindostana* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. laevigata (*D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. leucolaena* (G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

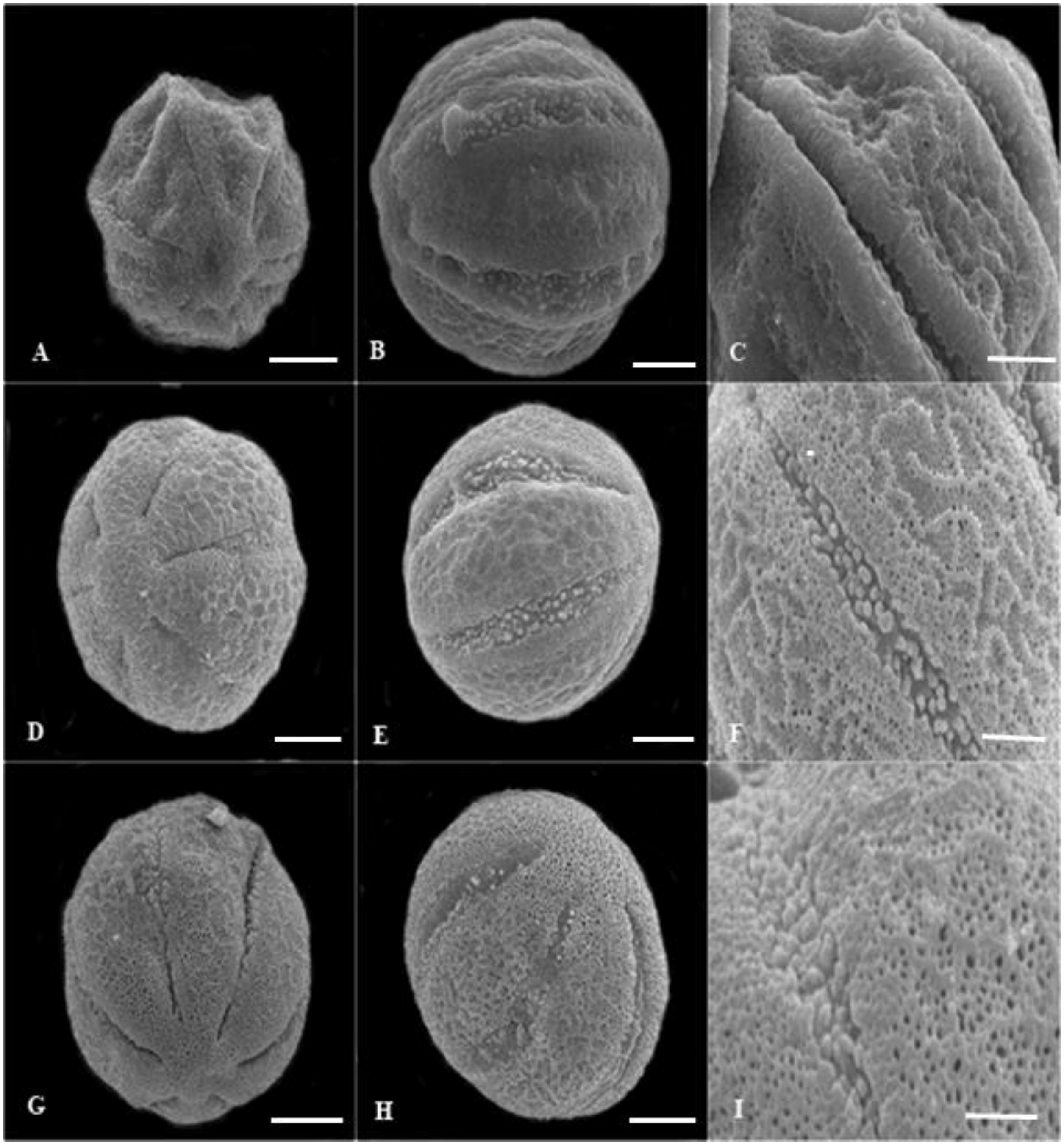

Plate. 60: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *N. linearis* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. nervosa* (D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. podostachy (*G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, for *(*A, G) 10 µm, scale bar 2µm for exine sculpturing, for (I) 1µm.

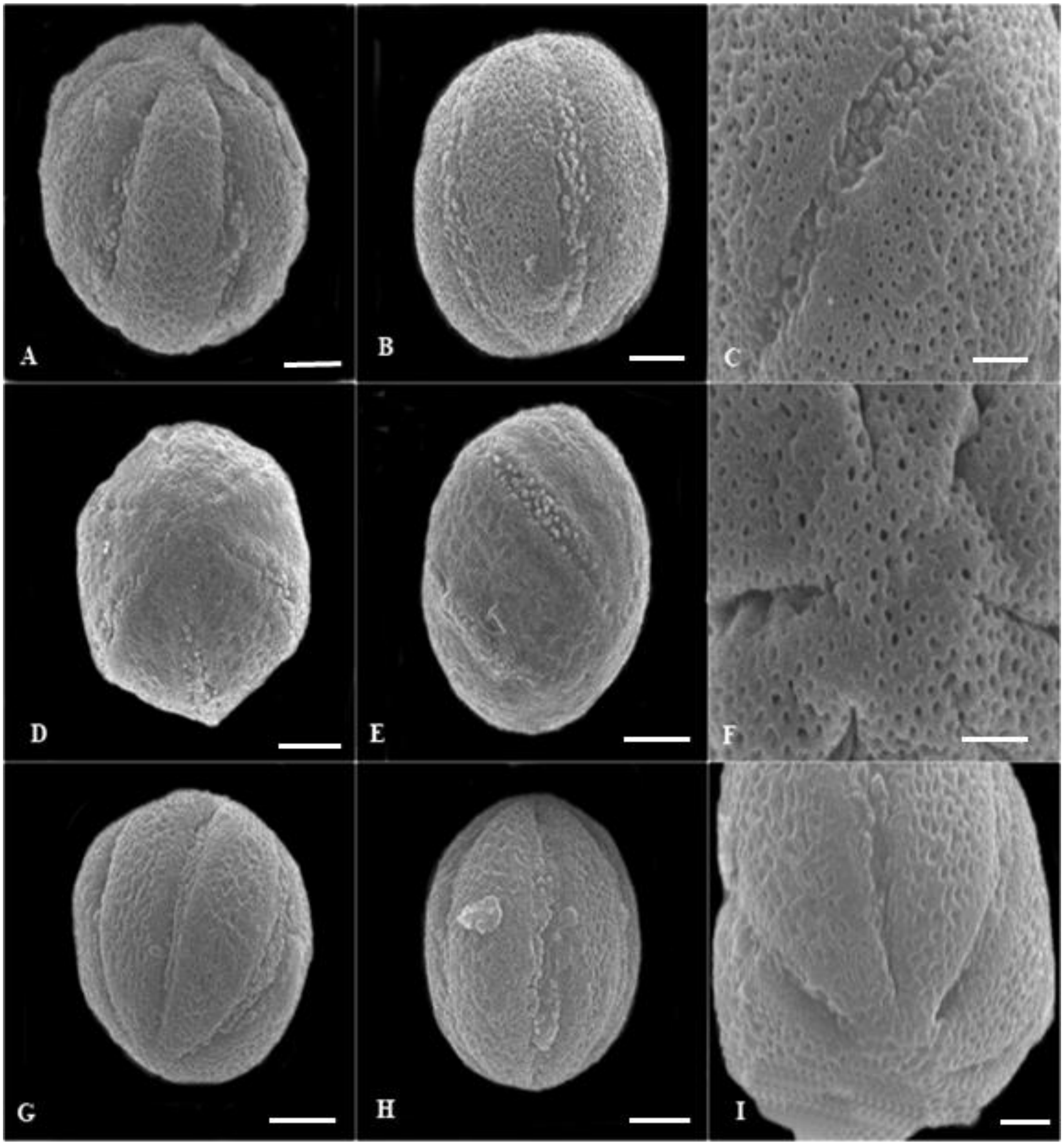

Plate. 61: Scanning electron micrographs of pollen illustrated polar view, equatorial view and exine sculpturing of Genus Nepeta taxa. (A-C) *N. praetervisa* (A) Polar view (B) equatorial view (C) exine sculpturing. (D-F) *N. raphanorhiza* (D) Polar view (E) equatorial view (F) exine sculpturing. (G-I) *N. schmidii* (G) Polar view (H) equatorial view (I) exine sculpturing. Scale bar 5µm for polar and equatorial micrographs, scale bar 2µm for exine sculpturing.

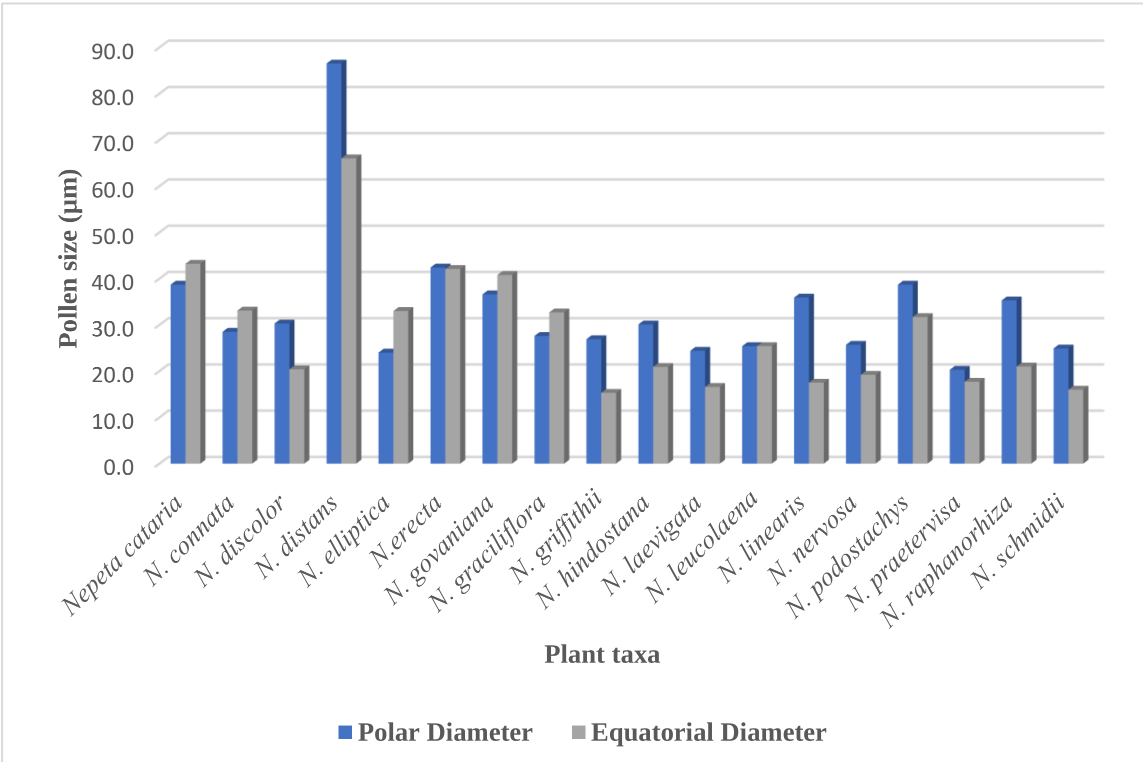

FIGURE. 23: Variation among polar and equatorial diameter in Nepeta taxa

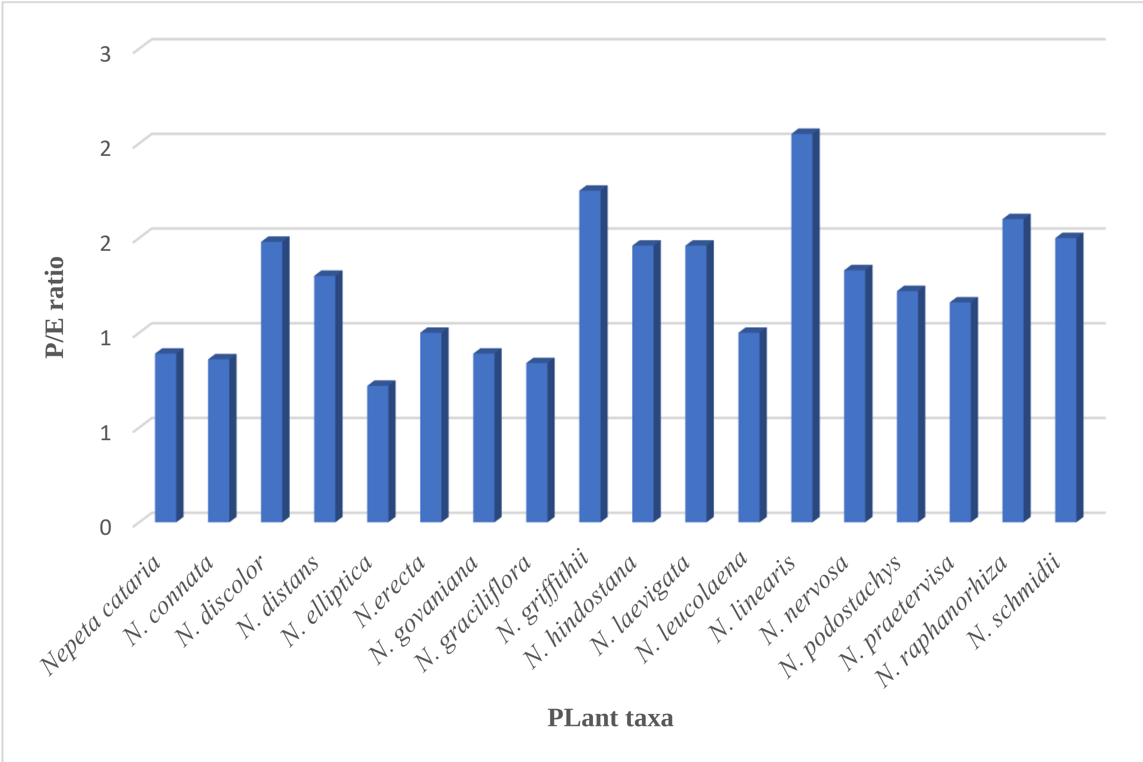

FIGURE. 24: Showing variation among P/E ratio (polar to equatorial diameter) in Nepeta species

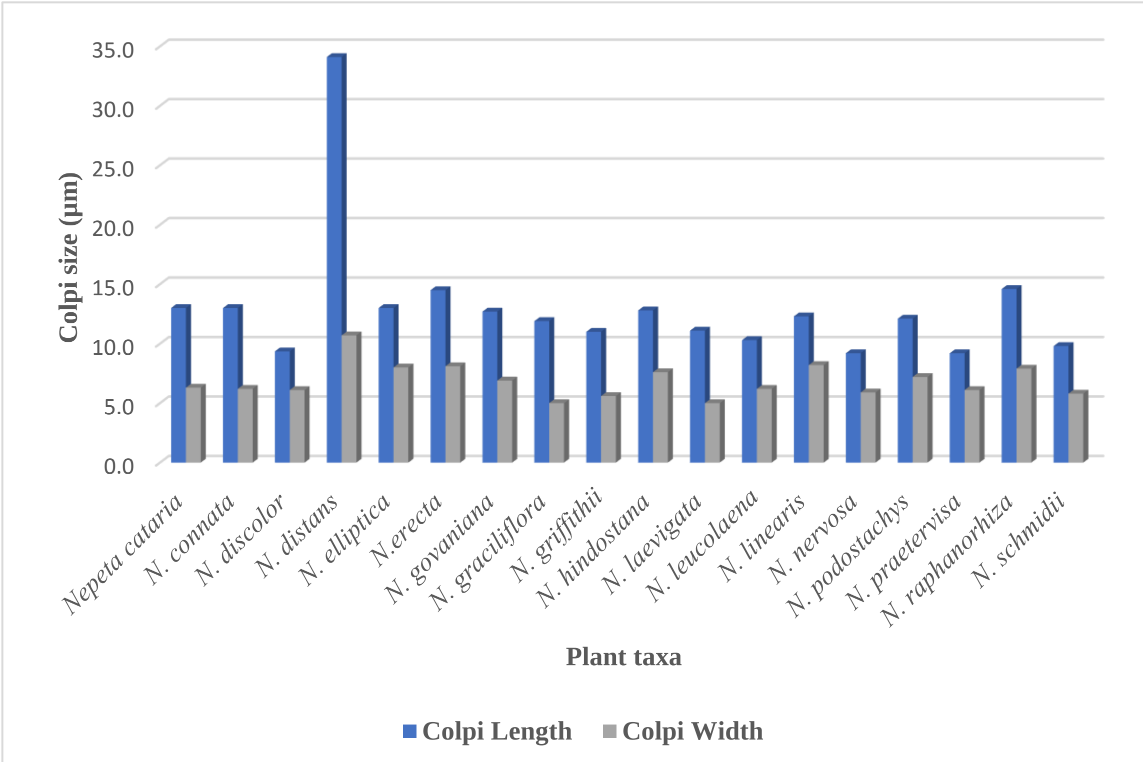

FIGURE. 25: Variation among colpi length and width in Nepeta taxa

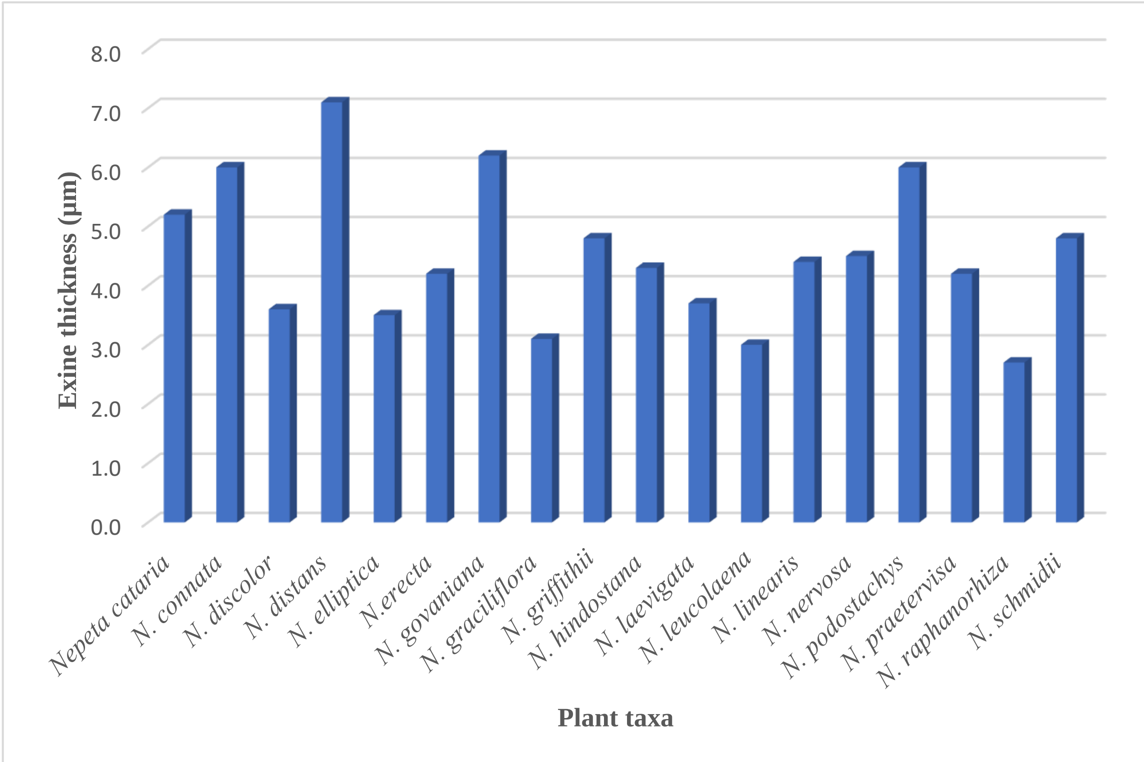

FIGURE. 26: Showing variation of exine thickness among the selected Nepeta species

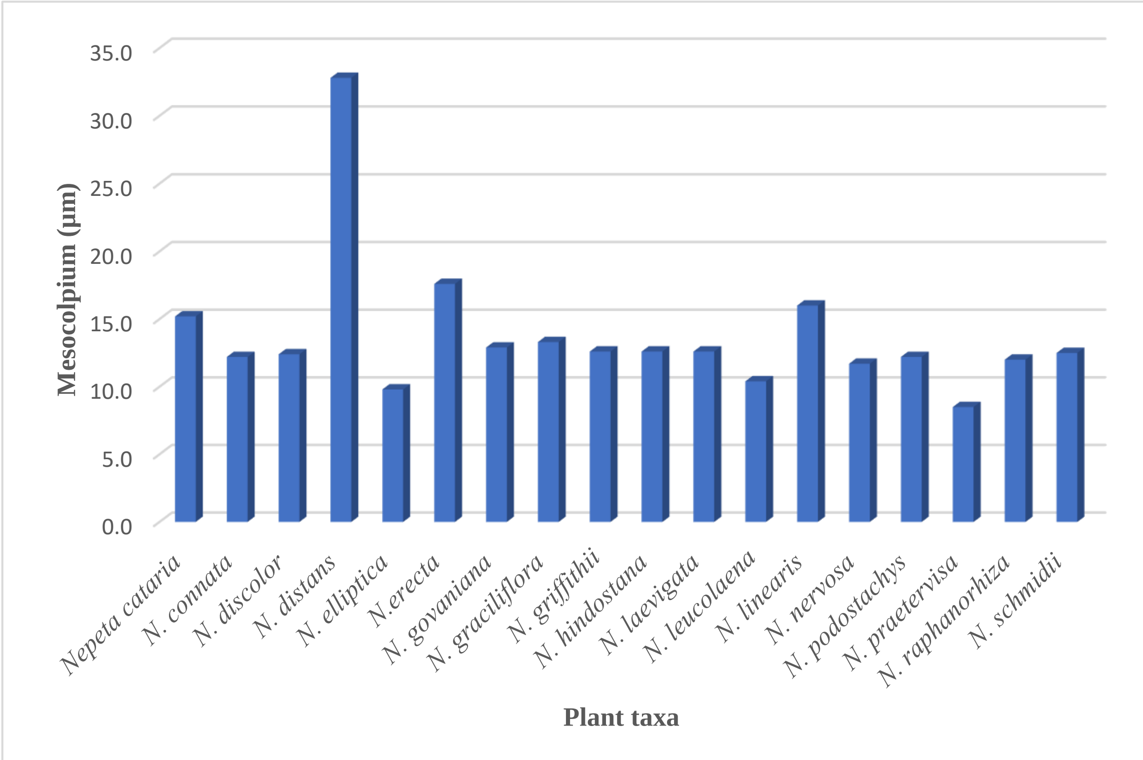

FIGURE. 27: Showing variation of mesocolpium among the studied Nepeta taxa

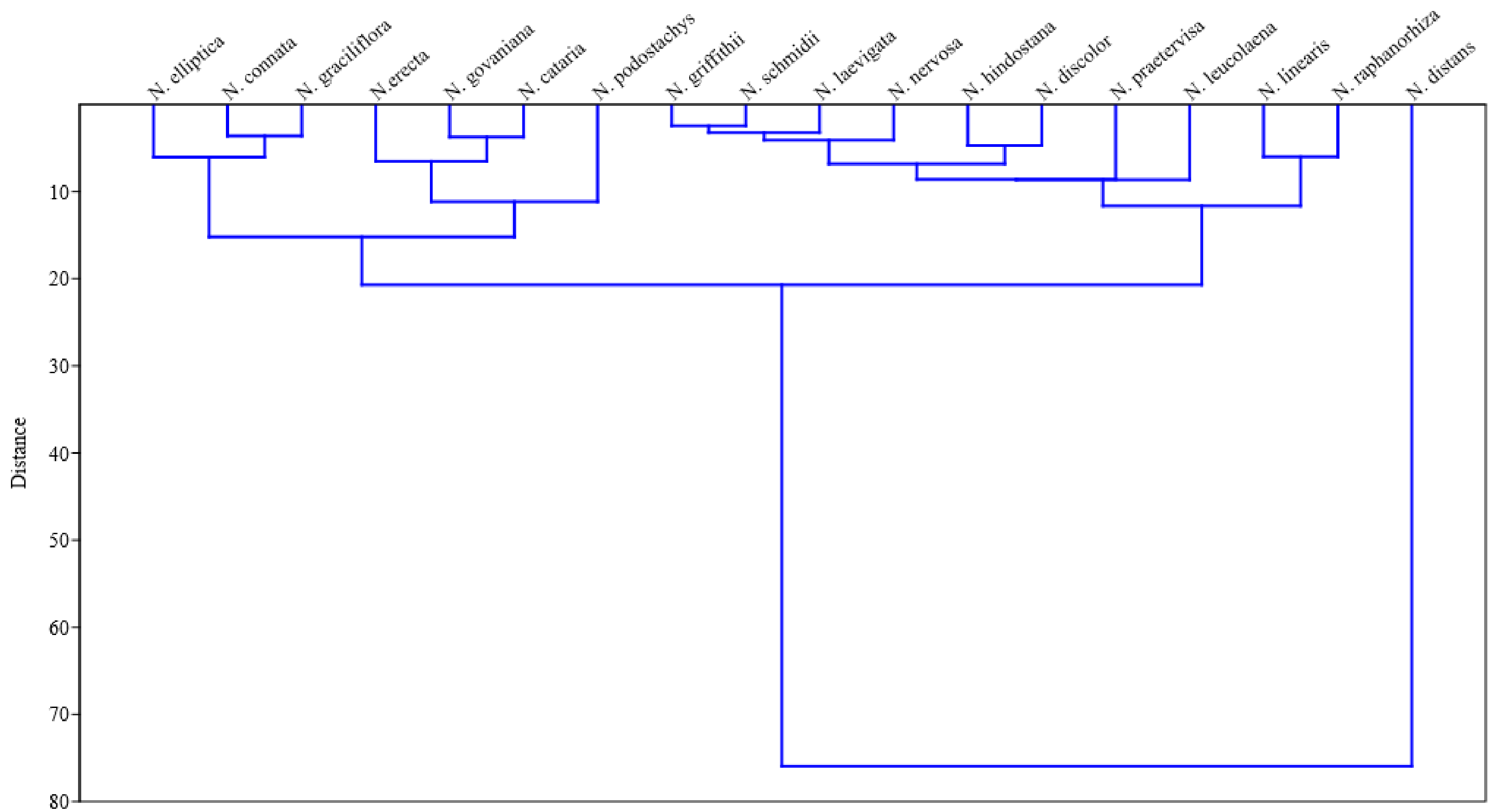

FIGURE. 28: Showing the cluster analysis of Genus Nepeta species based on pollen quantitative findings

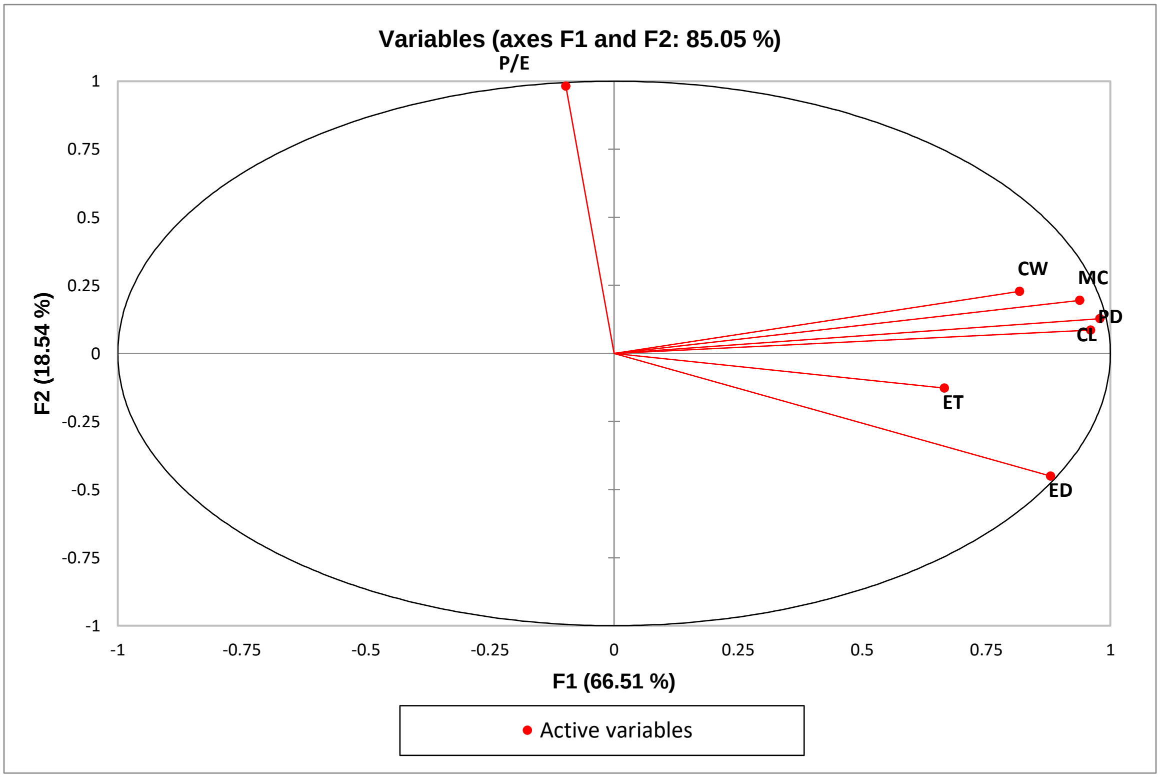

Figure. 29: Active variables of Nepeta pollen of the principal component analysis biplot

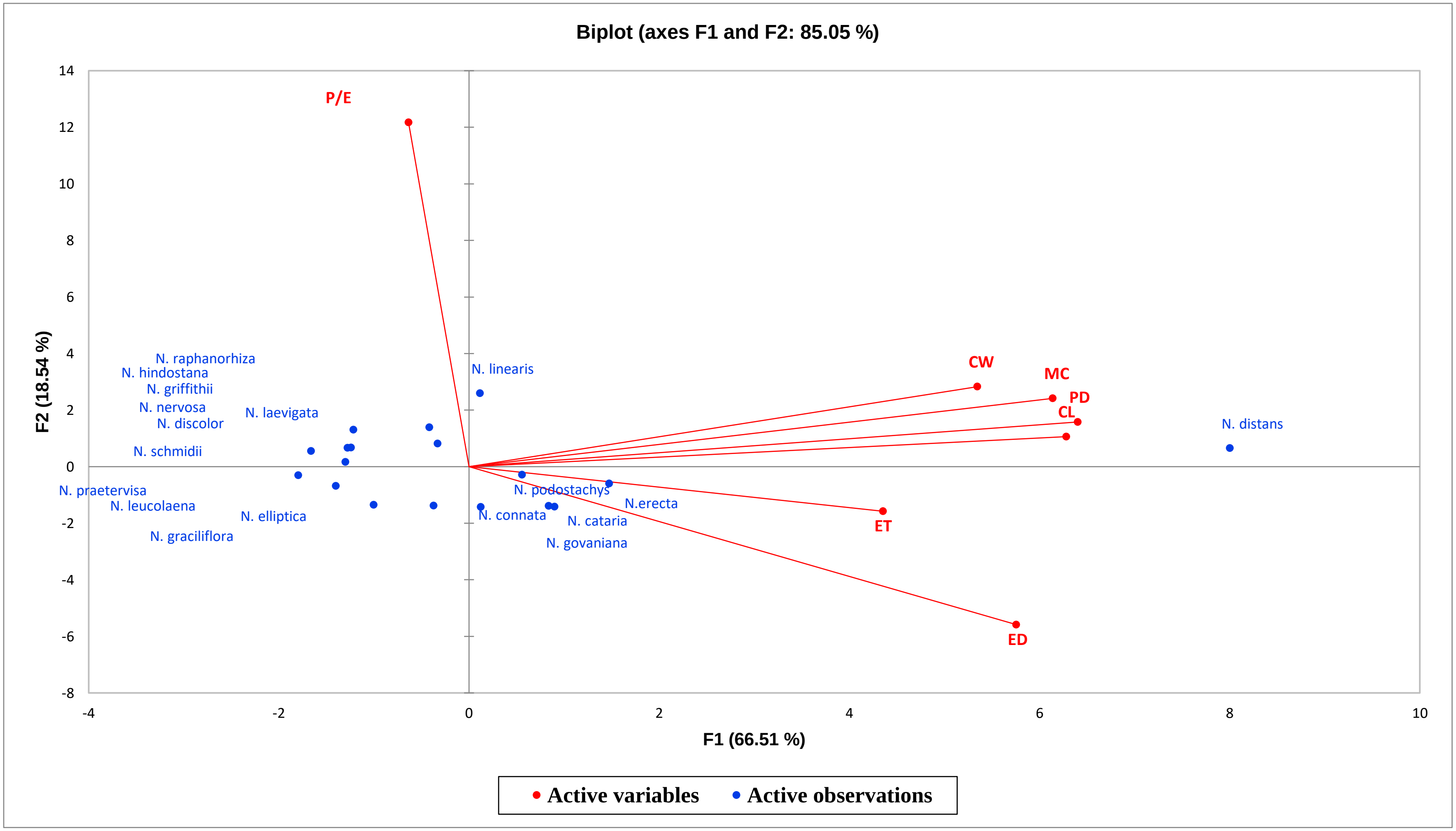

Figure. 30: PCA (Principal component analysis), based on seven pollen traits i.e., polar diameter, equatorial dimeter, polar to equatorial diameter, colpi length, colpi width, exine thickness and mesocolpium

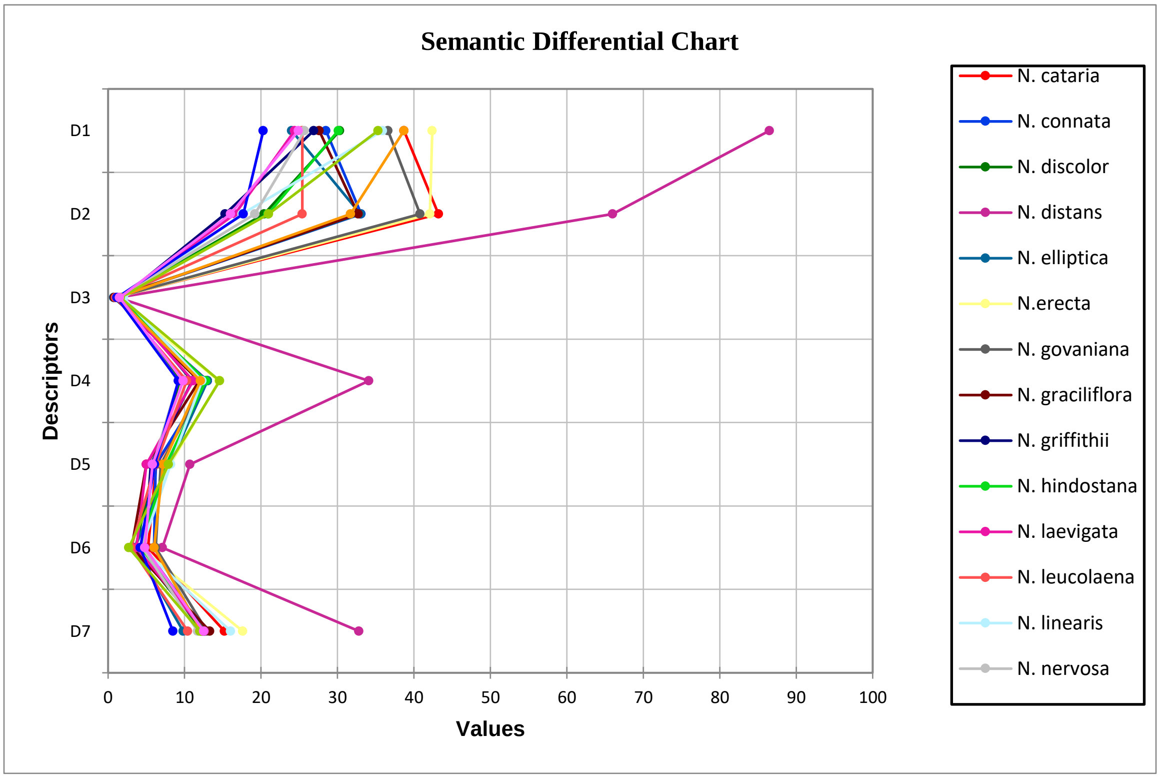

Figure. 31: Semantic Differential Chart of seven pollen variables i.e., polar diameter, equatorial dimeter, polar to equatorial diameter, colpi length, colpi width, exine thickness and mesocolpium

3.5 Pollen Micromorphological Structure of Genus Salvia

Twelve taxa of Salvia genus were studied with the help of light microscopy (LM) and scanning electron microscope (SEM). Scanning electron micrographs were presented on plates 62-65. Micromorphological variations were observed within pollens of genus Salvia for example, size and shape of pollens, pollen outline, colpi apex, Symmetry, polarity, aperture orientation, aperture sculpturing, exine sculpturing. Pollen quantitative measurements and qualitative characteristics were illustrated in table 12 and 13.

3.5.1 Shape of Pollen

The pollen grains are shed as monads. Pollen shapes were observed based on P/E ratio. The shapes of pollen grains are oblate in both polar and equatorial views of *Salvia reflexa* to sub oblate in *S. rhytidea* and prolate in both *S. plebeia* and *S. moorcroftiana*. The shape of pollen grain is prolate spheroidal in *S. santolinifolia* and *S. coccinea*. It is per prolate in *S. cabulica* and sub prolate in *S. aegyptiaca*, *S. leucantha* and *S. aegyptiaca*. Pollen shape is spherical in *S. lanata* and oblate spheroidal in *S. nubicola.* The dominant pollen shape sub prolate.

3.5.2 Size of Pollen

The polar axis size (P) of *S. leucantha* varies from (23.15 µm) to (60.65 µm) in *S. lanata.* In comparison, the equatorial axis size (E) varies from (15.75 µm) in *S. cabulica* to (60.65 µm) in *S. lanata* presented in Figure 32. Size of pollen varies from large to small based on polar and equatorial diameter. P/E ratio varies from (0.75 %) in *S. reflexa* to (2.34 %) in *S. cabulica* presented in Figure 33.

3.5.3 Apertures

In all taxa, pollen grains are radially symmetric and isopolar. They are predominantly hexazonocolpate except with two *Salvia* species which are hexacolpate. Colpi length varies from (6.25 µm) in *S. cabulica* to (26.75 µm) in *S. lanata* while width of colpi varies from (5 µm) in *S. plebeia* to (11.6 µm) in *S. lanata* presented in Figure 34. Colpi are narrower as they reach the poles, and their ends become acute. Mesocolpium is the distance between two colpi which varies from (7.75 µm) in *S. leucantha* to (22.8 µm) in *S. splendens* presented in Figure 36.

3.5.4 Exine Sculpturing

SEM examination of exine sculpturing reveals various surface structures i.e., reticulate, reticulate-perforate, slightly reticulate perforate, micro reticulate perforate and bireticulate perforate. SEM micrographs show that colpi are either raised or sunken. Exine thickness varies between (2.35 µm) in *S. santolinifolia* to (5 µm) in *S. aegyptiaca* presented in Figure 35. Reticulate sculpturing pattern is found in three taxa i.e., *S. lanata, S. leucantha* and *S. reflexa*. Reticulate perforate sculpturing pattern is found in four taxa i.e., *S.cabulica, S. coccinea, S. nubicola* and *S. plebeia.* Bireticulate perforate sculpturing is found in three taxa i.e., *S. aegyptiaca, S. moorcraftiana*, and *S. splendens*. Microreticulate perforate sculpturing is found in *S. santolinifolia* whereas, slightly reticulate perforate sculpturing is found in *S. rhytidea.*

3.5.5 Pollen Fertility and Sterility

The fertility of pollen grains to reproduce is a crucial trait that offers information concerning the fertility and pollen incompatibility. Pollen fertility is crucial in determining the variety of plants and where they are found in different ecosystems. The highest and the lowest percentage of fertility confirms their stability. The highest pollen fertility was found in *S. plebeia* (90.9) and lowest in *Salvia splendens* (80.4) while, the highest sterility was observed in *S. splendens* (19.5) and lowest in *S. plebeia* (9.09).

3.5.6 Principal Component Analysis (PCA) and Cluster Analysis of Salvia pollen as a Statistical Tool

The dendrogram depicting the *Salvia* taxa similarity index based on investigated quantitative character reveals a high degree of similarity between *S. coccinea* and *S. santolinifolia* (based on pollen size and shape) opposite to *S. reflexa* and *S.cabulica*. The dendrogram also shows that the two similar clades thate is *S. aegyptiaca* and *S. plebeia* and *S.leucantha* and *S. rhytidea* show greater similarity than *S. reflexa* and *S. cabulica* which were only slightly related. Similarly, *S. coccinea* and *S. santolinifolia are more similar than S. nubicola* and *S. morcraftiana and S.splendens are more related than S. lanata* The two species with the most similarities were *S. santolinifolia* and *S. coccinea* (Figure 37).

One of the significant statistical tests for analyzing a set of components is principal component analysis (PCA), which aims to represent the variation that exists among them. The observed data is represented in two-dimensional projection with axes PC (principal components). In the present study, the pollen size, (polar diameter, equatorial diameter), colpi size, (colpi length, colpi width), exine thickness and mesocolpium, of 12 *Salvia* species were used to explore pollen variability. Principal component analysis variable loadings for first seven components illustrated in Table 11. Total accumulative variance of (75.02 %)) was presented in the current study in (Figure. 39). PC1, PC2 and PC3 are regarded as the most significant because the eigen value is higher than these PCs. Additionally, PC1 showed a variability of (54.33 %) and PC2 showed a variability of (20.68 %), with a large positive loading element of the pollen quantitative traits. Polar to equatorial diameter (P/E ratio) followed by polar diameter and mesocolpium are the most valuable variables in PC1. *Salvia splendens*, *Salvia santolinifolia* and *Salvia coccinea* were positioned on the first axes positive side. Whereas *Salvia cabulica* and *Salvia aegyptiaca* were positioned on the first axes negative side. Equatorial diameter followed by colpi length, width and exine thickness are the significant components in PC2 Similarly, *Salvia morcraftiana*, *Salvia nubicola* and *Salvia lanata* were positioned on the second axes positive side. Whereas *Salvia plebeia*, *Salvia leucantha*, *Salvia rhytidea* and *Salvia reflexa* were positioned on the second axes negative side. Additionally, the active variables and semantic differential chart of the PCA biplot were displayed in Figures 38 and 40 respectively to better visualize and assess the relationships between these three factors.

3.5.7 Taxonomic keys based on qualitative features of Genus Salvia species:

1	a	Exine sculpturing coarsely reticulate perforate……………...	*Salvia rhytidea*
	b	Exine sculpturing other than coarsely reticulate perforate….	2
2	a	Exine sculpturing bireticulate……………………………….	*Salvia leucantha*
	b	Exine sculpturing other than bireticulate…………………….	3
3	a	Exine sculpturing reticulate perforate ……………………….	4
	b	Exine sculpturing bireticulate perforate…………………….	5
4	a	Pollen in equatorial view oblong…………………………….	*Salvia coccinea*
	b	Pollen in equatorial view broad elliptic……………………...	*Salvia nubicola*
5	a	Colpi apex slightly acute…………………………………….	*Salvia aegyptiaca*
	b	Colpi apex rounded………………………………………….	*Salvia splendens*
6	a	Exine sculpturing microreticulate…………………………...	7
	b	Exine sculpturing reticulate…………………………………	8
7	a	Pollen size large…………………………………………….	*Salvia moorcroftiana*
	b	Pollen size medium………………………………………….	*Salvia santolinifolia*
8	a	Colpi highly raised………………………………………….	*Salvia cabulica*
	b	Colpi highly sunken…………………………………………	*Salvia lanata*
9	a	Pollen in polar view spherical……………………………….	*Salvia plebeia*
	b	Pollen in polar view elliptic………………………………….	*Salvia reflexa*

Table 11. Factor loading of PCA **(**principal component analysis) using quantitative pollen characters.

Variables/factors	F1	F2	F3	F4	F5	F6	F7
PD	0.935	0.257	-0.014	0.040	0.228	-0.063	-0.044
ED	0.906	-0.318	-0.057	0.151	0.221	-0.016	0.043
P/E	-0.207	0.919	-0.137	-0.278	0.123	-0.013	0.023
CL	0.893	-0.067	0.240	-0.256	-0.221	-0.161	0.008
CW	0.930	-0.096	-0.086	-0.266	-0.058	0.211	-0.004
ET	-0.337	-0.139	0.906	-0.145	0.156	0.034	0.000
MC	0.536	0.634	0.387	0.364	-0.158	0.058	0.007
Eigenvalue	3.803	1.448	1.057	0.391	0.217	0.079	0.004
Variability (%)	54.332	20.684	15.097	5.585	3.105	1.134	0.063
Cumulative %	54.332	75.016	90.113	95.698	98.803	99.937	100.000

Keywords: PD=Polar diameter, ED=Equatorial diameter, P/E=Polar diameter divided by equatorial diameter, Cl= Colpi length, Cw=Colpi width

Table 12: Quantitative pollen micromorphological findings for the *Salvia* taxa examined.

S.no	Taxon	Polar diameter Mean (Min-Max) ± SE (µm)	Equatorial diameter Mean (Min-Max) ± SE (µm)	P/E ratio	Length of colpi Mean (Min-Max) ±SE (µm)	Width of colpi Mean (Min-Max) ± SE (µm)	Exine thickness Mean (Min-Max) ± SE (µm)	Mesocolpium Mean (Min-Max) ± SE (µm)	Fertility (%)	Sterility (%)
1.	*Salvia aegyptiaca* L.	33.05(32.25-33.75) ±0.26	28.65(27.25-31.25) ±0.69	1.15	12.75(12.25-13.25) ±0.17	5.75(5.25-6.25) ±0.17	5.00(4.50-5.50) ±0.17	15.15(14.50-15.75) ±0.23	81.3	18.6
2.	*Salvia cabulica* Benth.	36.95(33.50-43.75) ±1.7	15.75(15.25-16.25) ±0.17	2.34	6.25(5.75-6.75) ±0.17	6.25(5.75-6.75) ±0.17	2.95(2.25-3.50) ±0.21	13.95(13.25-15.25) ±0.34	87.3	12.6
3.	*Salvia coccinea* Buc'hoz ex Etl.	42.85(37.75-47.25) ±1.63	38.60(36.25-40.50) ±0.74	1.11	13.65(12.75-15.50) ±0.49	7.55(7.00-8.00) ±0.18	4.50(3.75-5.25) ±0.25	14.70(13.75-15.50) ±0.32	87.1	12.8
4.	*Salvia lanata* Roxb.	60.65(55.50-62.85) ±0.92	60.65(57.75-62.75) ±0.86	1	26.65(25.25-28.25) ±0.57	11.6(10.75-12.75) ±0.38	3.50(2.50-4.75) ±0.46	13.10(12.75-13.75) ±0.18	90.4	9.5
5.	*Salvia leucantha* Cav.	23.15(22.25-24.00) ±0.32	19.35(17.75-20.25) ±0.48	1.19	12.80(12.25-13.25) ±0.16	5.95(5.50-6.25) ±0.14	4.95(4.50-5.25) ±0.14	7.75(7.00-8.75) ±0.30	90.1	9.8
6.	*Salvia moorcroftiana* Wall. ex Benth.	50.65(48.00-53.00) ±1.01	47.70(45.25-50.25) ±0.88	1.06	25.00(23.75-26.25) ±0.44	11.1(10.25-12.75) ±0.44	2.90(2.50-3.25) ±0.12	11.75(10.25-13.00) ±0.50	88.8	11.1
7.	*Salvia nubicola* Wall. ex Sweet	46.15(41.50-49.75) ±1.57	47.25(42.75-53.25) ±1.75	0.97	9.20(8.25-10.25) ±0.33	7.85(6.75-9.00) ±0.40	3.10(2.50-3.75)	12.75(10.75-15.00) ±0.82	90.04	9.9

							±0.23			
8.	*Salvia plebeia* R.Br.	30.45(27.75-33.25) ±1.09	28.15(26.25-31.25) ±1.00	1.08	8.80(7.75-10.25) ±0.45	5.00(4.50-5.50) ±0.17	3.10(2.50-3.75) ±0.20	9.65(8.75-10.25) ±0.25	90.9	9.09
9.	*Salvia reflexa* Hornem.	27.25(25.25-30.25) ±0.86	36.00(33.00-39.00) ±1.00	0.75	10.30(9.50-11.25) ±0.32	6.30(5.75-6.75) ±0.16	3.75(3.50-4.25) ±0.13	7.90(7.25-8.75) ±0.24	82.5	17.4
10.	*Salvia rhytidea* Benth.	21.75(20.50-23.25) ±.493	25.9(23.25-27.50) ±.772	0.83	10.0(9.5-12.5) ±.562	7.70(7.0-8.25) ±.215	3.75(3.25-4.25) ±.176	9.7(8.7-11.7) ±.440	90.1	9.85
11.	*Salvia santolinifolia* Boiss.	43.20(41.25-45.25) ±0.65	41.65(37.75-46.25) ±1.49	1.03	18.00(17.25-18.75) ±0.25	8.60(7.75-10.25) ±0.44	2.35(2.00-2.75) ±0.12	14.65(13.75-15.50) ±0.34	82.2	17.7
12.	*Salvia splendens* Sellow ex Schult.	53.30(46.25-63.25) ±3.16	41.45(39.00-43.75) ±0.83	1.28	24.60(21.25-27.75) ±1.15	9.10(8.00-9.75) ±0.33	4.00(2.75-5.50) ±0.61	22.80(20.75-25.25) ±0.82	80.4	19.5

Keywords: Min= Minimum, Max= Maximum, SE= Standard Error, P= Polar Diameter, E= Equatorial Diameter, µm= Measurement in Micrometer

Table `13: Qualitative pollen morphological findings for the *Salvia* taxa examined.

S.no	Taxon	Pollen size	Pollen shape	Shape of pollen in polar view (Amb)	Shape of pollen in equatorial view	Aperture type	Exine sculpturing	Colpi apex	Colpi orientation	Pore P/A
1.	*Salvia aegyptiaca* L.	Medium	Sub prolate	Elliptic	Broad elliptic	Hexazonocolpate	Bireticulate perforate	Slightly acute	Colpi sunken	Absent
2.	*Salvia cabulica* Benth.	Small-medium	Per prolate	Spherical	Spherical	Hexazonocolpate	Reticulate	Slightly acute	Highly raised	Absent
3.	*Salvia coccinea* Buc'hoz ex Etl.	Medium	Prolate-spheroidal	Broad elliptic	Oblong	Hexazonocolpate	Reticulate perforate	Rounded	Highly raised	Absent
4.	*Salvia lanata* Roxb.	Large	Spherical	Spherical	Broad elliptic	Hexazonocolpate	Reticulate	Acute	Highly sunken	Absent
5.	*Salvia leucantha* Cav.	Small	Sub prolate	Spherical	Elliptic	Hexazonocolpate	Bireticulate	Slightly acute	Slightly sunken	Absent
6.	*Salvia moorcroftiana* Wall. ex Benth.	Large	Prolate	Spherical	Elliptic	Hexazonocolpate	Micro-reticulate perforate	Rounded	Slightly sunken	Absent
7.	*Salvia nubicola* Wall. ex Sweet	Large	Oblate - spheroidal	Elliptic	Broad elliptic	Hexazonocolpate	Reticulate perforate	Slightly rounded	Highly raised	Absent
8.	*Salvia plebeia* R.Br.	Medium	Prolate	Spherical	Elliptic	Hexazonocolpate	Reticulate	Slightly acute	Slightly sunken	Absent
9.	*Salvia reflexa* Hornem.	Medium	Oblate	Elliptic	Spherical	Hexazonocolpate	Reticulate	Acute	Deeply sunken	Absent

10.	*Salvia rhytidea* Benth.	Medium	Sub-oblate	Elliptic/ Ovate	Broad ovate	Hexazonocolpate	Coarsely reticulate perforate	Acute	Deeply sunken	Absent
11.	*Salvia santolinifolia* Boiss.	Medium	Prolate-spheroidal	Spherical	Elliptic	Hexazonocolpate	Micro-reticulate perforate	Acute	Highly raised	Absent
12.	*Salvia splendens* Sellow ex Schult.	Medium-large	Sub prolate	Spherical	Broad ovate	Hexazonocolpate	Bireticulate perforate	Rounded	Slightly sunken	Absent

Keywords: P= Present, A= Absent

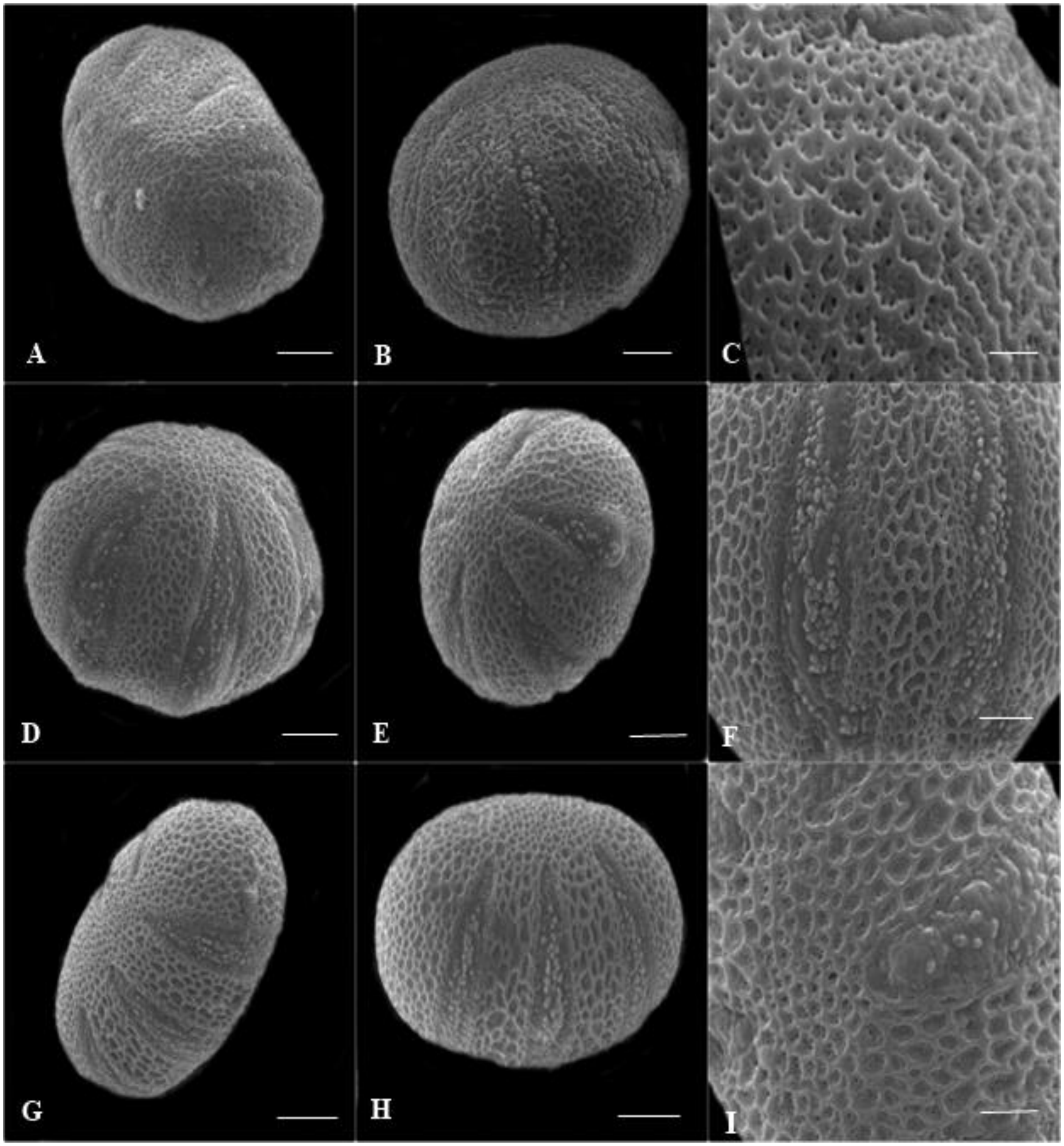

Plate. 62: Scanning electron micrographs of pollen of Salvia taxa, A polar view, B equatorial view, C exine sculpturing, of *S. aegyptiaca.* D polar view, E equatorial view, F exine sculpturing of *S. caubalica*. G polar view, H equatorial view, I exine sculpturing of *S. coccinea*. Scale bar 5µm for polar and equatorial micrographs, except in D, E, G and H (10 µm), scale bar 1µm for exine sculpturing in (C) and 5 µm in (F and I).

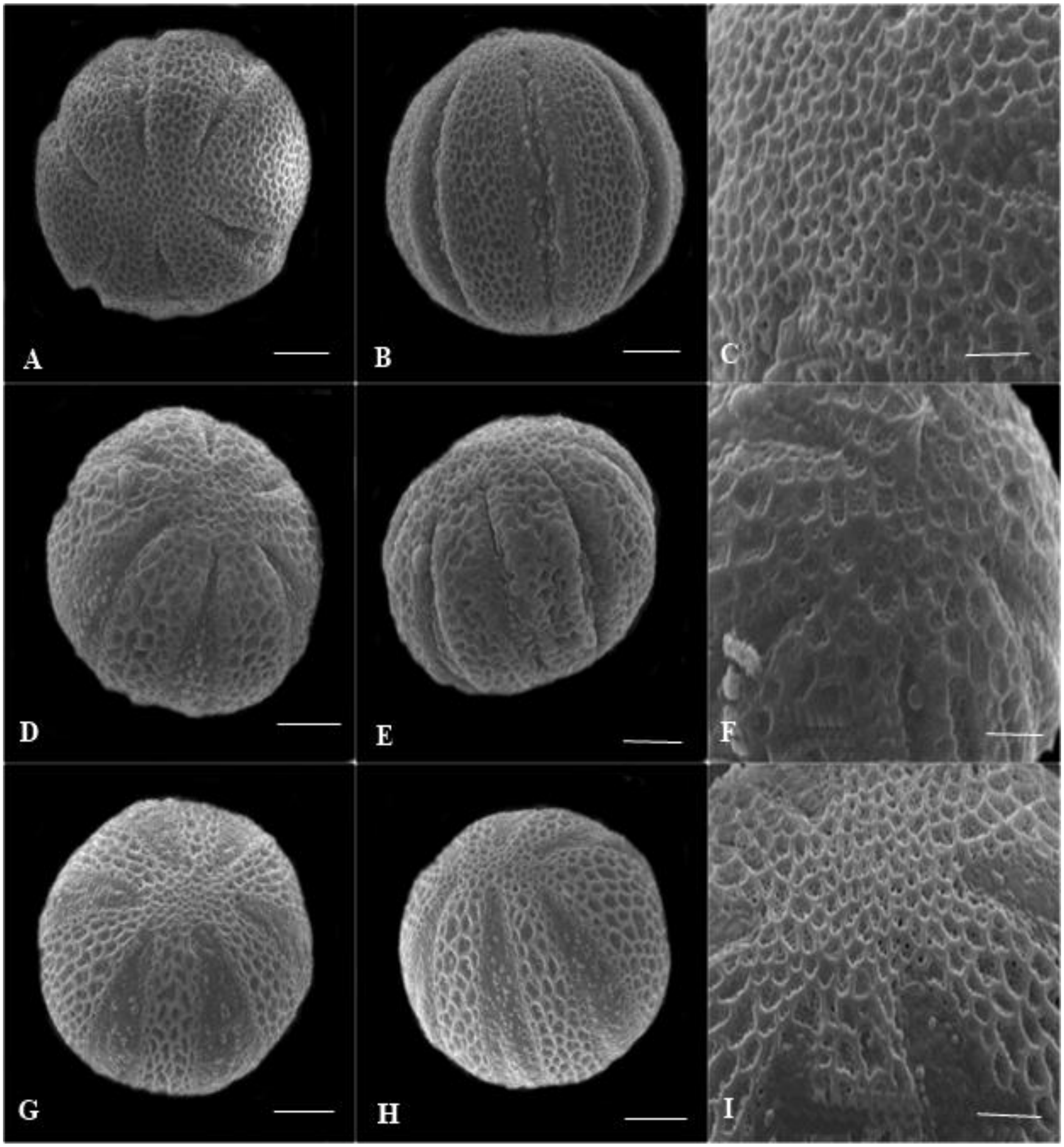

Plate. 63: Scanning electron micrographs of pollen of Salvia taxa, A polar view, B equatorial view, C exine sculpturing, of *S. lanata*. D polar view, E equatorial view, F exine sculpturing of *S. leucantha.* G polar view, H equatorial view, I exine sculpturing of *S. morcraftiana*. Scale bar 10µm for polar and equatorial micrographs, for (A, B, G and H) 10 µm, Scale bar 2µm for exine sculpturing.

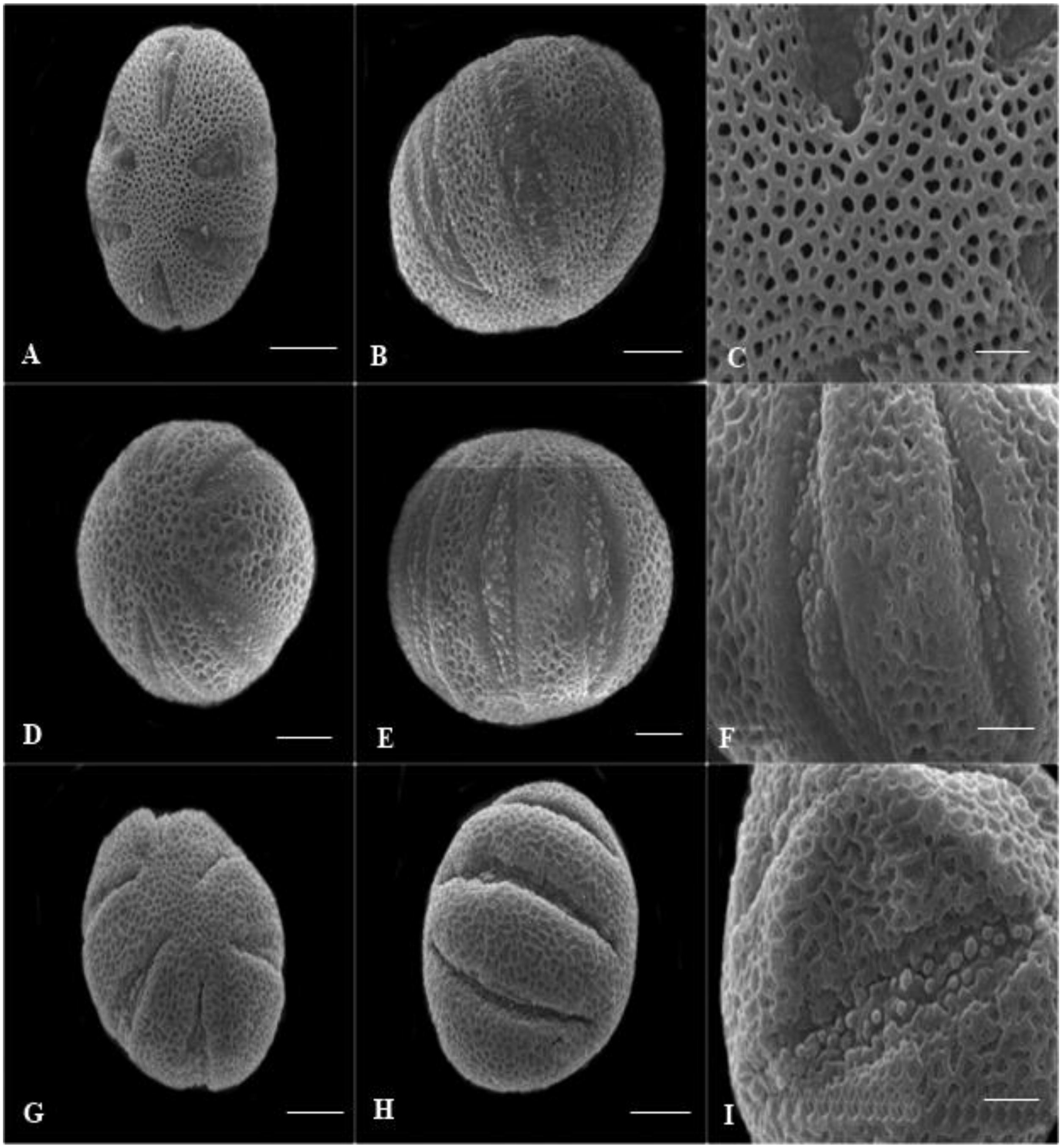

Plate. 64: Scanning electron micrographs of pollen of Salvia taxa, A polar view, B equatorial view, C exine sculpturing, of *S. nubicola*. D polar view, E equatorial view, F exine sculpturing of *S. plebia*. G polar view, H equatorial view, I exine sculpturing of *S. reflexa*. Scale bar 5µm for polar and equatorial micrographs, for (A, B) 10 µm, Scale bar 2µm for exine sculpturing.

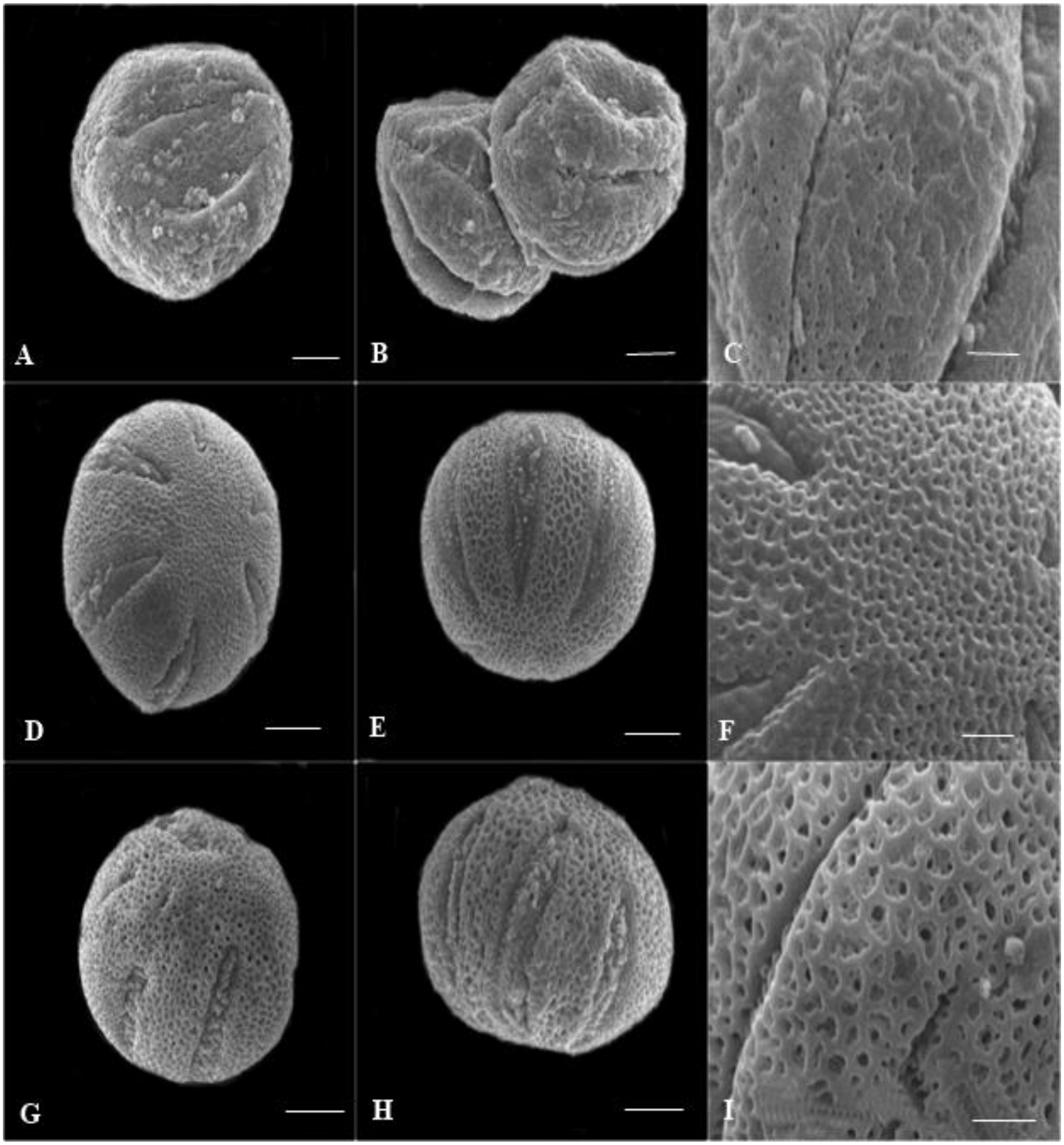

Plate. 65: Scanning electron micrographs of pollen of Salvia taxa, A polar view, B equatorial view, C exine sculpturing, of *S. rhytidea*. D polar view, E equatorial view, F exine sculpturing of *S. santolinifolia*. G polar view, H equatorial view, I exine sculpturing of *S. splendens*. Scale bar 10 μm for polar and equatorial micrographs, Scale bar 2μm for exine sculpturing.

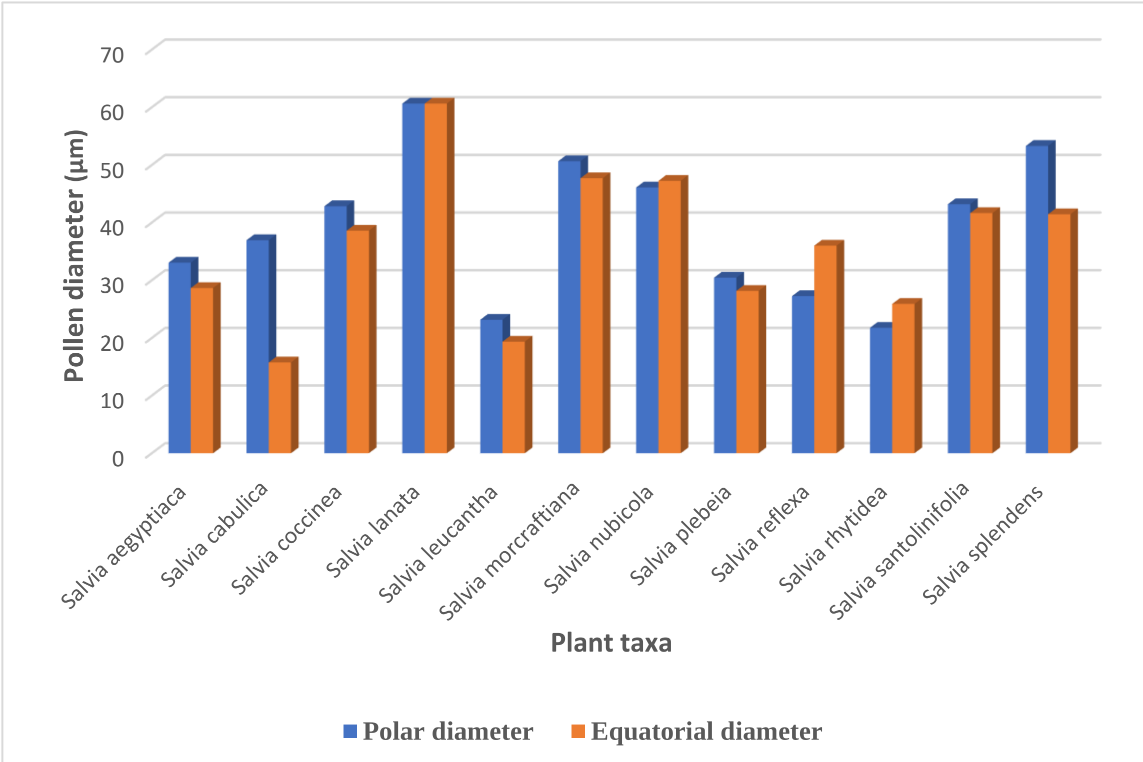

Figure 32: Variation among polar and equatorial diameter in different pollen taxa of genus *Salvia* L.

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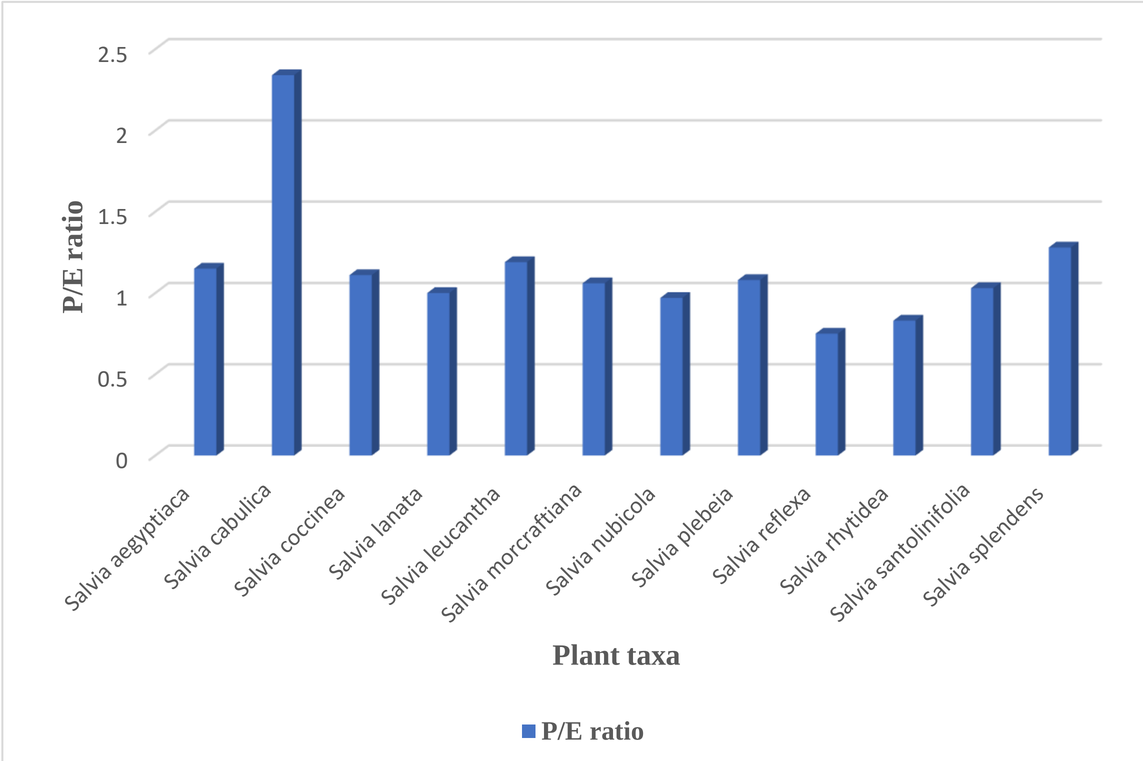

Figure 33: P/E ratio of pollen species of genus *Salvia* L.

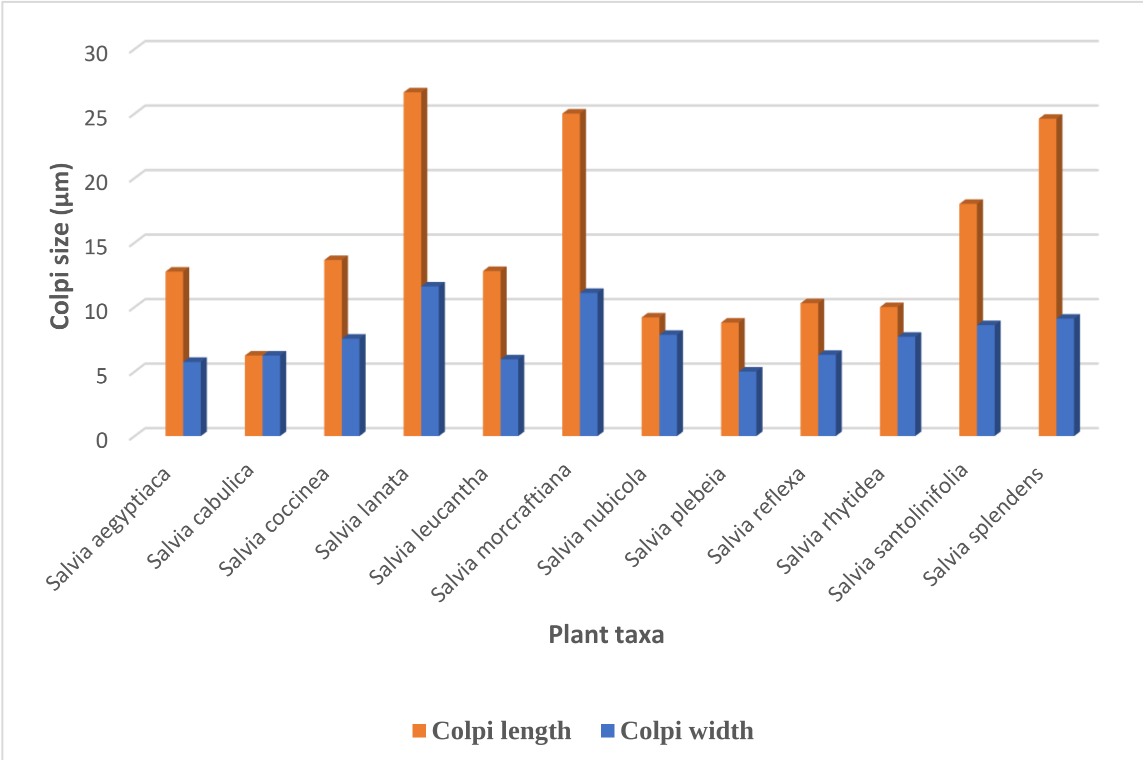

Figure 34: Variation among colpi length and width of genus *Salvia* L.

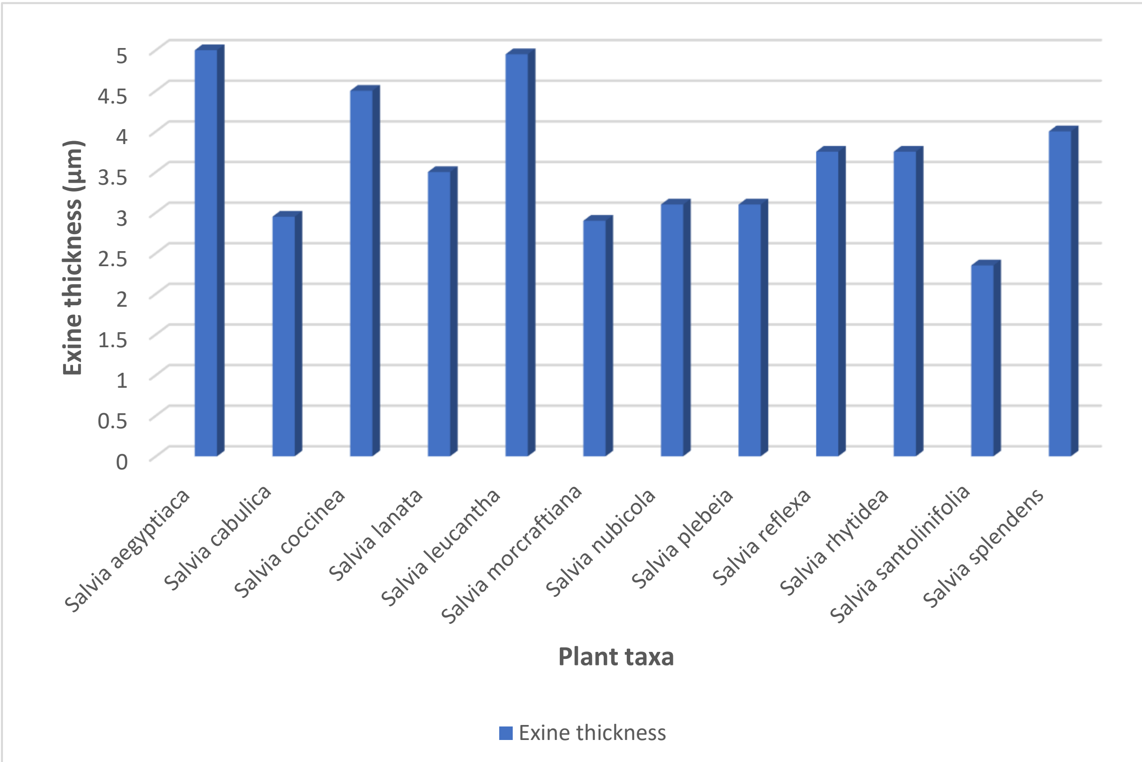

Figure 35: Showing variation in exine thickness in different taxa of genus *Salvia* L.

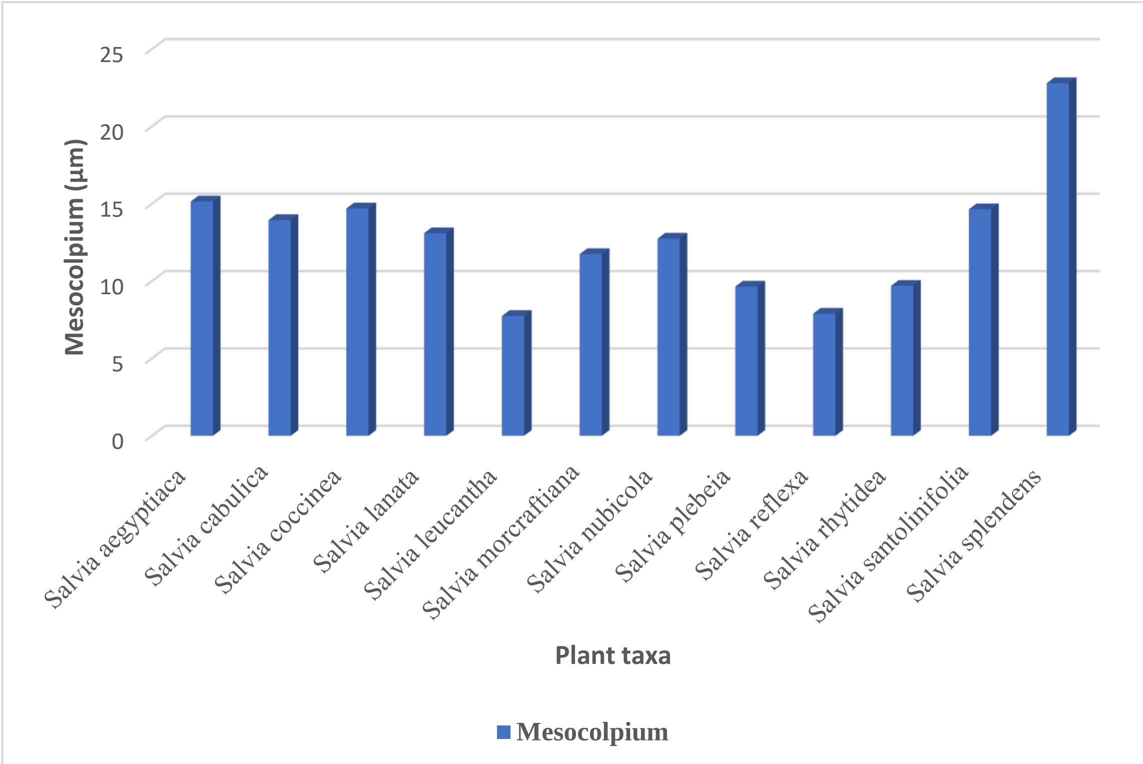

Figure 36: Showing variation in mesocolpium in different taxa of genus *Salvia* L.

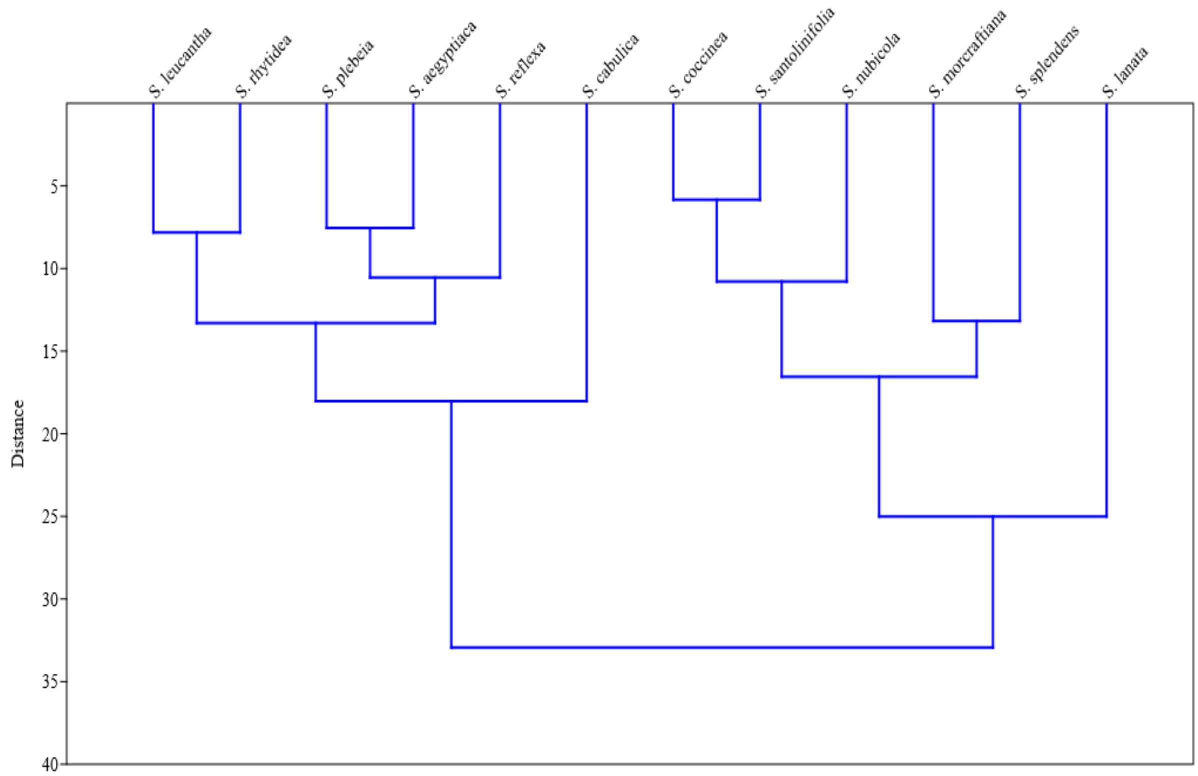

Figure 37: Cluster dendrogram exhibiting similarities among pollen (*Salvia* taxa) based on pollen quantitative morphological traits

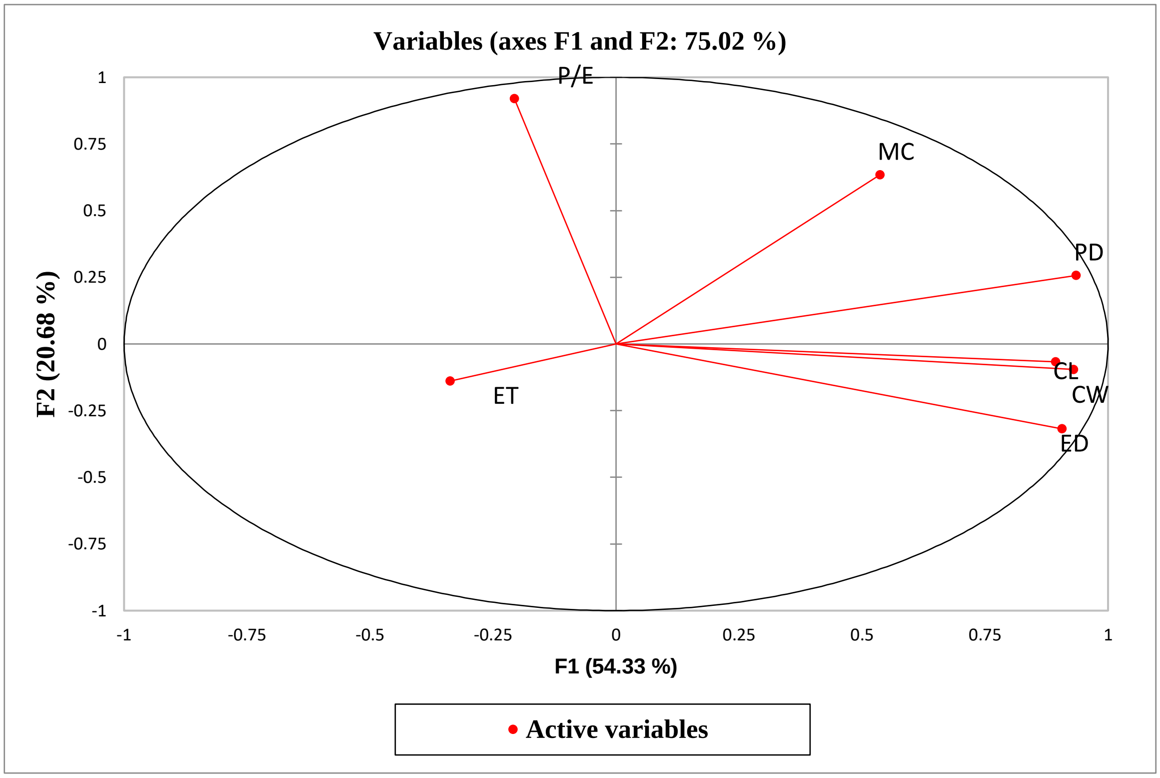

Fig. 38: Active variables of pollen of PCA biplot

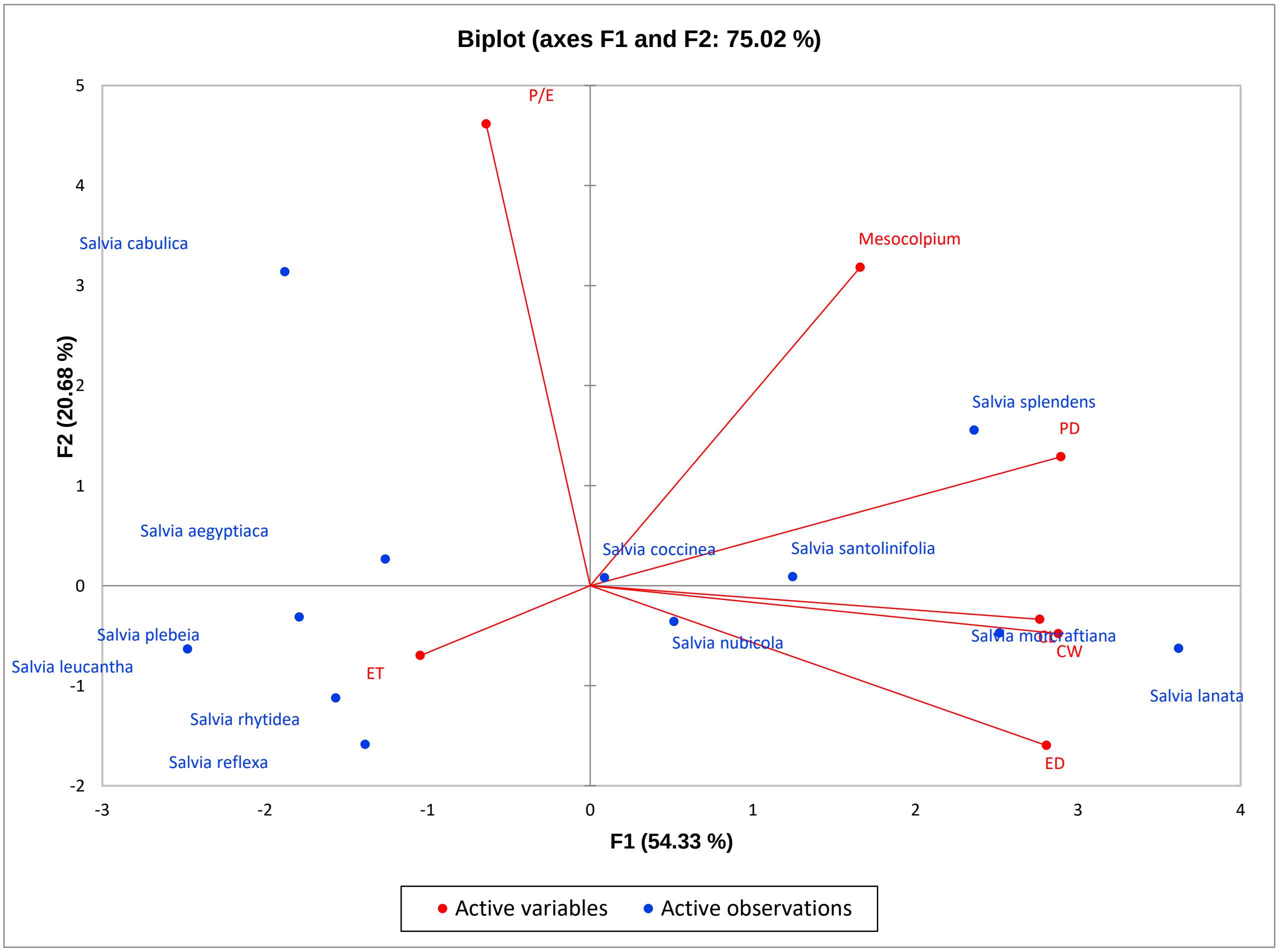

Figure 39: Multivar-Principal Component scatter analysis among the studied *Salvia* species based on palyno-morphological characteristics.

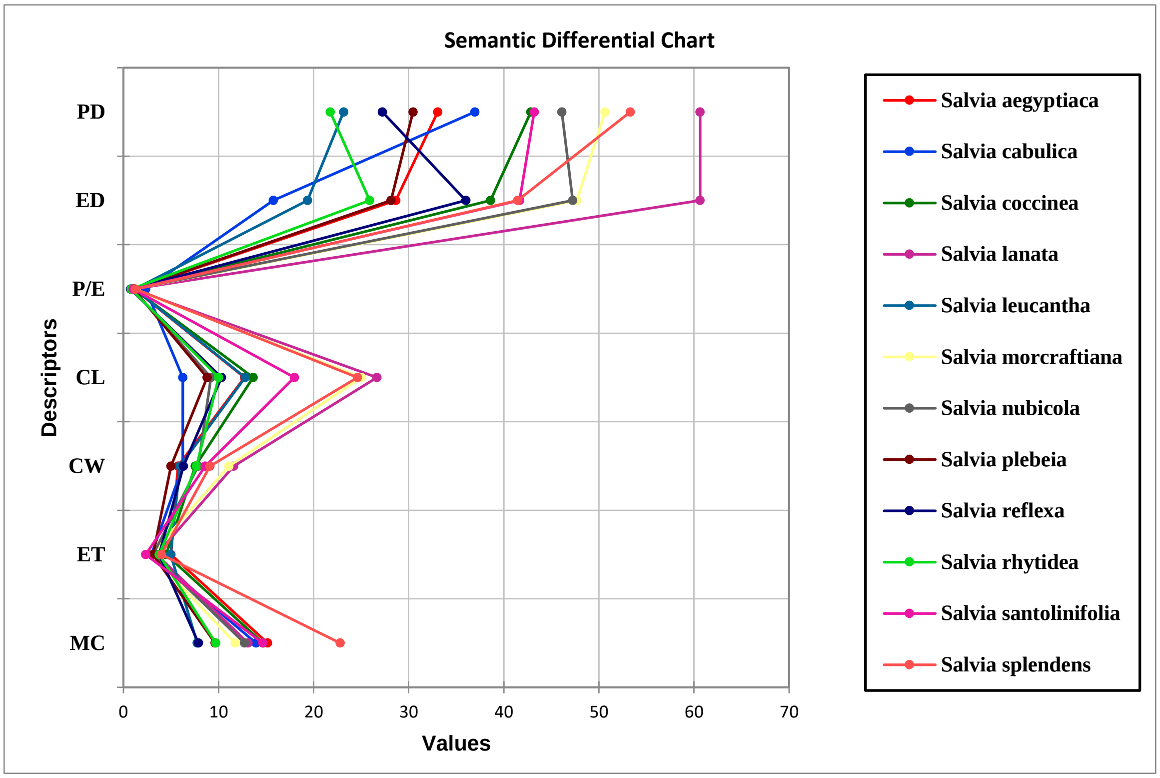

Fig. 40: Semantic Differential Chart based on pollen quantitative findings of Genus Salvia

Discussion

In present study, pollen of 12 *Salvia* taxa from Pakistan was studied using scanning electron microscopy (SEM). The size, shape, number of colpi, and surface characteristics of pollen grains of *Salvia* L. species were studied. Table 12 shows the pollen's quantitative statistics, whereas Table 13 shows the pollen's qualitative characteristics. Taxonomic keys based on palynological characteristics were constructed for identification and species delineation. The studied pollen size ranges from small to large, and pollen shape ranges from per oblate to per prolate. This shows that the pollen shapes of the studied species exhibited considerable differences and great differences of size among taxa. Largest pollen size (60.65 µm) is recorded in *S.lanata*, and the smallest one (23.15 µm) in *S. leucantha.*

Pollen is elliptic to spherical in polar view. The hydration state or fixation usually influences the size and shape of Lamiaceae pollen (Demissew and Harley 1992; Lens et al., 2005). The pollens are usually hexazonocolpate, previous investigations also possess only hexazonocolpate pollen grains Hassan et al., (2009) and Frat et al., (2017), like our investigation.

(Erdtman, 1945), studied Lamiaceae pollen and classified it into two subfamilies based on mature grains' number of apertures and nuclei. Tricolpate pollen is shed by the Lamioideae subfamily in a two-celled stage, while hexacolpate (sometimes 8 to 12 colpate) is shed by the Nepetoideae subfamily in a three-celled stage. Wunderlich's (1967), through extensive pollen survey significantly backed up Erdtman groups. Based on palynological characteristics, (Cantino et al., 1992) changed the taxonomy of numerous Lamiaceae taxa. He also assigned *Salvia* to the Nepetoideae subfamily because its pollen grains were hexacolpate.

Perveen and Qaiser (2004) placed the studied *S*alvia species in group IV i.e., (*S.cabulica, S.plebeia, S.lanata, S. moorcroftiana, S. aegyptiaca and S. nubicola*) based on aperture type, exine sculpturing and shape of pollen grains. According to their findings, the shape of pollens was oblate-spheroidal to sub oblate, and they were 6 colpate or 6 zonocolpate, exine sculpturing is finely to coarsely reticulate, colpus not sunken not in accordance with the pollen shapes of our studied taxa. In our study shapes of pollens are as follows i.e., *S. cabulica* is per prolate, spherical in *S. lanata*, sub prolate in *S. aegypiaca* and prolate in *S. moorcraftiana* and *S. plebeia*. Only one species shows similarity in pollen shape, that is *S. nubicola* i.e., oblate spheroidal. Aperture type is like Perveen and Qaiser (2004). Exine sculpturing is reticulate perforate in (*S. moorcroftiana, S. aegyptiaca, S. plebeia and S. nubicola*), which is different from previous study of Perveen and Qaiser (2004) while exine sculpturing is same in *S. cabulica* and *S. lanata* i.e., reticulate. In our findings colpi is either raised or sunken.

According to Hassan et al., (2009) the pollen shape of *S. aegypiaca* is prolate-spheroidal to spheroidal, which is different from our findings, i.e., pollen shape of *S. aegyptiaca* is sub prolate, while exine sculpturing is same in both studies, i.e., reticulate perforate. According to Azzazy (2016) the pollen grains of *S. splendens* are single, isopolar, and hexazonocolpate in equatorial view, the pollen shape is prolate, and in polar view, it is circular with reticulate exine ornamentation. While our study shows difference in shape and in exine ornamentation. It is sub prolate in equatorial view and exine sculpturing is reticulate perforate. The pollen in polar veiw is circular, as Azzazy (2016). Previous studies of Sales (2010) shows that the pollen shape of *S. plebeia* is prolate, like our findings. Exine sculpturing is bi-reticulate perforate, which is different from our investigations. Al-Watban et al., (2015) reportd that the pollen of *S. aegyptiaca* is medium size, which is similar in size to our studies, while pollen shape is sub spheroidal and exine sculpturing is bi-reticulate perforate which is different from our findings.

Previous studies by Kahraman et al., (2010) observed hexacolpate pollen, pollen shape is sub oblate to prolate spheroidal with bireticulate perforate exine sculpturing in *S. glutinosa and S. staminea*, similar to our studied *Salvia* taxa. Palynological studies revealed by Kahraman et al., (2009a) in *S. indica* also shows suboblate to prolate spheroidal pollen shape with bireticulate perforate exine sculpturing shows similarity to our investigation. Exine sculpturing in euryreticulate in *S. anatolica* pollen investigated by Hamzaoglu et al., (2005) which is dissimilar to our studied taxa. Palynological studies revealed by A.Jafri and M.Nikian (2008) show hexacolpate, pro oblate ellipsoid pollen with bireticulate surface sculpturing similar to our studies but shows difference in pollen shape of *S.macilenta* which is rectangular. Previous studies of Mehmet et al., (2017) finds hexacolpate, oblate, suboblate and spheroidal, isopolar pollen with reticulate or reticulate perforate exine sculpturing like our studies but shows difference in aperture type.

According to Kahraman et al., (2010) the pollen shape of *Salvia chrysophylla* is oblate spheroidal with bireticulate perforate exine sculpturing similar to our investigation. Kahraman et al., (2010) studied *S. macrochlamys* pollen which is hexacolpate, oblate spheroidal shape with bireticulate perforate exine sculpturing coincides with our investigation while shows difference in aperture type. According to Bedolla-Garcia et al., (2020) the pollen shape of *Salvia assurgens* is suboblate, pollen is hexacolpate with bireticulate exine ornamentation which is similar to our observations. Celep et al., (2014) reported that the pollen of *Salvia quezelii* are isopolar with prolate spheroidal to oblate spheroidal pollen shape and exine ornamentation is reticulate perforate which is similar to our findings. According to Özler et al., (2013) the pollen are shed as a monad, pollen shape in the polar view is elliptic to spherical which is similar to our studies but difference of shape in equatorial view and in our studies 100% pollen are hexazonocolpate which is similar to the previous study. Previous study by Akta et al., (2020) reported that the pollen grains dispersed as monad , isopolar , hexacolpate and pollen shapes are similar to our investigation but differences in exine sculpturing. According to Myoung and Yuon (2012) investigate pollen grains are medium size similar to our observation but different in pollen shape and exine ornamentation. According to Özler et al., (2011) the pollens are shed as monad and reticulate perforate in (19 taxa) exine ornamentation was similar to our finding and pollen shape in equatorial view is sub oblate to sub prolate and in polar view it is more or less circular which is different from our studied *Salvia* taxa.

Section-III

Foliar Anatomical Characterization of Lamiaceous Taxa

3.6 Anatomical Characterization of Lamiaceous Flora

This study considers the foliar epidermal micromorphological characters in addition to existing taxonomic information, mainly for the correct identification of Lamiaceous flora in Northern Pakistan. Due to difficulty in plant identification morphologically, this study was designed to use scanning electron microscopy to examine the foliar epidermal anatomy of selected species of Lamiaceae. The observed microstructural characteristics offer helpful data for the delimitation, subsequent identification, and taxonomy regarding the traits viz epidermal cell shape and nature, type and shape of stomata, type, and shape of trichomes.

The epidermal sculpturing patterns and foliar epidermal micromorphology of 60 Lamiaceae species showed stable foliar anatomical features that are diagnostic and are crucial for differentiating the taxa. Foliar epidermal investigation was carried out on 27 Lamiaceous taxa followed by subfamiliy Nepetoideae (33 species).

3.6.1 Foliar Epidermal Micromorphology of Lamiaceous taxa

The current study focused on the micromorphology of the foliar epidermis in 27 taxa of the Lamiaceae. Light microscopy (LM) and scanning electron microscope (SEM) were used to analyze the foliar epidermal micromorphology. We investigated the quantitative as well as qualitative traits of foliar epidermis in the data reported here and discovered that there were significant variations in foliar epidermal morphological attributes (Tables 14, 15, and 16). The scanning electron micrographs were illustrated in (Plate 66-74).

3.6.2 Foliar Epidermal Micromorphology

Most taxonomic research was focus on the leaf epidermis, and one of the most important taxonomic features in bio systemics is the foliar epidermal structure. Shapes and sizes, types, distribution, orientation, and frequency of epidermal cells, stomata, and trichomes, are all important phylogenetic indicators (James et al., 2021). According to Akinsulire et al., (2020) the leaf has a number of anatomical characteristics that are important in terms of taxonomy. According to Metcalfe (1968) several epidermal traits, such as the appearance of the subsidiary cells, trichomes, microscopic follicles & prickles, are of systematic value. According to Fajuke et al.,

(2018) the stomatal ratio and guard cell area provide values that may be utilized as comparison metrics across taxa, which can be helpful for taxon identification.

Significant differences were observed on both adaxial and abaxial foliar surfaces. Considerable variations were observed in epidermal cell shape and size of the examined species. Three different types of epidermal cell types were examined on both foliar surfaces i.e., irregular, hexagonal, and polygonal. Variation was also observed on lobes per epidermal cell that is a minimum of 3 to a maximum of 15 lobes were examined on both surfaces. 3-5 is the minimum lobe number at adaxial surface in *Vitex agnus-castus* while 13-15 is the maximum lobe number at abaxial surface studied in *Scutellaria grossa*. Different types of wall pattern were examined; sinuate, undulate beaded, angular, smooth-striate, smooth and angular, smooth and linear, smooth and undulate. The undulate wall pattern is dominant observed in eight species followed by sinuate wall pattern in five species. Smooth-striate wall pattern was observed in *Clerodendrum umbellatum* as a unique trait. Epidermal cells show variation in length and width. The highest epidermal cell length on adaxial and abaxial surfaces was observed in *Lamium album* (75.2 µm) and *Ajuga integrifolia* (67.5 µm), respectively. Similarly, the lowest epidermal cell length on adaxial and abaxial surfaces was observed in *Marrubium vulgare* (20 µm) and *Marrubium vulgare* (21 µm), respectively. The highest epidermal cell width on adaxial and abaxial surfaces was observed in *Ajuga reptans* (50 µm) and *Phlomis stewartii* (37 µm). Similarly, the lowest epidermal cell width on adaxial and abaxial surfaces was observed in *Scutellaria grossa* (12 µm) and *Leonurus sibiricus* (10 µm) (Fig. 41).

The subsidiary cells show less variation in cell shape, all the studied species have irregular subsidiary cells except in *Callicarpa macrophylla* where subsidiary cells are not visible. The highest subsidiary cell length on adaxial and abaxial side were observed in *Phlomis stewartii* (76 µm) and *Phlomis stewartii* (73 µm) respectively. Similarly, the lowest subsidiary cell length on adaxial and abaxial surfaces was observed in *Phlomidoschema parviflorum*, *Teucrium stocksianum* (24 µm of each) and *Ajuga parviflora*, *Callicarpa macrophylla* (20 µm of each), respectively. The highest subsidiary cell width on adaxial and abaxial surfaces was observed in *Ajuga integrifolia* (43 µm) and *Ajuga parviflora* (63 µm) respectively.

Similarly, the lowest subsidiary cell width on adaxial and abaxial surfaces was observed in *Scutellaria prostrata* (11µm) and *Leonurus sibiricus* (12 µm) respectively.

In order to solve identification issues between groups of plants from various phytogeographic regions of Pakistan, many scientists employed plant anatomical methodologies which includes the works of Rashid et al., (2019) on several species of the tribe Trifolieae; Gul et al., (2019) on Lamiaceous species; Shah et al., (2018) investigate some species of ferns from the Pteridaceae and Dryopteridaceae families; Ullah et al., (2018) on the species of the Caryophyllaceae; Raza et al., (2022) on some species of Acanthus; Ashfaq et al., (2019) on the convolvulaceous taxa; and Khan et al., (2019) on the identification of gymnosperms.

According to Zaman et al., (2022b) the epidermal cells shape of *Clerodendrum trichotomum* is trigonal to irregular, pentagonal with anomocytic and oblong stomata, similar to our studies in epidermal cell shape of *Clerodendrum inerme* and also similar in stomata type of the studied *clerodendrum* species but different in stomata shape. Similarly, in (*Leonurus japonicus*, *Marrubium vulgare* and S*cutellaria* species) similarity was observed in epidermal cell shape of *Marrubium vulgare,* dissimilarity in epidermal cell shape of *Leonurus japonicus* and S*cutellaria* species except in *Scutellaria linearis*, the stomata type is consistent to our studied taxa but inconsistent in stomata shape. According to Zaman et al., (2022a) the epidermal cell shape of *vitex negundo* not coincides with our results but shows similarity in stomata absences. In the current study the adaxial epidermal cells are larger in size than abaxial epidermal cells similar with Atalay et al., (2016) but dissimilar in epidermal cell shape. According to Herman, (1998) the epidermal cells of their studied *clerodendrum* species not in favor with our results but in favor in stomata type and trichome type.

3.6.3 Stomatal Complex Micromorphology

In the current research 13 species are hypostomatic, 12 species are amphistomatic and two species showed no stomata on either surface. This study shows a high number of stomata at abaxial surface as compared to adaxial surface. More than one type of stomata was observed in single taxa. In the current study four main types of stomata were observed: anomocytic, diacytic, anisocytic, and paracytic. Anomocytic stomata is dominant studied in 8 species followed by paractic in 5 species, anisocytic in 4 species and diacytic in 2 species that is in *Phlomis stewartii* and in *Ajuga reptans*. The shape of the stomatal pore is elliptic, oval, and broad elliptic. Elliptic shape stomata are dominant in the current study. Lamiaceous taxa shows a wide variation in stomata size. The largest stomata length at the adaxial surface was observed in *Ajuga reptans* (35 µm) and the lowest in *Scutellaria prostrata, Teucrium stocksianum* (20 µm for each). Similarly, the largest stomata width at the adaxial surface was observed in *Ajuga reptans* (26 µm) and the lowest in *Rydingia limbata* (13 µm). The largest stomata length at the abaxial surface was observed in *Clerodendrum splendens* (34 µm) and the lowest in *Vitex trifolia* (20 µm for each). Similarly, the largest stomata width at the abaxial surface was observed in *Ajuga parviflora* (29 µm) and the lowest in *Vitex trifolia* (12 µm). Fig. 42 summarized in Table 15 and 16.

Additionally, elongated kidney-shaped, narrow, and broad kidney-shaped guard cells appeared more frequently. Elongated shaped guard cell is studied only in *Ajuga integrifolia*. The guard cell size also shows great variation in the studied taxa. The maximum and minimum guard cell length at the adaxial surface was observed in *Ajuga reptans* (35 µm) and the lowest in *Scutellaria prostrata* (20 µm). Similarly, the maximum and minimum guard cell width at the adaxial surface was observed in *Phlomis stewartii* (14 µm) and the lowest in *Stachys palustris* and *Teucrium stocksianum* (5 *µm*). The maximum and minimum guard cell length at the abaxial surface was observed *Ajuga parviflora* (42 µm) and the lowest in *Callicarpa macrophylla* (14 µm*).* Similarly, the maximum and minimum guard cell width at the abaxial surface was observed in *Ajuga parviflora* (28 µm) and the lowest in *Callicarpa macrophylla, Clerodendrum inerme and Teucrium stocksianum* (5 µm) respectively.

In the present research, the stomatal pore shape can also differ greatly, for example, taking the form of an ovate, narrow, or broad ovate, elongated, or linear. Elongated stomatal pores are found only in *Clerodendrum splendens*. The maximum and minimum stomatal pore length at adaxial surfce was studied in *Moluccella aucheri* (25 µm) and *Ajuga parviflora, Stachys palustris* (9 µm of each) respectively. Similarly, the maximum and minimum stomatal pore width at adaxial was observed in *Ajuga reptans* (11 µm) and *Phlomidoschema parviflorum* (3 µm) respectively. The maximum and minimum stomatal pore length at abaxial was studied in *Ajuga parviflora* (50 µm) and *Clerodendrum inerme* (9 µm) respectively. Similarly, the maximum and minimum stomatal pore width at abaxial was observed in *Stachys floccosa* (12 µm) and *Callicarpa macrophylla* (4 µm) respectively.

The stomatal index indicates the highest and lowest densities of stomata on adaxial and abaxial surfaces. The highest stomata index (SI) at the adaxial surface was observed in *Moluccella aucheri* (32.1 %) and the lowest in *Stachys palustris* (1.9 %). Similarly, the highest stomata index (SI) at the abaxial surface was observed in *Marrubium vulgare* (58.7 %) and the lowest in *Phlomidoschema parviflorum* (4.5 %).

Thirty-three species in seventeen genera of the Lamiaceae were examined by Inamdar and Bhatt (1972) who discovered that the majority of the lamiaceae species only had stomata on the lower leaf surface (hypostomatic). However, Cantino (1990) noted that members of the family have stomata on both surfaces (amphistomatic) of leaves, with the latter type of leaves being present slightly more frequently. Gul et al., (2019b) observed stomata type of *Ajuga integrifolia*, *Ajuga parviflora*, *Marrubium vulgare* which were found similar in both results and in *vitex negundo* stomata were absent in both studies. Earlier studies of Haruna and Ashir (2017) investigate the epidermal cell shape of *vitex doniana* i.e., rectangular, isodiametric, or elongated similar to our observed taxa but different in stomata type and presence. According to the classification of Briquet (1895) observed *clerdendrum* species with hypostomatic leaves and anomocytic stomata similar to our studies in stomata type and location but different in stomata location in *Clerodendrum umbellatum.*

3.6.4 Trichome Micromorphology

Trichomes are unicelled or multicell hairs that develop from aerial epidermis cells (Werker, 2000). Different trichome types can produce within the same plant and can vary greatly in appearance, location, ability to secrete, and the way of secretion. We divided these into two groups, non-glandular and glandular, based on whether the trichome had a secretory head. Unicellular and multicellular, unbranched, and branched trichomes are the two forms of non-glandular trichomes. Studies of trichome type, size, and density in the Lamiaceae have revealed that some variations can occur within genera (Botanica, 2009) in same species (particularly in size and density) (Jurišić Grubešić et al., 2007) and between various organs of the same plant (Kahraman et al., 2010c). Majority of variations are species-specific in nature and can frequently be of taxonomic significance (Bini Maleci and Servettaz 1991; Navarro and El Oualidi 2000) also at the sub specific level (Gairola et al., 2009).

In the current research both foliar surfaces were covered with two main types of trichomes i.e., glandular trichomes and non-glandular but glandular trichomes are observed in most of the species as compared to the non-glandular. Lamiaceae has two types of glandular trichomes, small capitate and large peltate, which differ in size, structure, and distribution. But they varied from one another in terms of form, density, and positioning on leaves. Head cells of capitate and peltate trichomes can range from four to twelve. Following Cantino (1990) we made a distinction between capitate and subsessile trichomes for the glandular trichomes. In most of the Lamiaceae species have trichomes visible on both leaf surfaces.

3.6.4.1 Non glandular trichomes

Needle shape, non-glandular trichomes have pointed ends and are dragged towards the leaf's tip. They appear to be particularly numerous along the veins and midrib, especially on the abaxial surface. The four distinct forms of non-glandular trichomes are unicellular, multicellular, stellate, branched, and unbranched trichomes. In the present research ten species consist of non-glandular trichomes. Under SEM studies, non-glandular trichomes can also vary significantly. The shape, cell count, and surface ornamentation of non-glandular trichomes showed a large range of variance. Such trichomes were very diverse in length, width, and surface patterns in the SEM micrographs (Plates 66-74). Non-glandsular trichomes were further divided into subcategories, such as unicellular to multicellular trichomes with stellate, falcate, clavate, hook, conical, cylindrical, and simple shapes (up to six cells).

The maximum and minimum trichome length at adaxial was studied in *Ajuga integrifolia* (616 µm), *and Teucrium royleanum* (2 µm) respectively. Similarly, the maximum and minimum trichome width at adaxial was observed in *Stachys floccosa* (165 µm) and *Vitex agnus-castus* (9 µm) respectively. The maximum and minimum trichome length at abaxial was studied in *Clerodendrum umbellatum* (310 µm) and *Vitex negundo*, *Vitex trifolia* (56 µm of each) respectively. Similarly, the maximum and minimum trichome width at abaxial was observed in *Teucrium royleanum* (62 µm) and *Teucrium stocksianum*, *Vitex agnus-castus* (9 µm of each) Fig. 43.

The trichome index indicates the highest and lowest densities of trichomes on adaxial and abaxial surfaces. The highest trichome index (TI) at adxial surface was observed in *Vitex negundo* (92.6 %) and lowest in *Stachys palustris* (1.5 %). Similarly, the highest trichome index (TI) at abxial surface was observed in *Vitex negundo* (92.9 %) and lowest in *Stachys floccosa* (2 %).

According to de Oliveira et al., (2013) *Scutellaria agrestis* consist of diacytic stomata not agreed with our results, and also consists of peltate and capitate glandular trichomes similar to *Scutellaria prostrata* but different in *Scutellaria grossa* and *Scutellaria linearis* in terms of capitate trichomes. Earlier studies of Gerçek et al., (2022) investegate peltate and capitate glandular trichomes on leaf of *Stachys rizeensis* coincides to our results in mulicellular peltate and capitate GTs (glandular trichomes) in *stachys emodi* but different in capitate glandular trichome. Our studies shows the presence of glandular and non-glandular trichomes on both upper and lower epidermis of *Teucrium royleanum and Teucrium stocksianum* coincides the results of Dehshiri and Azadbakht (2012) but not coincides in upper and lower epidermis cell shape. According to Satil et al., (2007) *Hymenocrater bituminosus* conists of eglandular and glandular trichomes with diacytic stomata similar to our results. Earlier investegation of Sanoj and Deepa (2021) found only glandular trichomes in *Ocimum. basilicum* different from our results where glandular trichomes (peltate type) observed in *Ocimum americanum* but similar in terms of unicellular to multicellular head cells.

3.6.4.2 Glandular Trichomes

In the present research glandular trichomes are found on most of the foliar epidermal surface as compared to non-glandular trichomes. Capitate, peltate, Pilate and unicellular or multicellular are the four main types of trichomes in the current study. Peltate type was observed on both sides of the epidermis. GTs (glandular trichomes) are specialized structures formed from plant epidermal cells that serve a variety of biological functions and have taxonomic significance. Due to diverse secretors, capitate trichomes had different structures and functions (Kahraman et al., 2010a).

Capitate and peltate trichomes are the two main types of glandular trichomes. Peltate trichomes have a short stalk and head which is made up of 4-12 cells. Capitate is unicellular or multicellular (Serrato-Valenti et al., 1997) capitate trichomes are smaller than peltate trichomes. Previous studies of Celep et al., (2011) shows non glandular trichomes at adaxial surface of *Lamium truncatum* and capitate and peltate trichomes at abaxial surface different from our studied specie that is *Lamium amplexicaule*.

3.6.5 Principal Component Analysis (PCA) and Cluster Analysis of Leaf as a Statistical Tool

Cluster analysis has been confirmed the unique status of different plant groups (Candido et al., 2020, Arceo et al., 2021). Species were divided into two main clusters following (UPGMA) Euclidean distance based on 12 quantitative anatomical traits. The quantitative anatomical data distributes the studied taxa into two major clusters. Cluster 1is divided into two sub clusters, in which *Ajuga integrifolia* retains separate position as compared to *Ajuga reptans* and *Lamium amplexicaule* which shows great similarity. Cluster 2 is divided into 2 sub clusters which is further divided. In sub cluster 1 *Ajuga parviflora*, *Lamium album* and *Clerodendrum umbellatum* shows separate positions as compared to *Marrubium vulgare* and *Phlomidoschema parviflorum* which shows similarity. In sub cluster 2 *Clerodendrum splendens*, *Stachys emodi* and *Scutellaria grossa* showed isolated position as compared to *Vitex agnus-castus* and *Vitex negundo* showed greatest similarity as compared to the other studied taxa. (Fig. 44)

PCA reveals the highest contribution to the overall variability for each axis (Fig. 45, 46 and Table 17). The Eigen values show the overall number of variables and are frequently used to determine how many factors to keep (Sharma, 2006). In the present study, the epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each) of 27 Lamiaceous species were used to explore foliar anatomical variability. Principal component analysis variable loadings for first 12 significant components illustrated in Table 17. In the present study, five PCAs carried more than one eigenvalue and 63.79% of the total variance. Additionally, PC1 showed a variability of 48.45%, with a large positive loading element of the foliar epidermal characters, and PC2 showed a variability of 15.35%, with a large positive loading element of the foliar epidermal traits. Stomata pore length followed by stomata length are the valueable varibles on the positive se of the first axes. *Ajuga parviflora*, *Lamium album*, *Ajuga integrifolia* and *Scutularia palustris* show isolated position on the positive side of the first axes. *Teucrium stocksianum*, *Rydingia limbate*, *Vitex negundo* and *Vitex agnus-castus* were found on the negative side of the second axes. Moreover, the semantic differential chart shown in Fig. 47 (adaxial surface) and Fig. 48 (abaxial surface) were used to better illustrate and assess the studied foliar anatomical characteristics.

3.6.6 Dichotomous Key of Leaf of Lamiaceous taxa

1	+	Anticlinal wall pattern angular-undulate……………	*Callicarpa macrophylla*
	-	Anticlinal wall pattern other than angular-undulate….	2
2	+	Anticlinal wall pattern smooth-undulate……………	4
	-	Anticlinal wall pattern other than smooth-undulate…	3
3	+	Stomata type anomocytic…………………………...	*Lamium album*
	-	Stomata type paracytic……………………………….	*Scutellaria prostrata*
4	+	Anticlinal wall pattern smooth and linear……………	*Scutellaria linearis*
	-	Anticlinal wall pattern other than smooth and linear….	5
5	+	Anticlinal wall pattern beaded………………………...	*Vitex agnus-castus*

	-	Anticlinal wall pattern other than beaded……………	6
6	+	Plants are amphistomatic……………………………	*Rydingia limbata*
	-	Plants are hypostomatic……………………………….	*Phlomis bracteosa*
7	+	Anticlinal wall pattern smooth striate…………………	*Clerodendrum umbellatum*
	-	Anticlinal wall pattern other than smooth striate……	8
8	+	Stomata present……………………………………….	*Vitex trifolia*
	-	Stomata absent………………………………………	*Vitex negundo*
9	+	Anticlinal wall pattern smooth and angular…………	*Moluccella aucheri*
	-	Anticlinal wall pattern other than smooth and angular..	10
10	+	Anticlinal wall pattern sinuate beaded………………	13
	-	Anticlinal wall pattern other than sinuate beaded…….	11
11	+	Trichome sculpturing Slightly granular……………….	*Ajuga integrifolia*
	-	Trichome sculpturing smooth…………………………	12
12	-	Non glandular and glandular trichomes present………	*Ajuga parviflora*
	+	Only glandular trichome present……………………	*Clerodendrum inerme*
13	+	Anticlinal wall pattern sinuate………………………	17
	-	Anticlinal wall pattern other than sinuate…………….	14
14	+	Shape of stomatal pore linear…………………………	*Marrubium vulgare*
	-	Shape of stomatal pore other than linear……………	15
15	+	Guard cell kidney shape……………………………….	*Phlomis stewartii*
	-	Guard cell not clear……………………………………	*Stachys floccosa*
16	+	Stomata shape elliptic…………………………………	*Teucrium royleanum*
	-	Stomata shape oval……………………………………	*Teucrium stocksianum*
17	+	Anticlinal wall pattern undulate………………………	22
	-	Anticlinal wall pattern other than undulate…………	18
18	+	Trichome surface rough……………………………….	*Stachys emodi*
	-	Trichome surface other than rough……………………	19
19	+	Stomata diacytic……………………………………….	*Ajuga reptans*
	-	Stomata anisocytic…………………………………….	*Lamium amplexicaule*
20	+	Stomata paracytic……………………………………...	*Phlomidoschema parviflorum*
	-	Stomata other than paracytic………………………….	21

21	+	Shape of stomatal pore elongated……………………	*Clerodendrum splendens*
	-	Shape of stomatal pore ovate………………………….	*Leonurus sibiricus*
22	+	Stomata present……………………………………….	*Scutellaria grossa*
	-	Stomata absent ……………………………………….	*Stachys palustris*

Table 14: Qualitative characteristics of the leaf epidermal anatomy of observed Lamiaceae taxa

S. No	Plant name	Shape of epidermal cell Ad/Ab		Lobes per epidermal cell Ad/AB		Anticlinal Wall pattern	Stomata P/A Ad/AB		Stomata type	Shape of stomata	Shape of stomatal pore	Shape of guard cell	Subsidiary cell shape	Trichome P/A Ad/AB		Trichome type NGTs/GTs Ad/AB		Trichome sculpturing
		Ad	Ab	Ad	AB		Ad	AB						Ad	AB	Ad	AB	
1.	*Ajuga integrifolia* Buch. -Ham.	Irregular	Irregular	6-8	6-8	Sinuate-beaded	P	P	Amocytic-diacytic	Oval	Ovate	Elongated	Irregular	P	P	Multicellular NGTs, capitate and peltate GTs	Multicellular NGTs, capitate and peltate GTs	Slightly granular
2.	*Ajuga parviflora* Benth.	Hexagonal-Irregular	Hexagonal-Irregular	5-7	5-7	Sinuate-beaded	P	P	Anomocytic	Elliptic	Narrow ovate	Kidney shape	Irregular	P	P	Multicellular Pilate NGTs, capitate and peltate GTs	Multicellular NGTs, capitate and peltate GTs	Smooth
3.	*Ajuga reptans* L.	Irregular	Irregular	5-7	5-7	Undulate	P	P	Diacytic	Oval-elliptic	Ovate	Kidney shaped	Irregular	P	P	Multicellular and capitate GTs	Capitate and peltate GTs	Smooth
4.	*Callicarpa macrophylla* Vahl.	Irregular	Irregular	5-7	3-6	Angular-undulate	A	P	Anomocytic	Elliptic	Narrow ovate	Kidney shaped	Not visible	P	P	Uni cellular - Multicellular NGTs, peltate and capitate GTs	Uni cellular and Multicellular NGTs, peltate and capitate GTs	Smooth
5.	*Clerodendrum inerme* (L.) Gaertn.	Pentagonal-hexagonal	Irregular	5-6	4-6	Beaded-sinuate	A	P	Anomocytic	Elliptic	Ovate	Narrow Kidney shaped	Irregular	P	P	Peltate GTs	Peltate GTs	Smooth
6.	*Clerodendrum splendens* G.Don	Irregular	Irregular	8-11	6-8	Undulate	A	P	Anomocytic	Oval	Elongated	Slightly elongated	Irregular	P	P	Multicellular NGTs, peltate GTs	Unicellular NGTs, Peltate GTs	Slightly smooth
7.	*Clerodendrum umbellatum* Poir.	Irregular	Irregular	5-7	8-10	Smooth-striate	P	P	Anomocytic	Broad elliptic	Ovate	Kidney shaped	Irregular	P	P	Unicellular GTs	Unicellular GTs	Granular
8.	*Lamium album* L.	Irregular	Irregular	8-	10-	Smooth-	A	P	Anomocytic	Oval	Ovate	Slightly	Irregular	P	P	Unicellular	Multicellular	Slightly granular

				10	12	undulate						kidney shaped				clavate NGTs, Multicellular needle shape GTs	needle shape and peltate GTs	
9.	*Lamium amplexicaule* L.	Irregular	Irregular	10-12	9-10	Undulate	P	P	Anisocytic	Elliptic	Ovate	Kidney shaped	Irregular	P	P	Multicellular needle shape peltate, capitate GTs	Multicellular needle shape and peltate GTs	Granular
10.	*Leonurus sibiricus* L.	Irregular	Irregular	6-8	5-7	Undulate	A	P	Anomocytic	Oval	Ovate	Kidney shaped	Irregular	P	P	Multicellular needle shape NGTs, and peltate GTs	Multicellular needle shape NGTs, and peltate GTs	Slightly granular
11.	*Marrubium vulgare* L.	Irregular	Irregular	4-5	5-7	Sinuate	A	P	Anisocytic-anomocytic	Oval	Linear	Narrow kidney shaped	Irregular	P	P	Stellate NGTs, peltate GTs	Stellate NGTs, peltate GTs	Smooth
12.	*Moluccella aucheri* (Boiss.) Scheen	Polygonal	Polygonal	4-6	5-7	Smooth and angular	P	P	Anisocytic	Oval	Ovate	Narrow kidney shaped	Irregular	P	P	Multicellular and peltate GTs	Multicellular and Peltate GTs	Rough
13.	*Phlomidoschema parviflorum* (Benth.) Vved.	Irregular	Irregular	4-5	5-7	Undulate	P	P	Paracytic	Elliptic	Linear	Not clear	Irregular	P	P	Unicellular NGTs, peltate GTs	Branched NGTs	Smooth
14.	*Phlomis bracteosa* Royle ex Benth.	Polygonal	Irregular	5-7	4-6	Angular-sinuate	A	P	Not clear	Elliptic	Ovate	Kidney shaped	Irregular	P	P	Stellate NGTs	Stellate NGTs	Rough
15.	*Phlomis stewartii* Hook.f.	Irregular	Irregular	4-6	5-7	Sinuate	P	P	Diacytic-anomocytic	Oval	Linear	Kidney shaped	Irregular	P	P	Stellate NGTs	Stellate NGTs	Rough
16.	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	Polygonal	Polygonal irregular	4-6	6-7	Angular-sinuate	P	P	Paracytic	Oval	Narrow ovate	Not clear	Irregular	P	P	Multicellular NGTs, peltate GTs	Multicellular NGTs, peltate GTs	Granular
17.	*Scutellaria grossa* Wall.	Irregular	Irregular	7-9	13-15	Undulate	A	P	Anomocytic	Oval	Ovate	Kidney shaped	Irregular	P	P	Multicellular a GTs	Multicellular and NGTs,	Granular

																	peltate GTs	
18.	*Scutellaria linearis* Benth.	Polygonal	Polygonal	4-5	5-7	Smooth and linear	P	P	Parcytic	Elliptic	Linear	Slightly kidney shaped	Polygonal	P	P	Multicellular and peltate GTs	Multicellular and peltate GTs	Granular
19.	*Scutellaria prostrata* Jacquem. ex Benth.	Irregular	Irregular	8-10	5-7	Smooth and undulate	A	P	Parcytic	Oval	Ovate	Kidney shaped	Irregular	P	P	Multicellular a GTs	Multicellular and peltate GTs	Granular
20.	*Stachys emodi* Hedge	Irregular	Irregular	4-6	Not clear	Undulate	A	P	Not clear	Elliptic	Ovate	Not clear	Irregular	P	P	Multicellular NGTs and peltate, capitate GTs	Multicellular NGTs and peltate, capitate GTs	Rough
21.	*Stachys floccosa* Benth.	Irregular	Irregular	5-7	4-6	Sinuate	A	P	Anomocytic	Elliptic	Ovate	Not clear	Irregular	P	P	Multicellular a and peltate GTs	Multicellular a and peltate GTs	Smooth
22.	*Stachys palustris* L.	Irregular	Irregular	7-9	5-7	Undulate	P	P	Anomocytic	Broad elliptic	Broad ovate	Kidney shaped	Irregular	P	P	Multicellular NGTs	Multicellular NGTs, peltate GTs	Granulate
23.	*Teucrium royleanum* Wall. ex Benth.	Irregular	Irregular	5-7	4-6	Sinuate	A	P	Anisocytic-anomocytic	Elliptic	Ovate	Kidney shaped	Irregular	P	P	Multicellular cone shape NGTs	Multicellular cone shape NGTs peltate and capitate GTs	Granulate
24.	*Teucrium stocksianum* Boiss.	Irregular	Irregular	5-7	4-6	Sinuate	P	P	Anomocytic-paracytic	Oval	Narrow ovate	Not clear	Irregular	P	P	Unicellular conical and hook shape NGTs, peltate GTs	Unicellular conical and hook shape NGTs, peltate GTs	Granulate
25.	*Vitex agnus-castus* L.	Polygonal	Not visible	3-5	_	Beaded	A	A	_	_	_	_	_	P	P	Unicellular-multicellular conical NGTs, peltate GTs	Unicellular-multicellular conical NGTs	Smooth

26.	*Vitex negundo* L.	Polygonal	Not visible	4-5	_	Angular	A	A	_	_	_	_	_	P	P	Unicellular-multicellular conical NGTs	Unicellular-multicellular conical NGTs	Granular
27.	*Vitex trifolia* L.	Polygonal	Not visible	4-6	_	Angular	A	P	Not clear	Elliptic	Linear	_	_	P	P	Unicellular conical NGTs	Unicellular conical NGTs	Granular

Keywords: NGTs= Non glandular trichomes, GTs= Glandular trichomes

Table 15: Quantitative characteristics of foliar anatomy of the observed Lamiaceae taxa

S.no	Plant name	L× W	Epidermal cell size Min-Max = Mean±SE (μm) Ad/Ab		Guard cell size Min-Max = Mean±SE (μm) Ad/Ab		Stomata size Min-Max = Mean±SE (μm) Ad/Ab		Subsidiary cell size Min-Max = Mean±SE (μm) Ad/Ab	
1.	*Ajuga integrifolia* Buch. -Ham.	L	50.2-77.7=67.5±4.6	60.2-87.7=69.7±5.2	22.2-27.7=25.4±.98	23.7-30.5=26.2±1.2	22.2-27.7=25.4±.98	22.7-32.2=26.4±1.6	52.7-89.7=72.5±5.89	38.0-72.7=52.3±5.6
		W	29.7-59.7=44.8±5.5	24.7-45.7=32.6±4.0	5.2-7.7=7.0±.46	5.2-9.7=7.9±.84	15.2-24.7=19.8±1.6	14.7-20.2=17.9±.98	37.7-47.7=42.9±1.64	27.0-47.7=37.7±3.35
2.	*Ajuga parviflora* Benth.	L	55.7-78.2=67.2±3.7	34.7-49.5=41.6±2.9	22.2-26.0=24.6±.64	30.7-45.7=41.6±2.7	22.7-26.2=24.9±.58	5.2-6.0=5.5±.14	25.2-45.7=36.8±3.8	19.2-22.0=20.4±.47
		W	30.2-44.0=38.8±2.4	77.7-102.0=888.6±4.5	6.2-7.7=7.0±.25	26.7-29.7=28.2±.57	21.7-23.5=22.6±.30	27.0-30.2=28.5±.588	17.7-23.2=20.6±.94	57.7-68.2=62.9±1.88
3.	*Ajuga reptans* L.	L	71.2-76.5=73.6±1.0	42.2-49.2=45.4±1.1	33.7-35.7=34.8±.37	28.2-30.5=29.3±.40	32.0-36.2=34.8±.75	28.7-30.5=29.8±.35	43.5-53.2=48.6±1.66	25.2-45.2=34.4±4.1
		W	47.0-53.5=50.2±1.0	29.5-31.2=30.2±.31	12.0-13.2=12.6±.23	9.5-10.7=10.1±.23	24.7-26.2=25.5±.28	23.7-27.0=24.9±.56	29.7-34.0=31.7±.90	14.2-20.5=16.8±1.4

4.	*Callicarpa macrophylla* Vahl.	L	17.2-27.7=22.3±1.8	21.2-31.2=26.5±1.8	_	12.2-17.0=14.4±.81	_	12.7-17.2=14.7±.80	_	15.5-24.4=19.7±1.44
		W	12.2-19.7=14.7±1.3	11.2-24.7=18.1±2.2	_	3.2-5.5=4.5±.37	_	9.7-12.7=11.7±.51	_	7.7-15.5=11.7±1.26
5.	*Clerodendrum inerme* (L.) Gaertn.	L	30.2-34.5=32.2±.74	42.2-45.2=43.5±.51	_	22.7-27.2=25.6±.79	_	24.5-27.0=25.7±.42	_	27.0-34.7=30.0±1.34
		W	22.2-29.2=25.1±1.21	28.5-33.5=31.0±.83	_	4.5-5.5=4.9±.18	_	13.2-18.7=16.5±.94	_	22.7-27.2=25.2±.74
6.	*Clerodendrum splendens* G.Don	L	47.7-56.7=52.4±1.83	53.5-56.7=55.3±.572	_	27.2-42.2=32.8±2.64	_	27.7-47.7=34.1±3.51	_	22.7-32.2=28.0±1.71
		W	28.5-32.7=30.2±.745	25.2-36.7=30.1±2.15	_	5.25-6.50=5.80±.215	_	17.0-18.7=17.7±.306	_	20.2-25.2=22.7±.838
7.	*Clerodendrum umbellatum* Poir.	L	45.5-61.5=52.9±2.77	36.2-48.2=40.8±2.05	_	25.5-28.7=26.6±.682	_	24.7-28.7=26.6±.682	_	36.2-47.5=41.9±2.15
		W	26.2-35.7=31.3±1.	21.2-25.7=24.1±.7	_	8.2-10.5=9.1±.3	_	14.7-16.7=15.6±.	_	23.7-30.5=7.0±1.10

			62	81		75		375		
8.	*Lamium album* L.	L	66.2-83.2=75.2±3.2	55.5-67.7=63.5±2.1	_	24.0-25.7=24.9±.34	_	24.5-26.2=25.3±.32	_	36.7-68.7=55.5±6.7
		W	43.7-53.0=47.4±1.8	29.5-32.2=30.4±.49	_	8.7-10.0=9.2±.209	_	17.2-18.7=18.0±.28	_	14.5-27.5=22.0±3.0
9.	*Lamium amplexicaule* L.	L	59.0-76.2=64.8±3.1	46.7-63.2=54.9±3.33	27.5-29.7=28.3±.398	25.2-27.0=26.1±.367	27.2-29.0=28.5±.32	25.0-27.2=25.8±.40	44.2-62.7=55.5±4.1	51.2-70.2=58.7±3.4
		W	34.0-39.2=36.8±.882	25.7-43.7=33.8±3.4	12.5-13.7=13.0±.21	10.0-11.0=10.5±.17	24.5-26.0=25.3±.24	20.5-21.5=20.9±.20	35.0-38.0=36.6±.615	30.5-38.7=35.1±1.56
10.	*Leonurus sibiricus* L.	L	41.2-46.7=44.1±1.13	27.5-35.2=31.4±1.30	_	19.7-21.2=20.3±.257	_	19.7-21.0=20.4±.231	_	20.5-23.5=21.9±.562
		W	16.7-21.2=18.9±.780	9.0-11.2=10.1±.375	_	8.7-10.5=9.6±.322	_	14.5-15.7=15.0±.215	_	9.7-11.0=10.3±.254
11.	*Marrubium vulgare* L.	L	15.2-24.7=19.9±1.6	17.2-24.5=21.4±1.33	22.2-28.0=25.6±1.0	28.2-33.7=30.9±.94	22.7-28.0=25.5±.86	28.5-34.0=31.2±.92	15.2-25.2=21.6±1.8	17.2-30.2=23.7±2.4

		W	11.2-15.7=13.6±.87	9.7-17.0=13.3±1.23	5.5-9.2=7.3±.60	6.0-8.7=7.4±.50	13.7-20.7=17.1±1.1	14.2-22.7=18.6±1.5	10.2-16.0=13.6±1.0	9.7-17.7=14.7±1.6
12.	*Moluccella aucheri* (Boiss.) Scheen	L	43.0-62.7=52.2±3.3	27.7-44.7=33.7±3.0	24.7-29.5=27.4±.80	24.5-29.7=27.1±.98	25.2-29.7=27.7±.758	24.7-30.2=27.9±1.0	21.7-50.2=36.8±3.6	34.7-62.7=48.5±4.8
		W	26.2-56.0=39.4±5.0	25.2-37.7=30.0±2.3	5.2-7.2=6.0±.34	7.7-12.2=9.8±.76	21.0-24.7=22.7±.60	17.7-23.7=21.2±1.1	7.0-21.2=14.6±2.6	17.2-51.0=32.4±5.7
13.	*Phlomidoschema parviflorum* (Benth.) Vved.	L	22.2-31.0=26.2±1.78	19.5-41.0=29.3±3.69	24.2-27.2=25.3±.56	22.0-26.0=24.1±.75	24.5-27.7=25.7±.59	22.2-27.2=24.4±.89	20.2-27.2=23.7±1.20	21.2-27.2=24.3±1.00
		W	13.7-19.7=15.9±1.03	16.0-25.5=22.8±1.74	5.2-7.75=6.50±.44	6.25-8.0=6.9±.30	13.7-18.0=15.4±.70	13.2-21.0=17.6±1.65	12.2-17.2=14.4±.85	10.5-16.2=13.9±1.04
14.	*Phlomis bracteosa* Royle ex Benth.	L	18.7-50.2=31.0±5.21	38.5-47.0=43.2±1.61	90.0-125.0=1.09±6.64	22.7-25.0=24.1±.375	23.2-25.8=24.7±.440	24.2-25.7=24.9±.269	32.0-41.5=37.2±1.88	32.2-44.2=37.2±2.39
		W	14.5-16.2=15.3±.320	18.0-28.2=23.7±1.77	8.5-10.7=9.4±.503	8.75-10.2=9.5±.266	19.7-21.0=20.35±.231	19.7-21.2=20.6±.257	11.0-12.7=12.1±.269	12.0-13.7=12.9±.34
15.	*Phlomis*	L	46.2-63.7=54.9±3.	41.7-48.7=45.2±1.	28.7-30.0=29.4±.2	27.2-30.2=28.7±.	28.7-32.2=30.2±.6	29.5-31.2=30.1±.	64.2-88.0=76.2±	69.5-75.5=72.6±1.06

	stewartii Hook.f.		45	14	31	48	04	30	4.0	
		W	32.25-41.25=36.6±1.50	33.7-39.0=36.5±1.0	12.2-17.5=13.7±.966	12.2-16.2=13.7±.79	24.2-25.7=24.9±.266	22.2-25.5=24.5±.588	21.2-32.2=27.7±1.88	25.0-31.2=28.1±1.1
16.	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	L	23.7-27.5=25.6±.64	23.7-29.5=28.4±1.14	21.1-24.7=23.5±.60	17.2-26.2=21.7±1.5	24.5-25.7=25.0±.21	23.7-28.7=26.5±.83	28.7-31.5=30.1±.539	26.5-32.7=28.6±1.10
		W	14.5-17.0=15.5±.48	12.0-16.2=14.0±.87	7.2-8.7=7.9±.26	6.7-7.7=7.2±.176	12.0-13.5=12.6±.257	12.0-13.7=12.6±.30	16.2-18.0=17.0±.30	14.5-18.7=16.1±.80
17.	*Scutellaria grossa* Wall.	L	31.2-48.2=43.3±3.10	57.5-64.0=60.1±1.11	_	20.2-23.2=21.8±.514	_	21.2-23.0=22.2±.325	_	32.5-36.2=34.2±.702
		W	10.7-13.7=12.1±.491	15.5-20.7=17.7±±.911	_	9.5-10.5=10.0±.20	_	15.5-17.0=16.3±.266	_	7.0-11.2=9.1±.714
18.	*Scutellaria linearis* Benth.	L	41.7-53.7=48.5±2.0	25.5-30.5=27.4±.85	24.2-25.2=24.7±.17	15.5-18.0=16.9±.45	24.5-25.5=25.0±.17	16.2-17.7=17.1±.25	30.7-35.5=32.7±.86	32.0-34.0=33.0±.39
		W	33.0-39.0=36.7±1.0	18.0-23.7=20.3±.99	7.5-9.0=8.3±.26	7.5-9.2=8.3±.30	14.7-16.2=15.5±.25	12.5-14.7=13.5±.36	16.5-25.2=20.4±1.7	14.5-17.5=15.8±.58

19.	*Scutellaria prostrata* Jacquem. ex Benth.	L	36.2-43.2=39.9±1.21	36.2-45.5=41.0±1.7	18.7-20.2=19.5±.266	19.5-20.7=20.1±.231	19.0-20.5=19.8±.289	19.5-20.5=20.0±.20	16.7-32.5=25.8±2.9	18.2-32.5=27.1±2.5
		W	24.7-31.7=28.5±1.31	16.7-20.7=19.3±.73	7.0-8.0=7.5±.176	7.2-8.2=7.7±.176	14.0-15.5=14.7±.25	14.2-15.7=15.0±.254	8.5-13.7=11.1±1.05	8.7-14.7=12.4±1.06
20.	*Stachys emodi* Hedge	L	21.2-28.2=25.4±1.18	19.2-25.2=22.1±1.28	_	18.7-25.5=21.7±1.13	_	22.2-26.2=24.4±.66	_	19.5-26.0=22.2±1.30
		W	13.5-17.0=15.1±.73	13.7-17.2=15.5±.64	_	8.75-12.5=10.7±.61	_	14.5-17.0=15.6±.46	_	11.2-15.2=12.7±.67
21.	*Stachys floccosa* Benth.	L	24.7-30.7=27.3±1.1	19.2-26.2=22.3±1.3	_	20.0-25.0=23.0±.88	_	22.2-25.7=24.4±.64	_	19.5-26.0=22.8±1.1
		W	13.7-17.7=15.7±.70	14.5-17.2=15.5±.53	_	9.2-12.5=11.0±.61	_	14.7-15.7=15.0±.18	_	11.5-15.2=13.1±.66
22.	*Stachys palustris* L.	L	50.2-57.2=53.5±1.29	35.2-45.7=14.3±1.72	19.7-24.7=22.8±.91	20.2-24.0=22.1±.64	20.2-25.2=23.1±.90	21.2-22.5=21.8±.23	22.0-27.7=25.1±.96	45.7-51.5=48.2±1.09
		W	35.2-42.2=38.8±1.	13.2-37.2=33.3±1.	4.5-7.2=5.45±.48	7.75-8.75=8.25±.	12.2-18.0=14.3±1.	17.0-18.2=17.6±.	16.7-22.7=18.8±	36.2-41.0=38.4±.76

			30	43		17	03	23	1.06	
23.	*Teucrium royleanum* Wall. ex Benth.	L	16.0-25.2=20.7±1.66	20.2-37.7=27.6±2.95	_	22.5-24.0=23.4±.257	_	23.2-25.5=24.4±.428	_	29.5-31.0=30.2±.231
		W	8.0-22.2=14.2±2.37	15.2-27.7=21.3±2.17	_	6.0-7.5=6.85±.269	_	17.0-18.2=17.6±.231	_	17.0-18.2=17.5±.215
24.	*Teucrium stocksianum* Boiss.	L	25.2-42.7=34.4±3.09	27.2-43.5=32.8±2.8	16.0-24.4=19.3±1.4	18.5-24.7=22.1±1.0	16.2-24.7=19.6±1.4	18.7-25.2=22.5±1.0	19.65-27.7=23.7±1.3	20.2-31.0=25.3±1.7
		W	20.2-27.7=24.7±1.2	16.0-32.7=25.3±2.9	3.7-5.2=4.5±.25	3.5-6.0=4.7±.46	12.2-17.7=15.4±.9	11.2-21.5=18.1±1.8	12.2-21.0=15.9±1.5	11.2-22.2=15.0±1.9
25.	*Vitex agnus-castus* L.	L	17.2-27.2=2.4±2.12	26.2-28.2=27.4±.331	_	_	_	_	_	_
		W	20.0-22.2=21.2±.390	14.5-17.5=16.4±.532	_	_	_	_	_	_
26.	*Vitex negundo* L.	L	27.0-28.7=27.8±.322	26.2-30.5=28.5±.802	_	_	_	_	_	_

		W	18.7-21.7=20.6±.562	17.0-20.0=18.5±.596	_	_	_	_	_	_
27.	*Vitex trifolia* L.	L	22.5-34.5=28.5±2.04	21.2-25.0=22.8±.726	_	14.2-16.5=15.4±.451	_	14.5-17.0=15.7±.506	_	21.2-26.2=23.9±.803
		W	16.2-19.5=18.15±.573	14.5-17.0=15.75±.506	_	6.2-8.7=7.8±.437	_	13.7-15.5=14.8±.310	_	17.2-20.5=19.2±.586

Table 16: Quantitative characteristics of foliar anatomy of the observed Lamiaceae taxa

S.no	Plant name	L× W	Stomatal pore size Min-Max = Mean±SE (µm) Ad/Ab		Stomatal index Ad/Ab		Trichome size Min-Max = Mean±SE (µm) Ad/Ab		Trichome index Ad/Ab	
1.	*Ajuga integrifolia* Buch. -Ham.	L	12.2-17.2=14.3±.88	9.7-15.2=11.6±1.0	14.3	31.9	427.2-877.0=616±79.7	176.0-444.0=292±43.8	2.7	2.9
		W	4.7-9.7=6.8±.88	4.7-9.7=6.3±.966			55.7-77.2=63.3±3.7	15.2-34.7=22.3±3.48		
2.	*Ajuga parviflora* Benth.	L	7.7-9.7=8.6±.33	22.7-27.7=24.8±.95	5.5	30.9	182.7-248.2=212±11.4	196.2-226.0=205±5.4	4.6	14.2
		W	3.2-6.5=5.3±.56	5.2-9.7=7.0±.80			34.7-49.5=41.6±2.9	42.7-50.5=46.9±1.27		
3.	*Ajuga reptans* L.	L	15.0-16.5=15.7±.28	19.7-169.5=50.3±29.7	5.8	30.8	351.5-463.7=409±23.9	177.0-326.2=242±30.4	1.7	2.1
		W	10.0-11.7=10.9±.34	10.0-11.2=10.6±.20			48.7-55.5=52.0±1.2	26.2-28.7=27.3±.40		
4.	*Callicarpa macrophylla* Vahl.	L	_	7.7-9.5=8.7±.28	_	42.7	172.7-251.2=210±17.0	182.7-375.5=253±33.5	9.5	14.0
		W	_	3.2-4.2=3.7±.176			32.7-47.7=41.4±2.8	29.2-75.2=46.9±8.		
5.	*Clerodendrum inerme* (L.) Gaertn.	L	_	6.5-8.0=7.3±.25	_	6.0	_	100.5-150.7=120±9.27	_	2.3
		W	_	4.2-5.5=4.8±.231			_	4.7-77.2=57.9±13.8		
6.	*Clerodendrum splendens* G.Don	L	_	9.7-	_	56.7	50.2-	75.2-	4.7	11.2

				12.7=11.3±.561			125.2=91.7±12.8	126.7=91.2±10.0		
		W	_	3.5-5.25=4.15±.358			25.2-32.2=33±1.29	30.2-35.2=29±.934		
7.	*Clerodendrum umbellatum* Poir.	L	_	9.7-11.5=10.8±.302	_	28.2	289-338=313±8.7	276.25-336.2=310±10.4	2.9	7.7
		W	_	7.0-8.5=7.8±.289			27.2-35.2=32.0±1.42	28.5-38.5=33.4±1.8		
8.	*Lamium album* L.	L	_	19.5-21.0=20.2±.26	_	17.7	28.7-300.5=186±47.0	173.7-388.0=264±48.2	2.6	2.3
		W	_	7.5-8.7=8.1±.28			14.7-21.2=18.5±1.2	13.7-26.7=19.3±2.9		
9.	*Lamium amplexicaule* L.	L	12.5-14.0=13.3±.269	15.7-17.7=16.6±.40	18.4	29.7	351.5-462.7=418±19.8	152.0-301.2=229±25.0	2.7	10.2
		W	10.0-10.7=10.4±.127	8.2-9.5=8.8±.23			26.2-31.5=28.5±1.0	13.7-18.0=16.5±.75		
10.	*Leonurus sibiricus* L.	L	_	14.2-15.5=14.8±.215	_	24.8	88.2-201.2=161±19.3	174-238.0=203±10.8	12.5	12.7
		W	_	7.0-8.0=7.5±.176			15.0-17.5=16.4±.422	13.7-18.7=16.8±.838		
11.	*Marrubium vulgare* L.	L	9.7-15.2=12.8±1.12	8.7-14.5=12.0±.93	16.9	58.7	138.7-202.2=164±11.6	128.0-225.2=185±16.4	31.5	50
		W	4.0-4.7=4.3±.127	4.5-6.0=5.2±.28			12.7-28.5=21.6±2.88	19.5-31.5=27.1±2.37		
12.	*Moluccella aucheri* (Boiss.) Scheen	L	19.7-30.2=25.0±2.1	13.7-18.0=15.3±.79	32.1	34.7	62.2-125.5=101±10.65	76.0-163.0=116±14.3	51.7	11.3

		W	3.2-4.2=3.7±.17	4.7-7.0=5.9±.40			8.7-15.0=12.8±1.0	9.5-13.7=11.1±.76		
13.	*Phlomidoschema parviflorum* (Benth.) Vved.	L	10.2-14.7=12.9±.74	11.0-13.7=12.0±.48	15.4	4.5	147.2-200.2=166±9.68	125.2-206.0=175±13.5	6.0	23.0
		W	2.75-3.75=3.40±.18	4.0-5.2=4.55±.21			22.7-28.5=25.5±1.06	27.2-37.7=31.7±1.94		
14.	*Phlomis bracteosa* Royle ex Benth.	L	11.2-12.7=12.1±.269	11.2-13.5=12.5±.467	6.1	23.7	113.7-158.0=137±8.06	87.7-176.5=133±17.2	3.6	12.8
		W	4.7-6.5=5.6±.322	5.0-6.2=5.7±.215			13.2-16.2=14.6±.556	11.2-150.5=41.3±27.3		
15.	*Phlomis stewartii* Hook.f.	L	14.5-16.2=15.3±.322	14.7-16.5=15.5±.30	20.1	25.3	76.7-126.2=99.6±9.29	84.5-138.0=111±10.5	13.0	47.3
		W	7.2-8.2=7.7±.176	7.0-8.0=7.5±.20			12.2-18.0=15.2±1.0	9.7-17.2=13.4±1.5		
16.	*Rydingia limbata* (Benth.) Scheen & V.A.Albert	L	11.2-12.7=12.1±.257	9.7-12.7=11.3±.60	2.2	19.4	38.7-125.2=86.3±17.3	64.5-150.2=101±15.10	17.2	46.0
		W	5.0-6.5=5.9±.257	5.0-6.7=5.8±.322			10.0-16.7=13.0±1.25	10.7-15.0=12.9±.87		
17.	*Scutellaria grossa* Wall.		–	12.2-13.2=12.8±.183	–	24.5	–	176.5-263.0=272±16.6		2.3
			–	6.7-7.7=7.2±.176			–	21.7-26.2=24.4±.796		
18.	*Scutellaria linearis* Benth.	L	13.2-13.2=13.2±.00	10.5-12.5=11.6±.35	8.8	32.9	36.2-138.2=89.2±21.6	46.2-125.5=86.9±16.7	18.6	33.6
		W	4.7-6.2=5.5±.28	6.0-7.5=6.5±.26			11.0-14.2=12.5±.64	1.2-15.0=13.1±.62		

19.	*Scutellaria prostrata* Jacquem. ex Benth.	L	17.0-18.7=17.7±.310	18.7-20.2=19.6±.257	28.4	53.9	300.5-339.2=254±6.6	251.2-288.0=271±6.55	8	17.8
		W	9.2-11.2=10.3±.34	6.5-7.5=7.0±.176			16.2-18.0=17.1±.30	22.5-25.7=24.4±.594		
20.	*Stachys emodi* Hedge	L	_	11.2-15.0=13.0±.64	_	33.5	224.7-264.0=254±7.56	151.2-214.0=187±10.45	5.2	49.0
		W	_	3.7-5.2=4.5±.28			19.5-26.5=23.1±1.24	19.2-26.2=27±1.26		
21.	*Stachys floccosa* Benth.		_	9.7-12.5=10.9±.49	2.5	20.5	226.5-275.5=431±9.0	170.5-218.5=264±9.1	1.8	2.0
			_	4.5-42.5=12.3±7.5			20.7-25.7=165±.80	23.7-30.0=19±1.2		
22.	*Stachys palustris* L.	L	8.2-10.5=9.45±.45	14.5-16.2=15.3±.32	1.9	30.3	302.7-502.2=162±39.6	226.5-300.5=144±15.1	1.5	7.0
		W	4.75-6.0=5.45±.12	7.50-8.50=8.00±.17			12.7-248.2=45±26.2	16.2-22.7=45±1.28		
23.	*Teucrium royleanum* Wall. ex Benth.	L	_	14.5-16.2=15.2±.310	_	27.8	138.2-175.2=162±6.43	125.2-157.0=76±5.33	1.7	17.6
		W	_	7.5-8.7=8.2±.215			36.2-51.0=44.5±2.7	37.7-54.7=62±3.39		
24.	*Teucrium stocksianum* Boiss.	L	8.7-10.7=9.9±.33	6.0-10.7=8.6±.78	12.1	48.0	74.7-87.7=82.1±2.2	68.7-88.7=67±3.5	61.0	84.3
		W	5.0-6.0=5.5±.17	5.2-7.0=6.1±.34			10.2-74.7=46.4±10.8	54.2-68.7=9±2.3		
25.	*Vitex agnus-castus* L.	L			_	_	15.7-	52.0-	88.0	86.5

							126.7=58.7±25.2	88.2=67.35±6.75		
		W	–	–			6.25-10.0=8.6±.635	7.5-11.2=9.3±.625		
26.	*Vitex negundo* L.	L	–	–	–	–	49.7-93.0=68.3±7.46	17.25-130.0=58.7±25.0	92.6	92.9
		W	–	–			9.25-12.5=11.1±.709	6.5-10.0=9.10±.654		
27.	*Vitex trifolia* L.	L	–	12.0-13.0=12.5±.176	–	22.2	11.25-102.0=45.9±20.2	38.0-76.2=55.6±7.1	18.9	90.9
		W	–	5.7-7.2=6.5±.266			7.5-12.0=9.7±.834	10.2-16.2=13.3±1.14		

Keywords: Min= Minimum, Max= Maximum, SE= Standard Error, Ad= Adaxial surface, Ab= Abaxial surface, L= Length, W= Width, µm= Measurement in Micrometer

Table.17: Principal component analysis variable loadings for the first twelve significant components

Variable/ Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Epidermal cell length (AD)	0.719	0.276	0.550	0.102	-0.147	0.204	0.125	-0.010	-0.020	0.042	0.012	0.001
Epidermal cell width (AD)	0.719	0.119	0.530	0.141	0.039	0.239	0.076	-0.160	0.112	0.225	0.016	-0.036
Guard cell length (AD)	0.841	-0.481	-0.189	-0.044	0.059	0.015	0.005	-0.012	-0.020	0.058	0.019	0.027
Guard cell width (AD)	0.840	-0.468	-0.138	-0.013	-0.016	0.015	-0.071	0.008	0.014	-0.122	-0.067	-0.059
Stomata length (AD)	0.840	-0.484	-0.188	-0.046	0.054	0.012	0.011	-0.013	-0.014	0.062	0.025	0.025
Stomata width (AD)	0.882	-0.420	-0.134	-0.060	0.066	0.007	0.064	-0.012	-0.025	0.011	-0.060	0.019
Subsidiary cell length (AD)	0.872	-0.381	0.045	0.043	0.064	-0.160	0.045	0.015	-0.004	-0.130	-0.035	-0.139
Subsidiary cell width (AD)	0.872	-0.347	0.053	0.156	0.099	-0.088	0.055	-0.023	-0.073	-0.119	0.167	-0.114
Stomatal pore length (AD)	0.760	-0.523	-0.147	-0.021	0.003	-0.029	-0.030	0.054	0.080	0.240	-0.046	0.174
Stomatal pore width (AD)	0.826	-0.428	-0.095	0.139	0.000	0.114	-0.107	-0.012	-0.041	-0.115	0.006	0.133
Trichome length (AD)	0.576	0.214	-0.010	0.737	0.141	-0.078	0.033	0.136	-0.093	-0.045	0.076	-0.020
Trichome width (AD)	0.182	0.420	-0.391	0.605	0.057	-0.269	0.134	-0.382	-0.117	0.066	-0.092	0.002
Epidermal cell length (AB)	0.498	0.272	0.665	0.015	-0.090	-0.146	-0.182	0.134	-0.323	-0.149	-0.034	0.149
Epidermal cell width (AB)	0.713	0.180	0.466	-0.209	0.276	-0.086	-0.033	-0.264	-0.030	0.054	-0.142	-0.037
Guard cell length (AB)	0.667	0.556	-0.322	-0.231	-0.062	-0.151	0.025	0.079	-0.159	0.148	-0.005	-0.008
Guard cell width (AB)	0.599	0.410	-0.235	-0.280	-0.098	0.159	0.468	0.114	0.032	-0.217	-0.137	0.020
Stomata length (AB)	0.673	0.450	-0.261	-0.332	-0.110	-0.171	-0.156	0.165	-0.134	0.187	0.084	-0.070
Stomata width (AB)	0.808	0.352	-0.219	-0.347	-0.116	0.001	-0.068	0.010	-0.026	-0.010	-0.044	-0.043
Subsidiary cell length (AB)	0.717	0.158	0.303	-0.110	-0.172	-0.351	-0.256	0.034	0.352	-0.061	-0.030	-0.048
Subsidiary cell width (AB)	0.679	0.412	0.130	-0.244	0.311	-0.053	0.358	0.016	0.130	-0.007	0.180	0.084
Stomatal pore length (AB)	0.663	0.221	-0.141	0.048	-0.270	0.575	-0.203	-0.118	-0.086	-0.007	0.029	-0.075
Stomatal pore width (AB)	0.556	0.506	-0.284	0.217	-0.397	-0.050	-0.126	-0.214	0.208	-0.134	0.079	0.115

Trichome length (AB)	0.399	0.432	-0.107	0.573	0.250	0.147	-0.095	0.415	0.165	0.069	-0.108	-0.019
Trichome width (AB)	0.043	0.437	-0.247	-0.262	0.704	0.166	-0.330	-0.125	0.023	-0.131	0.019	0.038
Eigenvalue	11.627	3.683	2.097	1.919	1.109	0.841	0.718	0.578	0.420	0.356	0.156	0.148
Variability (%)	48.446	15.347	8.736	7.995	4.619	3.502	2.993	2.409	1.748	1.482	0.650	0.617
Cumulative %	48.446	63.793	72.529	80.524	85.143	88.646	91.639	94.048	95.796	97.278	97.928	98.545

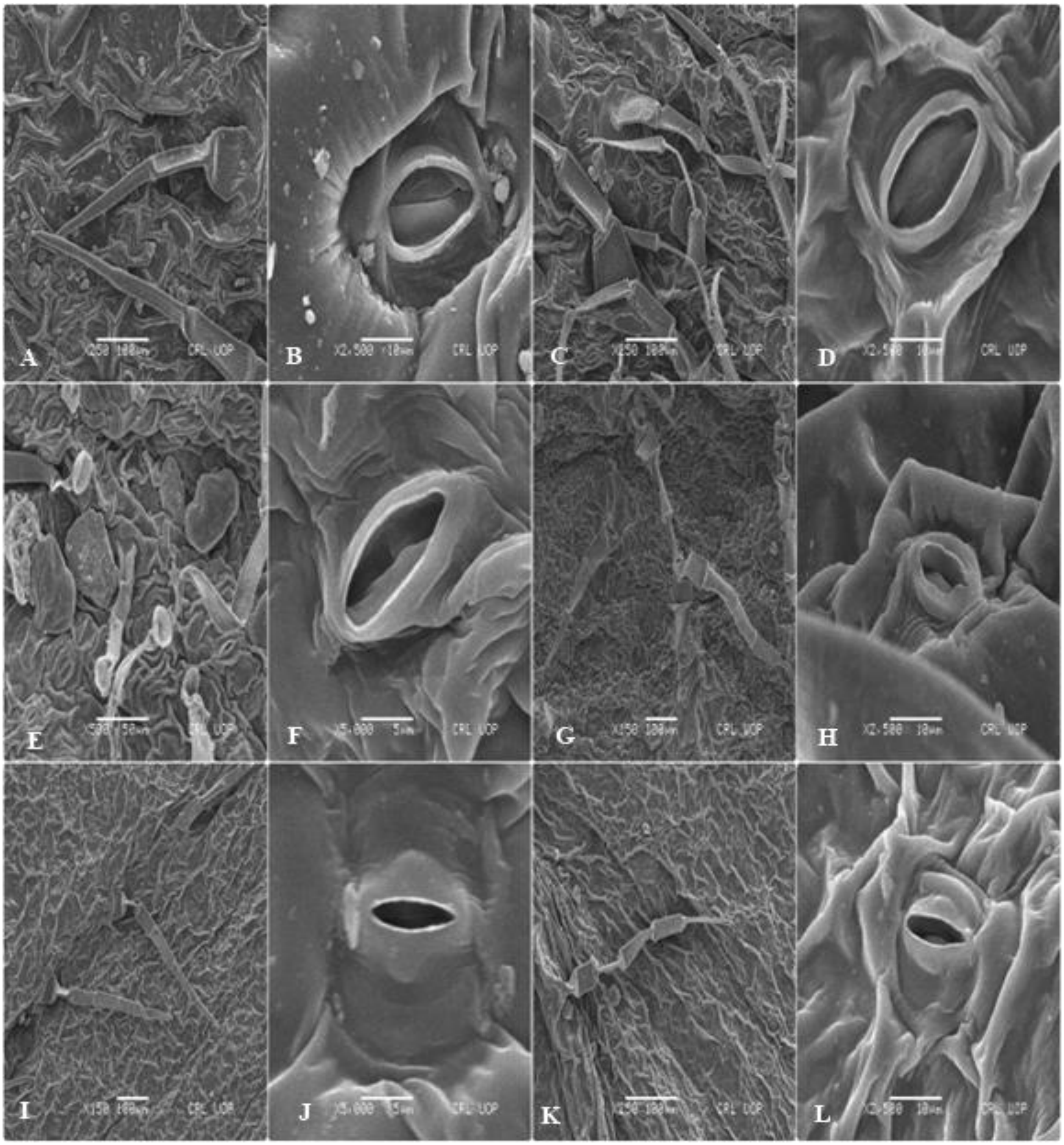

Plate. 66: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Ajuga integrifolia* (A-B) adaxial surface showing multicellular non glandular trichomes (C-D) abaxial surface showing anomocytic stomata. *Ajuga parviflora* (E-F) adaxial surface showing multicellular Pilate trichomes, (G-H) abaxial surface showing elliptic shape stomata. *Ajuga reptans* (I-J) adaxial surface showing irregular epidermal cells (K-L) abaxial surface.

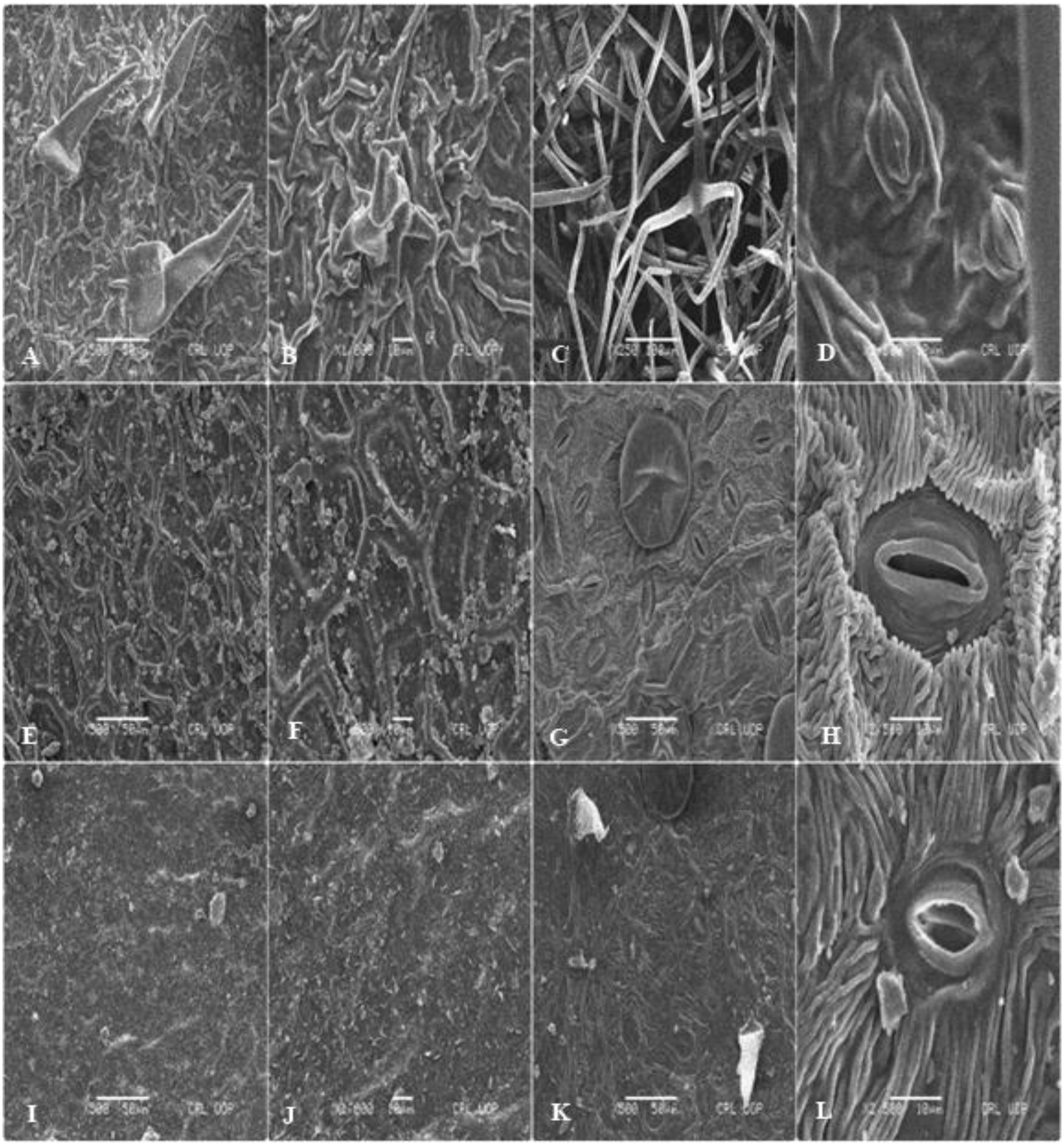

Plate. 67: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Callicarpa macrophylla* (A-B) adaxial surface showing unicellular conical stomata, (C-D) undulate wall pattern. *Clerodendrum inerme* (E-F) adaxial surface showing pentagonal epidermal cells (G-H) abaxial surface peltate glandular trichome. *Clerodendrum splendens* (I-J) adaxial surface showing irregular epidermal cells, (K-L) abaxial surface showing elliptic shape stomata.

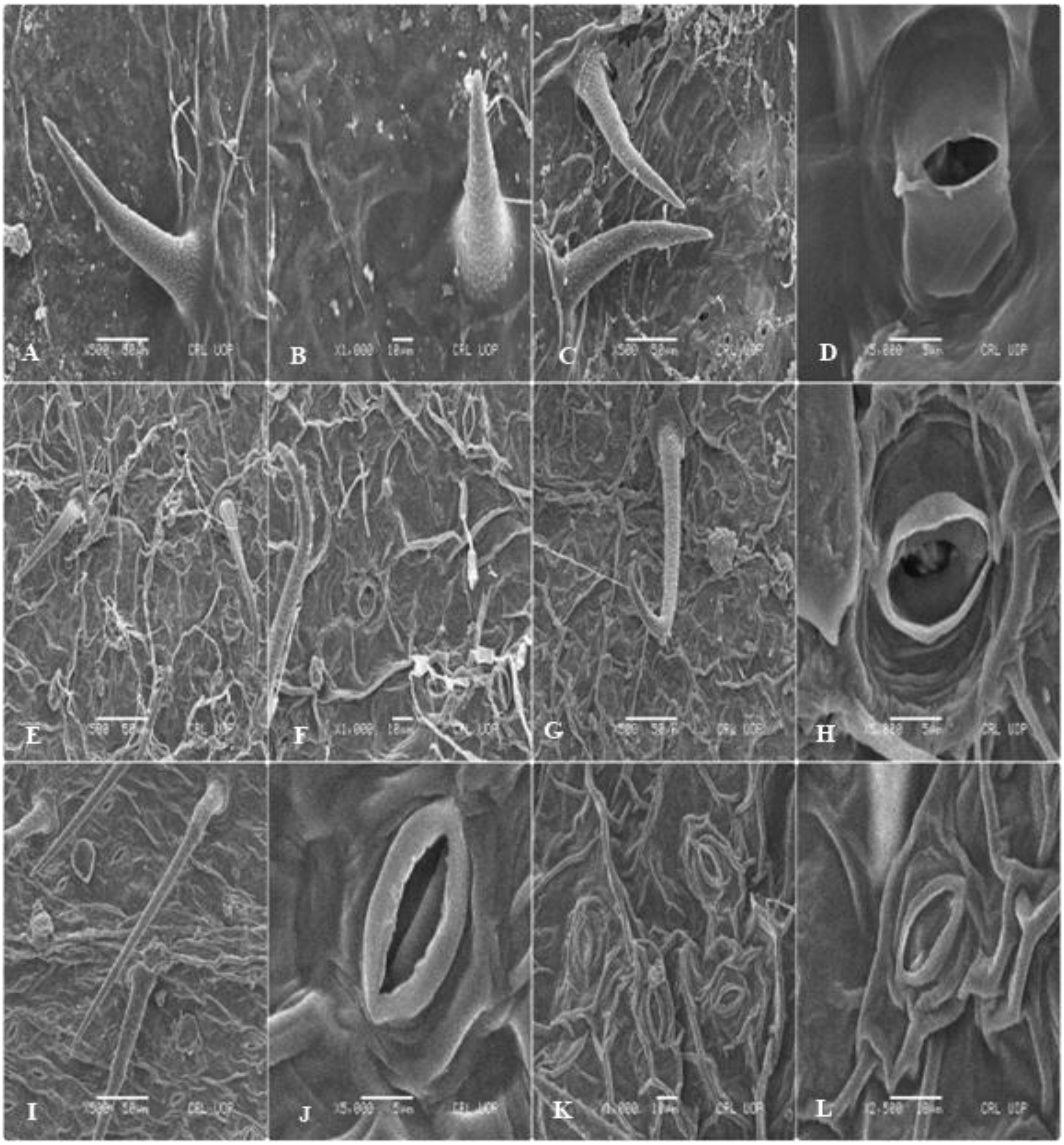

Plate. 68: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Clerodendrum umbellatum* (A-B) adaxial surface showing unicellular non glandular trichomes (C-D) abaxial surface showing broad elliptic shape stomata. *Lamium album* (E-F) adaxial surface showing irregular epidermal cells (G-H) abaxial surface showing clavate trichome. *Lamium amplexicaule* (I-J) adaxial surface showing multicellular needle shape trichomes (K-L) abaxial surface showing anisocytic stomata.

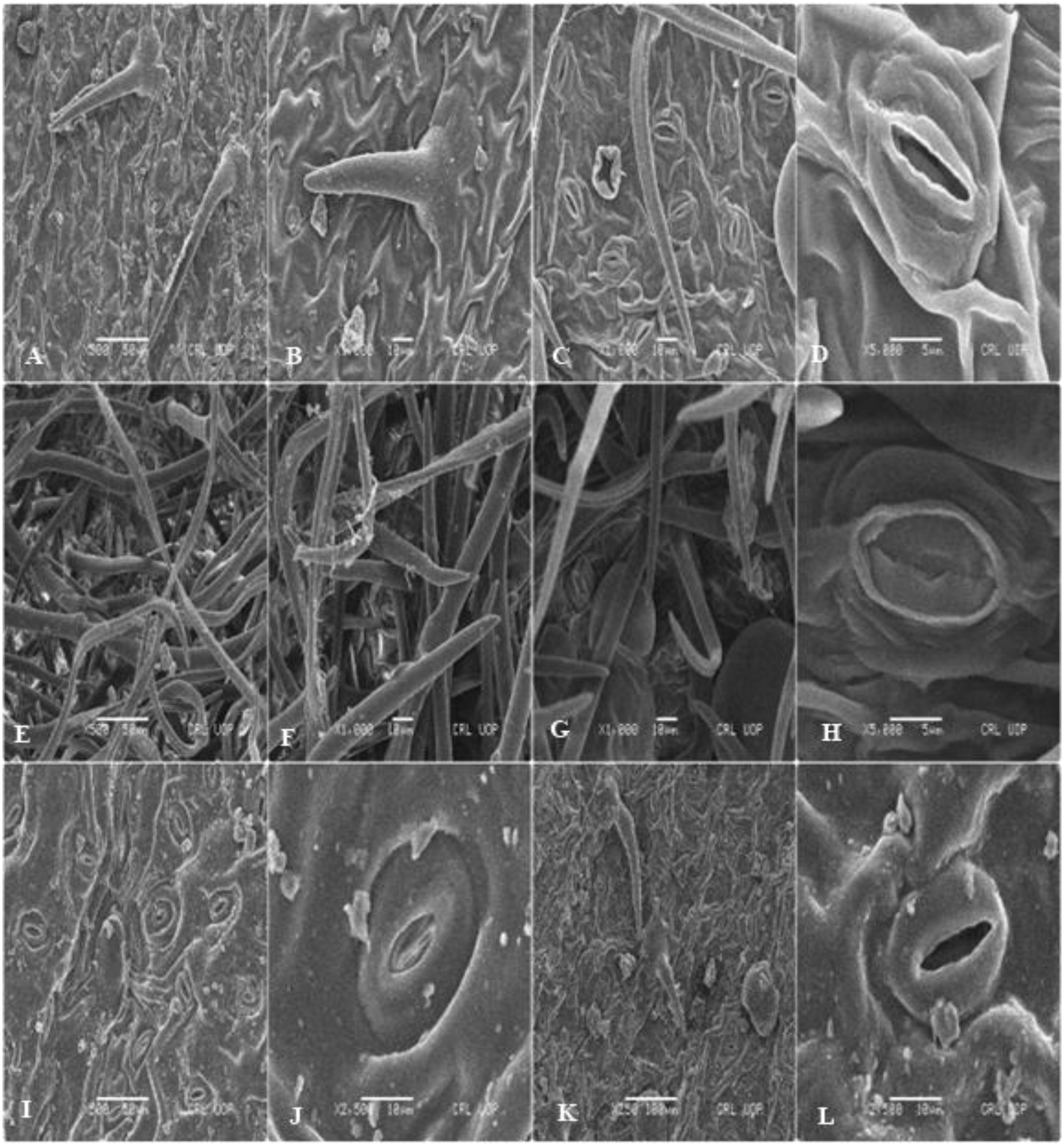

Plate. 69: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Leonurus sibiricus* (A-B) adaxial surface showing Stellate NGTs, (C-D) abaxial surface showing peltate trichome. *Marrubium vulgare* (E-F) adaxial surface showing stellate non glandular trichomes, (G-H) abaxial surface showing kidney shape guard cells. *Moluccella aucheri* (I-J) adaxial surface showing smooth wall pattern (K-L) abaxial surface showing ovate stomatal pore.

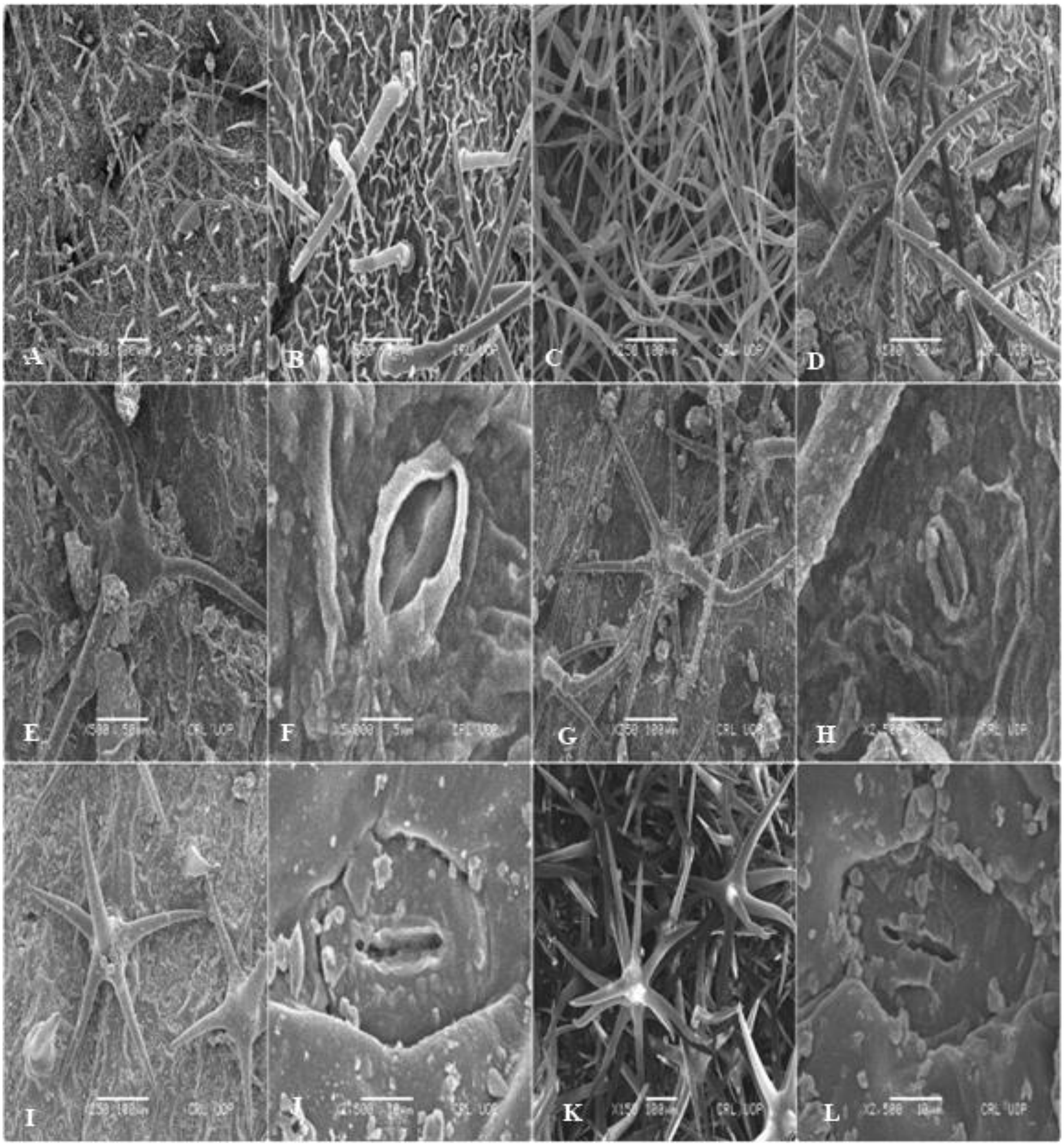

Plate. 70: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Phlomidoschema parviflorum* (A-B) adaxial surface showing irregular epidermal cells (C-D) abaxial surface showing branched trichome. *Phlomis bracteosa* (E-F) adaxial surface showing ovate stomatal pore (G-H) abaxial surface showing stellate trichome. *Phlomis stewartii* (I-J) adaxial surface showing stellate trichome (K-L) abaxial surface showing linear stomatal pore.

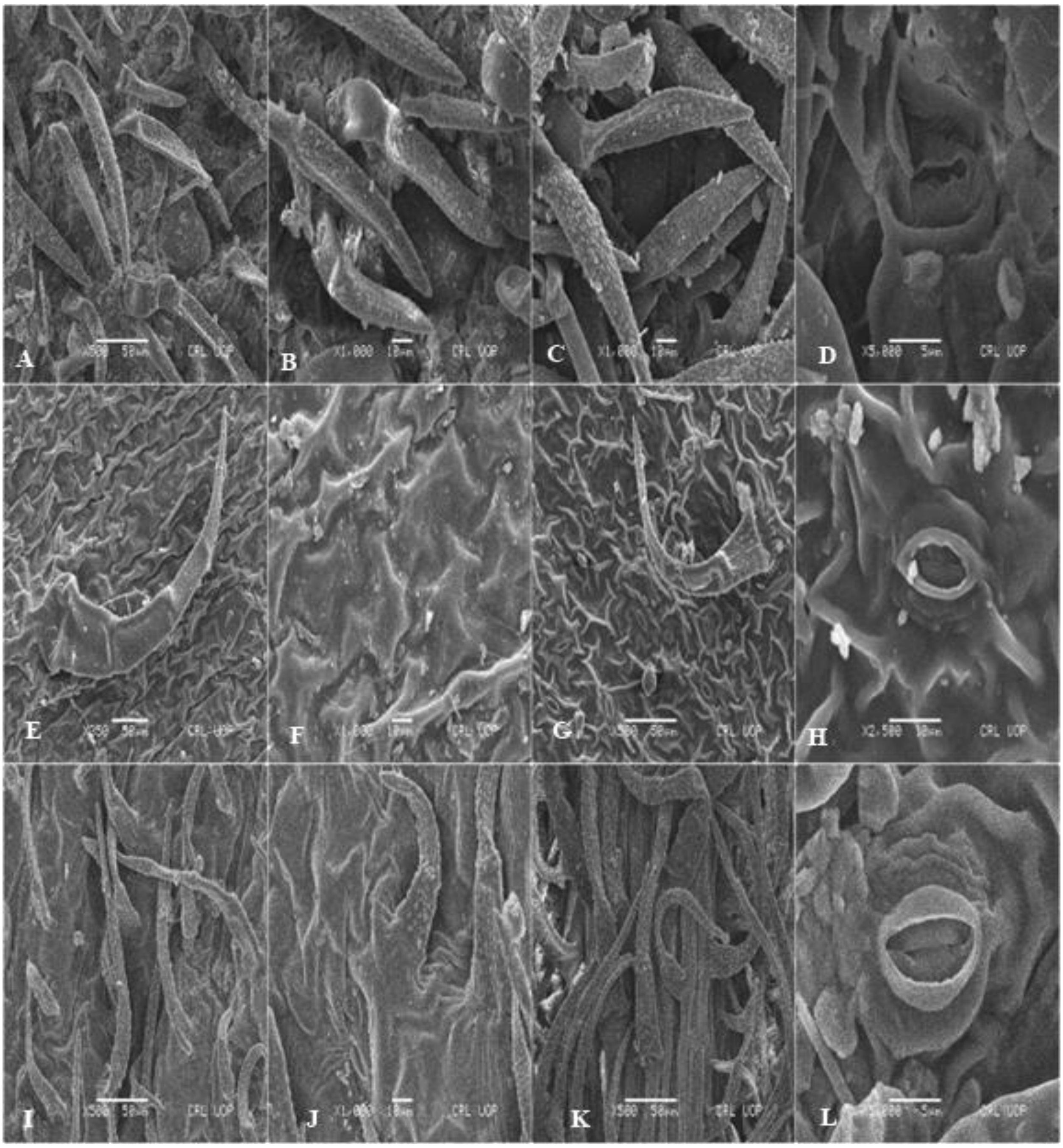

Plate. 71: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Rydingia limbata* (A-B) adaxial surface showing granular trichome surface, (C-D) abaxial surface showing elliptic shape stomata. *Scutellaria grossa* (E-F) adaxial surface showing undulate wall pattern (G-H) abaxial surface showing anomocytic stomata. *Scutellaria linearis* (I-J) adaxial surface showing multicellular glandular trichome (K-L) abaxial surface showing paracytic stomata.

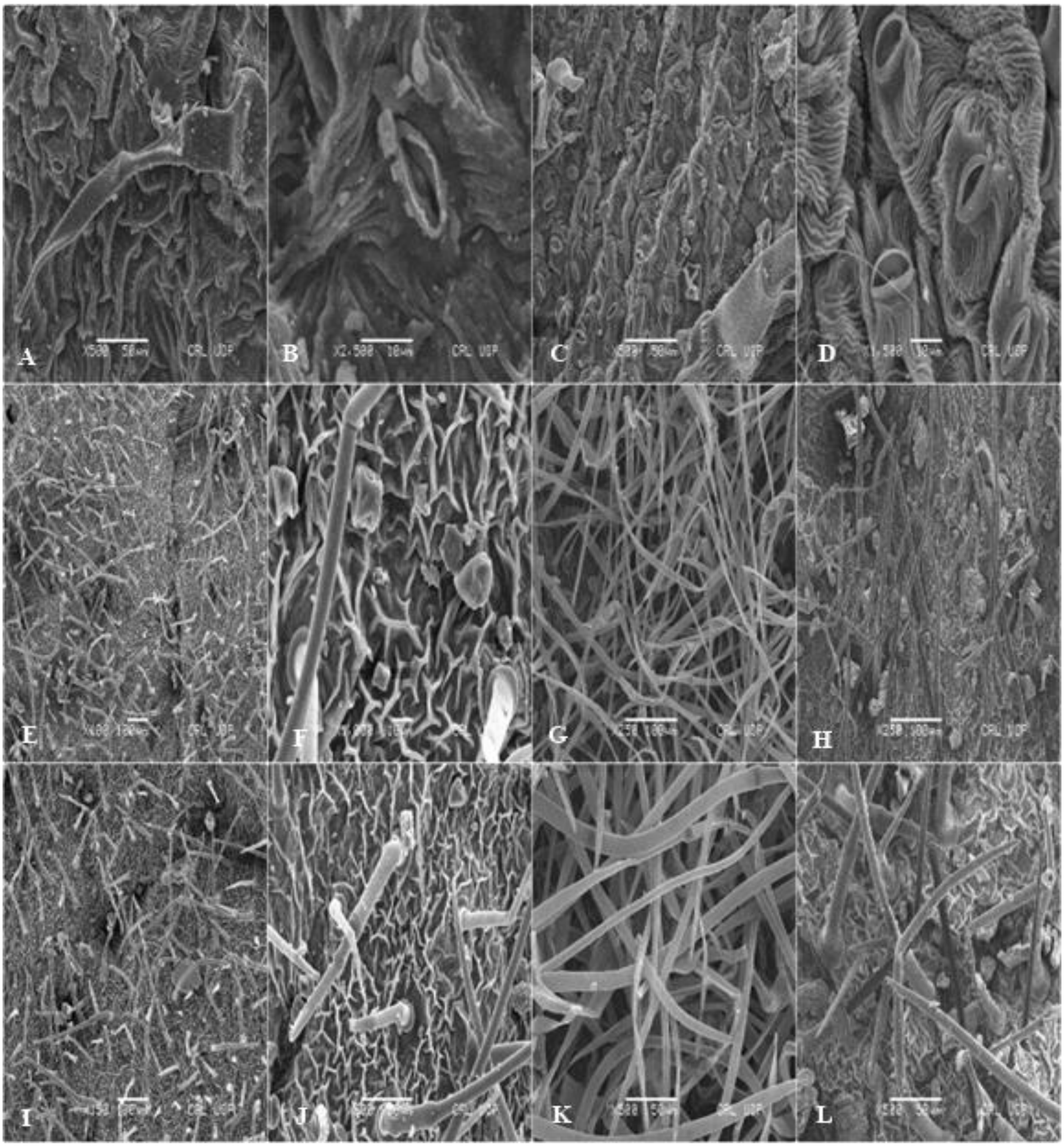

Plate.72: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Scutellaria prostrata* (A-B) adaxial surface showing multicellular glandular trichome (C-D) abaxial surface showing paracytic stomata. *Stachys emodi* (E-F) adaxial surface showing undulate wall pattern (G-H) abaxial surface showing mulicellular non glandular trichomes. *Stachys floccosa* (I-J) adaxial surface showing undulate wall pattern (K-L) abaxial surface showing smooth trichome surface.

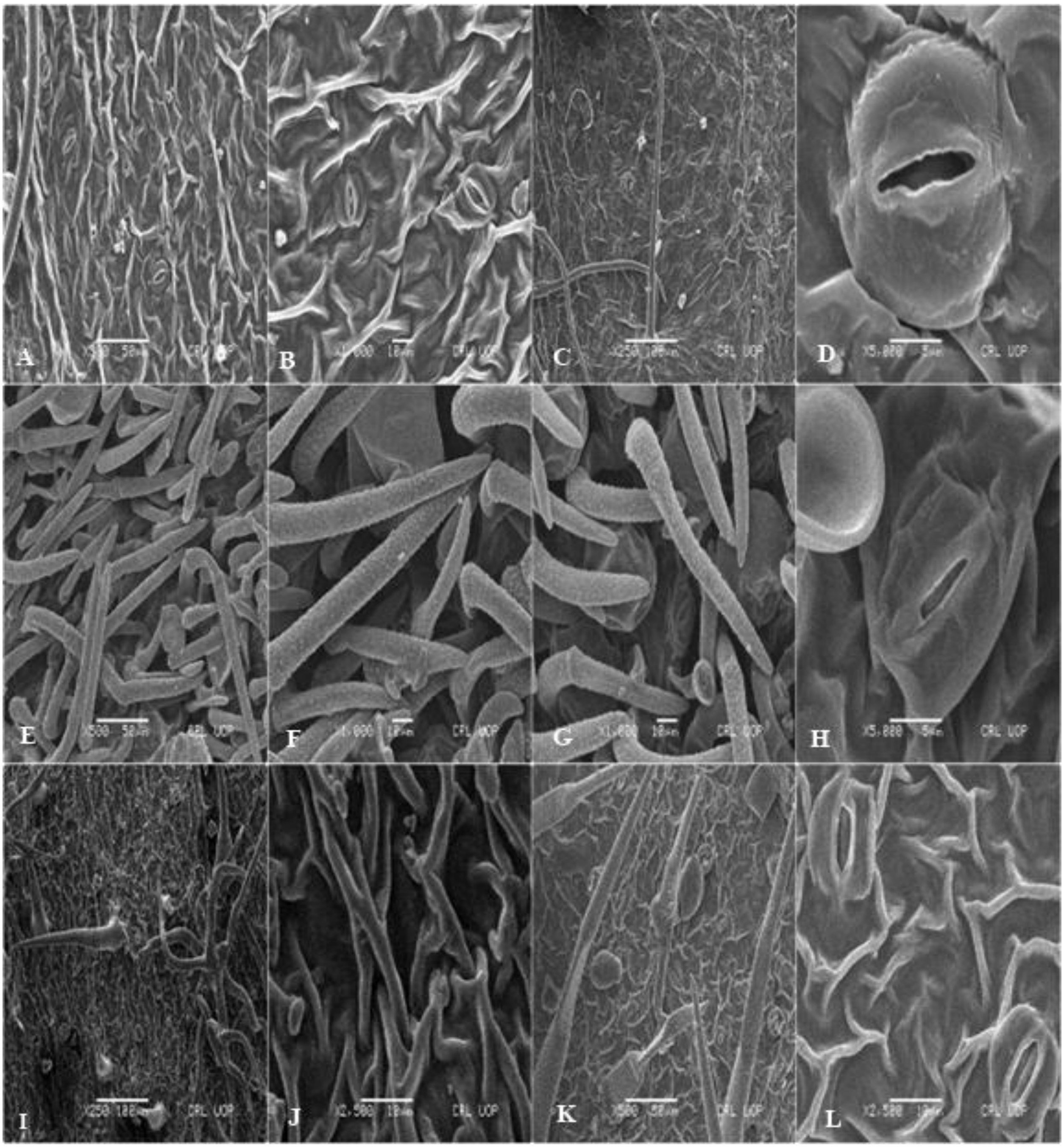

Plate. 73: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Stachys palustris* (A-B) adaxial surface showing undulate wall pattern (C-D) abaxial surface showing kidney shape guard cells. *Teucrium royleanum* (E-F) adaxial surface showing multicellular conical shape non glandular trichomes (G-H) abaxial surface showing anomocytic stomata. *Teucrium stocksianum* (I-J) adaxial surface showing irregular epidermal cells (K-L) abaxial surface showing sinuate wall pattern.

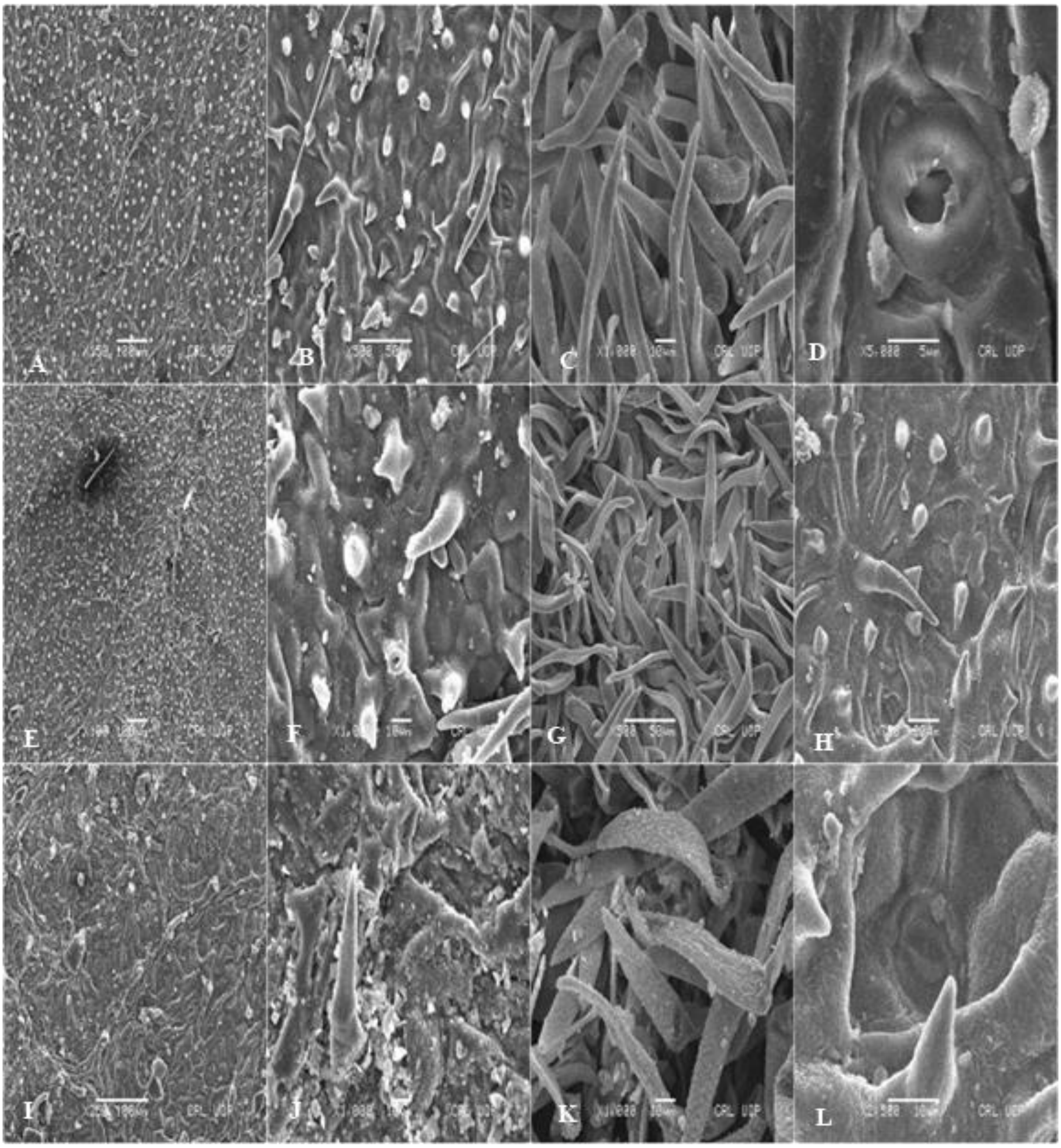

Plate.74: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type of stomata, anticlinal wall pattern and trichome type of Lamiaceous taxa. *Vitex agnus-castus* (A-B) adaxial surface showing unicellular conocal and hook shape trichome (C-D) abaxial surface showing smooth trichome surface. *Vitex negundo* (E-F) adaxial surface showing polygonal epidermal cells (G-H) abaxial surface showing unicellular conocal trichome. *Vitex trifolia* (I-J) adaxial surface showing rough epidermal surface (K-L) abaxial surface showing elliptic shape stomata.

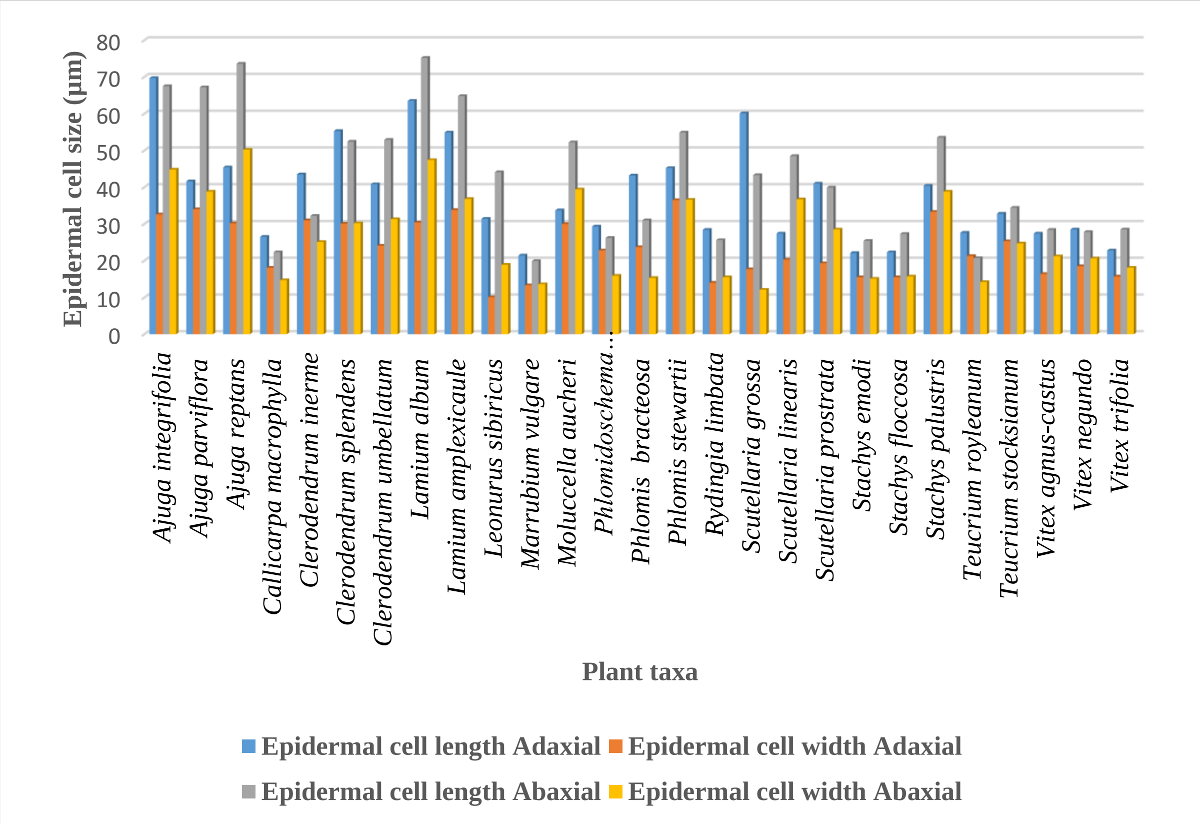

Figure. 41: Variation among epidermal cell length and width of both adaxial and abaxial surface of Lamiaceous taxa

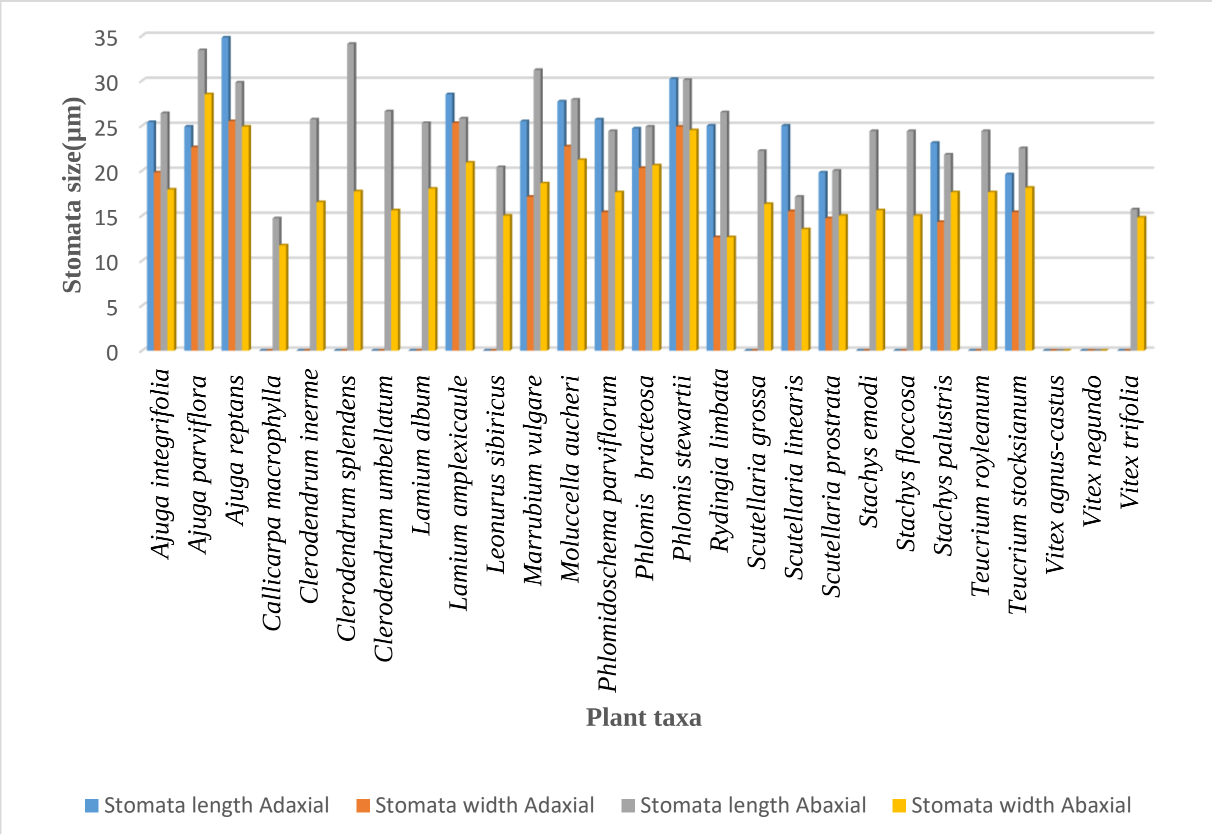

Figure. 42: Variation among stomata length and width of both adaxial and abaxial surface of Lamiaceous taxa

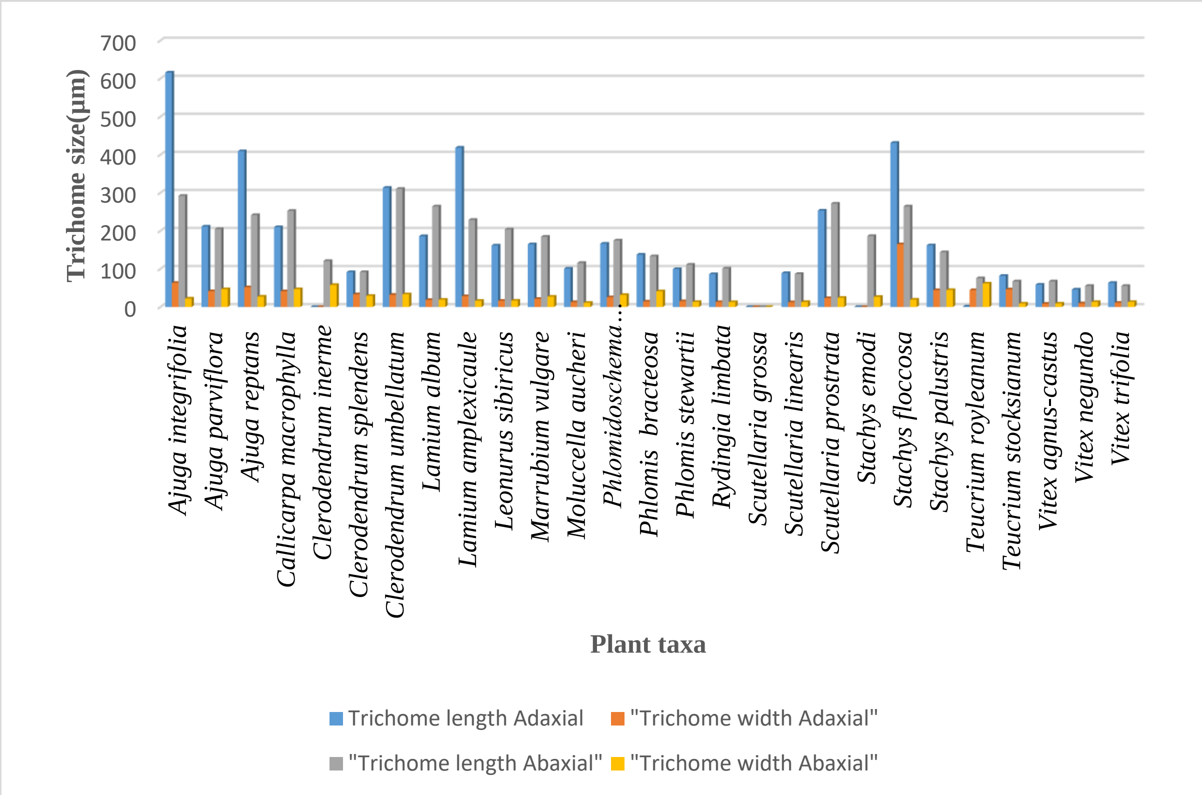

Figure. 43: Variation among trichome length and width of both adaxial and abaxial surface of Lamiaceous taxa

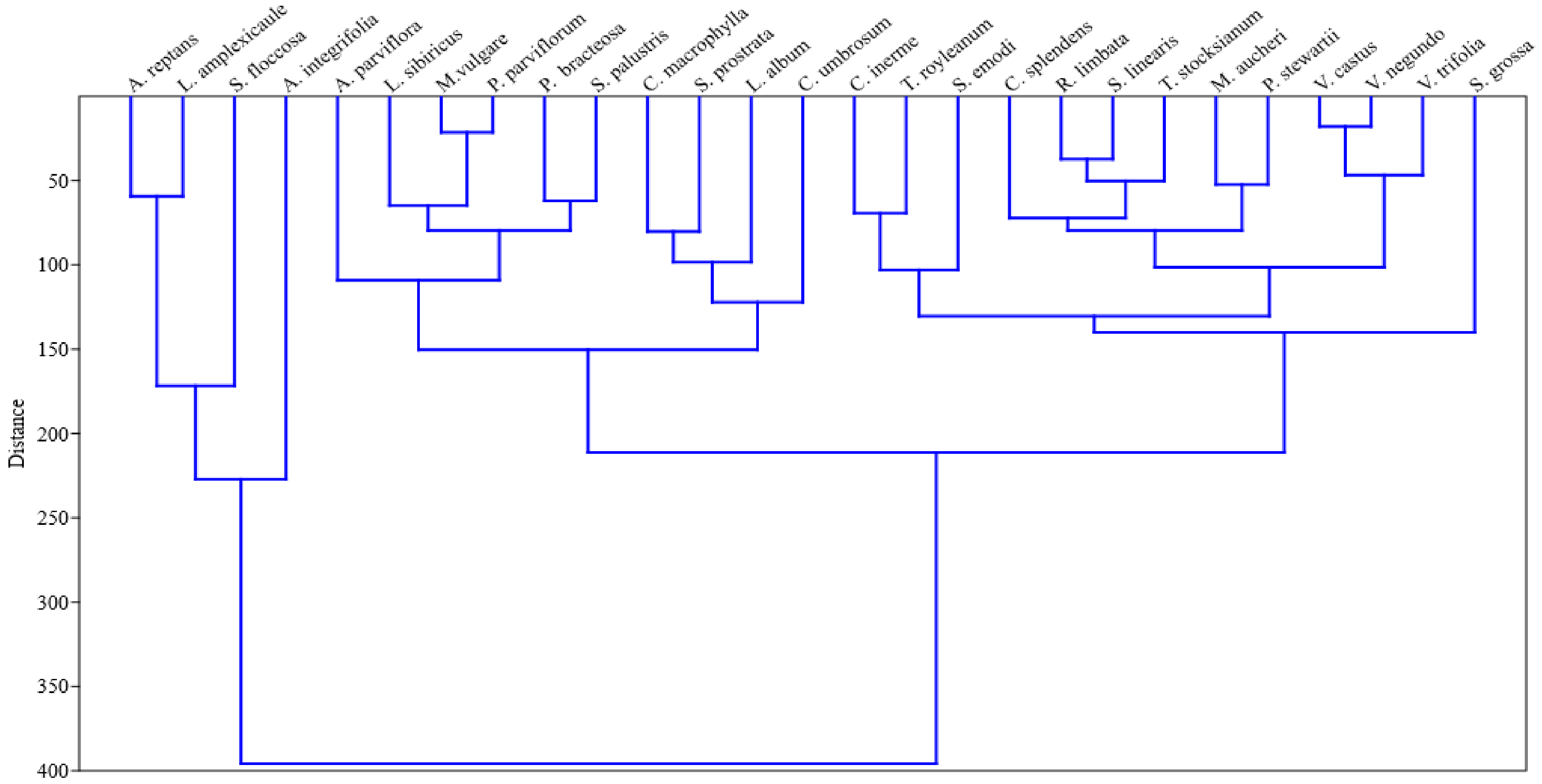

Figure. 44: Cluster analysis of the studied Lamiaceous taxa based on quantitative foliar anatomical traits

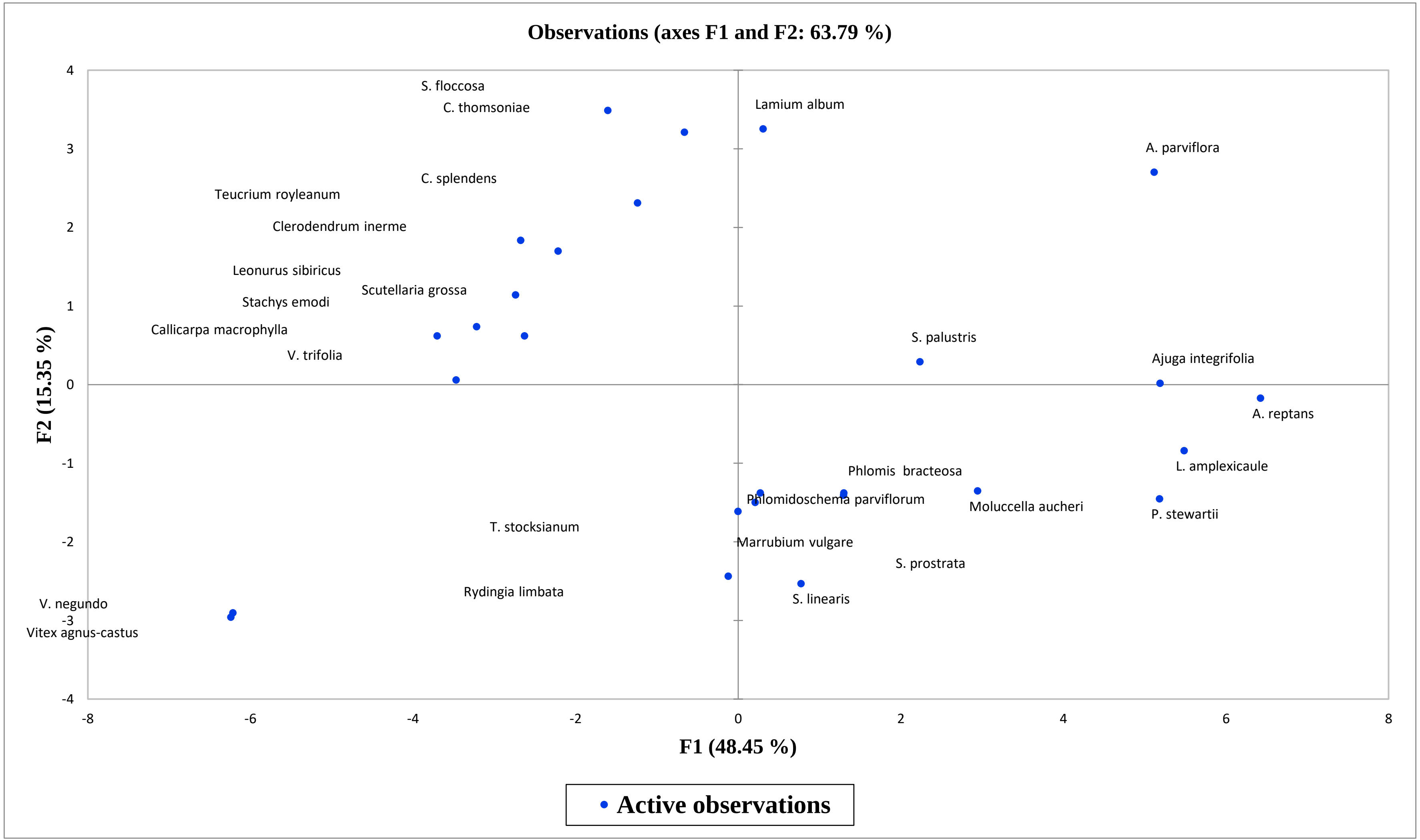

Figure. 45: Principal component analysis (PCA) of leaf active observation of the biplot

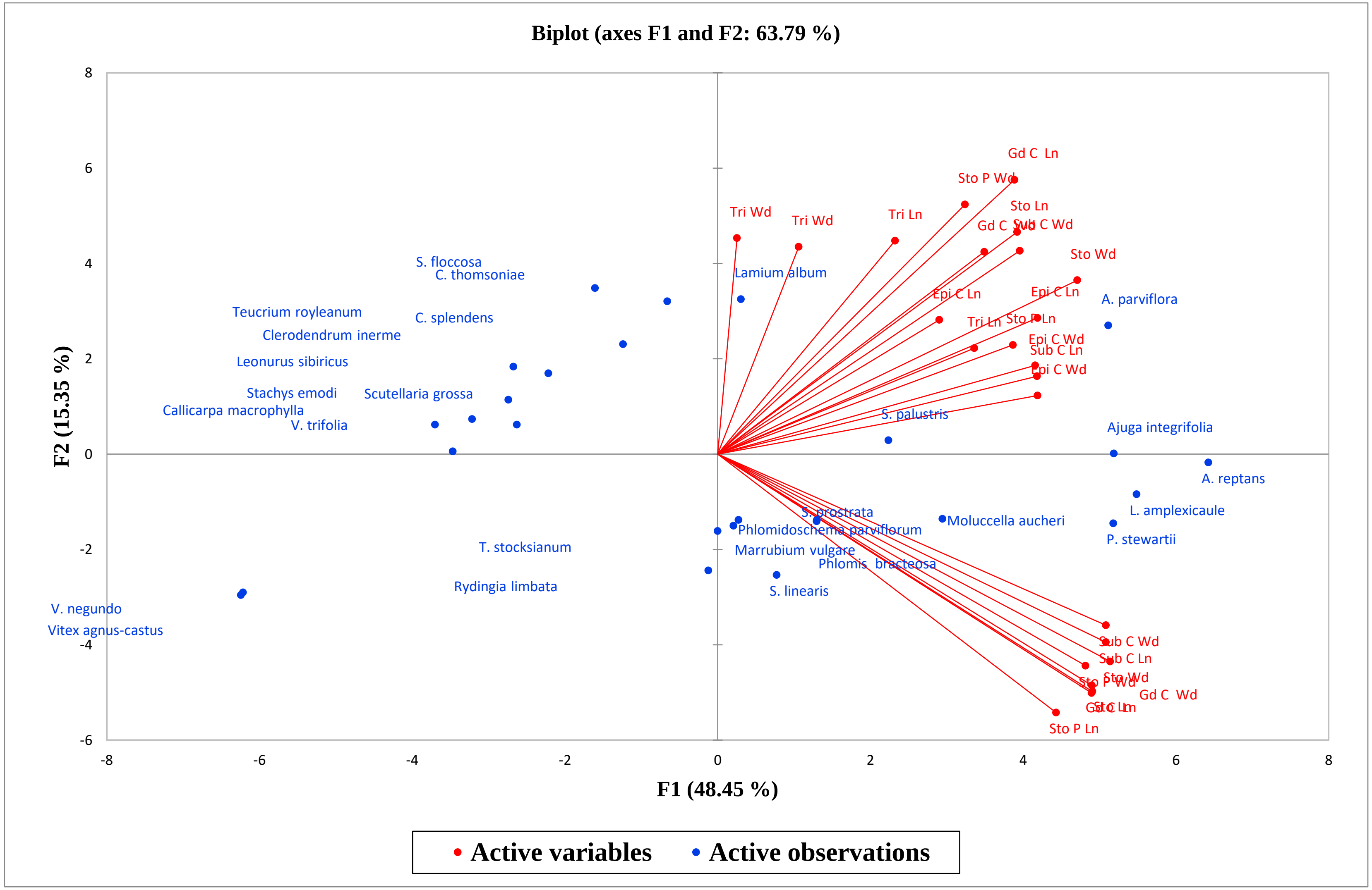

Figure. 46: Principal component analysis (PCA) biplot metric variables of leaf of Lamiaceous taxa showed variance account of PCA axes; axes 1, 48.45% and axes 2, 15.35%

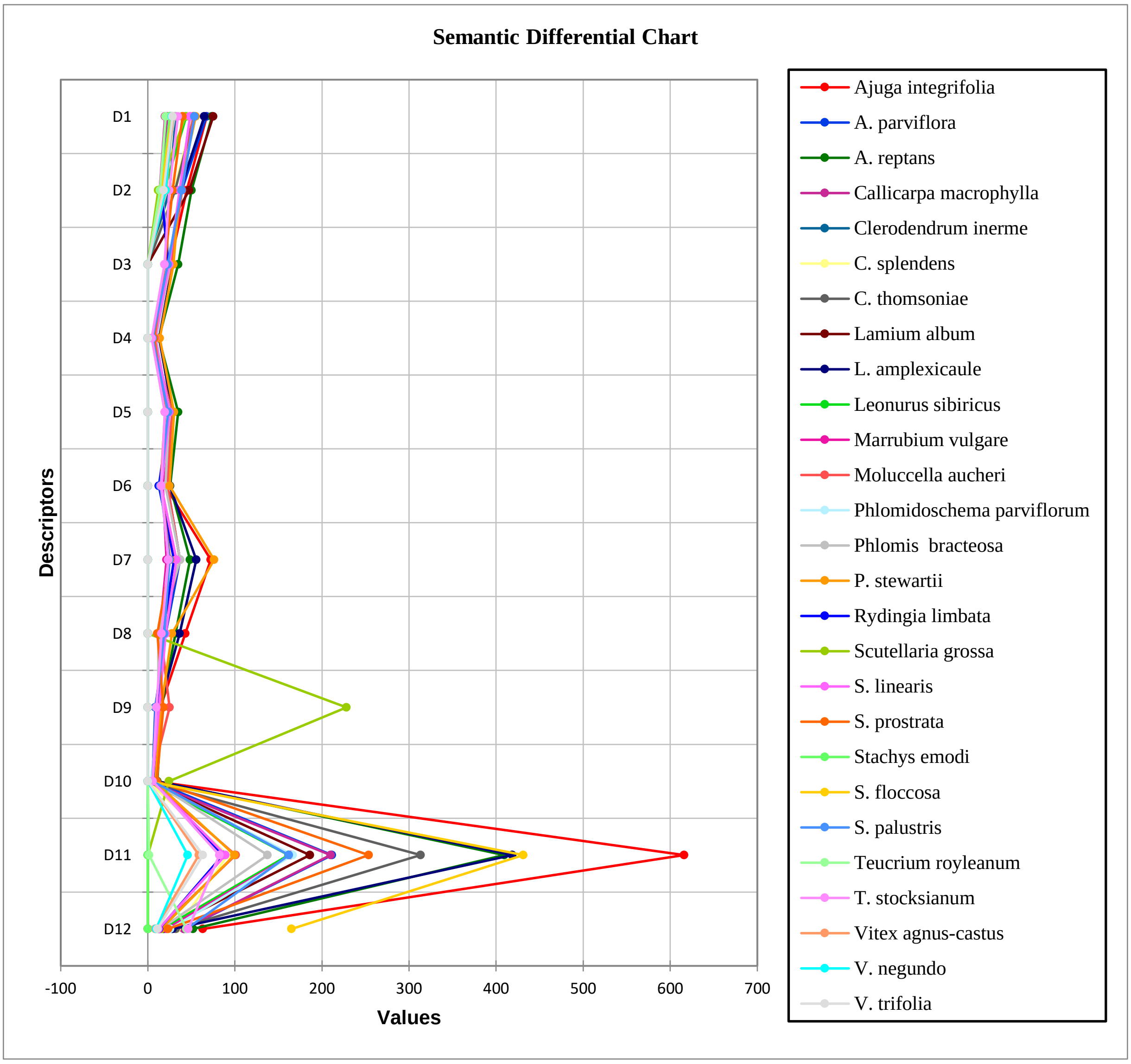

Figure. 47: Semantic differential chart of twelve variables of foliar adaxial surface that is epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each)

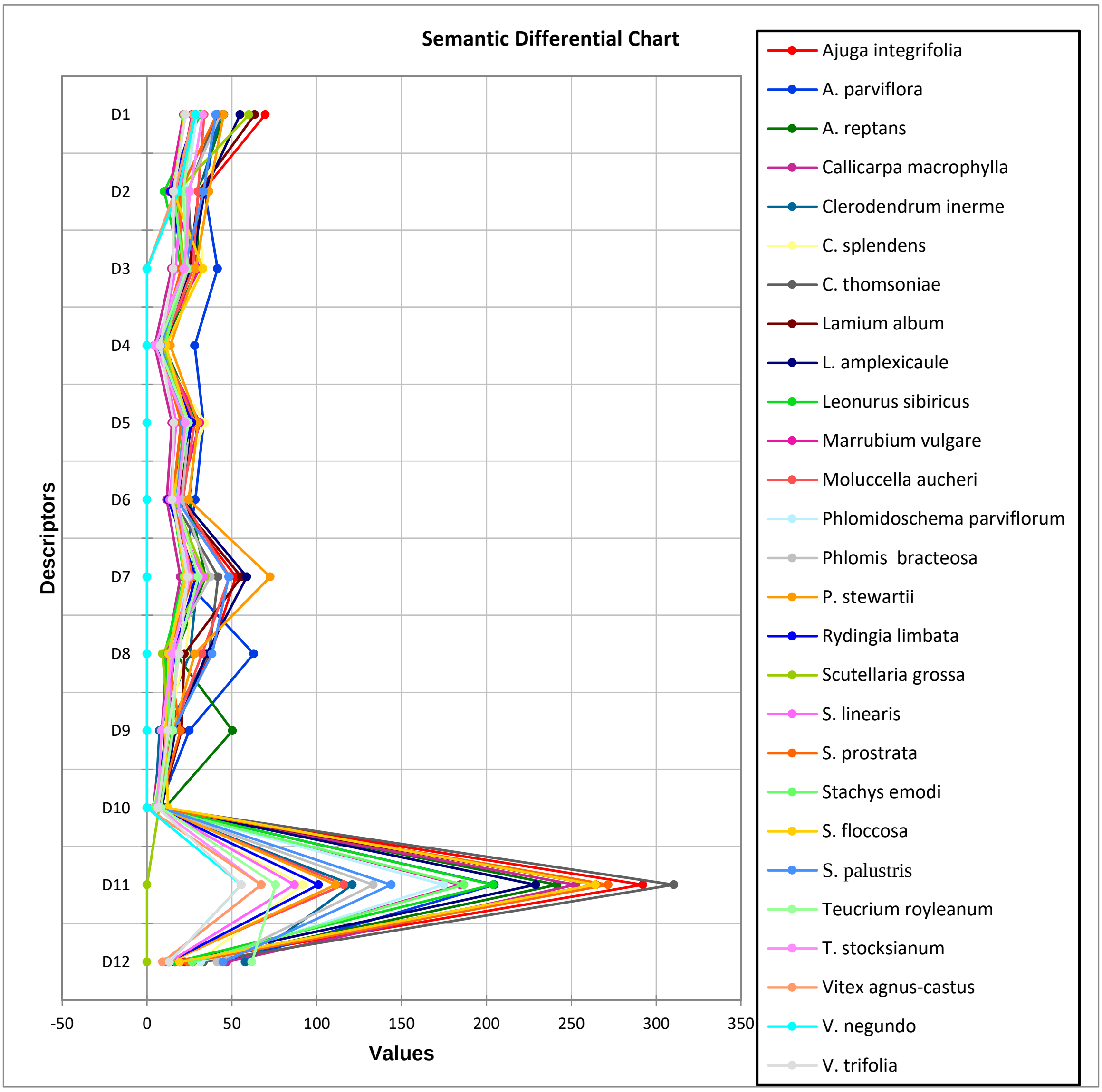

Figure. 48: Semantic differential chart of twelve variables of foliar abaxial surface that is epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each)

3.7 Anatomical Characterization of Subfamily Nepetoideae

This study focused on the foliar epidermal micromorphology of 33 species of the subfamily Nepetoideae. Foliar epidermal micromorphology was examined through light microscopy (LM) and scanning electron microscope (SEM). In the data presented here, we examined qualitative and quantitative characteristics of foliar epidermis and found that foliar epidermal morphological traits varied significantly (Tables.18,19, and 20).

This study was mainly concentrated on the shape and wall patterns of epidermal cells, the type and shape of stomata, guard cell shape, stomatal pores, subsidiary cells, trichome shape, and trichome sculpturing. A dichotomous key was constructed using the qualitative characteristics of these taxa for simple identification and species delimitation. Scanning electron micrographs are shown in Plates 75-85.

3.7.1 Foliar Epidermal Micromorphological Characters

Nepetoideae leaves differ significantly in their epidermal micromorphological characters, trichome structure and density, stomatal complex, and structure. Considerable variation in foliar epidermal anatomical characteristics on both upper and lower surfaces was observed between the subfamily Nepetoideae members. Epidermal cells show variation in length and width. The highest and lowest epidermal cell length on adaxial surface was observed in *Ocimum basilicum* (102 µm) and *Melissa officinalis* (31 µm), respectively. Similarly, the highest and lowest epidermal cell width on adaxial surface was observed in *Ocimum* × *africanum* (61 µm) and *Origanum majorana* (14 µm) respectively. The highest and lowest epidermal cell length on abaxial surface was observed in *Ocimum americanum* (76 µm) and *Mentha suaveolens* (30 µm), respectively. Similarly, the highest and lowest epidermal cell width on abaxial surface was observed in *Ocimum basilicum* (51 µm) and *Micromeria biflora* (14 µm) respectively (Fig. 49).

Most of the subsidiary cells are irregular, bean-shaped cells were investigated in *Mentha* species, and tetragonal to hexagonal (polygonal) subsidiary cells were found in *Perovskia atriplicifolia, Thymus linearis, and Thymus vulgaris*. The subsidiary cells show less variation in cell shape, all the studied species have irregular subsidiary cells except in *Callicarpa macrophylla* where subsidiary cells are not visible. The highest and lowest subsidiary cell length on adaxial side were observed in *Plectranthus ambonicus* (72 µm) and *Monarda fistulosa* (13 µm) respectively. Similarly, the highest and lowest subsidiary cell width on adaxial surfaces was observed in *Anisochilus carnosus* (42 µm) and *Mentha* × *villosa, Origanum majorana* and *Satureja hortensis* (11 µm of each), respectively. The highest and lowest subsidiary cell length on abaxial side were observed in *cimum × africanum* (75µm) and *Monarda fistulosa* (12 *µm*) respectively. Similarly, the highest and lowest subsidiary cell width on abaxial surfaces was observed in *Anisochilus carnosus* (42 µm) and *Mentha suaveolens* (8 µm), respectively.

The number of epidermal cell lobes, which ranged from 4 to 12, varied significantly. Most epidermal cells on both the abaxial and adaxial surfaces are irregular, followed by polygonal. Polygonal epidermal cells were observed in *Mentha* x *piperita citrate*, *Perovskia atriplicifolia*, *Rosmarinus officinalis*, *Thymus linearis,* and *Thymus vulgaris*. All investigated species have a similar irregular epidermal cell type, coincidees the results of earlier workers Gul et al., (2019a) except in *Mentha spicata* and *Thymus linearis*, but different in isodiametric epidermal cell shape. Epidermal cells with an irregular shape in *Mentha suaveolens* are similar with Ayaz et al., (2020). Epidermal cells with an irregular shape in the investigated species also show similarity with the results of previous workers Zaman et al., (2022a), Moon et al., (2009) and Gul et al., (2019b). In the present research, variation was observed in epidermal wall pattern, i.e., strongly undulate, undulate, sinuate, thickened, and convex thickened, varying from the results of Gul et al., (2019b). The pattern of epidermal cell walls may be slightly linked to ecological factors. Species found in drier habitats typically have curved and straight cell walls, whereas those found in humid environments typically have undulating cell walls (Stace, 1965). According to Zaman et al., (2022a) the shape of epidermal cells in *Dracocephalum rupestre, Perilla frutescens, Mentha canadensis* and *Thymus mongolicus* similar to our studied taxa but differences in stomata type and shape except in *thymus* that shows similarity in stomata type.

3.7.2 Stomatal Complex Micromorphological Characters

Nepetoideae has both hypostomatic and amphistomatic leaves, but amphistomatic leaves were more common, i.e., 28 species were amphistomatic and 5 species were hypostomatic (Table 18). Due to complex and numerous trichomes, stomata were not seen at the leaf's lower surface. In the current investigation, four main kinds of stomata were identified: anomocytic, diacytic, anisocytic, and paracytic. In most of the species, anomocytic stomata were more common. But diacytic, anisocytic, and anomocytic types vary between species. Paracytic stomata were present in two species, i.e., *Mentha villosa* and *Rosmarinus officinalis.*

In the current investigation, elliptic, broad elliptic, and narrow elliptic oval and ovate shaped stomata were more commonly seen. Only in *Prunella vulgaris* ovate shape stomate was observed. While *Anisochilus carnosus, ocimum sanctum* and *Thymus linearis have* oval stomata. But there have also been reports of stomata with a rectangular, oval, circular, or oblong shape (Gul et al., 2019a). Nepetoideae shows a wide variation in stomata size across taxa. The largest stomata length at the adaxial surface was observed in *Mentha x piperita citrata* (39 µm) and the lowest in *Mentha suaveolens* (13 µm). Similarly, the largest stomata width at the adaxial surface was observed in *Ocimum citriodorum, Plectranthus ambonicus* (27 µm of each) and the lowest in *Mentha arvensis* (3 µm). The largest stomata length at the abaxial surface was observed *Ocimum citriodorum* (40 µm) and the lowest in *Mentha suaveolens* (18 *µm*). Similarly, the largest stomata width at the abaxial surface was observed in *Anisochilus carnosus* (28 µm) and the lowest in *Mentha spicata* (12 µm) (Fig. 50).

The stomata index indicates the highest and lowest densities of stomata on adaxial and abaxial surfaces. The highest stomata index (SI) at the adaxial surface was observed in *Plectranthus ambonicus* (19%) and the lowest in *Micromeria biflora* (0.4%). Similarly, the highest stomata index (SI) at the abaxial surface was observed in *Anisochilus carnosus* (71.6%) and the lowest in *Mentha longifolia* (7.3%). Stomata types and locations in the current study are close to those in Cantino (1990).

In the present research, the stomatal pore's shape can also differ greatly, for example, taking the form of an oval, ovate, narrow, or broad ovate, elliptical, elongated, cylindrical, or linear. Only in *Lallemantia royleana* consists of dumbbell-shaped stomatal pore observed. The stomatal pore's size can also show great variation show in (Table. 20). The maximum and minimum stomatal pore length at adaxial was studied in *Plectranthus ambonicus* (28 µm) and *Mentha suaveolens* (12 µm) respectively. Similarly, the maximum and minimum stomatal pore width at adaxial was observed in *Mentha × villosa* (12µm) and *Dracocephalum moldavica, Hyssopus officinalis, Mentha longifolia* and *Monarda fistulosa* (5 µm of each) respectively. The maximum and minimum stomatal pore length at abaxial surface was studied in *Mentha spicata* (39 µm) and *Clinopodium hydaspidis* (8 µm) respectively. Similarly, the maximum and minimum stomatal pore width at abaxial was observed in *Mentha spicata* (23 µm) and *Prunella vulgaris* (4 µm) respectively. Additionally, kidney-shaped, narrow, and broad kidney-shaped guard cells appeared more frequently. In *Prunella vulgaris and Ocimum gratissimum* consists of elongated guard cells (Table. 18). The guard cell size also shows great variation in the studied taxa. The largest guard cell length at the adaxial surface was observed in *Ocimum citriodorum* (37 µm) and the lowest in *Mentha suaveolens* (13 µm). Similarly, the largest guard cell width at the adaxial surface was observed in *Mentha x piperita citrata, Ocimum americanum, Ocimum citriodorum and Ocimum sanctum* (13 µm of each) and the lowest in *Perovskia atriplicifolia* (4.9 µm). The largest guard cell length at the abaxial surface was observed in *Mentha spicata* (46 µm) and the lowest in *Mentha suaveolens* (19 µm). Similarly, the largest guard cell width at the abaxial surface was observed in *Mentha spicata* (30 µm) and the lowest in *Ocimum gratissimum, Perilla frutescens and Perovskia atriplicifolia* (6 µm of each).

Previous studies of Inamdar and Bhatt (1972) and Ramayya and RAO (1969) studied diacytic and anomocytic stomata type in *ocimum* species similar to our results but different in stomata location in *ocimum sanctum* and *Ocimum gratissimum*.

According to Gul et al., (2019b) investegate the shape of epidermal cells and stomata shape of *Ocimum americanum* and *Ocimum sanctum* similar to our studied species but different in stomata type. In the present study more than one kind of stomata was observed in a specie similar with Gul et al., (2019a), Moon et al., (2009) and Zaman et al., (2022a) . The stomate type of *Mentha suaveolens* is similar to the previous studies by Ayaz et al., (2020), but dissimilar in shape of stomata. The stomata types in most *Mentha* species were anomocytic and diacytic in the present study. The shape and type of stomata in *Dracocephalum, Origanum, and Mentha* species were different from earlier studies by Zaman et al., (2022a), except in *Mentha villosa.* Eearlier investegtion by Cantino (1990) shows amphistomatic leaves with anomocytic stomata type in *Perovskia atriplicifolia* and *Melissa officinalis* corroborated with our results but not corroborated in *Prunella vulgaris, Dracocephalum moldavica, Mentha arvensis, and Mentha piperita*. Although El-Gazzar and Watson (1968) examined stomatal configurations in a variety of Lamiaceae, they only listed the most common form for each genus. Amphistomatic leaves, which are thought to occur more frequently in xeric settings, were a prevalent feature of Mentheae Prakash et al., (2016) coincides with our results but, not coincides with Inamdar and Bhatt (1972). The amphistomatic species has more stomata on the abaxial surface in the present research. In this research, four species were hypostomatic, for example, *Melissa officinalis*, *Monarda fistulosa*, *Rosmarinus officinalis,* and *Clinopodium hydaspidis*. *Monarda fistulosa* is hypostomatic in the present research, different from Moon et al., (2009) but similar with Cantino (1990). Earlier research by Salama et al., (2019) has similar types of stomata as in our observed Nepetoideae species. Previous studies of Ozcan and Eminagaoglu (2014) found amphistomatic leaves in their studied *origanum* species with irregular epidermal cells and anomocytic stomata with densely covered trichomes were similar to our results but dissimilar in wall pattern.

3.7.3 Trichome Micromorphological Characteristics

Both the adaxial and abaxial foliar epidermis are covered with a high number of glandular and non-glandular trichomes.

We divided the trichomes into two groups, non-glandular and glandular, based on whether the trichome had a secretory head. Unicellular or multicellular, unbranched, and branched trichomes are the two forms of non-glandular trichomes. Nepetoideae has two types of glandular trichomes, small capitate and large peltate, which differ in size, structure, and distribution. But they varied from one another in terms of form, density, and positioning on leaves. Head cells of capitate and peltate trichomes can range from four to twelve. Following Cantino (1990) we made a distinction between capitate and subsessile trichomes for the glandular trichomes. In most of the Nepetoideae species have trichomes visible on both leaf surfaces.

According to several taxonomic levels and diverse studies (Abu-Asab and Cantino 1987; Ayodele and Olowokudejo; 2006, Cantino, 1990; Demissew and Harley 1992) found trichome diversity in the Lamiaceae may be taxonomically relevant. Trichomes have a variety of structures, and their densities can occasionally be too varied for phylogenetic analysis (Guerin, 2005). Trichomes are among the most crucial characteristics that contribute to plants' passive resistance to diseases, pests, and drought (Levin, 1973), and they may be crucial for their ability to adapt to situations involving high levels of radiation (Stenglein et al., 2005). However, species groups tend to have stable trichome types (Okpon, 1969; Stace, 1965).

The examined specimens indicated a larger number of trichomes found on the abaxial surface of the leaf surface than on the adaxial surface (Dehshiri and Azadbakht 2012). The characteristics and distributions of trichomes at the genus, species, and sub familial levels were among the key taxonomic and diagnostic characteristics of members of the Lamiaceae family (Abu-Asab and Cantino, 1987; Cantino and Sanders 1986; El-Gazzar and Watson 1970). The micromorphological characteristics of peltate and capitate glandular trichomes differ, reflecting differing roles and eventually different secretory processes. Capitate trichomes have variable sizes and shapes (Kahraman et al., 2010b). The glandular peltate-type trichomes in the Lamiaceae typically have a broad head with numerous secretory cells up to 16 in number, a short stalk, and radially arranged basal cells, which support the earlier findings. Callow et al., (2000) and Corsi and Bottega (1999) found little variation in the number of secretory cells. In the current research, the peltate glandular trichomes consist of four-twelve-celled heads organized in a circular position (Plate. 83 I), similar to Callow et al., (2000), Corsi and Bottega (1999), Kamatou et al., (2006), and Serrato-Valenti et al., (1997) but dissimilar in the research by Hanlidou et al., (1991) where the head cells of peltate glandular trichomes are arranged in two concentric spheres. According to Abdulrahaman and Oladele (2005) investigate similar epidermal cell shape and stomata type in *ocimum* species as our findings but dissimilar in wall pattern.

3.7.3.1 Non-Glandular Trichomes

Acicular, non-glandular, trichomes have a sharp end that is dragged towards the tip of the leaf. Particularly on the abaxial surface, they seem to be particularly numerous along the veins and midrib (Plate. 76 C, Plate. 80 I, Plate.83 G and Plate. 85 C). Unicellular and multicellular, stellate, branched, and unbranched trichomes are the four types of non-glandular trichomes that have been identified. When studied under SEM, non-glandular trichomes can also vary significantly. The shape, cell count, and surface ornamentation of non-glandular trichomes showed a large range of variance. It was unicellular to multicellular, uniseriate, and unbranched to branched. Such trichomes had very diverse length, width, and surface patterns in the SEM micrographs (Plates 76-85).

The current research investigates unicellular-multicellular, conical, and hook-shaped trichomes in *Lallemantia royleana*, *Mentha longifolia*, *Micromeria biflora*, and *Origanum vulgare* coincides with the results of Gul et al., (2019a) but not coincides in terms of glandular trichomes. In the present research, *Mentha spicata* shows dissimilarities in trichomes from previous investigations by Gul et al., (2019a). The largest trichome length at the adaxial surface was observed in *Mentha × villosa* (519 µm) and the lowest in *Mentha spicata, Thymus linearis* (19 µm of each). Similarly, the largest trichome width at the adaxial surface was observed in *Prunella vulgaris* (53 µm) and the lowest in *Thymus vulgaris* (10 µm). The largest trichome length at the abaxial surface was observed in *Plectranthus ambonicus* (90 µm) and the lowest in *Thymus linearis* (20 µm). Similarly, the largest trichome width at the abaxial surface was observed in *Clinopodium hydaspidis* at (66 µm) and the lowest in *Lavandula angustifolia, Micromeria biflora, and Rosmarinus officinalis* (11 µm of each) (Fig. 51).

The trichome index indicates the highest and lowest densities of trichomes on adaxial and abaxial surfaces. The highest trichome index (TI) at adxial surface was observed in *Thymus vulgaris* (61.9%) and lowest in *Micromeria biflora* (0.7%). Similarly, the highest trichome index (TI) at abxial surface was observed in *Thymus vulgaris* (48%) and lowest in *Lallemantia royleana* (1.7%).

Non-glandsular trichomes were further divided into subcategories, such as unicellular to multicellular trichomes with stellate, falcate, clavate, hook, conical, cylindrical, and simple shapes (up to six cells). Serrato-Valenti et al., (1997) further classified the NGTs of many Lamiaceae species into three subgroups. Non-glandular trichomes were more prevalent in the Lamiaceae family than glandular ones. In the present research, *Mentha suaveolens* is covered both with glandular and non-glandular trichomes, varying from Ayaz et al., (2020). Non-glandular trichomes were further divided into three types: (i) simple single celled, hook shape, or conical with a bulbous base and pointed tip (Plate. 80 C, Plate. 83 F), consistent with the findings of Abu-Asab and Cantino (1987) in *Micromeria biflora* and in *Perilla frutescens*, but difference in branched trichome from the present study in *Lavandula angustifolia* and *Perovskia atriplicifolia* which were mostly observed on the edges of both sides of the leaf surface and along the veins, (ii) short multicellular, 2-4 cells long, uniseriate, warts on the surface, broad pedestal, and sharp apex (Plate. 84 A and C); (iii) branched and constantly pointing towards the apex, long multicellular, four-eight cells, uniseriate or multiseriate (Plate. 83 K), in present research observed in *Perovskia atriplicifolia* corroborated with the results of Abu-Asab and Cantino (1987).

3.7.3.2 Glandular Trichomes

In the present research there were four main types of glandular trichomes: capitate, Pilate, peltate glandular trichomes, and unicellular and multicellular glandular trichomes. However, they were distinct from one another in terms of form, density and position on the leaf. The stalk of pilate glandular trichomes was made up of many cells with a gland at the top. Both the adaxial and abaxial leaf surfaces have peltate trichomes.

The large eight celled head of the peltate glandular trichomes was attached to a short stalk by a moth-like rounded top (Plate. 80 E and G). Particularly in mature leaves, the peltate trichomes appear to be totally swollen as they fill with the secretory substance (oil). The head cell of capitate glandular trichomes was linked to a single stalk cell (Plate. 78 C). These glandular trichomes had characteristic spherical heads because of the accretion of essential oil in the under cuticular region. When compared, capitate trichomes are smaller than peltate trichomes. Pilate glandular trichomes are found only in *Perovskia atriplicifolia*. Peltate glandular trichomes were present in the majority of Nepetoideae taxa but not in the abaxial surface of *Mentha* spicata, the *adaxial surface of Mentha suaveolens*, *Mentha* x *piperita citrate, Thymus linearis*, or on both surfaces of *Lallemantia royleana*, *Mentha villosa*, *Micromeria biflora*, *Prunella vulgaris*, *Rosmarinus officinalis*, *or Satureja hortensis*. In this study *Mentha spicata* consist of only glandular trichomes, different from Choi and Kim (2013) but similar to *Mentha suaveolens* in terms of trichome diversity, except with V-shaped trichomes in *Mentha suaveolens.* Previous investigation by Salama et al., (2019) was similar for *Mentha spicata* but dissimilar for *M. longifolia and M. piperita.*

3.7.4 Cluster Analysis and Principal Component Analysis (PCA) of Leaf as a Statistical Tool

The similarity index among the studied subfamily Nepetoideae taxa was analyzed using UPGMA cluster analysis (Karaismailoğlu et al., 2018). The quantitative data provides three principal clusters based on foliar anatomical characters. Cluster 1 indicates Plectranthus ambonicus which was totally distinct from the other studied taxa, but Cluster 1 also shows similarity between Mentha × villosa and Prunella vulgaris. Cluster 2 shows similarity between Ocimum × africanum and Ocimum basilicum. Cluster 3 is divided into subclusters 1 which is further subdivided. The greatest similarity was observed between Micromeria biflora and Thymus vulgaris among the subdivided cluster 3 (Fig. 52).

Principal Component Analysis (PCA), in accordance with (Sharma and Paliwal 2007) represents the highest contribution to the overall variability on each axis. The factor that is frequently used to determine how many variables to keep. The quantitative data analysis was used as the foundation for PCA. Cluster analysis and PCA are both statistical techniques for separating genera and species (Shah et al., 2018). In the current study, we employed PCA and cluster analysis to examine the foliar epidermal anatomy of the subfamily Nepetoideae. PCA reveals the highest contribution to the overall variability for each axis (Fig. 53, 54 and Table 21).

The Eigen values show the overall number of variables and are frequently used to determine how many factors to keep (Sharma, 2006). In the present study, the epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each) of 33 Nepetoideae species were used to explore foliar anatomical variability. Principal component analysis variable loadings for first 12 components illustrated in Table 21. In the present study, six PCAs carried more than one eigenvalue and 49.86% of the total variance. Additionally, PC1 showed a variability of 34.98%, with a large positive loading element of the foliar epidermal characters, and PC2 showed a variability of 14.88%, with a large positive loading element of the foliar epidermal traits. Principle component analysis (PCA) of the investigated species revealed that Nepetoideae species are more correlated to one another. Guard cell width followed by stomatal pore length, epidermal cell width, subsidiary cell width and trichome width are the most valuable variables. On the first axes positive side, *Ocimum* × *africanum* were found with the largest subsidary cell width followed by epidermal cell length. Similarly, *Plectranthus ambonicus* is also found on the positive side of first axes with high value subsidiary cell length. *Clinopodium hydaspidis, Rosmarinus officinalis, Melissa officinalis*, Dracocephalum *nutans*, Ocimum *gratissimum* and *Satureja hortensis* were found on the positive side of the second axes. Whereas *Mentha× villosa, Hyssopus officinalis, Mentha pulegium, Mentha longifolia, Monarda fistulosa*, *Lavandula angustifolia, Origanum majorana*, *Thymus Vulgaris* and *Micromeria biflora* were found on the negative side of the biplot. Moreover, the semantic differential chart shown in Figures 55 (adaxial) and 56 (abaxial) were used to better illustrate and assess the studied foliar anatomical characteristics.

3.7.5 Dichotomous Key of the Studied Sub Family Nepetoideae

1	+	Stomata anisocytic…………………………	*Mentha* x *piperita citrata*
	-	Stomata other than anisocytic…………….	2
2	+	Stomata anisocytic- diacytic………………	4
	-	Stomata other than anisocytic- diacytic……	3
3	+	Stomatal pore oval……………………………	*Dracocephalum moldavic*
	-	Stomatal pore linear…………………………	*Prunella vulgaris*
4	+	Stomata anomocytic- anisocytic……………	*Ocimum gratissimum*
	-	Stomata other than anomocytic- anisocytic…	5
5	+	Stomata paracytic……………………………	7
	-	Stomata other than paracytic…………………	6
6	+	Anticlinal wall pattern undulates…………	*Mentha × villosa*
	-	Anticlinal wall pattern thin and convex………	*Rosmarinus officinalis*
7	+	Stomata diacytic………………………………	10
	-	Stomata other than diacytic…………………	8
8	+	Stomata dumbbell shaped……………………	*Lallemantia royleana*
	-	Stomata other than dumbbell shaped…………	9
9	+	Peltate Glandular trichomes…………………	*Ocimum americanum*
	-	Glandular and non-glandular trichomes………	*Ocimum sanctum*
10	+	Stomata anomocytic- diacytic………………	16
	-	Stomata other than anomocytic- diacytic……	11
11	+	Subsidiary cell polygonal……………………	*Perovskia atriplicifolia*

	-	Subsidiary cell irregular………………………	*Ocimum basilicum*
12	+	epidermal cell polygonal……………………	*Mentha spicata*
	-	Epidermal cell other than polygonal………..	13
13	+	Stomata oval………………………………	*Anisochilus carnosus*
	-	Stomata cell other oval………………………	14
14	+	Anticlinal wall pattern undulates……………	*Ocimum × africanum*
	-	Anticlinal wall pattern other than undulates…	15
15	+	Abaxial epidermal cells elongated…………..	*Hyssopus officinalis*
	-	Abaxial epidermal cells irregular…………..	*Mentha × piperita*
16	+	Stomata anomocytic………………………..	19
	-	Stomata other than anomocytic………………	17
17	+	Anticlinal wall pattern buttressed…………..	*Lavandula angustifolia*
	-	Anticlinal wall pattern thickened sinuate……	*Micromeria biflora*
18	+	Anticlinal wall pattern undulate and beaded…	*Perilla frutescens*
	-	Anticlinal wall pattern thickened, convex……	*Thymus linearis*
19	+	Anticlinal wall pattern undulates……………	21
	-	Anticlinal wall pattern other than undulate…	20
20	+	Stomatal pore elongated /cylindrical………..	*Mentha pulegium*
	-	Stomatal pore narrow ovate…………………	*Mentha suaveolens*
21	+	Anticlinal wall pattern thickened…………..	23
	-	Anticlinal wall pattern other than thickened…	22
22	+	Trichome surface rough………………………	*Origanum majorana*
	-	Trichome surface granulate…………………	*Origanum vulgare*
23	+	Anticlinal wall pattern deeply undulates……	26
	-	Anticlinal wall pattern other than deeply undulates	24
24	+	Shape of stomatal pore linear…………………	*Satureja hortensis*
	-	Shape of stomatal pore other than linear……	25
25	+	Guard cells narrow ovate……………………	*Clinopodium hydaspidis*
	-	Guard cells broad ovate………………………	*Ocimum citriodorum*
26	+	Anticlinal wall pattern sinuate………………	30

	-	Anticlinal wall pattern other than sinuate……	27
27	+	Trichome surface striate and granulate………	*Melissa officinalis*
	-	Trichome surface rough……………………	*Thymus vulgaris*
28	+	Trichomes peltate glandular…………………	*Mentha arvensis*
	-	Guard cell broad kidney shape………………	*Monarda fistulosa*
29	+	Stomata elongated-elliptic……………………	*Plectranthus ambonicus*
	-	Stomata elliptic………………………………	*Mentha longifolia*

Table. 18: Qualitative characteristics of the foliar anatomy of Nepetoideae taxa

S. no	Plant name	Shape of epidermal cell Ad/Ab		Lobes per epidermal cell Ad/AB		Wall pattern	Stomata P/A Ad/Ab		Stomata type	Shape of stomata	Shape of stomatal pore	Shape of guard cell	Subsidiary cell Shape	Trichome P/A Ad/Ab		Trichome type Ad/AB		Trichome sculpturing
1.	*Anisochilus carnosus* (L.f.) Wall.	Irregular	Irregular	8-10	10-12	Sinuate	P	P	Anomocytic/diacytic	Oval	Elongated	Kidney shaped	Irregular	P	P	Multicellular NGTs, peltate GTs	Multicellular NGTs, peltate GTs	Slightly granulated
2.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	Irregular	Irregular	8-10	10-12	Deeply undulate	A	P	Anomocytic	Elliptic	Narrow ovate	Kidney shaped	Irregular	P	P	Multicellular clavate, capitate and peltate GTs	Unicellular conical NGTs, capitate and peltate GTs	Granulate
3.	*Dracocephalum moldavica* L.	Irregular	Irregular	4-5	4-5	Convex, slightly lobed	P	P	Anisocytic/diacytic	Elliptic	Oval	Kidney shaped	Irregular	P	P	Unicellular to multicellular conical and hook shape NGTs, Subsessile Capitate and Peltate GTs	Unicellular to multicellular conical and hook shape NGTs, Subsessile Capitate and Peltate GTs	Granulate
4.	*Hyssopus officinali*	Irregul	Elong	4-	4-	Thick	P	P	Anomocytic	Ellipt	Narro	Kidne	Irregul	P	P	Unicellular	Unicellular	Granulate

	s L.	ar	ated	5	5	ened			-diacytic	ic	w ovate	y shaped	ar			clavate NGTs, Peltate GTs	clavate NGTs, Peltate GTs	
5.	*Lallemantia royleana* (Benth.) Benth.	Irregular	Irregular	8-10	10-12	Undulate	P	P	Diacytic	Broad elliptic	Dumbbell shaped	Kidney shaped	Irregular	P	P	Multicellular conical NGTs	Multicellular falcate NGTs	Granulate
6.	*Lavandula angustifolia* Mill.	Irregular	Irregular	4-5	6-8	Buttressed	P	P	Anomocytic	Broad elliptic	Elongated	Kidney shaped	Irregular	P	P	Branched and stellate unicellular NGTs, Capitate and Peltate GTs	Branched and stellate unicellular NGTs, Capitate and Peltate GTs	Smooth
7.	*Melissa officinalis* L.	Irregular	Irregular	6-7	6-8	Sinuate	A	P	Anomocytic	Broad elliptic	Ovate	Kidney shaped	Irregular	P	P	Unicellular Conical (pointed apex) NGTs, Peltate GTs	Unicellular Conical some hook shape NGTs, Peltate and capitate GTs	Striate and granulate
8.	*Mentha arvensis* L.	Irregular	Irregular	9-12	9-12	Sinuate	P	P	Anomocytic	Elliptic	Narrow ovate to Ovate	Broad kidney shaped	Irregular	P	P	Peltate GTs	Peltate GTs	Smooth
9.	*Mentha longifolia* (L.) L.	Irregul	Irregu	5-	5-	Sinuat	P	P	Anomocytic	Ellipt	Ovate	Kidne	Irregul	P	P	Unicellular to	Multicellular	Smooth

		ar	lar	6	6	e				ic		y shaped	ar			multicellular conical and falcate NGTs, Peltate GTs	conical and falcate NGTs, Peltate GTs	and granulated
10.	*Mentha* × *piperita* L.	Irregular	Irregular	8-10	8-10	Convex, thickened	P	P	Anomocytic-diacytic	Elliptic	Narrow ovate to Ovate	Broad kidney shaped	Irregular	P	P	Unicellular to Multicellular conical and falcate NGTs, Subsessile Capitate and Peltate GTs	Multicellular conic NGTs, Subsessile Capitate and Peltate GTs	Slightly granulated
11.	*Mentha pulegium* L.	Irregular	Irregular	5-7	5-7	Undulate	P	P	Anomocytic	Broad elliptic	Elongated/ cylindrical	Narrow kidney shaped	Irregular	P	P	peltate GTs	Unicellular conical NGTs, Capitate and Peltate GTs	Granulate
12.	*Mentha spicata* L.	Polygonal	Polygonal	4-6	4-6	Convex, thickened	P	P	Anomocytic-diacytic	Narrow to broad elliptic	Narrow elliptic	Kidney shaped	Bean shaped	P	A	Peltate GTs	_	Smooth
13.	*Mentha suaveolens* Ehrh.	Irregular	Irregular	8-10	8-10	Undulate	P	P	Anomocytic	Broad ellipti	Narrow ovate	Kidney shape	Irregular to bean	P	P	Unicellular to multicellular conical and	Unicellular to multicellular conical	Slightly rough

										c		d	shaped			falcateNGTs, capitate GTs	NGTs, peltate GTs	
14.	*Mentha* x *piperita citrata* - (Ehrh.) Briq.	Polygonal	Irregular	5-6	6-7	Thickened	P	P	Anisocytic	Broad elliptic	Broad ovate	Narrow kidney shaped	Irregular	_	P	_	Peltate GTs	Rough striate
15.	*Mentha* × *villosa* Huds.	Irregular	Irregular	4-6	4-6	Undulate	P	P	Paracytic	Broad elliptic	Narrow ovate	Kidney shaped	Bean shaped	P	P	Unicellular to multicellular falcateNGTs	Unicellular to multicellular falcateNGTs	Roughly Granulate
16.	*Micromeria biflora* (Buch. -Ham. ex D.Don) Benth.	Irregular	Irregular	5-7	8-10	Thickened Sinuate	P	P	Anomocytic	elliptic	ovate	Kidney shaped	Irregular	P	P	Unicellular hook shape NGTs	Unicellular conical NGTs	Granulate and striate
17.	*Monarda fistulosa* L.	Irregular	Irregular	6-8	6-8	Sinuate	A	P	Anomocytic	Broad elliptic	Elongated	Broad kidney shaped	Irregular	P	P	Unicellular conical NGTs, capitate and peltate GTs	Unicellular conical NGTs, peltate GTs	Granulate
18.	*Ocimum* × *africanum* Lour.	Irregular	Irregular	10-12	11-13	Undulate	P	P	Anomocytic - diacytic	Elliptic	Ovate	Slightly kidney	Irregular	P	P	Peltate GTs	Multicellular NGTs, peltate GTs	Smooth

												shaped						
19.	*Ocimum americanum* L.	Irregular	Irregular	6-8	7-9	Smooth and sinuate	P	P	Diacytic	Elliptic	Ovate	Kidney shaped	Irregular	P	P	Peltate GTs	Peltate GTs	Smooth
20.	*Ocimum basilicum* L.	Irregular	Irregular	6-8	8-10	Irregularly thicken	P	P	Anomocytic - diacytic	Elliptic	Ovate	Slightly kidney shaped	Irregular	P	P	Peltate GTs	Multicellular NGTs, and peltate GTs	Smooth and granulated
21.	*Ocimum citriodorum* Vis.	Irregular	Irregular	8-10	8-10	Deeply undulate	P	P	Anomocytic	Broad elliptic	Broad ovate	Broad kidney shaped	Irregular	P	P	Multicellular NGTs, peltate GTs	Multicellular NGTs, peltate GTs	Slightly granulated
22.	*Ocimum gratissimum* L.	Pentagonal-hexagonal	Irregular	5-6	4-5	Straight sinuate	P	P	Anomocytic /Anisocytic	Slightly elliptic	Narrow elongated	Elongated	Irregular	P	P	Unicellular, Multicellular NGTs, and peltate GTs	Unicellular, Multicellular NGTs, and peltate GTs	Rough
23.	*Ocimum sanctum* L.	Irregular	Irregular	8-10	8-10	Sinuate-undulate	P	P	Diacytic	Oval	Ovate	Kidney shaped	Irregular	P	P	Peltate GTs	Multicellular NGTs, peltate GTs	Smooth and granulated

24.	*Origanum majorana* L.	Irregular	Irregular	5-7	5-7	Thickened	P	P	Anomocytic	Elliptic	Narrow ovate	Kidney shaped	Irregular	P	P	Unicellular falcateNGTs, peltate GTs	Unicellular falcateNGTs, peltate GTs	Rough
25.	*Origanum vulgare* L.	Irregular	Irregular	6-8	6-8	Thickened	P	P	Anomocytic	Broad elliptic	Broad ovate	Broad Kidney shaped	Irregular	P	P	Unicellular to multicellular conical and hook shape NGTs, peltate	Unicellular to multicellular conical and hook shape NGTs, peltate GTs	granulate
26.	*Perilla frutescens* (L.) Britton	Irregular	Irregular	8-10	10-11	Undulate and beaded	A	P	Anomocytic	Elliptic	Ovate	Kidney shaped	Irregular	P	P	Multicellular and unicellular NGTs, capitate and peltate GTs	Capitate and peltate GTs	Slightly granulated
27.	*Perovskia atriplicifolia* Benth.	Polygonal	Polygonal	4-6	4-6	Thickened, convex	P	P	Anomocytic-diacytic	Narrow elliptic	Narrow ovate	Narrow Kidney shaped	Polygonal	P	P	Unicellular branched and stellate NGTs, capitate and peltate GTs	Unicellular branched and stellate NGTs, capitate and peltate GTs	Rough
28.	*Plectranthus*	Irregular	Irregular		10 -	Sinuate	P	P	Anomocytic	Elongate-	Ovate	Kidney	Irregular	P	P	Multicellular NGTs, peltate	Multicellular NGTs, peltate	Smooth

	ambonicus (Lour.) Spreng.				12					elliptic		shaped				GTs	GTs	
29.	*Prunella vulgaris* L.	Irregular	Irregular	6--8	6-8	Undulate	P	P	Anisocytic-diacytic	Ovate	Linear	Elongated to narrow elliptic	Irregular	P	P	Multicellular GTs	Multicellular G Ts	Rough
30.	*Rosmarinus officinalis* L.	Polygonal	Irregular	5-6	4-6	Thin walled, convex	A	P	Paracytic	elliptic	Narrow ovate	Kidney shaped	Irregular	A	P	_	Unicellular conical and hook shape NGTs	Rough
31.	*Satureja hortensis* L.	Irregular	Irregular	8-10	10-12	Deeply undulate	P	P	Anomocytic	Elliptic	linear	elliptic	Irregular	P	P	Unicellular conical NGTs, capitate GTs	Unicellular conical NGTs	Scabrous
32.	*Thymus linearis* Benth.	Polygonal	Polygonal	5-6	5-6	Thickened, convex	P	P	Anomocytic	Oval	Elongated	Kidney shaped	Polygonal	P	P	Multicellular peltate and sessile capitate GTs	Unicellular conical NGTs	Rough
33.	*Thymus vulgaris* L.	Polygonal	Polygonal	4-6	4-6	Sinuate	P	P	Anomocytic	Elliptic	Narrow ovate	Broad Kidney	Polygonal	P	P	Unicellular conical NGTs, sessile to sub	Unicellular conical NGTs, sessile	Rough

shaped	sessile capitate and peltate GTs	to sub sessile capitate and peltate GTs

Table. 19: Quantitative characteristics of foliar anatomy of Nepetoideae taxa

S.no	Plant name	L× W	Epidermal cell size Min-Max = Mean±SE (µm) Ad/Ab		Guard cell size Min-Max = Mean±SE (µm) Ad/Ab		Stomata size Min-Max = Mean±SE (µm) Ad/Ab		Subsidiary cell size Min-Max = Mean±SE (µm) Ad/Ab	
1.	*Anisochilus carnosus* (L.f.) Wall.	L	55.2-67.2=61.8±2.21	53.5-62.2=57.4±1.60	27.0-32.7=29.5±1.23	29.5-34.5=31.3±.899	27.2-33.0=29.9±1.23	29.7-34.7=31.6±.878	35.2-60.2=48.5±4.84	30.2-70.2=52.3±7.13
		W	30.2-40.2=34.7±1.65	45.2-52.2=49.05±1.18	5.2-7.0=6.1±.375	6.0-8.25=7.30±.44	21.2-25.2=23.0±.681	25.5-30.2=28.1±.864	31.0-51.2=42.3±4.59	27.7-57.2=40.7±4.73
2.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	L	39.7-57.7=45.8±3.1	50.2-77.7=59.6±4.8	–	20.2-27.2=24.0±1.4	–	20.5-27.7=24.4±1.5	–	15.2-30.2=22.3±2.6
		W	24.7-38.5=31.6±2.2	31.0-49.7=43.5±3.3	–	7.7-10.2=8.8±.49	–	16.2-19.7=17.6±.58	–	10.0-23.7=15.0±2.3
3.	*Dracocephalum nutans* L.	L	40.2-50.2=44.3±1.96	43.0-52.2=47.8±1.56	18.0-22.2=20.7±.76	18.5-24.7=21.4±1.17	19.7-22.7=21.3±.55	18.7-23.7=21.3±.940	24.7-28.5=26.9±.66	24.5-33.7=29.9±1.51
		W	22.7-32.2=28.6±1.66	31.0-39.7=35.5±1.52	4.50-5.75=5.15±.23	3.75-4.75=4.25±.176	16.2-18.5=17.5±.38	15.2-15.7=17.0±.68	12.0-17.7=15.0±1.16	14.2-18.7=15.8±.79

4.	*Hyssopus officinalis* L.	L	31.2-45.5=38.3±2.56	41.5-50.5=45.9±1.56	22.7-24.2=23.5±.250	22.7-25.0-24.05±.382	24.0-25.5=24.7±.285	24.5-25.5=25.0±.176	24.7-27.5=25.7±.480	20.0-31.2=25.2±2.36
		W	26.2-31.2=29.5±.890	31.2-36.2=33.3±.90	8.25-10.2=9.45±.365	8.75-10.25=9.60±.269	17.0-18.2=17.5±.215	17.2-18.7=17.9±.266	8.50-10.2=9.55±.339	11.0-23.25=14.2±2.29
5.	*Lallemantia royleana* (Benth.) Benth.	L	39.5-53.7=45.8±2.70	51.2-63.7=56.8±2.1	24.7-27.2=25.9±.51	24.7-28.0=25.8±.594	23.5-25.5=24.6±.40	24.7-28.2=26.4±.730	44.7-50.7=47.1±1.0	46.5-55.5=50.0±1.59
		W	22.0-28.0=24.4±1.3	26.0-31.2=28.8±1.00	6.2-8.0=7.5±.32	6.7-8.0=7.4±.231	14.2-15.2=14.7±.176	13.7-15.5=14.5±.289	22.2-25.7=24.0±.62	21.2-26.2=23.8±.956
6.	*Lavandula angustifolia* Mill.	L	63.7-84.0=74.8±3.52	31.2-38.2=35.3±1.22	23.7-25.2=24.5±.266	24.5-25.5=25.0±.176	24.5-25.5=25.0±.176	24.2-26.2=24.9±.34	27.2-31.2=29.5±.715	24.7-31.2=28.9±1.11
		W	44.0-56.2=50.3±2.35	13.7-18.2=15.7±.75	8.2-9.2=8.7±.176	9.5-10.7=10.0±.215	17.0-17.7=17.3±.127	14.5-16.2=15.3±.34	12.0-15.2=13.3±.584	11.2-13.7=12.6±.4`15
7.	*Melissa officinalis* L.	L	23.5-36.2=30.7±2.15	24.7-36.7=31.2±2.09	–	22.2-28.7=25.7±1.15	–	22.7-28.2=25.9±1.04	–	24.5-31.2=28.5±1.19
		W	18.5-25.2=22.3±1.09	17.2-26.7=22.0±1.70	–	5.75-8.25=7.15±.527	–	17.7-23.7=21.4±1.03	–	12.0-19.7=16.2±1.35
8.	*Mentha arvensis*	L	51.7-	44.7-	32.0-	26.2-	32.0-	26.7-	30.7-	46.2-

	L.		64.2=58.1±2.10	56.2=50.1±2.17	33.25=32.6±.231	28.5=27.4±.413	33.7=32.8±.320	29.5=27.8±.502	38.7=35.9±1.56	50.7=49.2±.784
		W	21.2-23.7=22.3±.465	23.0-26.2=24.4±.635	10.2-11.2=10.7±.176	9.7-11.2=10.6±.257	22.5-23.7=23.2±.215	20.5-21.2=20.8±.169	14.2-17.2=15.8±.625	13.2-16.2=14.9±.649
9.	*Mentha longifolia* (L.) L.	L	38.0-64.0=46.2±5.0	25.5-39.7=33.9±2.5	20.7-23.0=21.8±.40	20.2-23.2=21.8±.594	19.7-23.2=21.6±.64	20.5-25.5=22.4±.867	27.0-38.2=34.2±1.9	26.7-38.2=33.5±2.17
		W	13.0-26.0=22.1±2.4	13.5-19.5=15.7±1.08	8.7-10.2=9.5±.27	8.0-11.0=8.85±.556	15.7-19.7=17.6±.81	14.0-18.5=16.7±.811	12.2-15.0=14.0±.49	10.5-15.2=13.05±.834
10.	*Mentha × piperita* L.	L	50.5-55.0=52.8±.84	39.5-45.7=43.0±1.20	22.5-25.0=23.7±.496	36.2-39.0=37.6±.503	23.2-28.7=25.0±.993	36.5-39.2=37.9±.515	21.5-26.2=23.7±.852	22.2-23.7=22.9±.289
		W	27.7-30.0=28.9±.365	20.2-23.5=22.1±.615	8.75-9.75=9.15±.203	12.0-12.7=12.35±.127	18.2-21.5=20.2±.575	24.2-25.7=25.0±.289	11.2-13.7=12.6±.451	11.25-12.7=12.05±.266
11.	*Mentha pulegium* L.	L	34.5-41.2=37.7±1.18	38.7-46.2=42.0±1.40	19.5-20.7=20.15±.231	24.7-26.0=25.5±.231	21.2-22.7=21.9±.289	24.7-27.2=25.8±.45	20.7-26.2=24.5±1.03	25.7-38.2=30.4±2.74
		W	14.5-16.7=15.5±.433	27.0-36.2=29.4±1.73	6.5-7.5=7.0±.176	6.2-7.5=6.95±.215	9.7-11.2=10.4±.266	15.0-17.0=16.0±.348	11.2-13.7=12.7±.435	11.2-13.2=12.1±.331
12.	*Mentha spicata* L.	L	38.2-50.5=43.3±	37.7-125.2=66.4±15.2	21.0-30.2=25.0±1.5	25.5-63.0=45.6±6.	20.7-30.5=25.1±1.	25.4-31.0=27.7±1.18	33.2-45.5=39.0±2.	25.5-31.2=28.2±1.1

			2.31	8	7	37	63		0	9
		W	21.2-31.2=27.6±1.79	19.7-26.2=22.6±1.35	8.0-14.5=11.2±1.27	24.7-49.5=30.4±4.78	16.2-20.5=19.0±.871	10.5-13.2=11.8±.539	13.0-25.5=18.0±2.28	21.2-25.7=23.7±.908
13.	*Mentha suaveolens* Ehrh.	L	36.2-50.2=42.3±2.5	26.7-34.0=30.2±1.40	12.7-13.7=13.3±.165	18.5-20.2=19.1±.302	11.7-13.0=12.5±.242	16.25-20.0=18.35±.605	31.5-23.7=22.7±.413	13.2-20.7=17.8±1.37
		W	19.2-29.7=24.0±1.8	19.0-22.5=21.1±.635	8.2-10.7=9.4±.496	8.0-9.2=8.50±.22	8.2-10.5=9.4±.375	13.0-15.7=14.6±.465	8.2-9.5=8.95±.215	7.5-8.7=8.05±.215
14.	Mentha x piperita citrata - (Ehrh.) Briq.	L	76.7-86.5=81.5±1.75	38.7-44.5=40.5±1.08	34.7-37.2=36.4±.444	31.7-33.7=32.7±.390	33.7-40.5=38.5±1.22	31.2-34.5=33.1±.682	35.7-41.2=38.7±.996	35.7-37.5=36.5±.348
		W	47.0-55.0=51.2±1.49	26.5-30.7=28.9±.896	12.7-13.7=13.3±.165	3.7-10.7=10.2±.176	23.5-25.7=24.4±.483	20.0-21.2=20.7±.215	15.7-16.7=16.15±.187	14.7-16.0=15.4±.203
15.	*Mentha × villosa* Huds.	L	62.0-70.75=65.3±1.47	34.5-47.7=40.7±2.7	22.5-24.0=23.2±.34	22.0-24.5=23.0±.44	23.2-24.5=23.8±.23	22.2-24.2=23.4±.35	26.2-30.0=28.1±.73	26.2-30.5=28.4±.74
		W	27.2-36.2=31.7±1.48	25.2-31.2=28.4±1.0	6.7-8.2=7.4±.26	7.2-7.7=7.4±.09	15.0-17.0=16.1±.35	14.5-16.0=15.3±.31	10.0-13.7=11.2±.65	12.0-15.0=13.0±.54
16.	*Micromeria biflora* (Buch. -Ham. ex D.Don)	L	28.7-35.0=32.2±1.0	30.0-36.2=33.3±1.25	17.0-19.5=18.1±.46	18.7-20.5=19.7±.289	17.2-19.7=18.3±.45	19.0-20.7=20.0±.325	27.5-30.0=28.7±.40	28.7-31.5=30.2±.520

	Benth.	W	16.5-25.5=21.2±1.59	12.7-16.2=14.2±.717	9.0-10.5=9.8±.23	8.7-10.7=10.0±.348	17.0-18.7=17.9±.34	17.5-18.7=18.2±.215	14.5-15.5=15.0±.17	14.7-16.2=15.7±.278
17.	*Monarda fistulosa* L.	L	24.5-40.2=31.9±3.0	29.2-39.7=33.3±1.8	21.0-22.0=21.5±.176	20.0-21.7=20.8±.322	22.0-22.7=22.4±.127	21.7-22.7=22.2±.176	10.5-14.2=12.6±.66	10.7-12.2±11.5±.266
		W	17.7-25.2=21.5±1.2	19.7-27.5=23.6±1.4	7.75-8.7=8.3±.169	7.0-8.0=7.5±.176	14.7-15.7=15.2±.165	14.7-16.7=15.7±.33	7.5-9.5=8.4±.35	8.2-9.7=8.9±.269
18.	*Ocimum × africanum* Lour.	L	88.0-102.0=94.8±2.86	51.2-63.7=59.5±2.17	33.7-35.0=34.4±.215	31.2-34.7=33.1±.67	33.7-36.7=35.3±.538	33.7-36.2=35.1±.45	43.2-88.2=60.9±10.2	63.7-88.7=74.6±4.08
		W	59.0-63.7=61.0±.849	25.2-28.0=26.7±.506	8.75-9.75=9.25±.176	8.7-10.0=9.3±.21	17.2-19.2=18.2±.374	22.2-24.2=23.1±.40	19.7-32.2=25.1±2.85	28.7-35.2=32.6±1.12
19.	*Ocimum americanum* L.	L	63.7-83.7=74.5±3.6	67.7-83.0=76.2±2.98	29.5-32.0=30.5±.564	26.7-30.2=28.7±.77	26.2-34.0=30.4±1.25	29.5-301.5=30.4±.40	56.2-88.7=69.6±5.96	56.2-80.5=69.9±4.1
		W	28.7-36.2=31.7±1.45	25.0-28.7=26.2±.68	12.7-13.5=13.2±.145	12.5-13.7=13.0±.215	24.7-26.2=25.7±.262	24.7-25.5=25.0±.145	23.7-28.7=25.5±.915	22.7-26.2=23.7±.65
20.	*Ocimum basilicum* L.	L	95.7-108.0=1.0±2.25	67.0-70.5=67.9±.64	22.2-24.0=23.3±.302	28.0-30.2=28.8±.39	26.2-29.2=28.1±.57	29.5-31.7=30.6±.43	50.2-75.5=64.9±5.80	38.2-68.0=51.1±6.13
		W	53.0-	48.7-	10.2-	9.2-	17.2-	24.5-	27.2-	26.2-

				60.5=56.4±1.43	53.7=50.9±.81	11.2=10.7±.17	10.5=9.8±.23	19.2=18.2±.35	25.7=25.1±.23	32.0=29.6±.86	33.2=29.8±1.15
21.		*Ocimum citriodorum* Vis	L	83.7-93.2=88.4±1.76	50.2-58.7=55.3±1.54	36.2-38.5=37.3±.43	36.2-46.5=40.2±2.14	35.2-38.7=37.2±.64	33.2-45.7=39.6±2.36	30.7-33.7=31.7±.53	26.7-33.5=30.2±1.13
			W	32.7-38.7=35.5±1.05	26.2-30.5=27.8±.73	12.0-13.2=12.6±.23	12.5-15.2=13.6±.45	25.5-28.7=27.2±.58	23.7-28.7=25.8±.83	11.2-13.0=12.3±.31	7.5-12.7=10.4±.90
22.		*Ocimum gratissimum* L.	L	49.7-56.2=53.3±1.25	62.0-68.0=65.4±1.12	23.0-25.0=24.0±.37	22.2-23.2=27.2±.17	24.7-26.2=25.6±.24	19.7-21.2=20.6±.6	31.2-40.2=35.1±1.83	23.7-41.2=31.7±3.46
			W	34.7-38.7=37.2±.74	6.2-30.5=28.5±.70	9.75-11.0=10.4±.23	5.7-7.0=6.3±.23	11.25-13.7=12.4±.41	12.2-13.2=12.7±.20	13.7-26.5=19.3±2.74	8.75-13.7=11.0±.96
23.		*Ocimum sanctum* L.	L	50.5-68.0=59.0±2.97	50.5-60.2=56.5±1.71	21.5-25.5=23.7±.68	22.0-25.7=24.0±.80	28.7-31.2=30.2±.43	29.5-30.7=30.1±.23	47.2-61.2=49.5±.69	31.2-53.5=43.4±4.99
			W	16.2-25.5=21.2±1.76	24.7-26.5=25.9±.31	11.7-13.5=12.5±.32	8.25-9.50=8.8±.21	19.5-22.2=20.9±.56	19.5-20.2=19.9±.15	23.0-26.2=24.9±.64	10.5-16.7=14.1±1.33
24.	a.	*Origanum majorana* L.	L	31.2-38.7=34.9±1.22	27.5-33.0=30.5±.99	20.5-22.7=21.7±.41	23.7-25.2=24.6±.25	21.7-23.0=22.4±.231	24.5-26.0=25.2±.266	33.0-38.2=36.4±.92	31.2-38.5=35.2±1.33
			W	12.2-16.5=14.1±.93	16.2-19.2=17.7±.55	7.5-8.7=8.2±.21	7.2-9.0=8.4±.31	14.7-16.5=15.7±.3	13.7-15.5=14.5±.89	9.5-12.2=10.7±.5	8.7-12.2=10.4±.65

			7				0		0	
25.	*Origanum vulgare* L.	L	46.2-53.5=49.3±1.24	34.2-38.2=36.1±.74	26.0-27.7=27.1±.302	25.2-28.7=27.0±.629	27.2-28.7=28.1±.312	27.0-28.7=27.8±.34	28.7-42.2=36.9±2.96	31.2-39.5=36.1±1.8
26.	*Perilla frutescens* (L.) Britton	L	52.2-77.7=66.8±4.56	46.0-50.2=48.4±.78	24.5-29.7=27.2±.84	23.5-28.5=25.0±.88	24.7-30.2=27.6±.87	23.7-28.7=25.3±.88	22.2-50.2=34.0±4.67	20.2-38.0=28.5±3.25
		W	41.0-70.2=52.5±5.09	28.2-38.5=33.0±2.12	4.0-7.2=5.4±.70	4.75-8.0=6.4±.65	16.7-22.2=18.7±1.01	15.5-22.7=19.6±1.23	10.2-17.7=14.2±1.45	7.75-26.2=15.5±3.21
27.	*Perovskia atriplicifolia* Benth.	L	37.0-49.7=43.6±2.3	31.2-50.2=41.6±3.3	27.2-29.5=28.4±.40	29.7-32.2=30.8±.40	27.7-29.7=28.7±.37	30.2-32.7=31.5±.44	33.0-37.7=35.6±.86	38.7-42.7=40.9±.80
		W	18.0-24.7=21.9±1.1	22.0-42.7=31.6±3.9	4.5-5.5=4.9±.18	4.7-7.0=5.8±.45	18.0-19.7=19.0±.31	20.2-24.7=22.4±.81	29.2-32.2=30.5±.53	28.5-39.7=35.3±2.0
28.	*Plectranthus ambonicus* (Lour.) Spreng.	L	47.5-63.7=56.0±3.03	50.5-63.0=56.8±2.55	34.7-37.2=35.8±.430	29.5-30.2=29.9±.127	31.2-35.5=33.9±.755	29.5-30.7=30.0±.215	64.0-78.0=71.5±2.75	44.0-50.5=47.2±1.11
		W	26.7-55.7=42.4±6.08	28.7-33.7=31.2±.96	8.7-10.7=10.0±.348	12.0-13.2=12.6±.231	26.2-28.2=27.2±.325	21.2-23.2=22.4±.358	31.2-38.5=35.3±1.40	24.5-25.7=25.0±.215
29.	*Prunella vulgaris* L.	L	64.0-76.2=71.1±2.23	33.7-38.2=36.7±.825	24.2-26.5=24.8±.23	23.7-25.0=24.4±	24.7-26.2=25.4±.266	24.5-26.5=25.2±.344	58.2-63.2=61.2±.880	31.2-38.7=35.2±1.38

						.215				
		W	35.0-38.0=36.7±.54	28.7-31.2=39.6±.451	9.7-11.5=10.5±.306	8.7-10.7=9.8±.358	19.7-21.2=20.4±.269	19.5-20.7=20.0=.215	24.7-27.5=26.3±.451	19.2-22.5=20.9±.583
30.	*Rosmarinus officinalis* L.	L	33.0-37.0=35.1±.760	37.2-40.7=39.3±.634	–	30.0-33.7=32.0±.656	–	35.0-37.5=36.2±.425	–	30.7-31.7=31.4±.187
		W	24.5-26.2=25.2±.306	23.7-28.0=25.4±.713	–	13.0-14.5-13.7±.285	–	25.7-27.5=26.6±.322	–	22.5-24.5=23.6±.340
31.	*Satureja hortensis* L.	L	27.2-56.0=43.9±5.0	26.2-47.2=35.3±3.9	26.7-28.2=27.4±.269	24.5-32.2=28.3±1.7	27.0-28.5=27.7±.26	24.5-32.7=28.6±1.7	24.7-42.7=33.0±3.9	27.7-43.7=36.6±3.3
		W	22.2-26.7=24.5±.88	8.8-44.0=24.6±5.9	8.5-11.2=9.6±.53	3.7-7.7=5.6±.73	16.2-22.7=20.2±1.13	14.0-24.7=19.1±1.7	8.0-13.0=10.8±.94	17.2-27.2=21.2±1.9
32.	*Thymus linearis* Benth.	L	51.7-67.7=60.6±2.9	44.0-54.2=48.9±1.7	24.5-25.5=25.0±.176	25.2-26.7=26.0±.266	24.5-26.2=25.3±.322	26.2-28.2=27.2±.379	38.7-63.0=53.5±5.4	29.5-32.0=30.8±.51

		W	41.5-45.7=43.7±.80	34.2-38.7=36.5±.860	7.5-8.7=8.0±.21	5.7-9.25=8.1±.62	14.5-15.5=14.9±.183	16.0-17.2=16.5±.21	13.6-28.0=21.3±3.0	25.0-26.2=25.5±.22
33.	*Thymus vulgaris* L.	L	34.7-38.2=36.8±.63	29.5-32.7=31.0±.61	23.2-25.5=24.5±.382	23.0-25.5=23.6±.269	24.5-27.2=25.4±.48	23.7-25.0=24.3±.215	24.0-260=25.2±.36	23.7-26.2=25.4±.44
		W	24.7-26.2=25.4±.269	26.2-29.0=27.6±.62	9.2-12.5=9.9±.21	9.5-10.5=10.0±.17	19.2-20.7=19.8±.25	20.2-21.2=20.7±.158	12.2-13.5=12.8±.23	12.5-14.0=13.3±.266

Table. 20: Quantitative characteristics of foliar anatomy of Nepetoideae taxa

S. No.	Plant name	L× W	Stomatal pore size Min-Max = Mean±SE (µm) Ad/Ab		Stomatal index Ad/Ab		Trichome size Min-Max = Mean±SE (µm) Ad/Ab		Trichome index Ad/Ab	
1.	*Anisochilus carnosus* (L.f.) Wall.	L	7.7-15.5=11.5±1.43	13.5-22.2=17.8±1.5	18.6	71.6	105.2-122.7=117±3.22	124.7-147.7=134±4.39	13.1	30.6
		W	7.5-9.7=8.7±.398	8.2-11.2=9.8±.53			37.7-49.7=41.7±2.13	39.7-44.7=42.6±.84		
2.	*Clinopodium hydaspidis* (Falc. ex Benth.) Kuntze	L	_	5.0-10.5=7.7±.90	1.4	3.1	39.7-76.2=58.3±6.9	125.2-247.7=170±21.3	1.4	3.1
		W	_	3.7-5.0=4.6±.23			21.2-31.2=25.6±1.6	45.2-89.2=66±7.7		
3.	*Dracocephalum nutans* L.	L	3.50-10.2=7.15±1.29	7.25-10.5=8.70±.57	14.6	35.6	57.7-67.7=63.0±1.79	49.0-57.25=53.3±1.67	27.9	20.4
		W	4.25-4.75=4.55±.09	4.0-5.75=4.70±.348			19.5-33.5=26.1±2.56	19.7-41.7=27.1±3.87		
4.	*Hyssopus officinalis* L.	L	10.0-12.5=11.2±.447	14.7-16.7=15.9±.369	10	9.6	89.0-156.2=111±11.9	120.7-163.7=134±7.8	6.0	12.7
		W	4.50-5.50=5.0±.176	5.0-8.25=7.25±.58			16.0-23.7=18.9±1.28	17.2-24.25=20.3±1.20		
5.	*Lallemantia royleana* (Benth .) Benth.	L	21.0-24.3=22.6±.63	21.2-24.0=22.8±.527	4.3	19.3	287.5-338.5=313±8.7	321.7-364.0=339±8.4	0.9	1.7
		W	6.5-7.5=6.8±.18	6.2-7.5=6.8±.215			24.4-39.0=29.1±2.76	22.2-31.7=26.3±1.55		
6.	*Lavandula angustifolia* Mill.	L	19.7-	14.7-16.5=16.0±.325	11.8	41.8	113.7-	113.7-	18.9	29.9

			21.2=20.5±.285				163.7=134±9.11	138.0=126±4.28		
		W	7.2-8.2=7.7±.176	4.7-5.7=5.2±.183			8.7-15.5=11.7±1.25	9.5-12.7=10.8±.58		
7.	*Melissa officinalis* L.	L	_	12.75-15.7=14.3±.625	_	54.6	49.2-75.2=61.1±4.36	57.2-63.7=60.0±1.22	46.5	28.6
		W	_	3.75-5.50=4.50±.306			22.2-31.0=26.5±1.58	29.7-49.2=38.2±3.92		
8.	*Mentha arvensis* L.	L	23.7-25.5=24.7±.306	12.0-13.7=12.9±.340	3.7	20.0	_	_	_	_
		W	7.25-8.25=7.65±.203	7.0-8.25=7.6±.231			_	_		
9.	*Mentha longifolia* (L.) L.	L	11.7-15.5=13.4±.76	11.25-16.0=13.25±.766	3.5	7.3	76.5-176.0=129±17.0	188.5-250.7=219±11.61	5.9	11.4
		W	4.5-6.2=5.2±.32	3.7-7.5=5.7±.627			13.2-30.7=23.1±2.9	16.75-25.5=21.6±1.59		
10.	*Mentha × piperita* L.	L	25.0-27.7=26.5±.456	11.25-13.5=12.2±.467	1.2	37.2	31.2-106.2=57.1±13.7	38.0-113.0=61.7±13.7	3.7	5.5
		W	8.7-10.2=9.6±.260	8.75-10.5=9.5±.32			19.5-31.5=25.3±2.32	20.0-30.7=24.9±2.1		
11.	*Mentha pulegium* L.	L	15.0-16.2=15.6±.203	12.2-13.5=12.9±.215	7.4	44.2	_	31.2-43.7=89±2.25	_	2.2
		W	7.0-8.0=7.5±.176	5.75-7.0=6.45±.215			_	15.0-16.2=15.6±.203		
12.	*Mentha spicata* L.	L	15.2-20.5=17.5±.971	30.7-45.2=38.6±2.35	0.8	12.8	_	16.0-21.0=186±1.01		1.4

		W	4.5-8.5=5.85±.705	18.7-25.5=23.0±1.22			_	3.7-6.5=5.5±.467		
13.	*Mentha suaveolens* Ehrh.	L	11.2-12.5=11.8±.215	11.5-13.2=12.3±.28	2.96	12.8	38.7-377.0=227±64.4	101.7-452.0=177±69.4	31.96	35.6
		W	7.5-8.5=8.05±.215	7.2-8.2=7.75±.176			13.2-25.7=18.4±2.25	13.7-26.2=18.5±2.42		
14.	*Mentha x piperita citrata* - (Ehrh.) Briq.	L	25.7-28.2=27.0±.46	20.7-23.0=21.8±.45	6.6	36.6	_	_	3.1	_
		W	10.0-10.7=10.4±.127	7.50-8.50=8.0±.176			_	_		
15.	*Mentha* × *villosa* Huds.	L	14.2-15.7=15.0±.28	14.5-16.2=15.3±.32	2.8	9.8	476.7-551.7=519±13.4	63.7-376.2=376±67.2	6.6	13.9
		W	11.2-12.7=12.0±.26	8.7-11.7=10.4±.56			13.7-39.5=20.6±4.7	15.2-57.7=31.4±9.4		
16.	*Micromeria biflora* (Buch. - Ham. ex D.Don) Benth.	L	17.2-19.2=18.0±.44	17.5-19.2=18.4±.289	0.4	7.4	26.2-56.2=38.0±4.9	27.0-32.5=30.1±.989	0.7	7.8
		W	7.0-8.0=7.4±.17	7.5-8.2=7.8±.127			8.7-13.2=10.7±.758	9.5-12.5=11.1±.515		
17.	*Monarda fistulosa* L.	L	11.5-13.7=12.9±.39	10.7-12.2=11.4±.289	6.4	14.1	31.0-51.0=40.7±4.0	27.2-39.2=33.2±2.0	37.4	32.9
		W	5.0-5.7=5.3±.12	5.0-6.2=5.7±.20			20.2-30.5=24.4±1.8	17.7-28.5=23.0±1.9		
18.	*Ocimum* × *africanum* Lour.	L	15.7-20.5=17.6±.99	28.7-35.2=32.6±1.12	5.3	36.4	_	51.2-901.2=481±1.87	_	5.3
		W	6.2-7.5=6.8±.23	20.0-21.2=20.7±.21			_	38.7-93.7=61.7±12.5		
19.	*Ocimum americanum* L.	L	17.0-18.0=17.5±.176	18.2-20.7=19.7±.502	9.8	43.9	97.7-188.2=158±15.6	94.2-175.2=139±17.5	4.6	4.8
		W	9.7-10.7=10.3±.165	9.5-10.5=10.0±.176			27.7-41.2=33.2±2.22	31.5-34.2=32.7±.55		
20.	*Ocimum basilicum* L.	L	13.0-14.0=13.5±.17	9.75-11.2=10.5±.28	11.8	45.8	_	151.2-600.5=333±1.04	_	7.9

		W	5.2-6.0=5.6±.12	8.2-9.0=8.6±.12			–	16.2-33.7=23.3±3.76		
21.	*Ocimum citriodorum* Vis	L	20.2-21.7=21.0±.25	24.7-26.0=25.3±.23	6.0	38.2	269.2-288.5=276±3.40	138.7-258.7=207±25.8	2.3	4.8
		W	7.5-9.0=8.2±.28	6.2-10.5=8.95±.78			34.5-39.2=36.5±.78	21.2-33.7=27.4±2.30		
22.	*Ocimum gratissimum* L.	L	12.0-13.0=12.5±.176	11.7-13.0=12.3±.21	5.1	9.4	69.5-412.7=191±58.01	126.2-176.5=194±29.7	5.4	9.3
		W	7.50-8.25=7.9±.145	6.0-6.75=6.3±.14			21.0-55.7=33.5±5.89	26.2-31.2=27.9±1.06		
23.	*Ocimum sanctum* L.	L	20.7-23.7=22.5±.50	21.2-23.7=22.5±.49	4.8	23.2	250.5-288.7=269±6.36	195.2-208.7=199±2.46	4.3	7.3
		W	7.75-8.75=8.25±.17	8.5-9.0=8.8±.093			36.2-38.2=37.3±.33	26.2-29.7=28.3±.59		
24.	*Origanum majorana* L.	L	14.5-15.7=15.1±.23	11.2-13.5=12.3±.37	4.5	32.7	36.5-67.7=51.4±6.3	113.2-163.7=129±8.8	3.8	27.5
		W	6.2-7.7=7.1±.25	6.2-7.7=6.9±.24			10.2-13.7=11.6±.65	12.2-16.2=14.5±.69		
25.	*Origanum vulgare* L.	L	17.0-18.7=17.7±.306	17.5-18.7=18.0±.237	2.7	32.7	127.2-202.0=164±12.4	152.2-264.2=204±22.3	6.0	6.3
		W	8.5-9.7=9.1±.231	8.5-9.2=8.8±.127			18.2-23.7=20.8±1.06	16.2-21.2=18.2±.869		
26.	*Perilla frutescens* (L.) Britton	L	12.2-17.2=14.6±.82	10.5-17.7=14.4±1.37	6.1	39.2	102.0-160.2=136±10.5	72.2-175.2=95±20.08	5.0	13.3
		W	5.0-6.0=5.4±.16	6.0-8.7=7.35±.45			25.2-75.2=50.6±8.0	29.2-63.0=43.8±6.22		

27.	*Perovskia atriplicifolia* Benth	L	15.2-16.7=16.0±.289	11.2-14.5=12.9±.56	9.6	64.1	75.5-112.7=98.6±6.37	45.2-127.0=81.5±14.9	2.9	16
		W	5.25-6.75=5.9±.26	6.0-7.7=6.7±.32			17.7-49.7=39.3±5.6	39.2-75.2=53.3±6.7		
28.	*Plectranthus ambonicus* (Lour.) Spreng.	L	27.0-28.0=27.5±.176	24.2-25.7=25.0±.250	19.0	22.3	451.2-475.7=465±4.78	600.5-663.2=621±11.5	12.8	14.7
		W	5.0-6.0=5.4±.16	6.0-8.7=7.35±.45			25.2-75.2=50.6±8.0	29.2-63.0=43.8±6.22		
29.	*Prunella vulgaris* L.	L	20.5-22.0=21.1±.257	17.0-19.0=17.9±.407	16.4	46.7	450.2-488.2=472±6.22	201.2-488.7=411±53.2	3.2	9.7
		W	3.7-5.2=4.6±.257	3.25-4.25=3.75±.176			48.7-58.7=52.9±1.84	36.7-45.5=41.2±1.59		
30.	*Rosmarinus officinalis* L.	L	_	10.5-11.7=11.1±.231	_	46.8	101.-133.0=114±6.15	101.2-155.7=129±10.5	_	5
		W	_	7.5-8.7=8.2±.215			8.75-12.0=10.5±.625	10.5-12.5=11.2±.370		
31.	*Satureja hortensis* L.	L	11.2-13.5=12.5±.38	8.2-11.7=10.1±.56	12.8	65.3	_	52.0-104.7=83.3±9.2	24.4	17.8
		W	5.0-7.0=6.1±.35	3.2-6.5=4.9±.64			_	40.2-77.7=62.9±8.0		
32.	*Thymus linearis* Benth.	L	12.5-13.7=13.0±.21	13.2-14.7=14.0±.289	16.7	42.2	18.0-20.2=18.9±.40	17.5-21.7=19.7±.75	2.5	2.4
		W	4.0-10.5=8.8±1.2	8.5-9.5=9.0±.176			11.0-13.0=12.3±.34	11.2-13.5=12.4±.41		
33.	*Thymus vulgaris* L.	L	14.5-16.7=15.7±.46	14.5-16.2=15.3±.320	8.6	16.8	11.2-38.7=20.5±4.8	21.2-65.2=45.4±9.3	61.9	48.0.
		W	7.5-8.0=7.8±.09	7.0-8.0=7.5±.17			7.5-13.7=9.8±1.1	10.0-13.0=11.7±.524		

Keywords: Min= Minimum, Max= Maximum, SE= Standard Error, Ad= Adaxial surface, Ab= Abaxial surface, L= Length, W= Width, µm= Measurement in Micrometer

Table. 21: Principal component analysis variable loadings for the first twelve significant components

Variables/ Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F 10	F 11	F 12
Epidermal cell length (AD)	0.746	0.200	-0.038	-0.189	-0.202	0.499	-0.062	-0.022	0.064	-0.006	0.095	0.093
Epidermal cell width (AD)	0.548	0.289	0.019	-0.151	-0.383	0.530	-0.187	0.041	-0.234	-0.108	-0.125	0.168
Guard cell length (AD)	0.849	-0.299	-0.228	-0.163	0.060	-0.036	-0.081	0.144	-0.018	0.002	-0.153	-0.133
Guard cell width (AD)	0.656	-0.580	-0.120	-0.101	0.037	0.003	0.100	-0.125	-0.042	-0.148	0.332	-0.152
Stomata length (AD)	0.834	-0.266	-0.249	-0.211	0.044	0.013	-0.163	0.165	-0.014	-0.038	-0.135	-0.106
Stomata width (AD)	0.767	-0.236	-0.287	-0.019	0.250	-0.055	-0.143	0.046	-0.233	-0.109	0.156	-0.037
Subsidiary cell length (AD)	0.873	0.051	-0.228	0.060	-0.226	-0.182	0.086	-0.093	0.051	-0.143	0.015	-0.015
Subsidiary cell width (AD)	0.800	0.215	-0.231	0.008	-0.051	-0.429	-0.018	-0.128	-0.064	0.017	-0.121	0.088
Stomatal pore length (AD)	0.699	-0.526	-0.218	-0.020	0.135	0.054	0.118	-0.067	0.093	-0.016	-0.232	-0.046
Stomatal pore width (AD)	0.555	-0.525	-0.285	-0.220	-0.026	-0.040	-0.084	0.077	0.118	0.442	0.142	0.175
Trichome length (AD)	0.252	0.049	-0.587	0.632	0.181	0.185	0.116	-0.183	0.037	0.194	0.025	0.056
Trichome width (AD)	0.111	0.345	-0.524	0.355	0.485	-0.063	-0.342	0.083	0.076	-0.152	0.006	0.234
Epidermal cell length (AB)	0.576	0.351	0.266	0.178	-0.223	-0.040	-0.329	-0.022	0.492	-0.060	0.051	-0.053
Epidermal cell width (AB)	0.268	0.676	-0.117	-0.154	-0.121	-0.085	-0.383	-0.371	-0.110	0.164	0.084	-0.201
Guard cell length (AB)	0.482	0.072	0.689	0.162	0.364	0.057	-0.154	0.029	0.052	0.115	-0.164	-0.113
Guard cell width (AB)	0.292	-0.337	0.712	0.389	0.072	0.007	-0.131	-0.250	-0.039	-0.118	0.082	-0.001
Stomata length (AB)	0.537	0.223	0.465	-0.260	0.477	0.238	0.171	-0.035	0.071	0.097	-0.075	-0.045
Stomata width (AB)	0.384	0.480	0.197	-0.415	0.465	0.096	0.248	-0.187	0.006	-0.061	0.148	0.142

Subsidiary cell length (AB)	0.703	0.336	0.081	-0.096	-0.210	-0.212	0.391	0.159	0.271	-0.093	0.044	0.071
Subsidiary cell width (AB)	0.521	0.583	0.231	-0.080	-0.049	-0.442	0.104	-0.028	-0.261	0.078	-0.069	0.082
Stomatal pore length (AB)	0.659	-0.239	0.385	0.456	-0.022	-0.016	0.056	0.130	-0.145	-0.086	0.003	0.099
Stomatal pore width (AB)	0.520	-0.149	0.654	0.248	-0.195	-0.057	-0.039	0.231	-0.126	0.199	0.138	0.062
Trichome length (AB)	0.447	0.361	-0.291	0.488	-0.164	0.253	0.407	-0.131	-0.059	0.085	-0.055	-0.151
Trichome width (AB)	0.042	0.728	-0.209	0.133	0.162	0.062	0.007	0.524	-0.062	0.020	0.159	-0.201
Eigenvalue	8.395	3.571	3.151	1.731	1.381	1.185	0.982	0.770	0.601	0.465	0.416	0.356
Variability (%)	34.978	14.877	13.128	7.214	5.755	4.938	4.093	3.209	2.503	1.939	1.733	1.483
Cumulative %	34.978	49.855	62.984	70.198	75.953	80.891	84.984	88.193	90.696	92.635	94.368	95.851

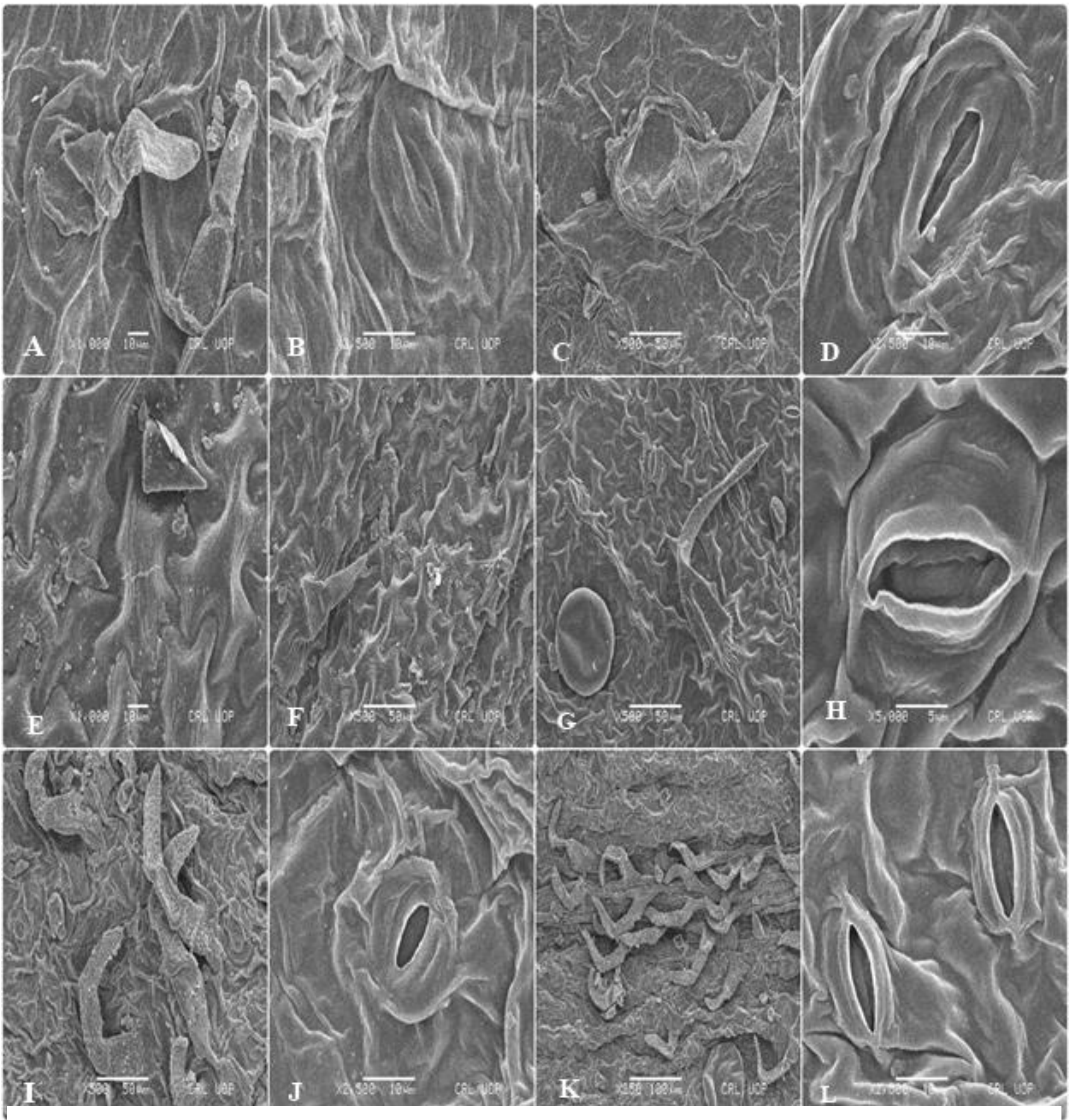

Plate.75: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape of stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Anisochilus carnosus (*A-B) adaxial surface showing multicellular non glandular trichomes (C-D) abaxial surface showing elongated stomatal pore. *Clinopodium hydaspidis* (E-F) adaxial surface showing undulate wall pattern, (G-H) abaxial surface showing elliptic shape stomata and peltate trichome. *Dracocephalum moldavica* (I-J) adaxial surface showing irregular epidermal cells (K-L) abaxial surface showing narrow ovate stomatal pore.

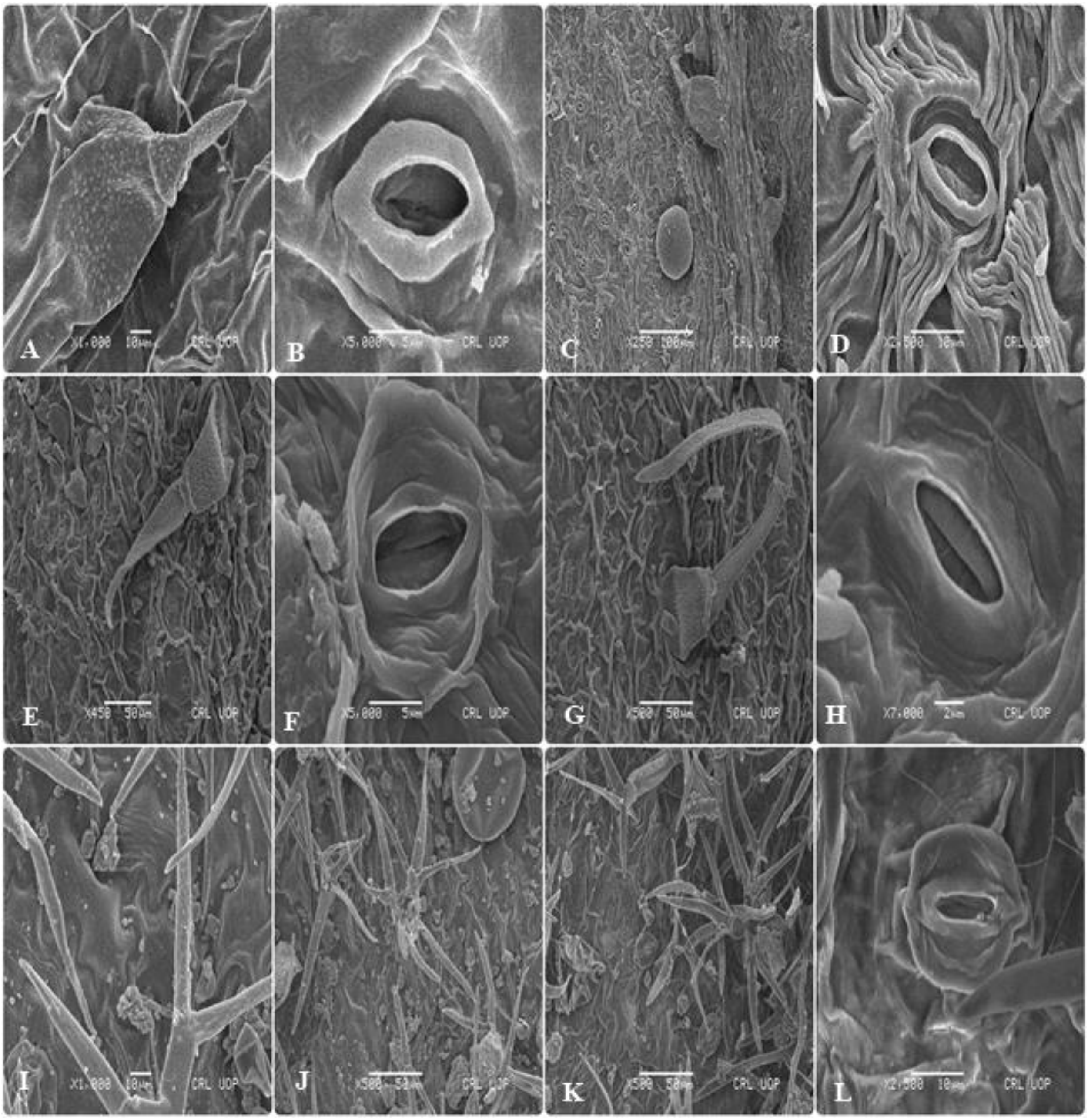

Plate. 76: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Hyssopus officinalis* (A-B) adaxial surface showing unicellular clavate trichome (C-D) abaxial surface showing striated epidermal thickening. *Lallemantia royleana* (E-F) adaxial surface showing multicellular anomocytic stomata (G-H) abaxial surface showing falcate shape trichome. *Lavandula angustifolia* (I-J) adaxial surface showing stellate trichomes (K-L) abaxial surface showing kidney shape guard cells.

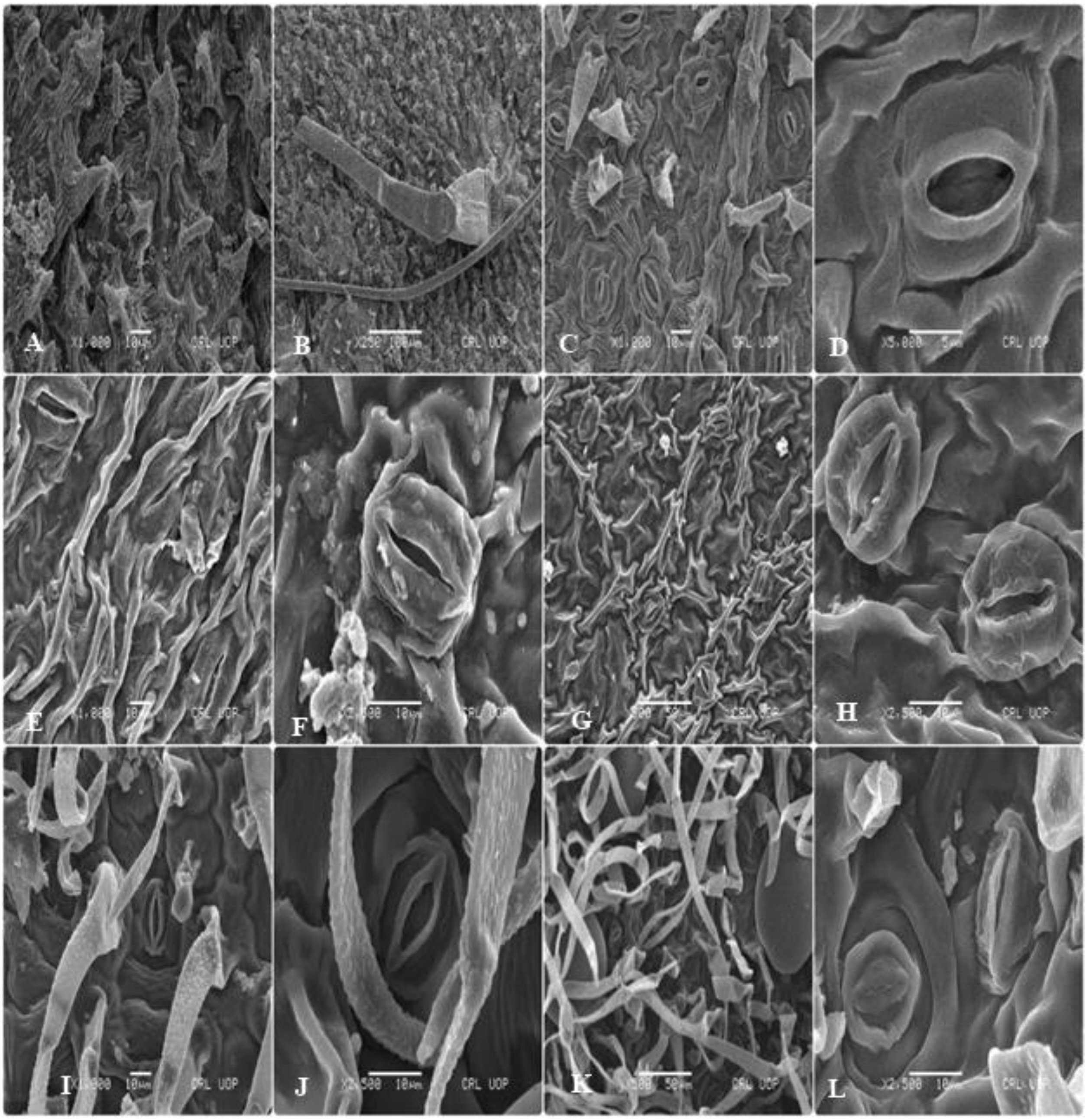

Plate. 77: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Melissa officinalis* (A-B) adaxial surface showing sinuate wall pattern (C-D) abaxial surface showing broad elliptic stomata. *Mentha arvensis* (E-F) adaxial surface showing irregular epidermal cells (G-H) abaxial surface showing elliptic shape stomata. *Mentha longifolia* (I-J) adaxial surface showing granulate trichome surface (K-L) abaxial surface showing anomocytic stomata.

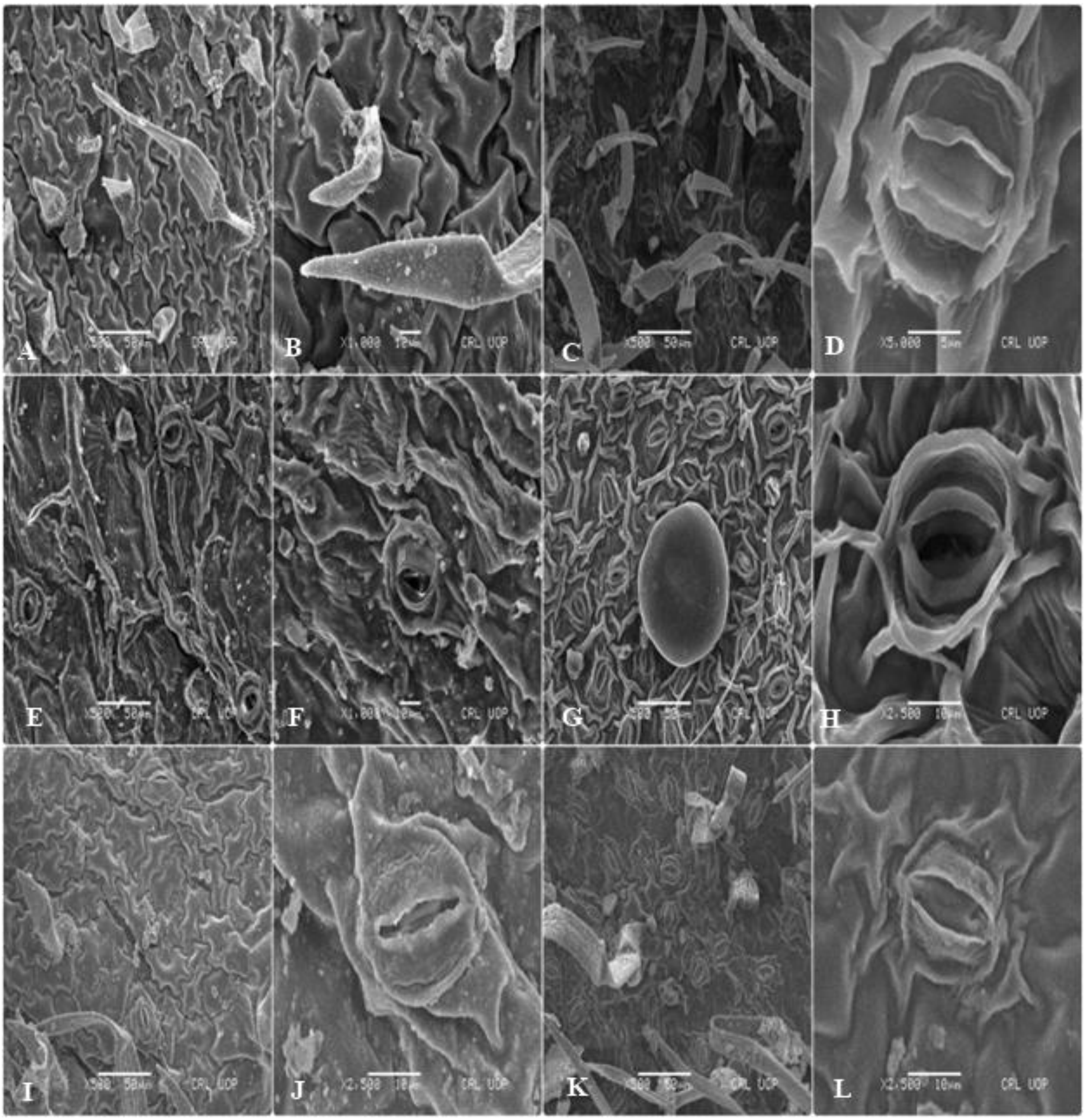

Plate. 78: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Mentha × piperita* (A-B) adaxial surface showing Irregular epidermal cells (C-D) abaxial surface showing elliptic stomata. *Mentha pulegium* (E-F) adaxial surface showing peltate trichomes (G-H) abaxial surface showing anomocytic stomata. *Mentha spicata* (I-J) adaxial surface showing polygonal epidermal cells (K-L) abaxial surface showing peltate

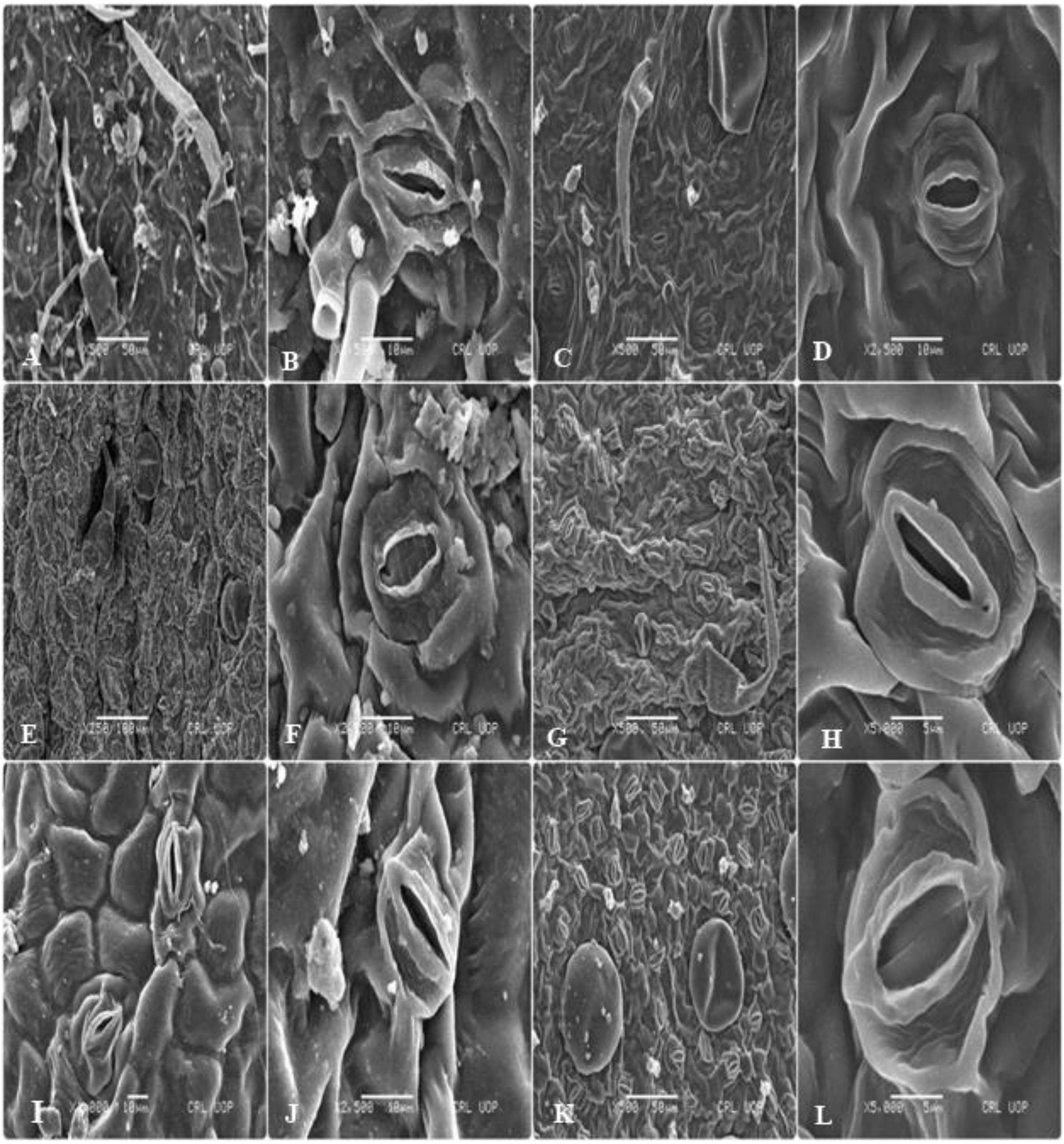

Plate. 79: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Mentha suaveolens* (A-B) adaxial surface showing undulate wall pattern (C-D) abaxial surface showing anomocytic stomata. *Mentha* x *piperita citrata* (E-F) adaxial surface showing irregular epidermal cells, (G-H) abaxial surface showing elliptic shape stomata. *Mentha* × *villosa* (I-J) adaxial surface showing undulate wall pattern. (K-L) abaxial surface showing falcate trichome.

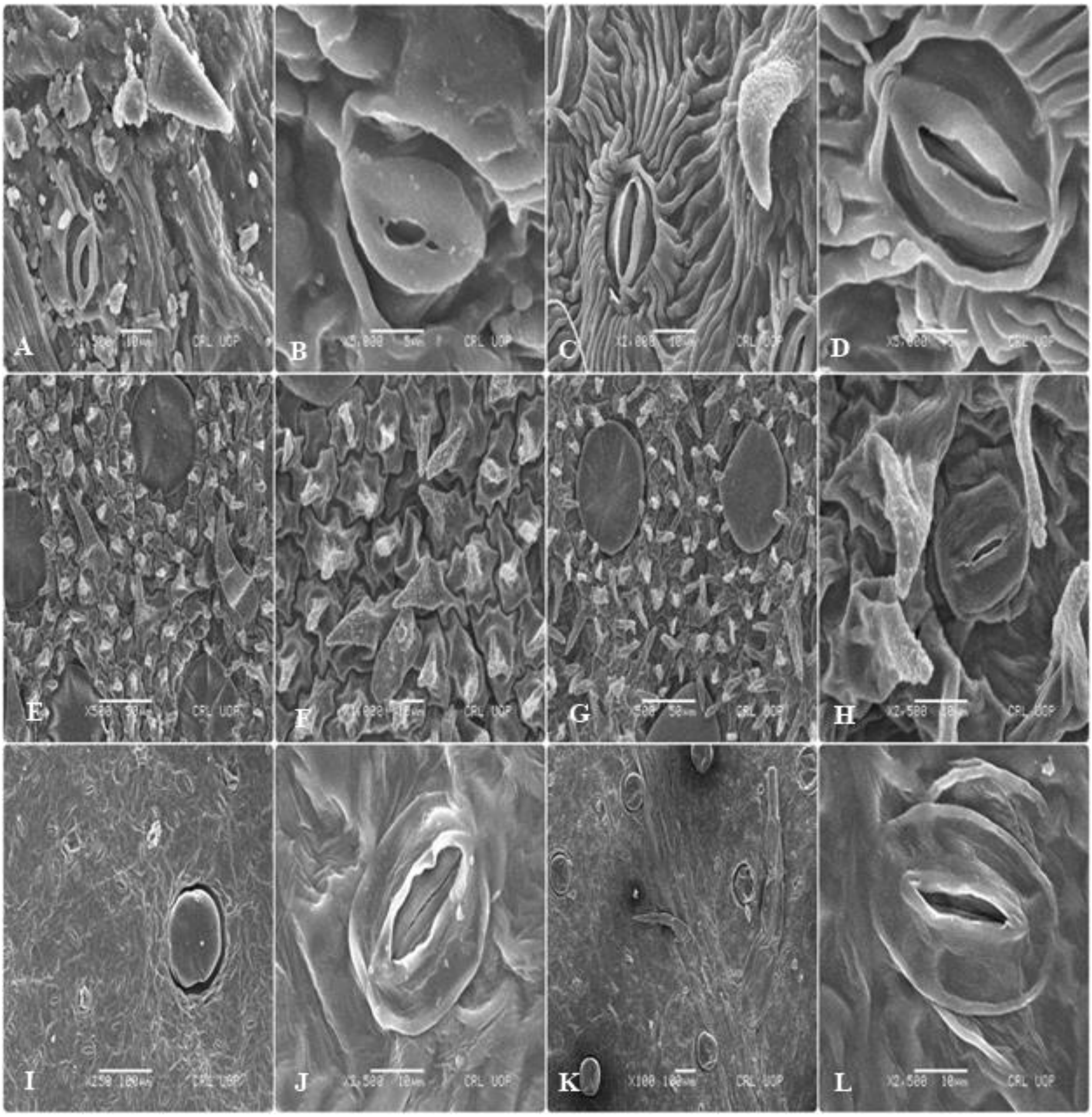

Plate. 80: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Micromeria biflora* (A-B) adaxial surface showing conical non glandular trichomes (C-D) abaxial surface showing anomocytic stomata and hook shape trichome. *Monarda fistulosa* (E-F) adaxial surface showing undulate wall pattern (G-H) abaxial surface showing peltate trichome. *Ocimum* × *africanum* (I-J) adaxial surface showing irregular epidermal cells (K-L) abaxial surface elliptic stomata.

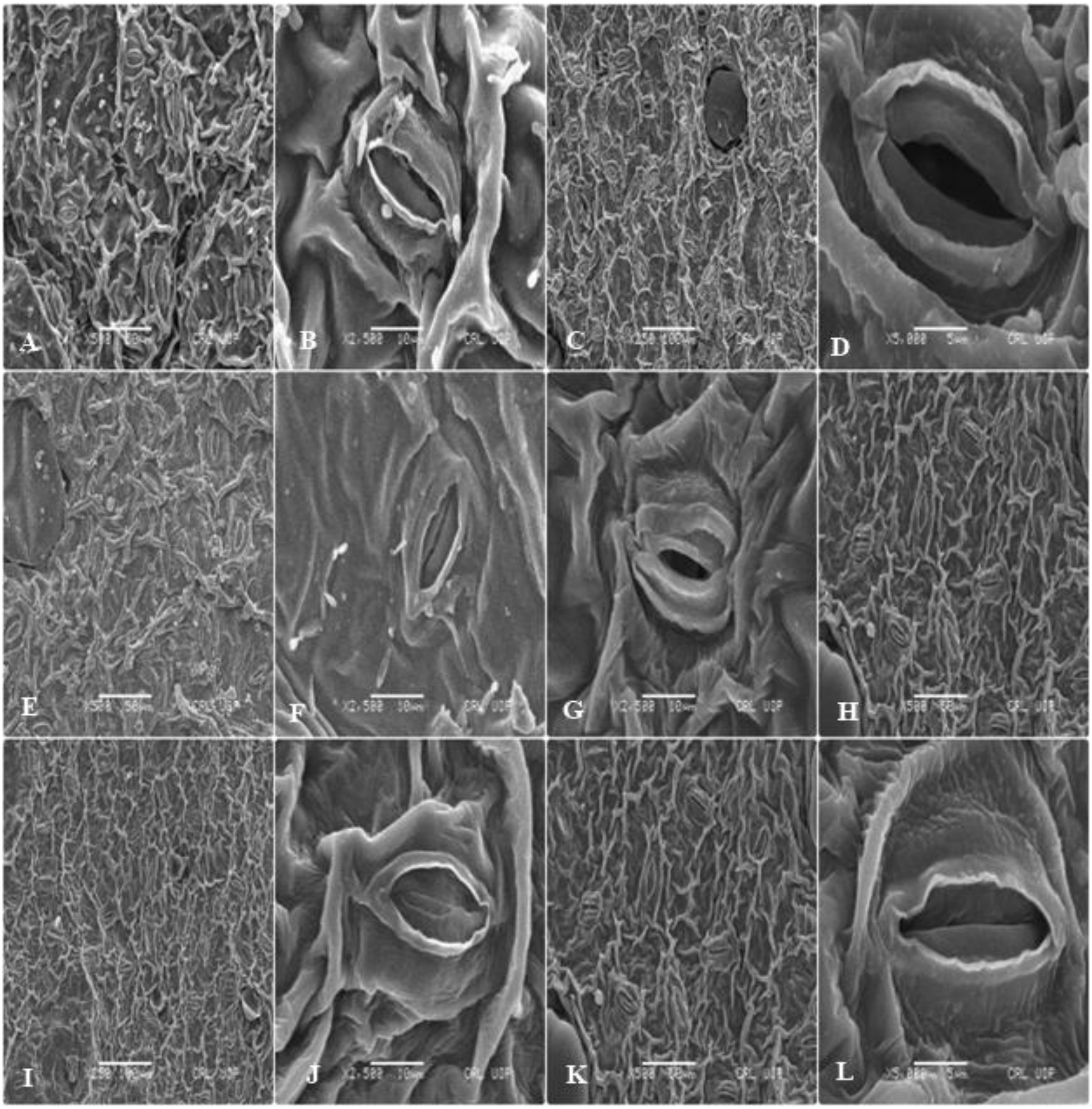

Plate. 81: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Ocimum americanum* (A-B) adaxial surface showing irregular epidermal cells (C-D) abaxial surface showing diacytic stomata. *Ocimum basilicum* (E-F) adaxial surface showing peltte trichomes (G-H) abaxial surface showing anomocytic stomata. *Ocimum citriodorum* (I-J) adaxial surface showing irregular epidermal cells (K-L) abaxial surface showing broad elliptic stomata.

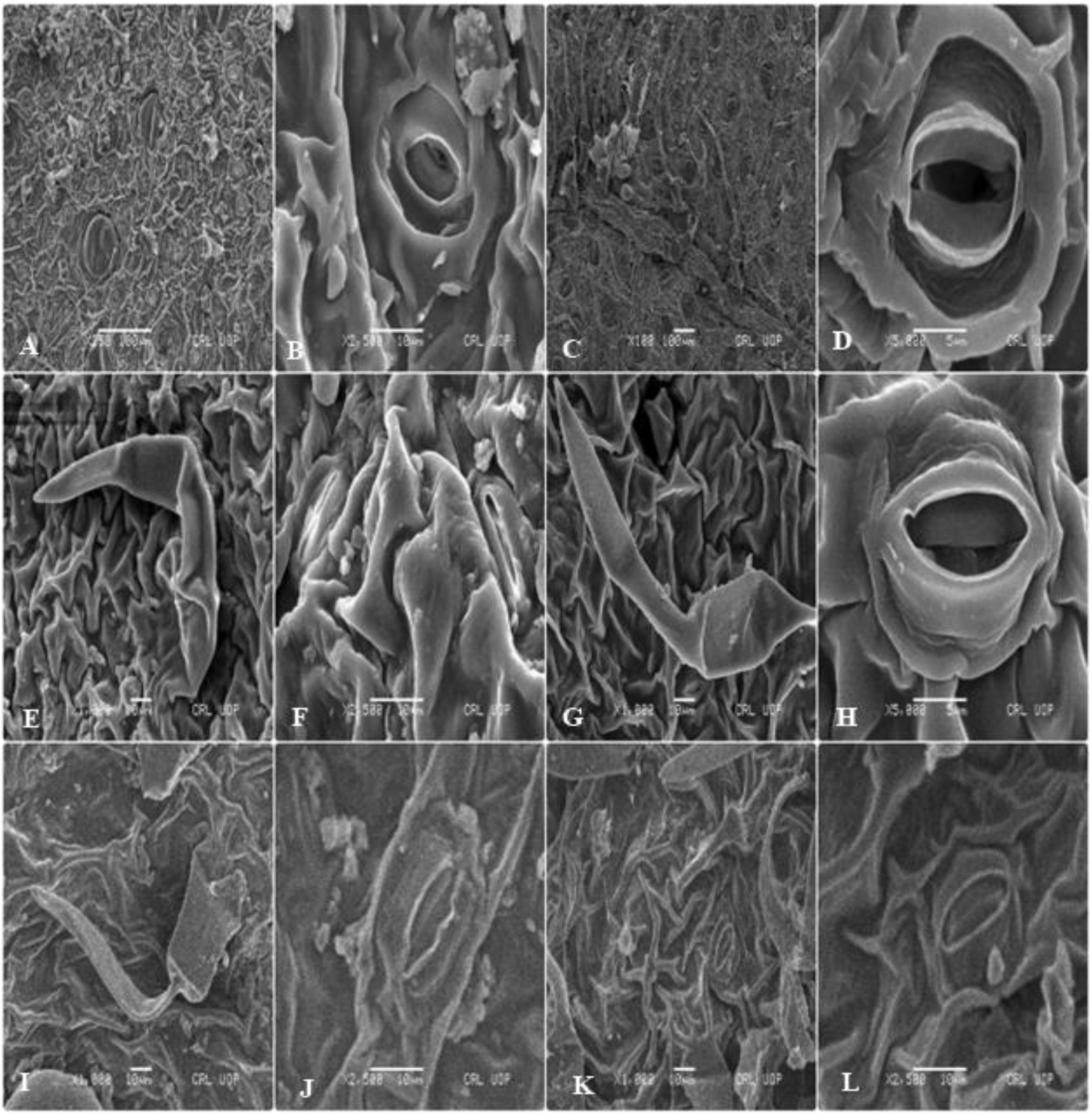

Plate. 82: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Ocimum gratissimum* (A-B) adaxial surface showing peltate trichomes (C-D) abaxial surface showing anomocytic stomata. *Ocimum sanctum* (E-F) adaxial surface showing undulate wall pattern (G-H) abaxial surface showing elliptic shape stomata. *Origanum majorana* (I-J) adaxial surface showing thickened wall pattern (K-L) abaxial surface showing elliptic shape stomata.

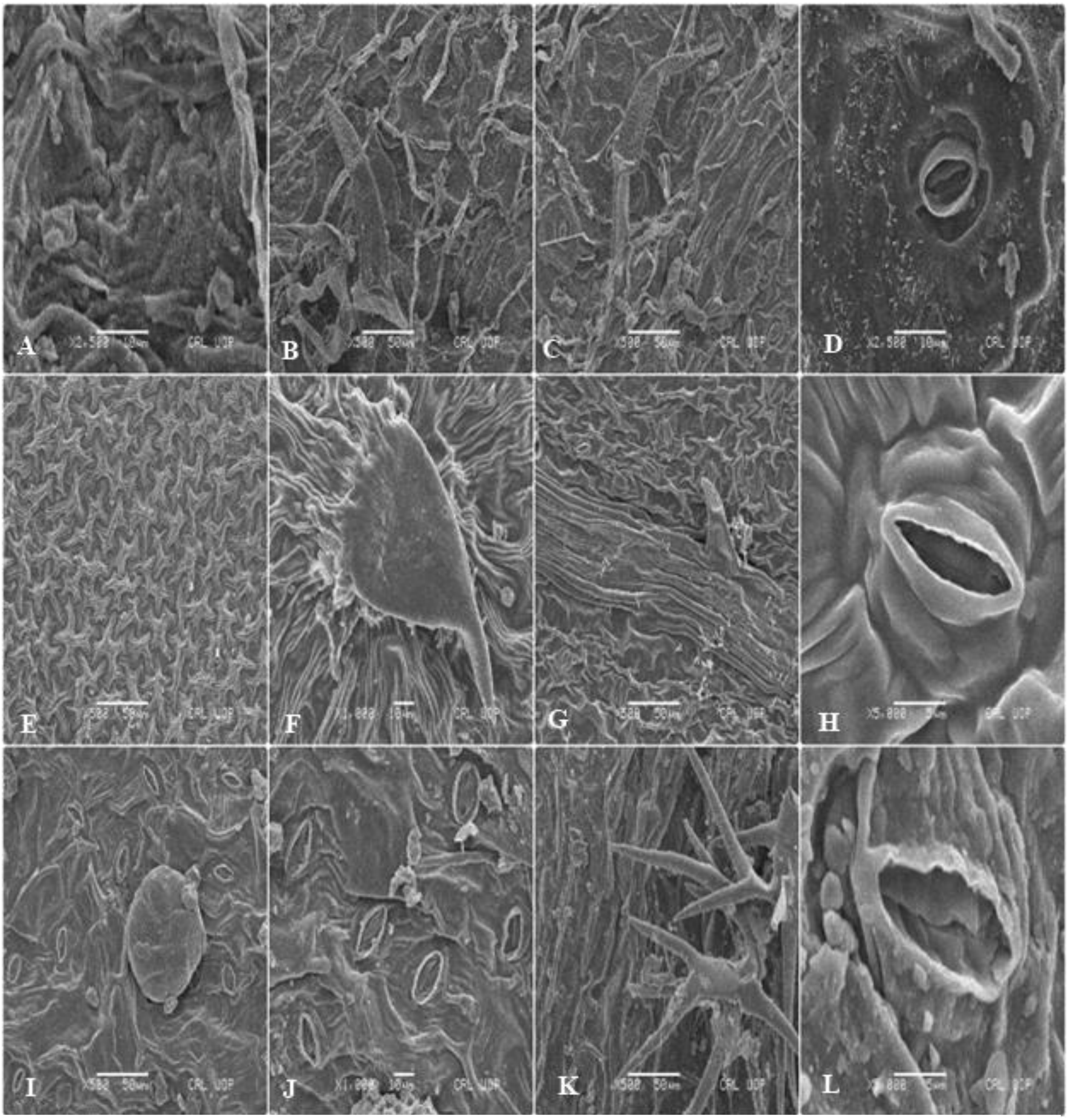

Plate. 83: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Origanum vulgare* (A-B) adaxial surface showing multicellular non glandular trichomes (C-D) abaxial surface showing kidney shape stomatal pore. *Perilla frutescens* (E-F) adaxial surface showing undulate wall pattern, (G-H) abaxial surface showing elliptic shape stomata. *Perovskia atriplicifolia* (I-J) adaxial surface showing peltate trichome(K-L) abaxial surface showing branched trichome.

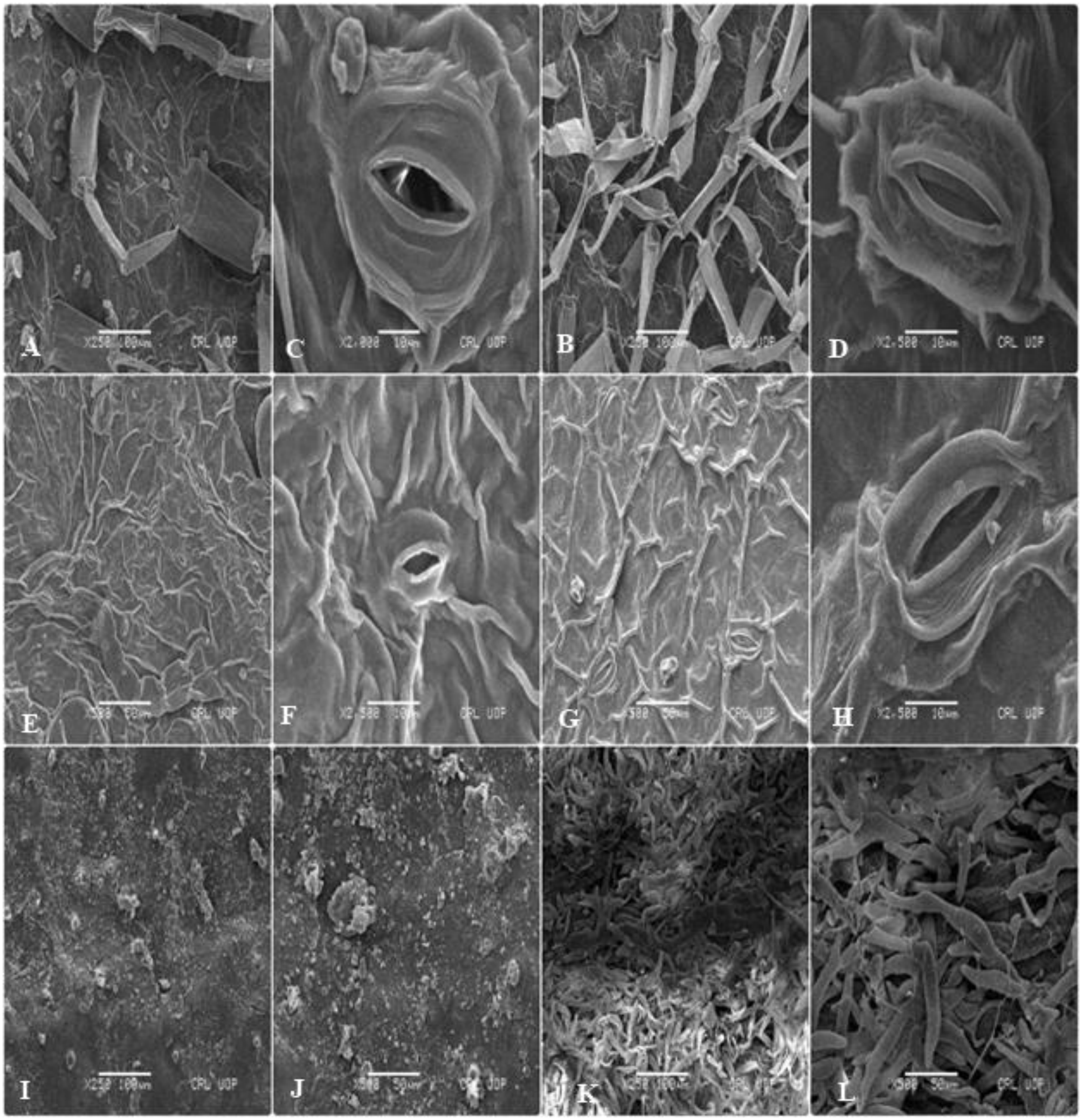

Plate. 84: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Plectranthus ambonicus* (A-B) adaxial surface showing multicellular non glandular trichomes (C-D) abaxial surface showing anomocytic stomata. *Prunella vulgaris* (E-F) adaxial surface showing multicellular glandular trichomes (G-H) abaxial surface showing elongated stomatal pore. *Rosmarinus officinalis* (I-J) adaxial surface showing blank epidermal surface (K-L) abaxial surface showing trichomes.

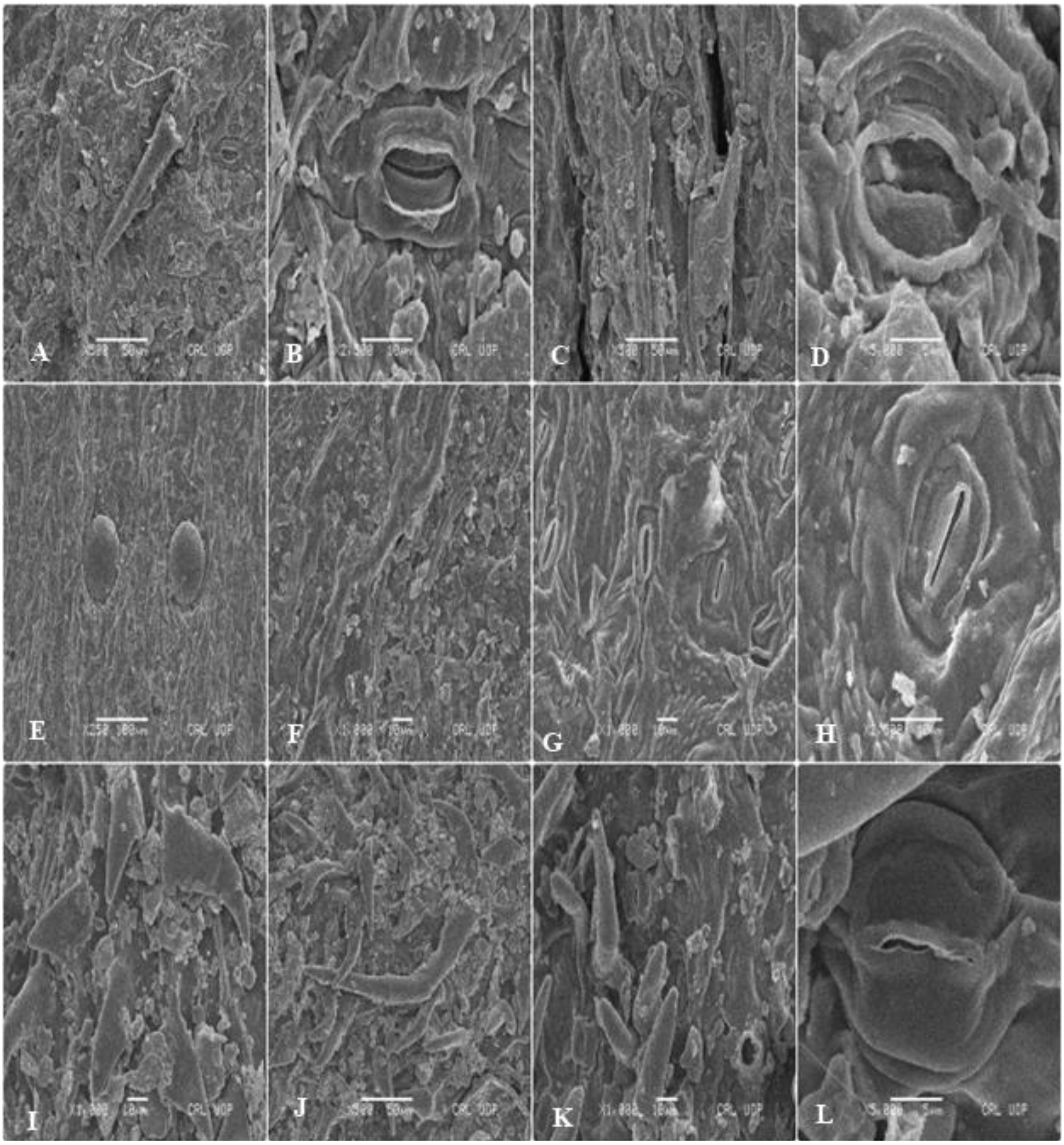

Plate. 85: Scanning Electron microscopy (SEM) of leaf illustrated shape of epidermal cells, type and shape oof stomata, anticlinal wall pattern and trichome type of sub family Nepetoideae taxa. *Satureja hortensis* (A-B) adaxial surface showing unicellular conical non granular trichomes (C-D) abaxial surface showing anomocytic stomata. *Thymus linearis* (E-F) adaxial surface showing multicellular peltate trichome (G-H) abaxial surface showing oval shape stomata. *Thymus vulgaris* (I-J) adaxial surface showing unicellular conical non granular trichomes (K-L) abaxial surface showing elliptic shape stomata.

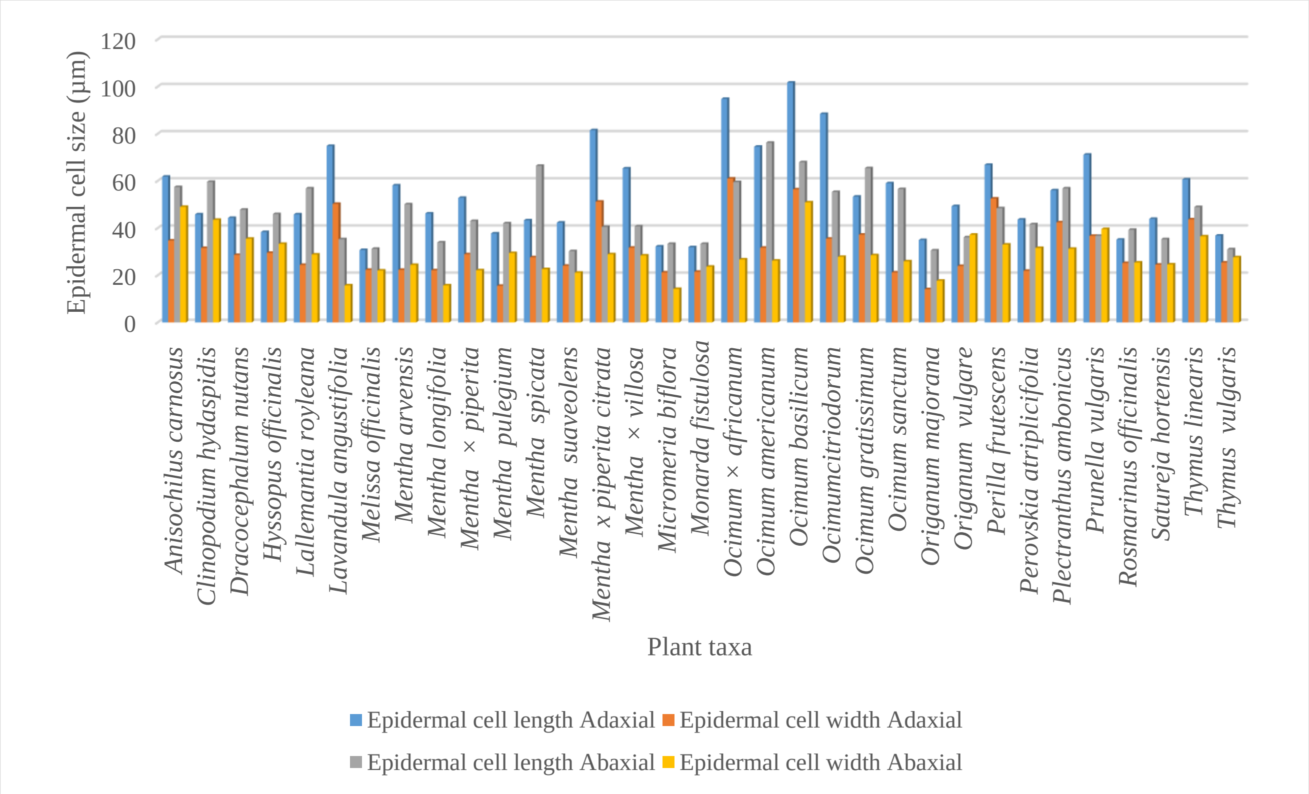

Figure. 49*:* Variation among epidermal cell length and width of both adaxial and abaxial surface of Nepetoideae taxa

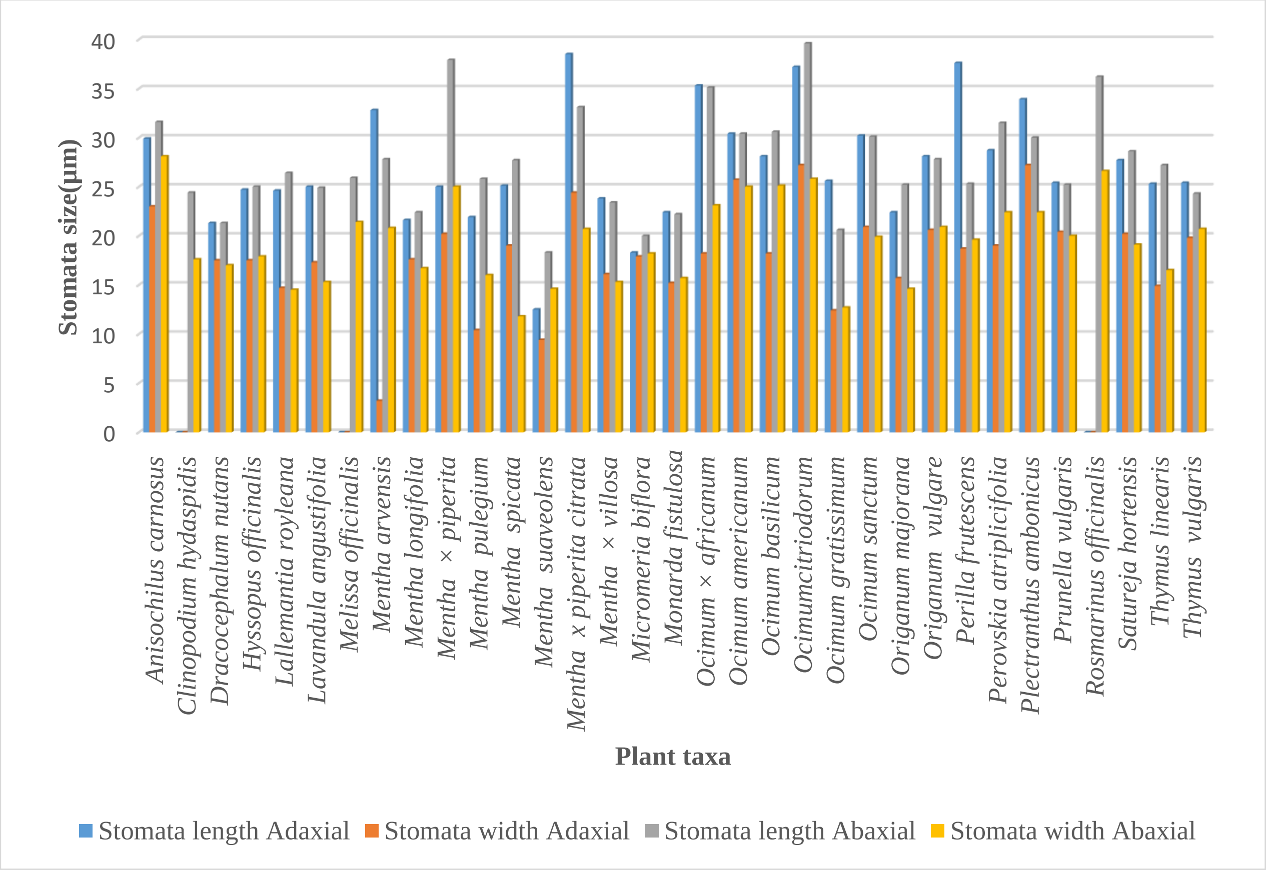

Figure. 50: Variationamong stomata length and width of both adaxial and abaxial surface of t Nepetoideae taxa

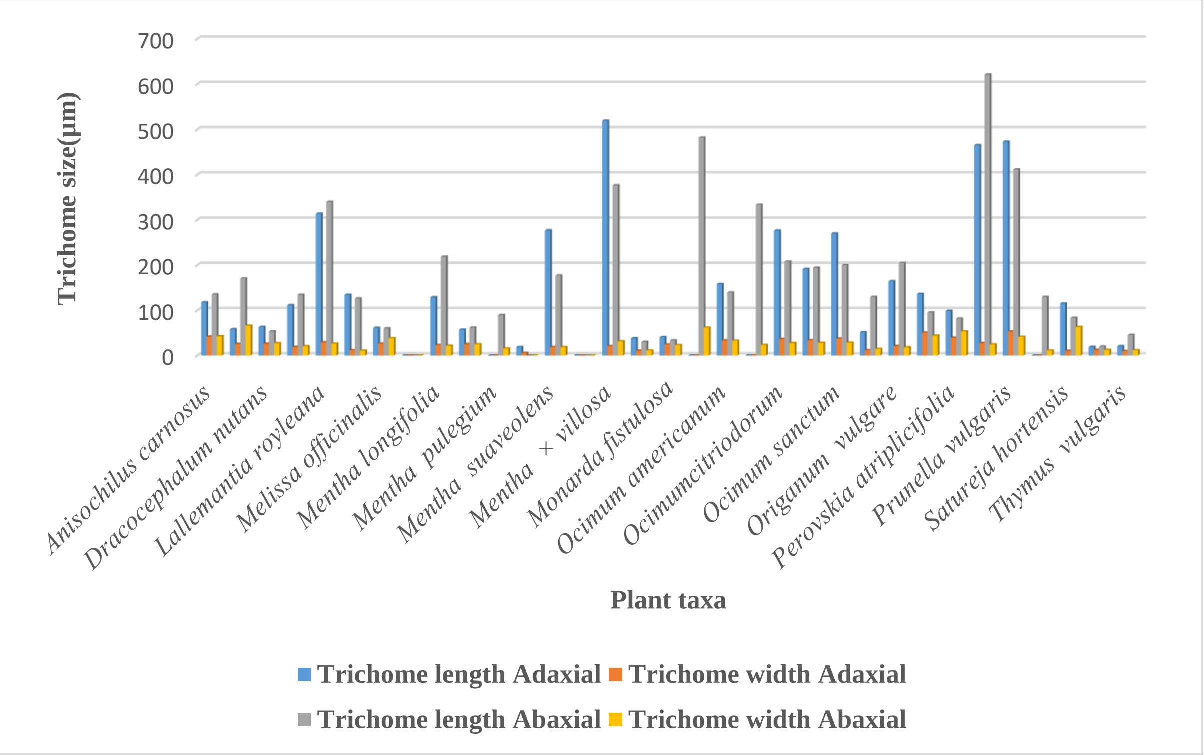

Figure. 51: Variation among trichome length and width of both adaxial and abaxial surface of Nepetoideae taxa

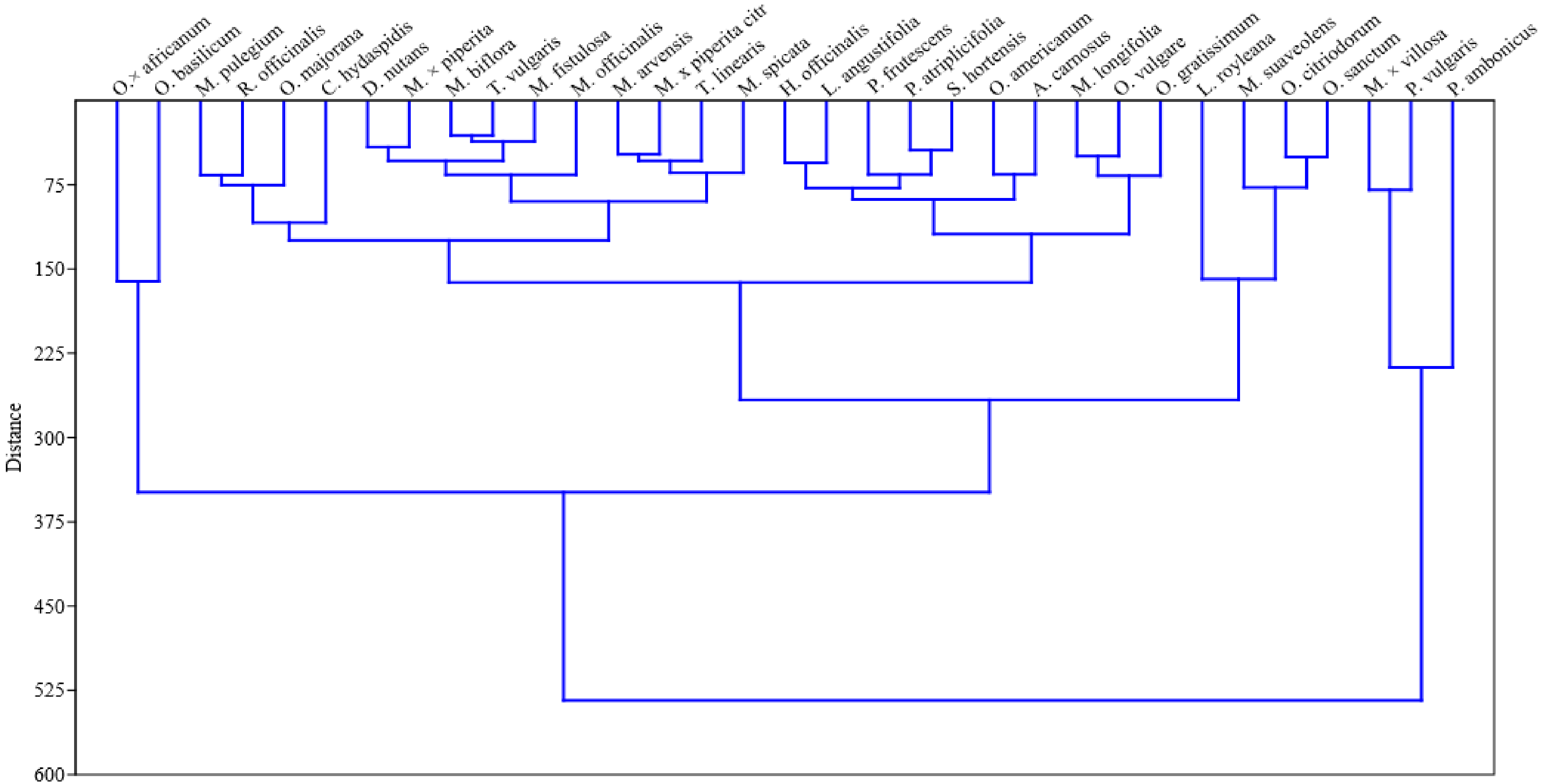

Figure. 52: Cluster analysis of the studied Nepetoideae taxa based on quantitative foliar anatomical traits

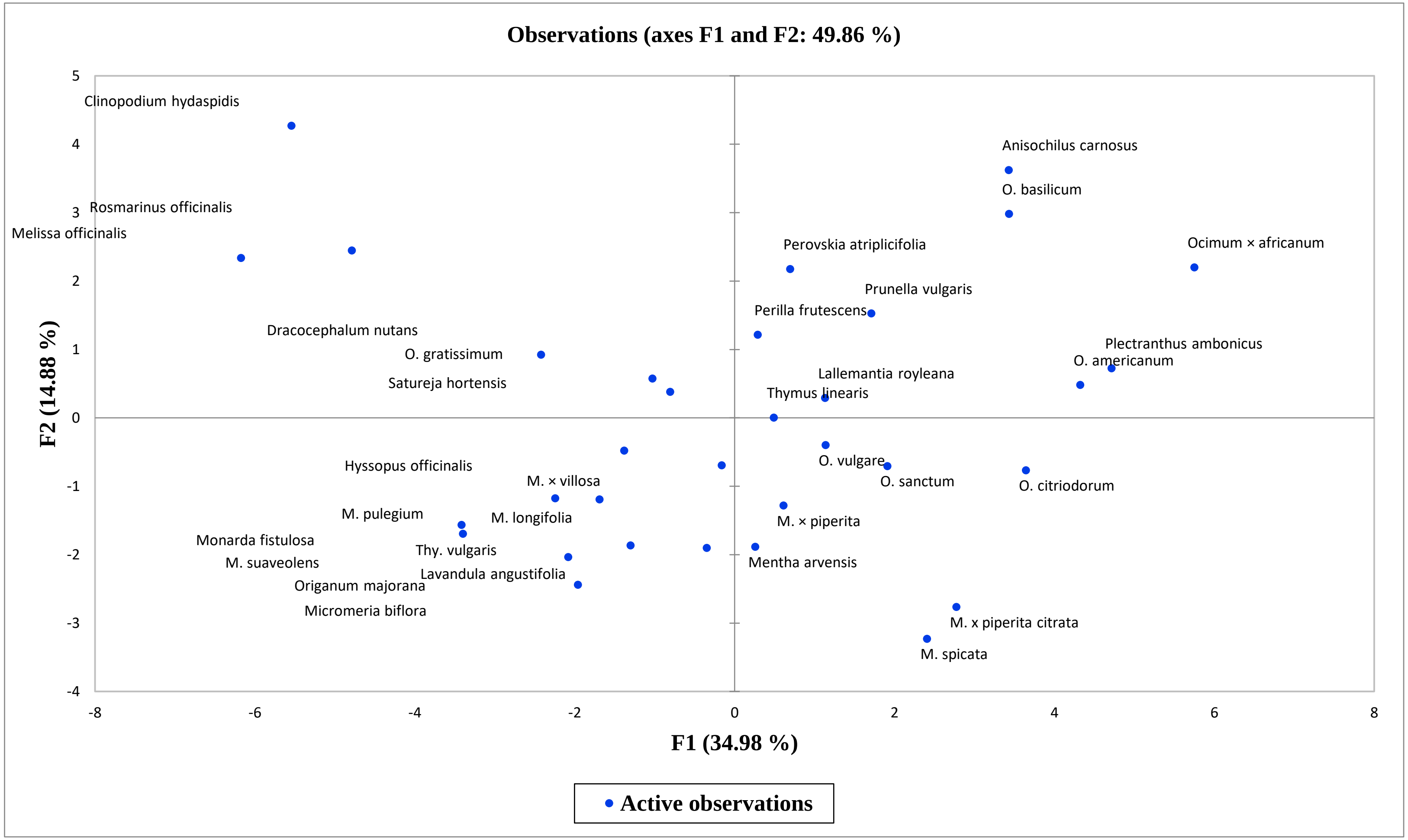

Figure. 53: Principal component analysis (PCA) of foliar active observation of the biplot

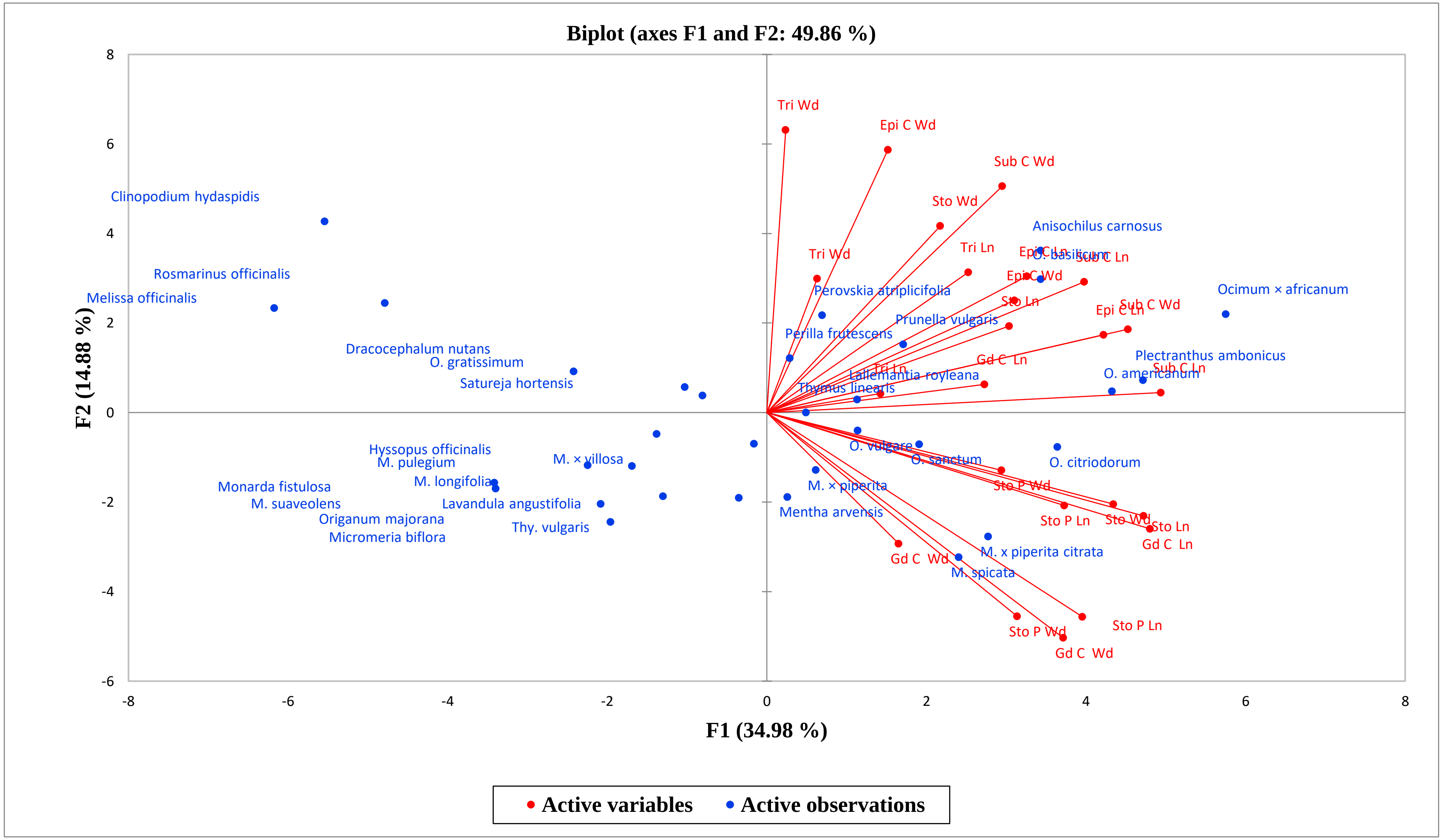

Figure. 54: Principal component analysis (PCA) biplot metric variables of leaf of Nepetoideae taxa showed variance account of PCA axes; axes 1,34.98% and axes 2, 14.88%

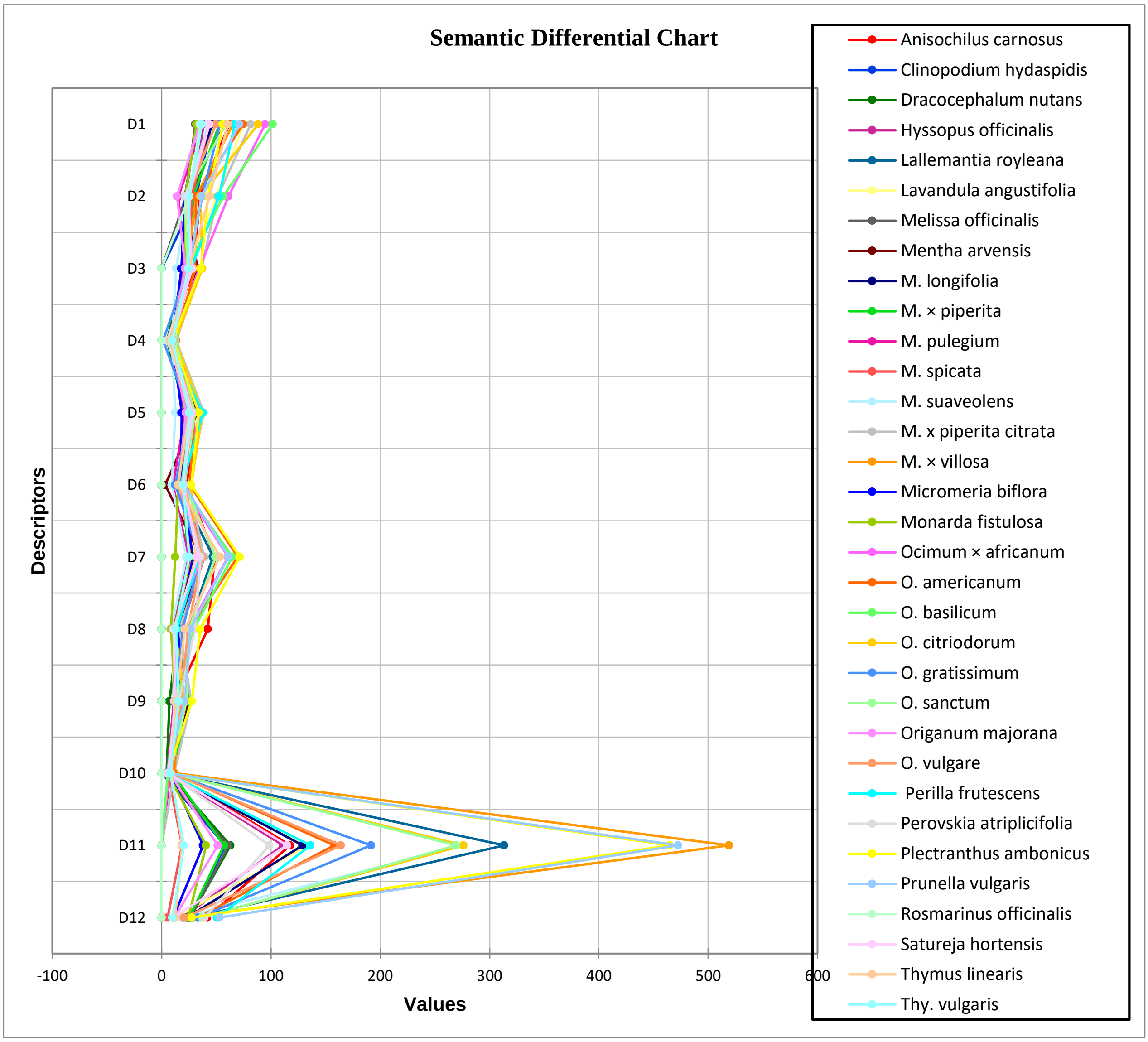

Figure. 55: Semantic differential chart of twelve variables of leaf adaxial surface that is epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each)

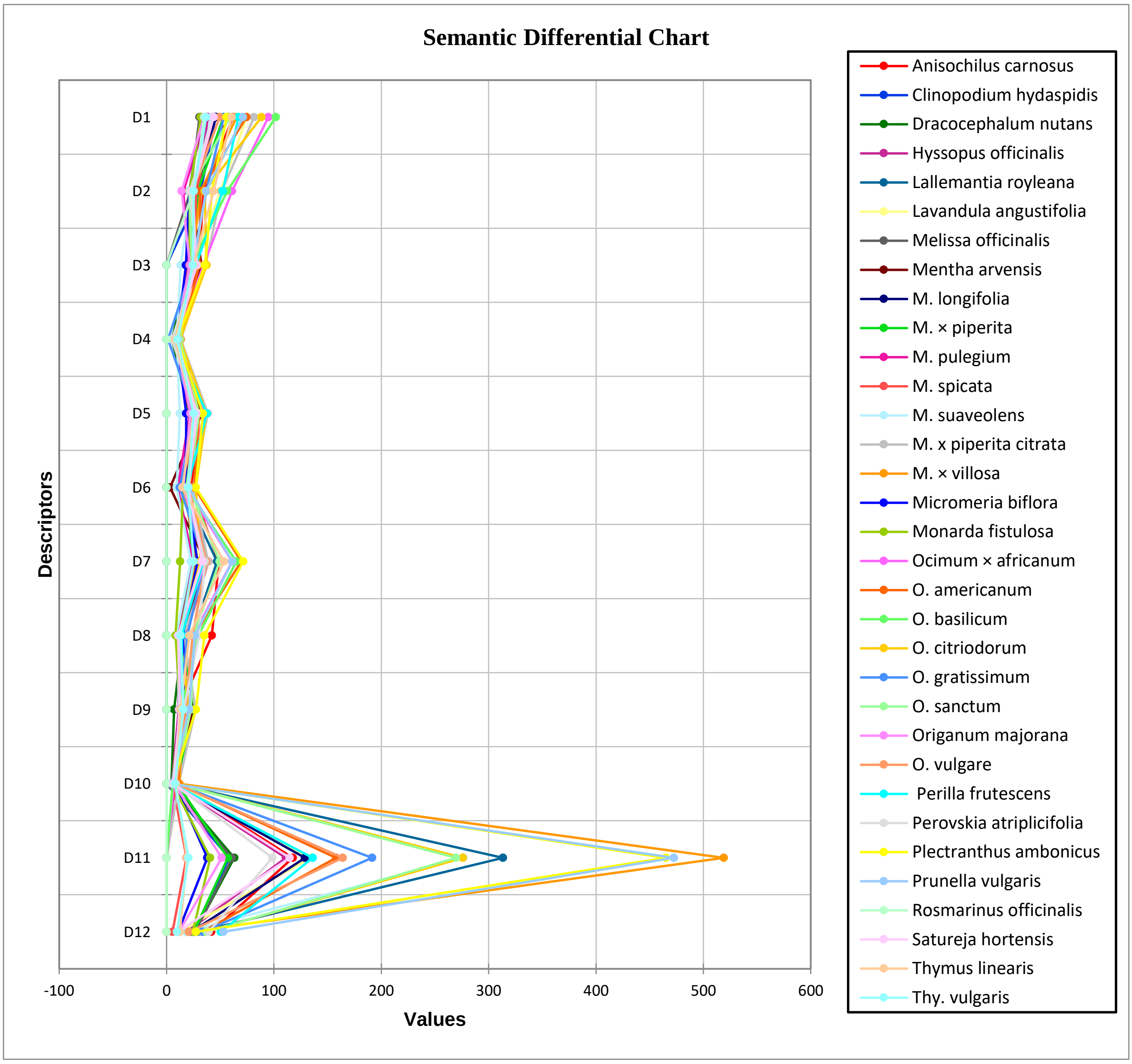

Figure. 56: Semantic differential chart of twelve variables of leaf abaxial surface that is epidermal cell size, guard cell size, stomata size, subsidiary cell size, stomatal pore size and trichome size, (length and width of each)

Section-IV

Seed Micromorphology of Lamiaceous Taxa

3.8 Seed Micromorphology of Lamiaceous Taxa

The seed morphological traits like (seed shape, color, size, texture, seed apex, base, compression, and hilum) of 22 Lamiaceous species were summarized in (Table. 23). The seed micromorphological characteristics like (seed outline, wall ornamentation, surface sculpturing, anticlinal wall pattern, periclinal wall pattern and epidermal cell arrangement) were summarized in (Table. 24). By including these new aspects, our knowledge of seed morphology has been enhanced with a focus on micromorphological traits (Jabeen et al., 2023). SEM micrographs were shown in (Plate. 86-92). In various genera of Lamiaceae, the significance of nutlet shape, particularly its micro-morphological characteristics, has already been investigated (Budantsev and Lobova 1997; Hassan and Dar 2012; Kaya and Dirmenci 2008; Moon et al., 2009; Padure et al., 2005). In the current research the seed micromorphology of 22 Lamiaceous taxa was observed in detail for the first time in Pakistan.

3.8.1 Variations in Seed Shape, Size, and Texture

Lamiaceae seeds show great variation in shape, size, and texture. Seed shapes can be described as semi-spheroid, spherical, oblong, globose oblong, trigonous, obovate, fusiform, spheroid, oval, however, in this study, the seed shapes were mostly spheroid to oblong. The seed textures are mostly rough, smooth, smooth, shiny, and scabrous. Previous studies of Fıra (2016) observed brown, large, and eliptic nutlet of *Marrubium eriocephalum* with polygonal epidermal cells and verrucate ornamentation not coincides with our observed *Marrubium* specie except in epidermal cell shape. The seeds ranged in size from (1 mm) in *Anisomeles indica, Callicarpa macrophylla and Scutelaria linearis* to (4 mm) in *Phlomoides vicaryi in* length and from (0.75 mm) in *Phlomoides vicaryi to* (3.5 mm) in *Vitex agnus-castus* and *Vitex negundo* in width (Fig. 57, Table 23). On average *Phlomoides vicaryi*, followed by *Eremostachys superba* had the largest nutlets. The seeds of *Scutelaria linearis* are the smallest. Table 23 lists the nutlet size ranges for all species. The highest length to width ratio (4 %) was found in *Phlomis bracteosa* and lowest (1 %) in four species that is *Callicarpa macrophylla*, *Eremostachys superba*, *Phlomidoschema parviflorum* and *Stachys palustris* (Fig. 58). The seed shape of *Marrubium vulgare* is grey-black in color with smooth outline, clavate surface and polygonal cells found dissimilar from Akçin and Camili (2018) except in epidermal cell shape. The shape of *stachys* species in our results are spheroid with either rough or smooth texture and reticulate or striate surface found dissimilar to Hassan and Al-Thobaiti (2015) from their studied *Stachys sp. aff. Schimperi* in shape and surface ornamentation. According to Salmaki et al., (2008) the shape of *Stachys sylvatica* is broad ovate with reticulate surface, concave periclinal wall and raised anticlinal wall was found similar to our studied *stachys* species except in seed shape.

3.8.2 Variations in the Color of Seeds

The color of the nutlets (inner and outer) in the studied taxa varies (Table. 23), outer color ranging from off-white, light brown, black, brown, dark brown, black, grey, light green and dark gray and inner color: light to dark brown, off white, white, grey, skin color, dark gray and grey, white. (Plate. 87 and 90 D), can be easily recognized from others based solely on their scabrous texture and trichomes on the surface. The common seed color in the current research was observed as brown. Grey, and light green was observed as unique one. The color of seeds can vary from light to dark brown, grey, or black. However, investigations by Chaung & Heckard, (1983) and Husain et al., (1990) indicate that taxonomic significance of seed color in taxa delimitations is restricted. This is because it varies within the same taxon and is generally inconsistent.

Earlier studies vulgare seed found micromorphological traits of of *Marrubium vulgare* seed and observed trigonous seed with grey color, rough texture and reticulate surface sculpturing coincides with our observed *Marrubium vulgare* in color and shape but not in texture and surface sculpturing. The seed shape of *Marrubium vulgare* is grey-black and trigonous shape not consistent to Ya'ni et al., (2018) in color but consistent in shape.

3.8.3 Variations in the Seed Apex and Base

Lamiaceous seeds show great variation in seed apex and base. Five types of seed apex were observed: truncate, round, acute, mammiform and scabrous. The dominant seed apex was acute followed by truncate, and the less found seed apex was scabrous. Similarly, four types of seed base were observed: truncate, round mammiform and depressed. The dominant seed base was round followed by truncate, and the less found seed base was mammiform. Seed apex shows variation as compared to seed base. Only *Eremostachys superba*, shows scabrous seed apex (Plate. 87 G). Table 23 lists the nutlet apex and base shapes for all studied species. According to Güner et al., (2019) the seed shape and color of *Stachys Kurdica* is brown and obovate to oblong with reticulate surface and acute apex similar to our results except in surface sculpturing.

3.8.4 Variations in Compression and Hilum

Three types of seed compression were observed in the present research i.e., lateral, ventral and dorsoventral. Mostly seed compression was ventral. Hilum is not visible in five species and its position is of two types i.e., terminal and sub terminal. Terminal hilum position is the dominant one in the current research. The hilum was either raised or depressed, raised hilum was observed in most of the studied taxa., Hilum occurrence, position and level were shown in (Table. 23).

3.8.5 Variations in Wall ornamentation and Surface Sculpturing

Great variation was observed in wall ornamentation of the studied taxa. Twelve types of wall ornamentations were observed in the studied taxa, i.e., thick with ridges and furrows, thick and raised, raised, irregularly thickened, ridges and furrows, sinuate, straight and smooth, rounded, buttressed, verrucate, branched, and angular. Eleven types of surface sculpturing were observed in the analyzed Lamiaceae taxa that are taxonomically very significant (Table. 24). These surface sculptures are alveolate, irregular undulating ridges, verrucate, rugose with peltate trichomes, striate, colliculate, clavate, rough reticulate, scabrate with trichomes, rugulate with trichomes, and reticulate. The observed reticulate surface in *Stachys* seed aligns with the findings of Satıl et al. (2012), emphasizing the importance of surface sculpturing as a distinguishing feature within the Lamiaceae family. Unique seed sculpturing was observed in the current study and is used as distinguishing feature of the family. Therefore, we observed these unique surfaces, not considering them as dominant. According to Sajna and Sunojkumar (2008) the seed shape and surface sculpturing of *Leucas aspera* and *Leucas cephalotes* are narrow oblong and scalariform respectively disagreed with our results. Hasaninejad et al., (2009) observed densely stellate, papillate, scattered hairs surface of *scutelaria* species do not coincide to our studied *scutelaria* specie. Previous studies of Satıl et al., (2012) observed reticulate surface in their studied *stachys* seed with obovoid shape similar to our studies in surface ornamentation of *stachys* seed but dissimilar in seed shape. The most significant character has been said to be provided by the nutlet sculpturing (Oran, 1996). The surface sulpturing is an important character and have systematic importance in Lamiaceae (Husain et al., 1990).

3.8.6 Variations in Anticlinal, Periclinal wall Pattern and Epidermal Cell Shape

Anticlinal wall patterns show great variations, these are raised and elevated, thick and raised, thick and buttressed, irregularly thickened, depressed with irregular thickenings, depressed, straight, raised, convex, thick and slightly concave, wavy and thick, convex and thick, depressed and thin, straight and depressed. Depressed anticlinal wall was observed in five analyzed taxa and considered as dominant because great variation was observed. Therefore, these are the unique anticlinal walls among the analyzed taxa. While the periclinal walls are flat convex and raised, thick with ridges and furrows, slightly concave, thick, raised and elevated, straight, thick and straight, depressed, convex, buttressed, raised, raised and convex and very thick and raised or deep and convex. Thick and straight is the prominent periclinal walls observed among the studied species. Arrangement of the epidermal cells are dominantly irregular (eleven species) followed by polygonal (five species) among the studied taxa. The anticlinal and periclinal wall of *Lamium album* and *Lamium amplexicaule* are depressed and raised respectively was found similar to Krawczyk and Głowacka (2015) in periclinal wall but dissimilar in anticlinal wall pattern.

3.8.7 Cluster Analysis and Principal Component Analysis (PCA) of Seed as a Statistical Tool

The similarity index among the studied Lamiaceous taxa was analyzed using UPGMA cluster analysis (Lopes et al., 2022). The quantitative data provides three principal clusters based on seed micromorphological characters. The quantitative seed data distributes the studied taxa into three major clusters (Fig.3). Cluster 1 (C1) is divided into sub clusters which is further divided into two clades. Greater similarity was observed among *Vitex agnus-castus* and *Vitex negundo.* Cluster 2 (C2) is divided into sub cluster, of which similarity was observed among *Phlomis bracteosa* and *Leucas cephalotes.* Cluster 3 (C3) is divided into three sub clusters which were further divided into minor clusters. *Leucas aspera and Pseudocaryopteris bicolor* show similarity as compared to *Phlomis stewartii*. The greatest similarity was observed between

Ajuga parviflora and *Lamium amplexicaule* as compared to *Anisomeles indica* may be due to their quantitative measurement or their distribution (Fig. 59).

One of the most significant statistical tests for examining a set of elements is principal component analysis (PCA), which aims to explain the variation among them. Typically, it involves projecting sample data in two dimensions with principal component axes (Zhao et al., 2020). Principal Component analysis (PCA) was used to evaluate the variation among seed size of the studied taxa based on three important factors i.e., seed length, seed width, and length/width ratio. Using a small number of essential variables in PCA improved the accuracy of mathematical categorization. The data set was represented visually using two-dimensional representations. In current investigation, the cumulative variance sums up at (71.23%), as shown in (Fig. 61). The results of the PCA analysis showed that PC1 had an eigenvalue greater than 1 (1.542) and was the most important factor. PC2 Eigenvalue was found to be the second major component and is near to one (0.819). Analyzed data revealed that the PC1 has (51.40 %) variance of the entire data variation. PCA variable loadings for these three components are presented in (Table 22). The most important factor in PC1 was seed width. The positive side of the first axis was occupied by *Vitex agnus-castus*, *Vitex negundo*, and *Leucas cephalotes*, while the negative side was lined by *Anisomeles indica, Stachys palustris, Callicarpa macrophylla, Phlomidoschema parviflorum, Stachys floccose*, *Ajuga integrifolia* and *Stachys emodi*. Analyzed data revealed that the PC2 has (27.31 %) variance of the total data variation. The most significant variable in PC2 was found to be the length/width ratio (%) followed by seed length. The positive side of the second axis was occupied by *Phlomis stewartii, Eremostachys superba, Phlomoides vicaryi, Leucas aspera* and *Pseudocaryopteris bicolor*, while the negative side was lined by *Lamium album, Ajuga reptans, Scutellaria linearis, Lamium amplexicaule, Marrubium vulgare* and *Ajuga parviflora*. The active variables of three principal components, which are seed length, seed width, and length/width ratio are visualized in (Fig. 60). Moreover, the semantic differential chart shown in (Fig. 62) was used to better illustrate and assess these three characteristics.

3.8.8 Dichotomous key of the Studied Lamiaceous Taxa Based on Seed Micromorphological Traits.

1	a	Seed shape semi-spheroid, fusiform…………………….	*Lamium amplexicaule*
	b	Seed shape spheroid-obovate…………………………	*Stachys emodi*
2	a	Seed shape globose……………………………………	*Anisomeles indica*
	b	Seed shape oval…………………………………………	*Scutellaria linearis*
3	a	Seed shape oblong………………………………………	*Leucas aspera*
	b	Seed shape semi-spheroid………………………………	4
4	a	Seed apex truncate………………………………………	*Ajuga integrifolia*
	b	Seed apex round………………………………………	*Ajuga parviflora*
5	a	Seed shape trigonous……………………………………	6
	b	Seed shape oblong-trigonous…………………………	7
6	a	Surface sculpturing Striate……………………………	*Eremostachys superba*
	b	Surface sculpturing Clavate…………………………….	*Marrubium vulgare*
7	a	Seed outline smooth…………………………………….	*Leucas cephalotes*
	b	Seed outline scabrate……………………………………	*Pseudocaryopteris bicolor*
8	a	Seed shape spherical……………………………………	9
	b	Seed shape obovate……………………………………	10
9	a	Epidermal cell pentagonal to hexagonal………………	*Ajuga reptans*
	b	Epidermal cell irregular………………………………	*Callicarpa macrophylla*
10	a	Surface sculpturing colliculate………………………….	*Lamium album*
	b	Surface sculpturing other than colliculate………………	11
11	a	Seed compression ventral……………………………….	*Phlomoides vicaryi*
	b	Seed compression other than ventral……………………	12
12	a	Hilum depressed………………………………………	*Phlomis bracteosa*
	b	Hilum raised…………………………………………….	*Phlomis stewartii*
13	a	Seed shape spheroid…………………………………….	14
	b	Seed shape other than spheroid…………………………	
15	a	Wall ornamentation angular…………………………….	*Stachys palustris*
	b	Wall ornamentation other than angular…………………	16
16	a	Seed outline smooth…………………………………….	*Phlomidoschema parviflorum*
	b	Seed outline other than smooth…………………………	17

17	a	Seed base truncate…………………………………………	*Vitex negundo*
	b	Seed base other than truncate…………………………	18
18	a	Periclinal wall pattern raised and convex……………….	*Stachys floccosa*
	b	Periclinal wall pattern thick and straight………………	*Vitex agnus-castus*

Table. 22: Principal component analysis variable loadings for first three seed components

Variables/Factors	**F1**	**F2**	**F3**
Seed Length (mm)	0.782	-0.114	-0.612
Seed Width (mm)	0.648	0.724	0.237
L/W Ratio	0.715	-0.531	0.455
Eigenvalue	1.542	0.819	0.639
Variability (%)	51.402	27.307	21.291
Cumulative %	51.402	78.709	100.000

Table. 23: Seed micromorphological characteristics of Lamiaceae

Sr. no	Plant taxa	Seed shape	Seed color		Seed texture	Seed apex	Seed base	Seed Compression	Hilum			Seed length (mm)	Seed width (mm)	L/w ratio
			Outer	Inner					Occurrence	Position	Level			
1.	*Ajuga integrifolia* Buch. -Ham.	Semi-Spheroid	Off-White-Brown	Brown	Rough	Truncate	Truncate	-	Visible	Sub-Terminal	Depressed	1-2	1-2	1.5
2.	*Ajuga parviflora* Benth.	Semi-Spheroid	Light Brown	Light Brown	Rough	Round	Round	-	Visible	Sub-Terminal	Raised	2-3	1-2	2
3.	*Ajuga reptans* L.	Spherical	Light Brown	Off-White	Rough	Round	Round	-	Visible	Terminal	Depressed	1-2	1-2	1.5
4.	*Anisomeles indica* (L.) Kuntze	Globose	Black	Light Brown to Yellow	Smooth And Shiny	Mammi-Form	Round	-	Visible	Terminal	Raised	0.5-1.5	0.5-1.5	1
5.	*Callicarpa macrophylla* Vahl	Spherical	Brown	Off-White	Rough	Truncate	Mammi-Form	Lateral	Visible	Terminal	Depressed	0.5-1.5	0.5-1.5	1
6.	*Eremostachys superba* Royle ex Benth.	Trigonous	Dark Brown	Light Brown	Scabrous	Scabrous	Depressed	Ventral	Visible	Terminal	Raised	4-7	2-3	2.5
7.	*Lamium album* L.	Obovate	Gray	White	Rough	Truncate	Truncate	-	Not Visible	-	-	1-3	1-2	1.33
8.	*Lamium amplexicaule* L.	Semi Spheroid, Fusiform	Gray, Brown	White	Rough And Shiny	Mammiform	Truncate	Lateral	Visible	Terminal	Raised	2-3	1-2	1.67

9.	*Leucas aspera* (Willd.) Link	Oblong	Brown	Gray-White	Smooth	Truncate	Truncate	Ventral	Visible	Terminal	Depressed	2-4	0.5-1.5	3
10.	*Leucas cephalotes* (Roth) Spreng.	Oblong-Trigonous	Dark Brown	Gray-White	Rough	Acute	Truncate	Ventral	Visible	Terminal	Raised	2-4	0.5-1.5	3
11.	*Marrubium vulgare* L.	Trigonous	Gray, Black	Brown	Smooth	Truncate	Round	Lateral	Not Visible	-	-	2-3	1-2	1.67
12.	*Phlomidoschema parviflorum* (Benth.) Vved.	Spheroid	Brown	White	Smooth	Acute	Round	Dorsoventral	Visible	Terminal	Raised	2-4	2-4	1
13.	*Phlomis bracteosa* Royle ex Benth.	Obovate	Brown	White	Rough	Acute	Depressed	Dorsoventral	Visible	Terminal	Depressed	3-5	0.5-1.5	4
14.	*Phlomis stewartii* Hook.f.	Obovate	Brown	Brown	Smooth	Round	Truncate	Dorsoventral	Visible	Terminal	Raised	3-4	1-2	2.33
15.	*Phlomoides vicaryi* (Benth. ex-Hook.f.) Kamelin & Makhm.	Obovate	Light Green	Off White	Rough	Truncate	Truncate	Ventral	Visible	Terminal	Depressed	5-7	3-4	1.71
16.	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D.Cantino	Oblong-trigonous	Brown	Skin	Rough	Acute	Truncate	-	Not Visible	-	-	2-4	0.5-1.5	3
17.	*Scutellaria linearis* Benth.	Oval	Gray	Off White	Rough	Truncate	Round	Ventral	Not Visible	-	-	0.5-1.5	0.5-1	1.33

18.	*Stachys emodi* Hedge	Spheroid-Obovate	Brown To Gray	Skin	Smooth	Acute	Round	Ventral	Visible	Terminal	Raised	1-3	0.5-1.5	2
19.	*Stachys floccosa* Benth.	Spheroid	Dark Gray to Brown	Gray	Smooth	Acute	Round	Ventral	Visible	Terminal	Raised	1-3	0.5-1.5	2
20.	*Stachys palustris* L.	Spheroid	Brown	White	Smooth	Acute	Round	-	Not Visible	-	-	1-3	1-3	1
21.	*Vitex agnus-castus* L.	Spheroid	Gray, Brown	Dark Brown	Rough	Acute	Round	Dorsoventral	Visible	Terminal	Raised	4-5	3-4	1.2
22.	*Vitex negundo* L.	Spheroid	Gray, Brown	Dark Brown	Rough	Mammiform	Truncate	-	Visible	Terminal	Raised	5-6	3-4	1.5

Keywords: (mm) = millimeter, L= Length W=Width

Table. 24: Seed SEM qualitative findings of Lamiaceae taxa examine

S.no	Plant Taxa	Seed outline	Wall ornamentation	Surface sculpturing	Anticlinal wall pattern	Periclinal wall pattern	Epidermal cell arrangement
1.	*Ajuga integrifolia* Buch. -Ham.	Random/Irregular	Raised, Thick with Ridges and Furrows	Alveolate	Raised And Elevated	Flat	Irregular
2.	*Ajuga parviflora* Benth.	Rough	Raised	Alveolate	Thick And raised	Convex And raised	Irregular
3.	*Ajuga reptans* L.	Regular	Thick And raised	Alveolate	Thick And buttressed	Thick With Ridges and Furrows	Pentagonal To Hexagonal
4.	*Anisomeles indica* (L.) Kuntze	Irregular And Smooth	Thick And raised	Irregular Undulating Ridges, Verrucate	Irregularly Thickened	Slightly Concave	Irregular
5.	*Callicarpa macrophylla* Vahl	Rough	Irregularly Thickened	Rugose With Peltate Trichomes	Thick And buttressed	Thick, Raised and Elevated	Irregular
6.	*Eremostachys superba* Royle ex Benth.	Rough And Scabrate	Irregularly Thickened	Striate	Not Visible	Not Visible	Not Visible
7.	*Lamium album* L.	Scabrate	Ridges And Furrows	Colliculate	Depressed With Irregular Thickenings	Raised And Convex	Irregular
8.	*Lamium amplexicaule* L.	Rough	Sinuate	Colliculate	Depressed	Convex And raised	Regular
9.	*Leucas aspera* (Willd.) Link	Smooth And Shiny	Straight And Smooth	Reticulate	Straight	Straight	Regular
10.	*Leucas cephalotes* (Roth) Spreng.	Smooth	Irregularly Thickened	Striate	Depressed	Thick And straight	Regular

11.	*Marrubium vulgare* L.	Smooth And Shiny	Rounded	Clavate	Raised	Depressed	Polygonal
12.	*Phlomidoschema parviflorum* (Benth.) Vved.	Smooth	Rounded	Rough Reticulate	Convex	Thick And straight	Polygonal
13.	*Phlomis bracteosa* Royle ex Benth.	Smooth	Buttressed	Striate	Thick And Slightly Concave	Straight And Thick	Irregular
14.	*Phlomis stewartii* Hook.f.	Rough	Irregularly Thickened	Striate	Wavy And Thick	Convex	Irregular
15.	*Phlomoides vicaryi* (Benth. ex-Hook.f.) Kamelin & Makhm.	Rough And Scabrate	Verrucate	Striate	Convex And Thick	Buttressed	Irregular
16.	*Pseudocaryopteris bicolor* (Roxb. ex Hardw.) P.D.Cantino	Scabrate	Branched	Scabrate With Trichomes	Not Visible	Not Visible	Not Visible
17.	*Scutellaria linearis* Benth.	Rough And Scabrate	Branched	Rugulate With Trichomes	Not Visible	Not Visible	Not Visible
18.	*Stachys emodi* Hedge	Smooth	Buttressed	Striate	Depressed	Raised	Irregular
19.	*Stachys floccosa* Benth.	Rough	Rounded	Reticulate	Depressed	Raised And Convex	Polygonal
20.	*Stachys palustris* L.	Smooth	Angular	Reticulate	Depressed And Thin	Raised And Convex	Polygonal
21.	*Vitex agnus-castus* L.	Rough	Irregularly Thickened	Colliculate	Straight And Depressed	Thick And straight	Irregular
22.	*Vitex negundo* L.	Rough	Irregularly Thickened	Striate And Colliculate	Depressed	Very Thick and Raised or Deep and Convex	Irregular

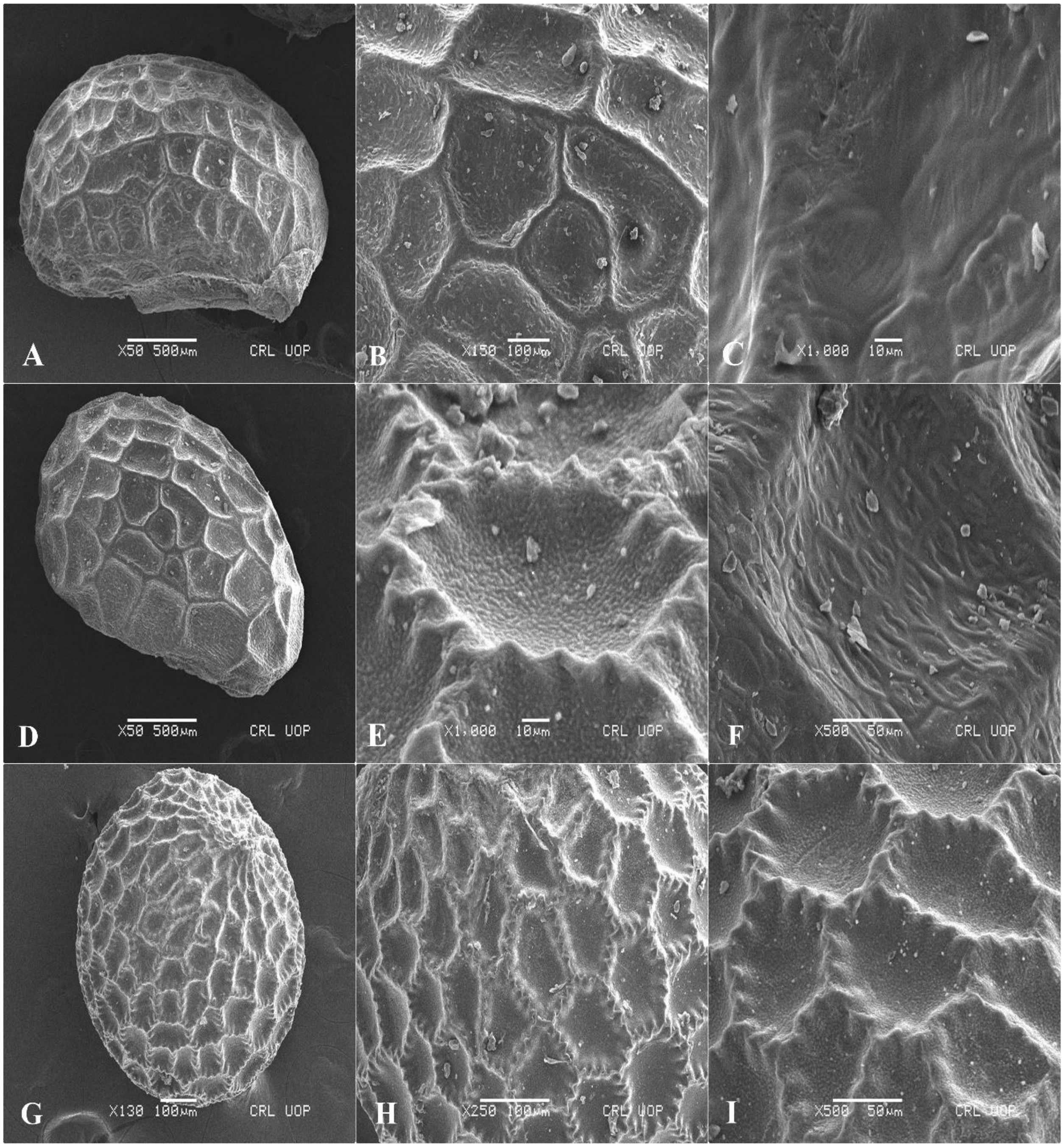

Plate. 86. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Ajuga integrifolia* (A) Truncate apex (B) Random outline (C) Alveolate surface. (D-F) *Ajuga parviflora* (D) Round base (E) Compression absent (F) Irregular epidermal cells. (G-I) *Ajuga reptans* (G) Rough texture (H) Pentagonal to hexagonal epidermal cells (I) Alveolate surface.

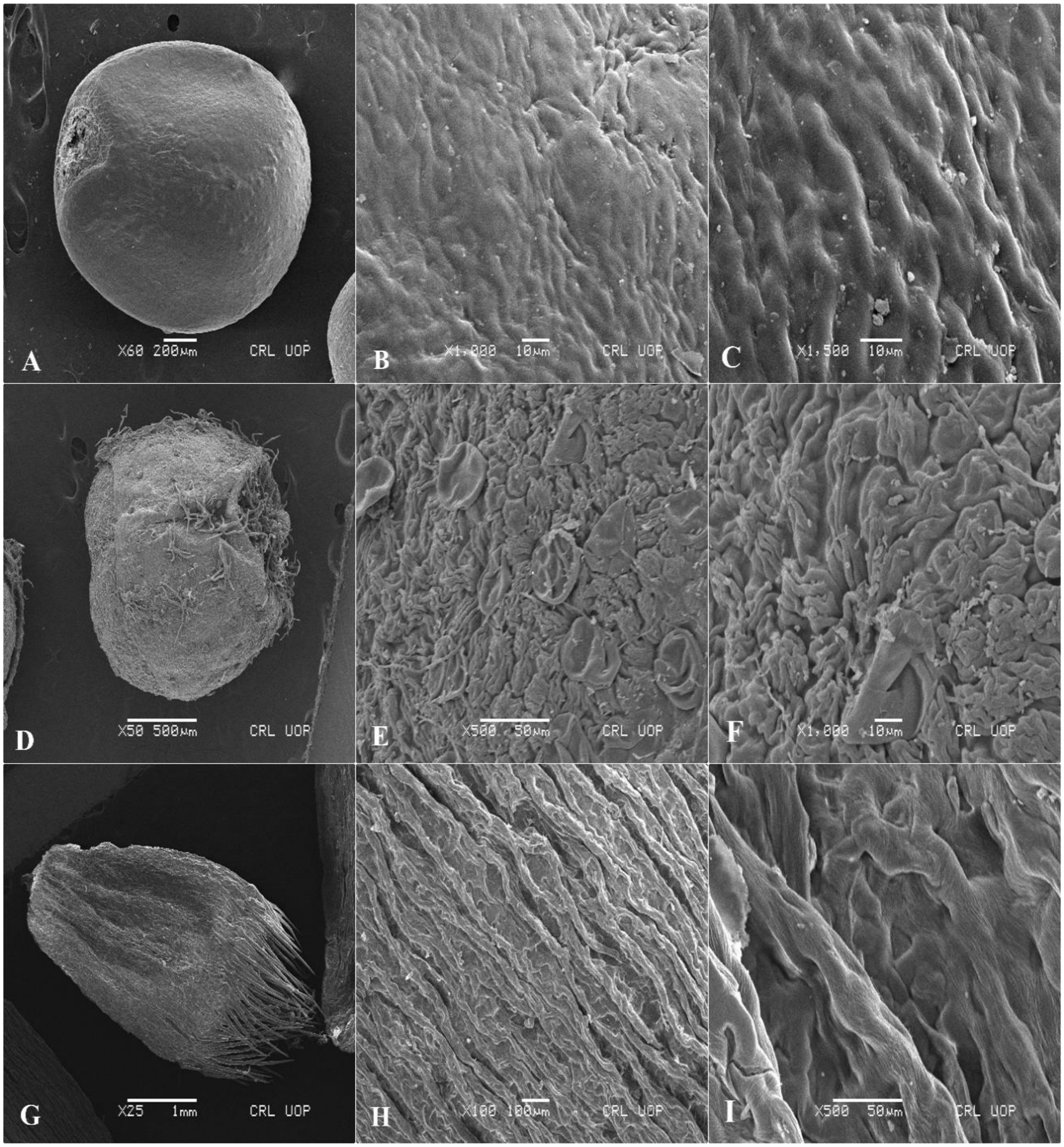

Plate. 87. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Anisomeles indica* (A) Smooth and shiny texture (B) Thick and raised wall (C) Verrucate surface (D-F) *Callicarpa macrophylla* (D) Rough texture (E) Peltate trichomes (F) Polygonal Rugose surface. (G-I) *Eremostachys superba* (G) Scabrous apex (H) Striate surface (I) Irregularly thickened wall.

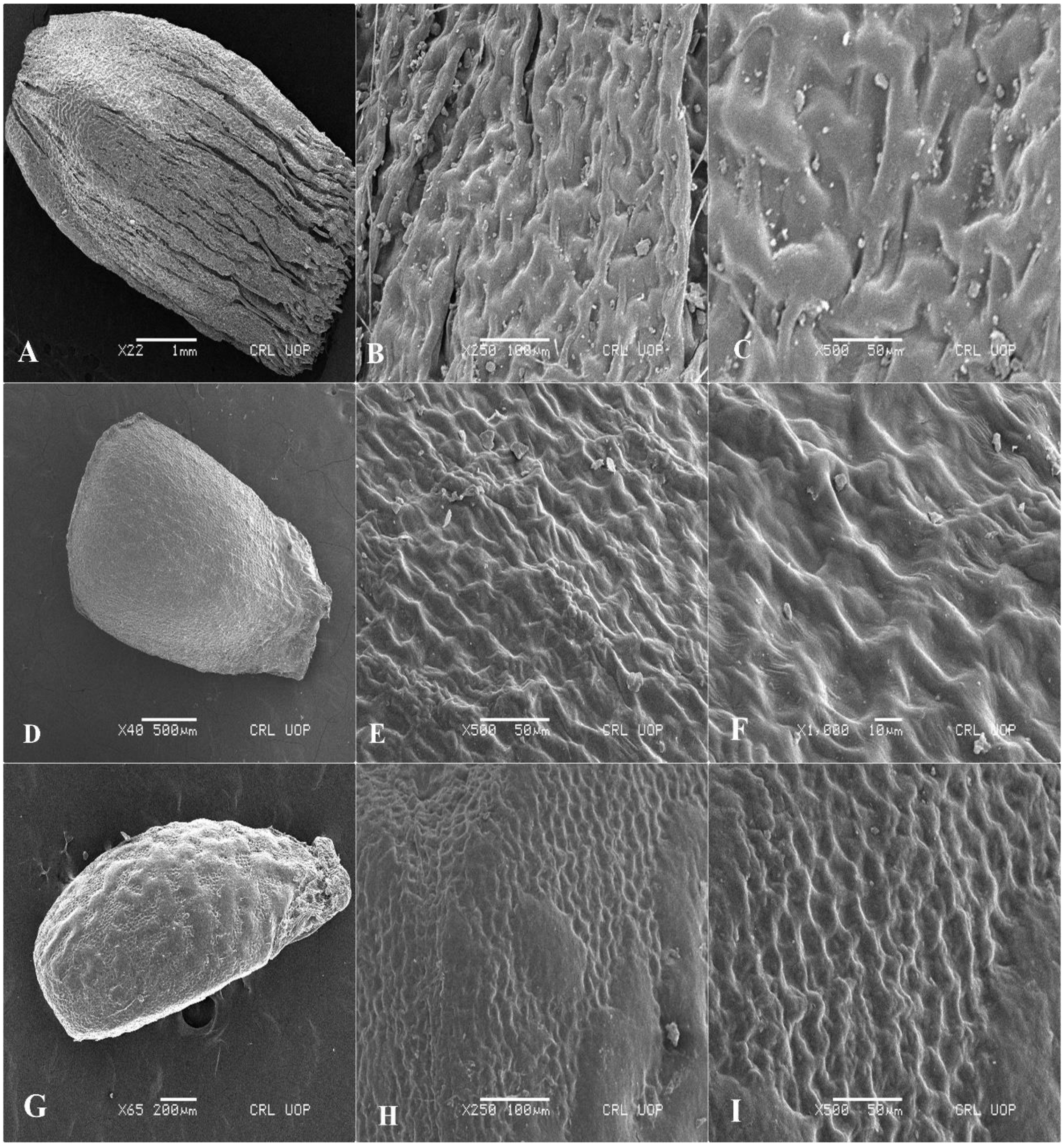

Plate. 88. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Phlomoides vicaryi* (A) Rough texture (B) Irregular epidermal cells (C) Striate surface. (D-F) *Lamium album* (D) Truncate base (E) Colliculate surface (F) Irregular epidermal cells. (G-I) *Lamium amplexicaule* (G) Semi spheroid (H) Sinuate wall(I) regular epidermal cells.

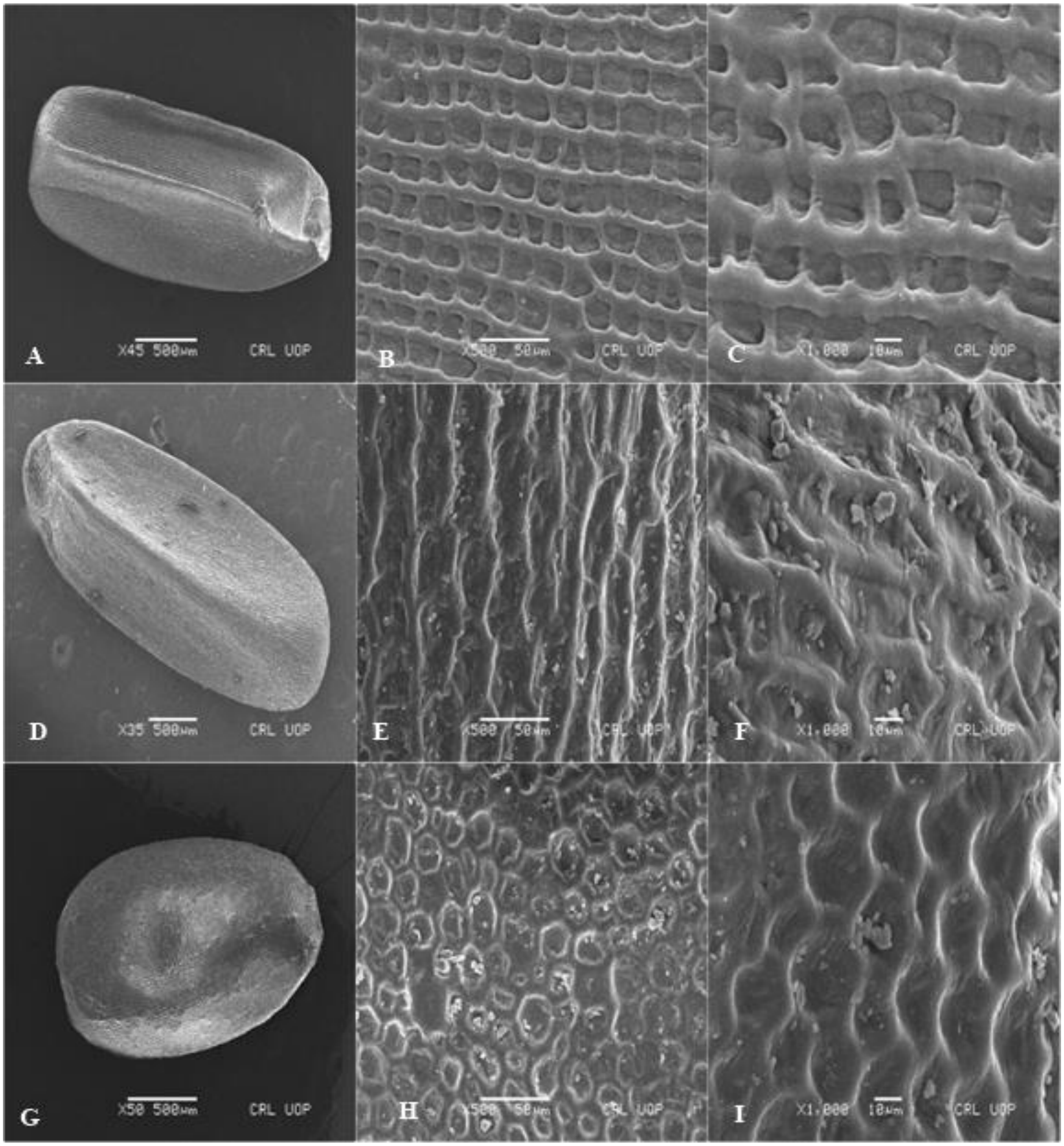

Plate. 89. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Leucas aspera* (A) Oblong (B) Compression ventral (C) Reticulate surface (D-F) *Leucas cephalotes* (D) Oblong shape (E) Striate surface (F) regular epidermal cells. (G-I) *Marrubium vulgare* (G) Rounded wall ornamentation (H) Polygonal epidermal cells (I) Clavate sculpturing.

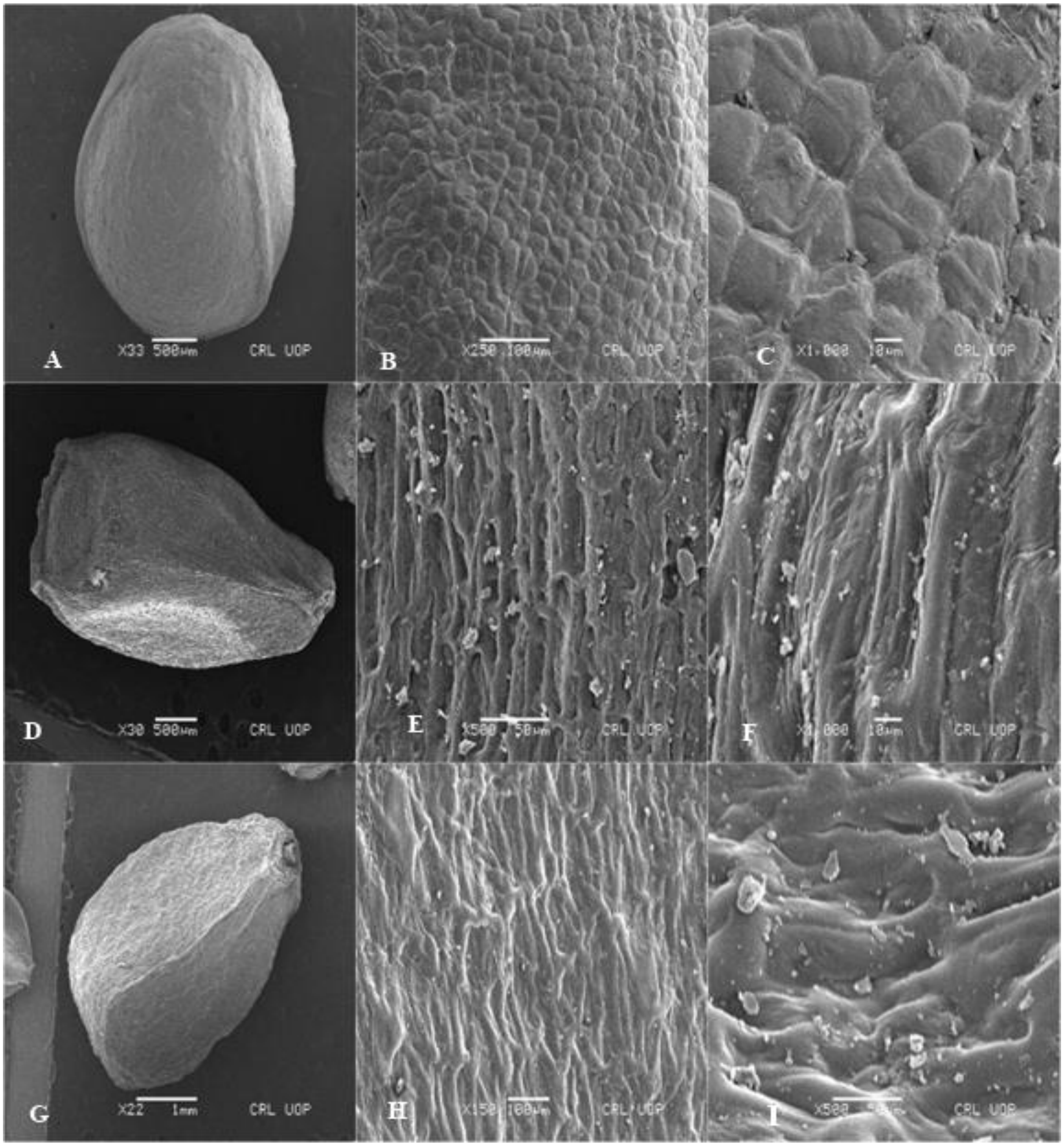

Plate. 90. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Phlomidoschema parviflorum* (A) Smooth texture (B) Rough reticulate surface (C) Polygonal epidermal cells. (D-F) *Phlomis bracteosa* (D) Obovate shape (E) Striate surface (F) Buttressed walls. (G-I) *Phlomis stewartii* (G) Terminal hilum (H) Striate surface (I) Irregular epidermal cells.

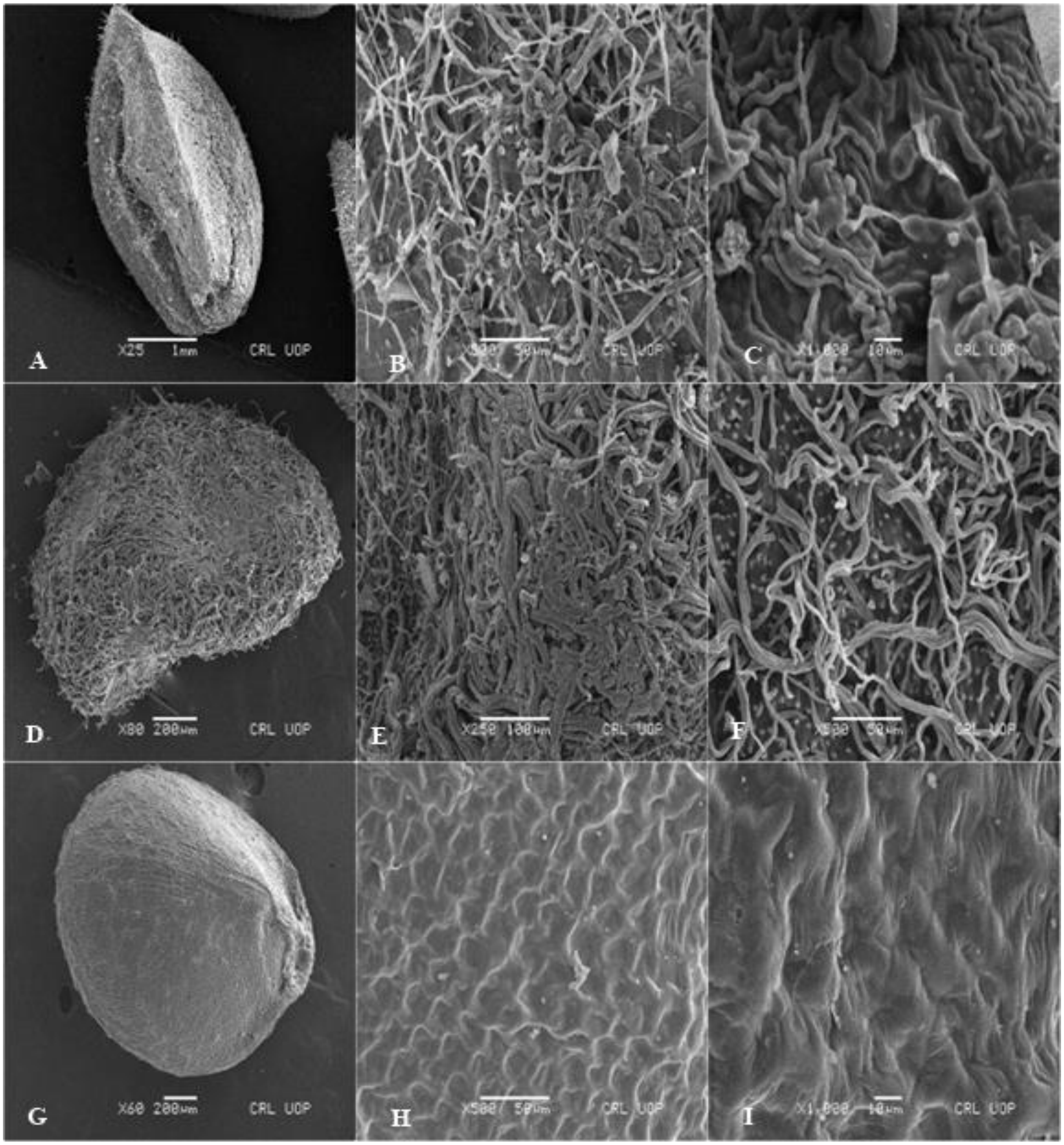

Plate. 91. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Pseudocaryopteris bicolor* (A) Oblong shape (B) Rough surface with trichomes (C) Epidermal cells not visible. (D-F) *Scutellaria linearis* (D) Oval shape (E) Rugulate and echinate surface (F) Epidermal cells not visible. (G-I) *Stachys emodi* (G) Smooth texture (H) Reticulate surface (I) Irregular epidermal cells.

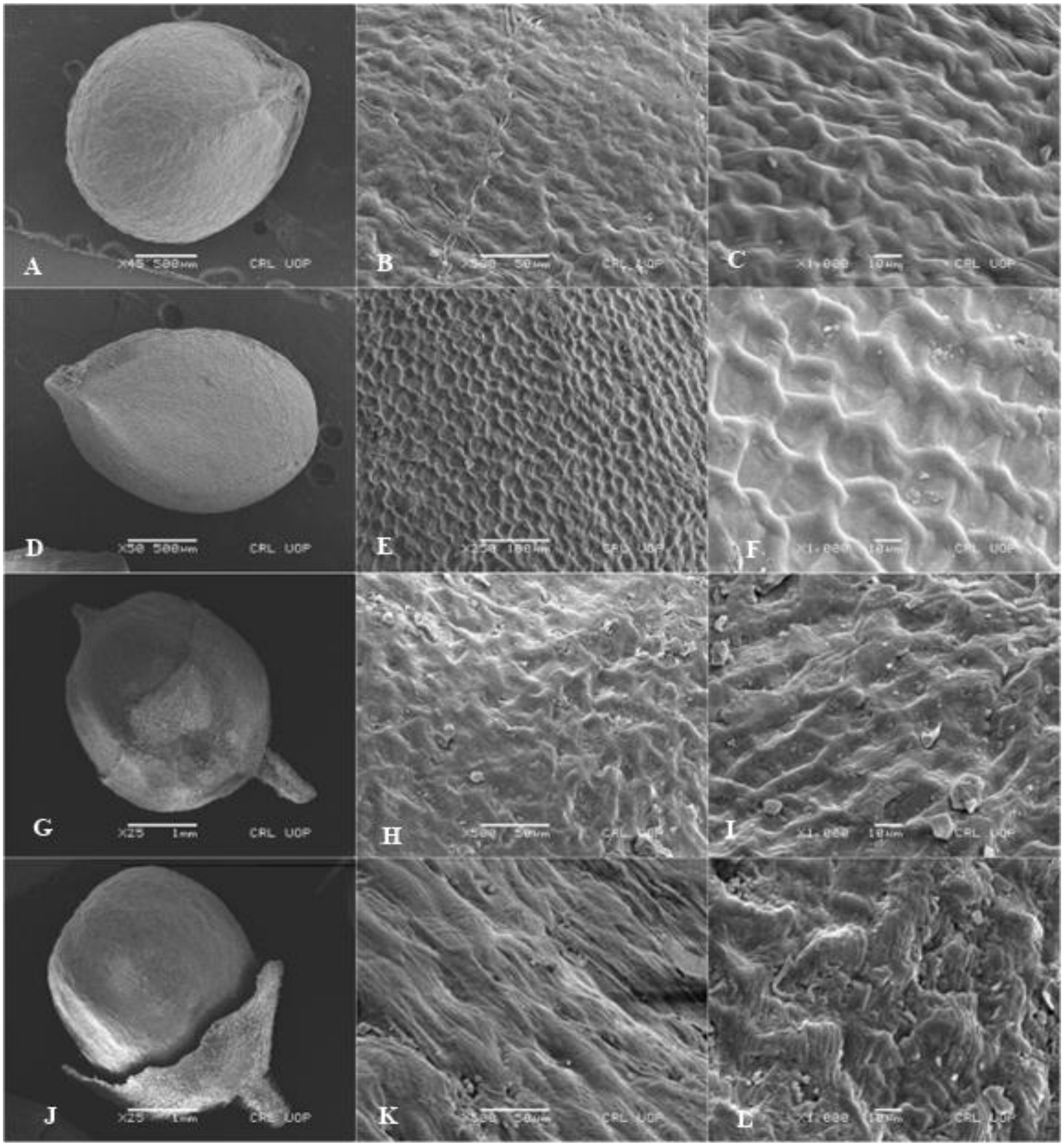

Plate. 92. Scanning electron micrographs of the Lamiaceous seed micromorphology; (A-C) *Stachys floccosa (*A) Acute apex (B) Reticulate C) Polygonal epidermal cells. (D-F) *Stachys palustris* (D) Elliptic to spheroid shape (E) Reticulate surface (F) Angular walls. (G-I) *Vitex agnus-castus* (G) Rough texture (H) Colliculate surface (I) Irregular epidermal cells. (J-L) *Vitex negundo* (J) Rough texture (K) Striate and colliculate surface (L) Irregular epidermal cells.

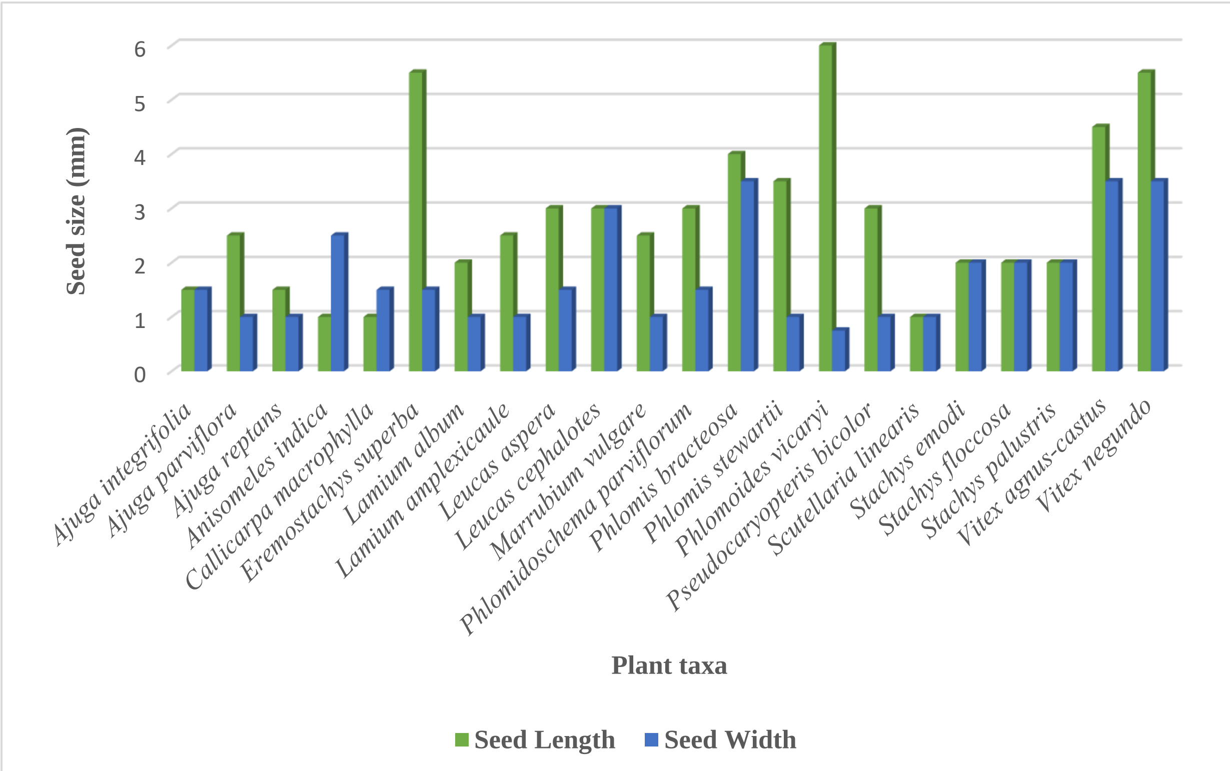

Fig. 57: Shows variation in seed length and width among the Lamiaceous taxa

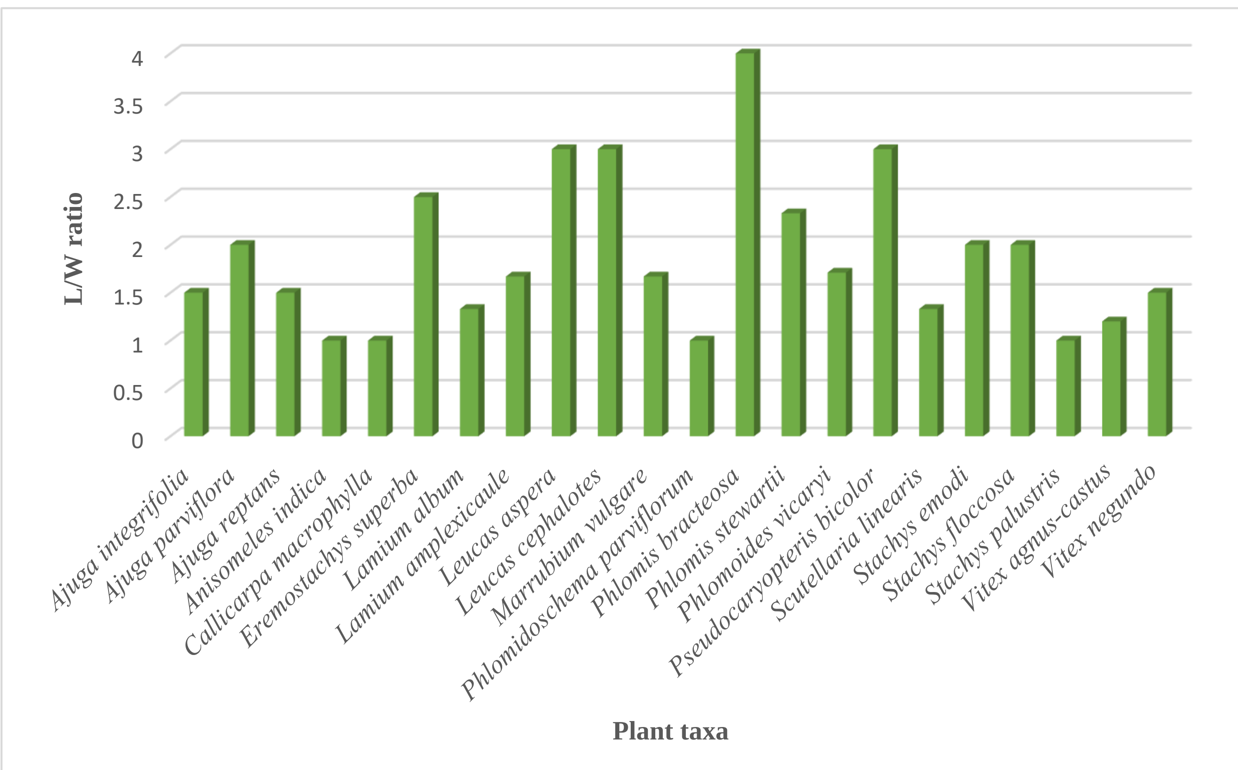

Fig. 58: Shows variation in seed length/width ratio of Lamiaceous taxa

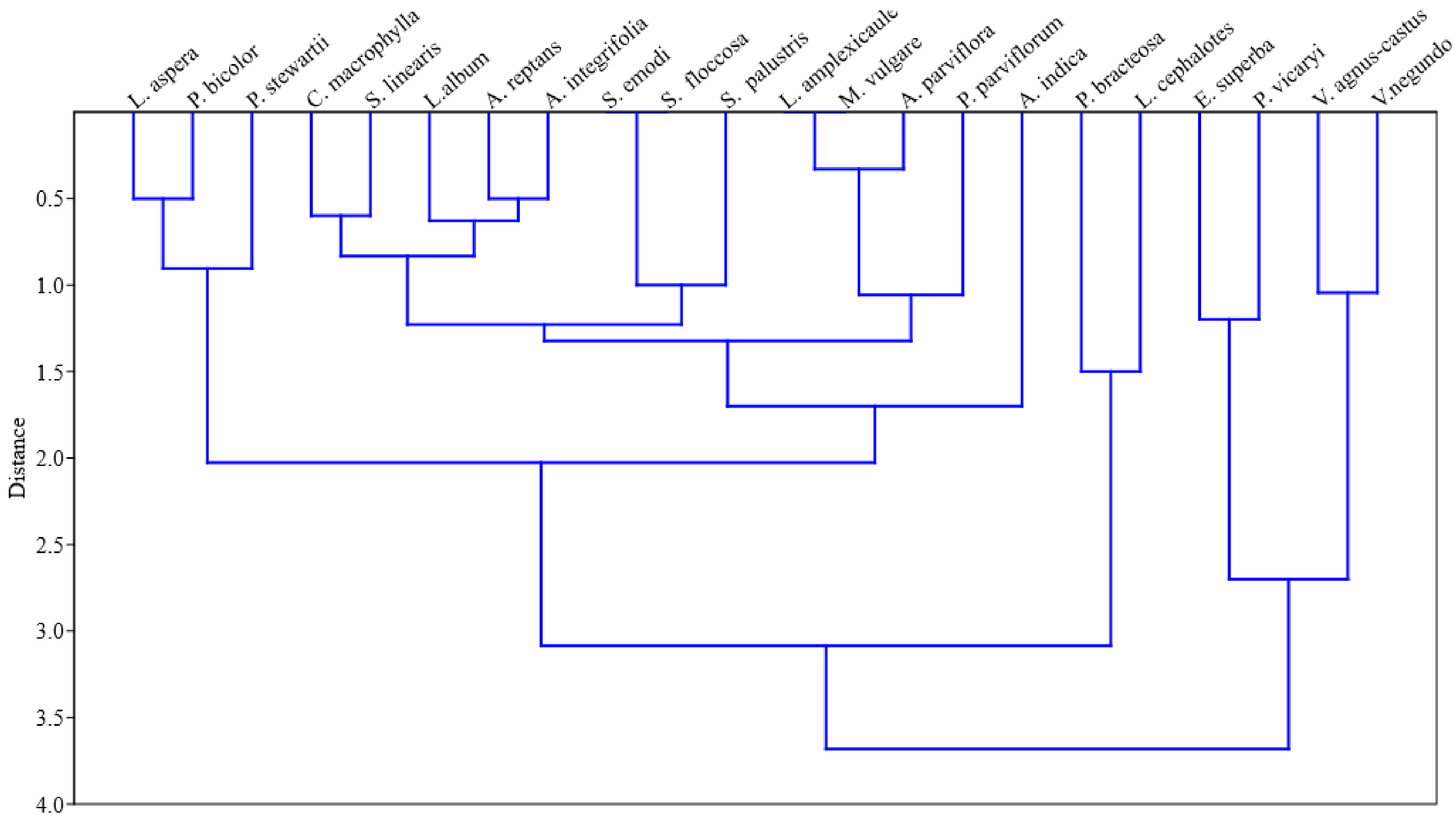

Fig. 59: Clusters analysis shows the similarity index among the Lamiaceous taxa based on quantitative seed micromorphological characteristics.

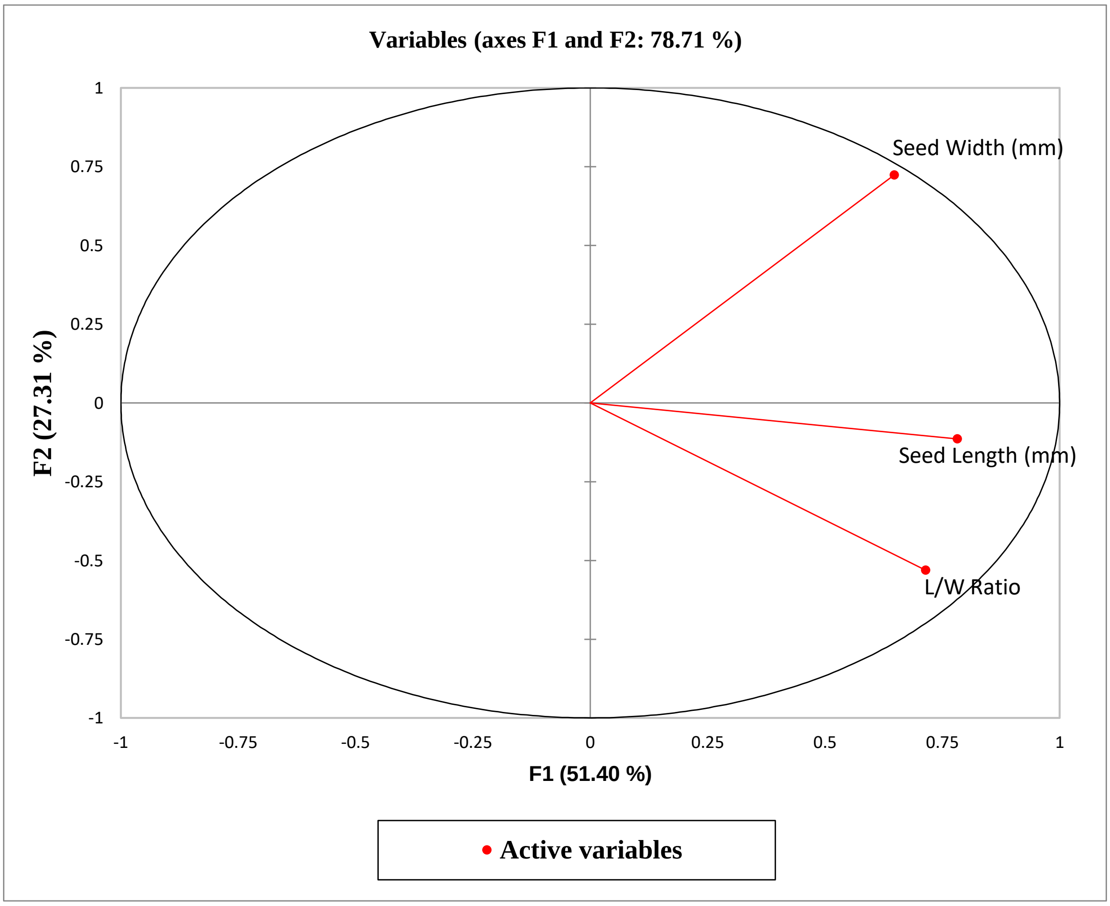

Fig. 60: Active variables of Principal component analysis (PCA) biplot of selected Lamiaceae seed

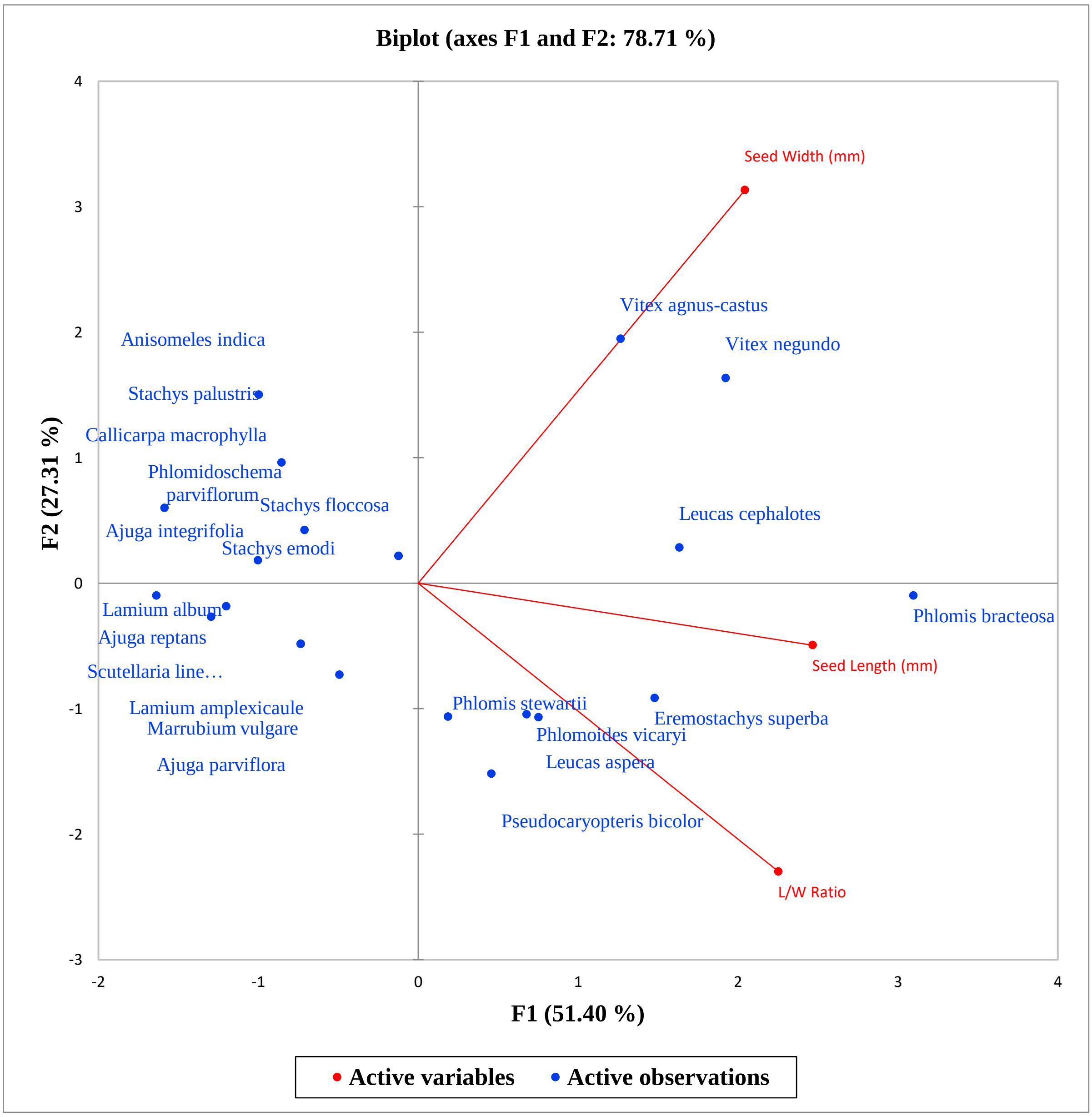

Fig. 61: Principal component analysis (PCA) biplot of matric variables of the selected Lamiaceous seed

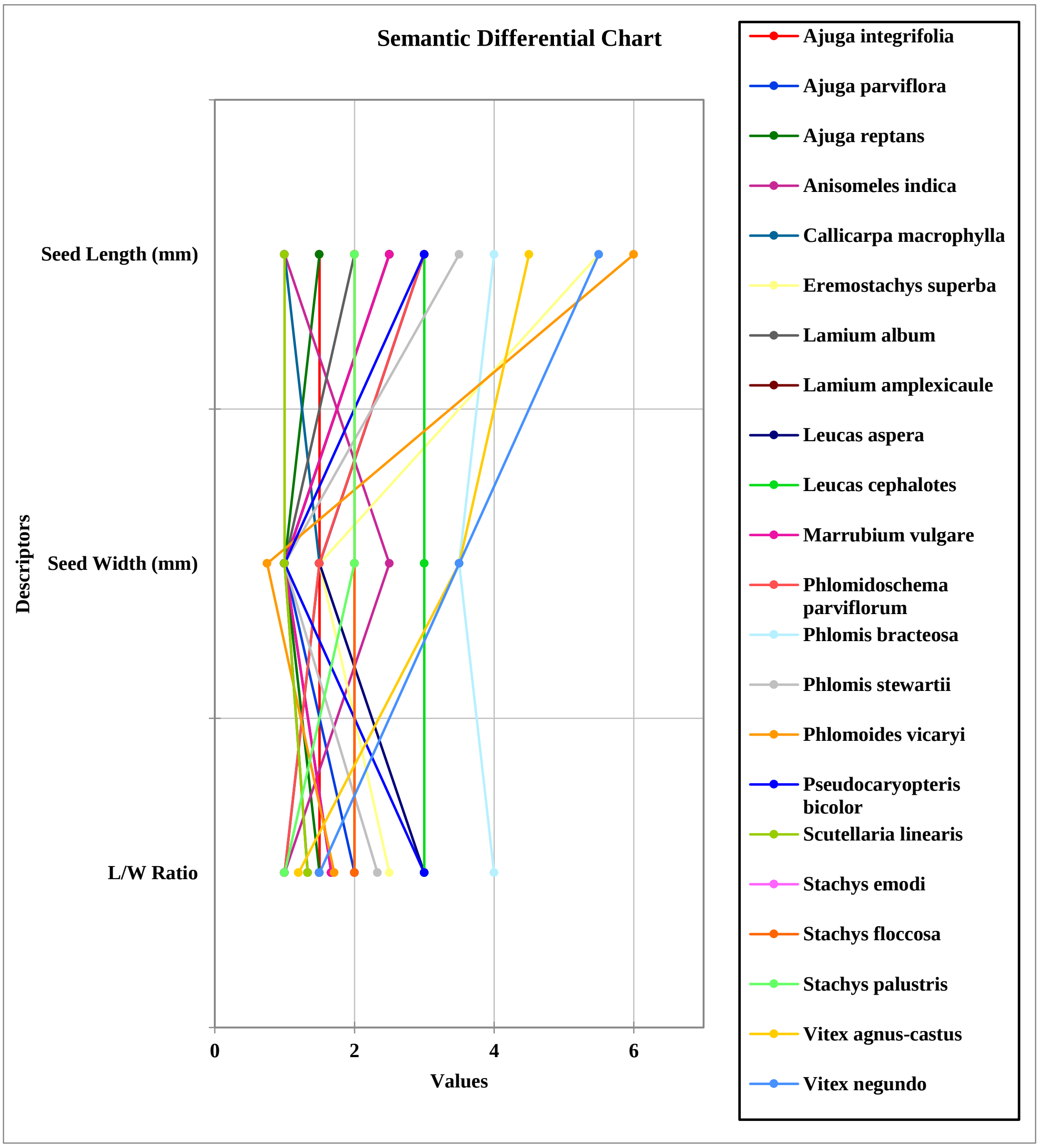

Fig. 62: Semantic differential chart of three variables, that is, seed length, seed width and length to width ratio (L/W)

3.9 Seed Micromorphology of Genus Nepeta

The seed morphological traits like (seed shape, color, size, texture, seed apex, base, compression, and hilum) of 11 *Nepeta* species were summarized in (Table. 26). The seed micromorphological characteristics like (seed outline, wall ornamentation, surface sculpturing, anticlinal wall pattern, periclinal wall pattern and epidermal cell arrangement) were summarized in (Table. 27). SEM micrographs were shown in (Plate. 93-96). In various genera of Lamiaceae, including *Nepeta*, the significance of nutlet shape, particularly its micro-morphological characteristics, has already been demonstrated (Budantsev and Lobova 1997; Padure et al., 2005; Kaya and Dirmenci 2008; Moon et al., 2009; Hassan and Dar 2012).

3.9.1 Variations in Seed Shape, Size, and Texture

Nepeta seeds show great variation in shape and texture. Seed shapes can be described as oblong, elliptic, spheroid, oval, trigonous, rhomboid, spherical, broad elliptic and broad obovate however, in this study, the seed shapes were mostly oblong to elliptic. The seed textures are mostly rough, smooth, smooth and shiny. Previous studies of Martín Mosquero et al., (2002) observed smooth surface of *N. cataria* like our results. According to Kaya and Dirmenci (2008) the seed surface of *N. cataria* is smooth, similar to our results. The seeds ranged in size from (0.16 mm) *N. cataria* to (2.5 mm) in *N. distans* in length and from (0.16 mm) in *N. cataria* to (1.5mm) in *N. connata*, *N. distans*, *N. graciliflora* in width (Fig. 63, Table 26). On average, *N. distans*, followed by *N. erecta* and *N. griffithii* had the largest nutlets. The seeds of *N. cataria* are the smallest. According to Martín Mosquero et al., (2002) the seed size of *N.cataria* is 1.2-1.6 x 0.7-1.0 similar or close to our results. Table 26 lists the nutlet size ranges for all species. The highest length to width ratio was found in six Nepeta species (Fig. 64). According to Amirmohammadi et al., (2019) the shape of *N.* cataria is ovoid-oblong, however, our results show elliptic seed shape. Previous studies of Padure et al., (2005) shows elliptic or ovate seed shape of *N. cataria* similar to our results.

3.9.2 Variations in the Color of Seeds

The color of the nutlets (inner and outer) in the studied taxa varies (Table. 26), ranging from black/ off white in *N. adenophyta*, light brown/ dark brown in *N. cataria*, black/grey, white in *N. connata*, dark brown/ off white in *N. distans*, Dark brown/ light Brown in *N. discolor, N. graciliflora* etc. Some species, such as *N. lavigata* with shiny black color (Plate. 96 A), can be easily recognized from others based solely on their shiny black color. Previous studies of Amirmohammadi et al., (2019) investigated black seed color in *N. cataria*, which is different from our results. Earlier studies of Kaya and Dirmenci (2008) showed black- brown color of *Nepeta cataria*, similar to our results. According to Ya'ni et al., (2018) the seed shape and color of *Nepeta deflersiana* is oblong -trigonous and black respectively coincides with our results, but different in surface sculpturing. Previous studies of Hassan and Al-Thobaiti (2015) observed the seed shape and color of *Nepeta deflersiana* and *N. sheliae* are broad elliptic and black respectively, similar to our results. Therefore, seed morphology is a useful tool for the pharmaceutical industry, particularly for regional and local endemic taxa, for quick and accurate identification of species (Kahkeshani et al., 2014).

3.9.3 Variations in the Seed Apex and Base

Nepeta seeds show great variation in seed apex and base. Seed apex shows variation as compared to seed base. Seed bases are mostly round in the studied species, only *N. cataria*, shows truncate seed base (Plate. 93 D). The truncate seed apex is found in five taxa followed by round in three taxa and acute in two taxa. Depressed seed shape was only found in *N. discolor*. Table 26 lists the nutlet apex and base shapes for all studied species. According to Padure et al., (2005) the apex of *N. cataria* is round or truncate agreed with our results.

3.9.4 Variations in Compression and Hilum

Mostly seed compression was ventral. Only two species show variation in seed compression, dorsoventral in *N. adenophyta*, and lateral in *N. praetervisa*. In all studied taxa the hilum was visible excep in *N. hindostana* (Plate. 95 G). The hilum was terminal and raised in five species, while in *N. praetervisa* the hilum was terminal and depressed (Plate. 96 D). Hilum was found subterminal and depressed in five species (Table. 26).

3.9.5 Variations in Wall Ornamentation and Surface Sculpturing

Great variation was observed in wall ornamentation of the studied taxa. Eight types of wall ornamentations were observed in the studied taxa, i.e., rounded in *N. adenophyta* (Plate. 93 A), irregular thick in *N. cataria and N. graciliflora* (Plate. 93 D, Plate. 95 E), psilate in *N. connata* and *N. discolor,* evenly thickened in *N. erecta*, thick and angular in *N. griffithii* and *N. laevigata,* buttressed in *N. hindostana*, and regular thickenings *N. praetervisa* (Plate. 96 F, Table. 27). Eight types of surface sculpturing were observed in the analyzed *Nepeta* taxa that are taxonomically very significant (Table. 27). These surface sculptures are negative reticulate, Rugulate, Smooth reticulate, Reticulate, Verucate and pitted, Gemmate, Verucate and gemmate and Striate (Table. 27). Negative reticulate was only found in *N. adenophyta,* gemmate surface was found in *N. griffithii* and striate surface in *N. praetervisa.* Therefore, we observed these unique surfaces, not considering them as dominant. According to Budantsev and Lobova (1997) the surface patterns of *N. connata* and *N. discolor* are undulate., while the surface pattern of *N. cataria* is reticulate, hence found dissimilar with our result. Only *N. distans* shows similarity in surface pattern. Hassan and Dar (2012) observed reticulate surface pattern in *N. connata* and *N. discolor,* coincides with our results but different in anticlinal and periclinal wall pattern. According to Amirmohammadi et al., (2019) found the seed surface of *Nepeta cataria* is reticulate, different from our results.

3.9.6 Variations in Anticlinal, Periclinal Wall Pattern and Epidermal Cell Shape

Anticlinal wall patterns show great variations, these are convex, thin and straight, thick and depressed, thick and raised, slightly thickened, thick and straight, convex and depressed. Convex anticlinal wall was only found in *N. adenophyta,* convex and depressed in *N. praetervisa* and slightly thickened in *N. griffithii*. Therefore, these are the unique anticlinal walls among the analyzed taxa. While the periclinal walls are straight and depressed, convex and raised, thin and straight, thick and raised, thick and straight, convex and thin, slightly thick and convex, thick and convex, slightly thick and raised. Thin and straight and thick and raised are the two prominent periclinal walls observed among the studied species. Arrangement of the epidermal cells are dominantly polygonal (six species) followed by irregular (five species) among the studied taxa. According to Hassan and Dar (2012) the anticlinal and periclinal wall of *N. discolor* are depressed and flat respectively with elongated cells not coincide with our results. According to Hassan and Al-Thobaiti, (2015) the texture of *Nepeta deflersiana* and *N. sheliae* was rough, and the anticlinal wall was thick and raised agreed with our results. Earlier studies of Kamel (2014) observed thin anticlinal wall pattern in *Nepta septemcrenata* similar to our results but different in surface sculpturing.

3.9.7 Cluster Analysis and Principal Component Analysis (PCA) of Seed as a Statistical Tool

The similarity index among the studied Genus *Nepeta* taxa was analyzed using UPGMA cluster analysis based on quantitative seed characters (Akhtar et al., 2022). The quantitative data provides three principal clusters based on seed micromorphological characters. The quantitative seed data distributes the studied taxa into three major clusters (Fig.3). Cluster 1 indicates *Nepeta cataria,* cluster 2 indicates *Nepeta distans*, *Nepeta adenophyta*, *Nepeta praetervisa*, *Nepeta lavigata* and *Nepeta hindostana* which are similar to each other as compared to *Nepeta cataria* may be due to their quantitative measurement or their distribution. Cluster 3 is further divided into four minor clusters, in which great similarity was observed among *Nepeta praetervisa* and *Nepeta hindostana.* Similarly, *Nepeta erecta* and *Nepeta discolor* also show similarity as compared to *Nepeta connata*.

Principal Component Analysis (PCA), in accordance with (Sharma and Paliwal 2007) represents the highest contribution to the overall variability on each axis. The factor that is frequently used to determine how many variables to keep. The quantitative data analysis was used as the foundation for PCA, which reveals a very dominating variation of 69%–87%. Cluster analysis and PCA are both statistical techniques for separating genera and species (Shah et al., 2018). In the current study, we employed PCA and cluster analysis to examine the seed micromorphological features of the analyzed taxa. PCA reveals the highest contribution to the overall variability for each axis (Fig. 65).

The Eigen values show the overall number of variables and are frequently used to determine how many factors to keep (Sharma, 2006). In the present study, two PCAs carried more than one eigenvalue and 97.152% of the total variance. PCA variable loadings for these three components are presented in (Table 25). The active variables of the biplot were shown in (Fig. 66). The most important factor in PC1 was seed L/W ratio followed by seed length. *Nepeta erecta* and *N. griffithii* were positioned on the positive side of the first axes. Whereas *N. hindostana*, *N. discolor* and *N. laevigata* were positioned on the first axes negative side. Additionally, PC1 showed a variability of 52.818%, with a large positive loading element of the seed quantitative characters. The most important factor in PC2 was seed width. PC2 showed a variability of 44.334%, with a large positive loading element of the seed quantitative traits. *N. connata*, *N. cataria*, *N. praetervisa* and *N. graciliflora* were positioned on the positive side of second axes. N. adenophyta was positioned on the second axes negative side (Fig. 67). Principle component analysis (PCA) of the investigated species revealed that *Nepeta* species are more correlated to one another. Only *N. adenophyta* was found on the negative side of the biplot. *N. adenophyta* and *N. distans* showed separate positions most peculiar due to their distribution. Moreover, the semantic differential chart shown in (Fig. 68) is used to better illustrate and assess seed length, seed width and length to width ratio.

3.9.8 Dichotomous key of the Studied Genus *Nepeta* Taxa Based on Seed Micromorphological Traits.

1	a	Seed compression present….	*2*
	b	Seed compression absent…………	8
2	a	Seed compression lateral…………………………….	*N. praetervisa*
	b	Seed compression non lateral………………………...	3
3	a	Seed compression dorsoventral……………………………….	*Nepeta adenophyta*
	b	Seed compression ventral………………………………………	4
4	a	Seed apex depressed………………………………….	*Nepeta discolor*

	b	Seed apex not depressed …………………………	5
5	a	Seed apex acute ……………………………………………	*Nepeta erecta*
	b	Seed apex truncate……………………………………………	6
6	a	Seed texture smooth…………………………	*Nepeta cataria*
	b	Seed texture rough……………………….	7
7	a	Inner color off white…………………………………………	*Nepeta distans*
	b	Inner color light brown……………………………………	*Nepeta graciliflora*
8	a	Seed outer color black……………………………………	*Nepeta connata*
	b	Seed outer color not black……………………………………	9
9	a	Seed outer color dark brown……………………	*Nepeta griffithii*
	b	Seed outer color not dark brown……………………………	10
10	a	Seed outer color shiny black…………………………………	*Nepeta lavigata*
	b	Seed outer color brown……………………………………	*Nepeta hindostana*

Table. 25: Principal component analysis variable loadings for first three seed components

Variables/ Factors	**PC1**	**PC2**	**PC3**
Seed Length	0.764	0.622	0.174
Seed Width	0.960	-0.216	-0.143
L/W ratio	-0.284	0.947	-0.132
Eigenvalue	1.585	1.330	0.085
Variability (%)	52.818	44.334	2.848
Cumulative %	52.818	97.152	100.000

Table. 26: Seed micromorphological features of Genus Nepeta

Sr. no	Plant taxa	Seed shape	Seed color		Seed texture	Seed apex	Seed base	Seed Compression	Hilum			Seed length (mm)	Seed width (mm)	L/w ratio
			Outer	Inner					Occurrence	Position	Level			
1.	*Nepeta adenophyta* Hedge	Oblong	Black	Off white	Smooth	Round	Round	Dorsoventral	Visible	Terminal	Raised	0.5-1	1-1.5	0.6
2.	*Nepeta cataria* L.	Elliptic	Dark Brown	Light Brown	Smooth	Truncate	Truncate	Ventral	Visible	Subterminal	Depressed	0.5-1.5	0.5-1.5	1
3.	*Nepeta connata* Royle ex Benth.	Spheroid	Black	Gray-white	Smooth and shiny	Truncate	Round	-	Visible	Subterminal	Depressed	1-2	1-2	1
4.	*Nepeta distans* Royle	Oval	Dark Brown	Off white	Rough	Truncate	Round	Ventral	Visible	Terminal	Raised	2-3	1-2	2
5.	*Nepeta discolor* Royle ex Benth.	Elliptic	Dark Brown	Light Brown	Smooth	Depressed	Round	Ventral	Visible	Subterminal	Depressed	1-2	0.5-1	2
6.	*Nepeta erecta* (Royle ex Benth.) Benth.	Trigonus	Black	Light Brown	Smooth and Shiny	Acute	Round	Ventral	Visible	Terminal	Raised	1-3	0.5-1.5	2
7.	*Nepeta graciliflora* Benth.	Rhomboid	Dark Brown	Light Brown	Rough	Truncate	Round	Ventral	Visible	Terminal	Raised	1-2	1-2	1
8.	*Nepeta griffithii* Hedge	Broad elliptic	Dark brown	White	Rough	Round	Round	-	Visible	Subterminal	Depressed	1-3	0.5-1.5	2
9.	*Nepeta hindostana* (B.Heyne ex Roth) Haines	Oblong	Brown	Light Brown	Smooth	Round	Round	-	Not visible	-	-	1-2	0.5-1	2
10.	*Nepeta lavigata* (D.Don) Hand.-Mazz.	Broad obovate	Shiny black	Off white	Smooth	Acute	Round	-	Visible	Terminal	Raised	1-2	0.5-1	2
11.	*Nepeta praetervisa* Rech.f	Oblong	Brown	Light Brown	Smooth	Truncate	Round	Lateral	Visible	Terminal	Depressed	0.5-1.5	0.5-1.5	1

Keywords: (mm) = millimeter, L= Length W=Width

Table. 27: Scanning electron microscopy (SEM) based seed qualitative findings of Genus Nepeta

S.no	Plant Taxa	Seed outline	Wall ornamentation	Surface sculpturing	Anticlinal wall pattern	Periclinal wall pattern	Epidermal cell shape
1.	*Nepeta cataria* L.	Rough	Rounded	Negative reticulate	Convex	Straight and depressed	Polygonal
2.	*Nepeta cataria* L.	Smooth	Irregularly thick	Rugulate	Not visible	Convex and raised	Irregular
3.	*Nepeta cataria* L.	Smooth and Shiny	Psilate	Smooth retculate	Thin and straight	Thin and straight	Polygonal
4.	*Nepeta cataria* L.	Rough	Sinuate	Verrucate	Thick and depressed	Thick and raised	Irregular
5.	*Nepeta cataria* L.	Smooth and Shiny	Psilate	Smooth retciulate	Thin and straight	Thin and straight	Polygonal
6.	*Nepeta cataria* L.	Rough and scabrate	Evenly thickened	Reticulate	Thick and raised	Thick and raised	Polygonal
7.	*Nepeta cataria* L.	Rough and scabrate	Irregularly thick	Verrucate and pitted	Thick and depressed	Thick and straight	Irregular
8.	*Nepeta cataria* L.	Rough	Thick and angular	Gemmate	Slightly thickened	Convex and thin	Polygonal
9.	*Nepeta cataria* L.	Rough	Buttressed	Verucate and gemmate	Thick and straight	Slightly thick and convex	Irregular
10.	*Nepeta cataria* L.	Smooth and shiny	Thick and angular	Reticulate	Thick and straight	Thick and convex	Polygonal
11.	*Nepeta cataria* L.	Smooth	Regular thickenings	Striate	Convex and depressed	Slightly thick and raised	Irregular

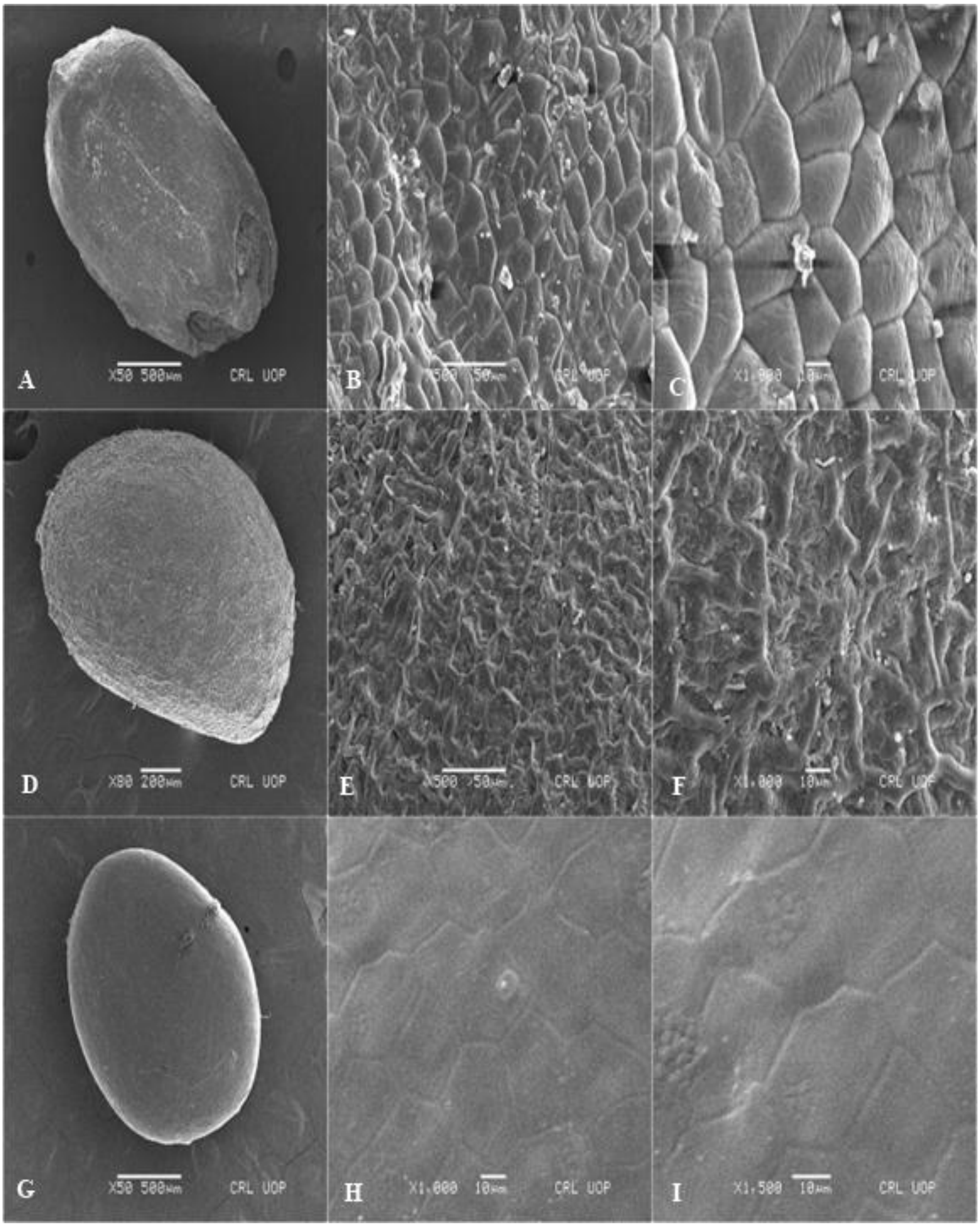

Plate. 93. Scanning electron micrographs of the *Nepeta* seed micromorphology; (A-C) *Nepeta adenophyta* (A) Oblong shape (B) Negative reticulate (C) Polygonal epidermal cells. (D-F) *N. cataria* (D) Elliptic shape (E) Rugulate surface (F) Irregular epidermal cells. (G-I) *N. connata* (G) Smooth texture (H) Smooth reticulate (I) Polygonal epidermal cells.

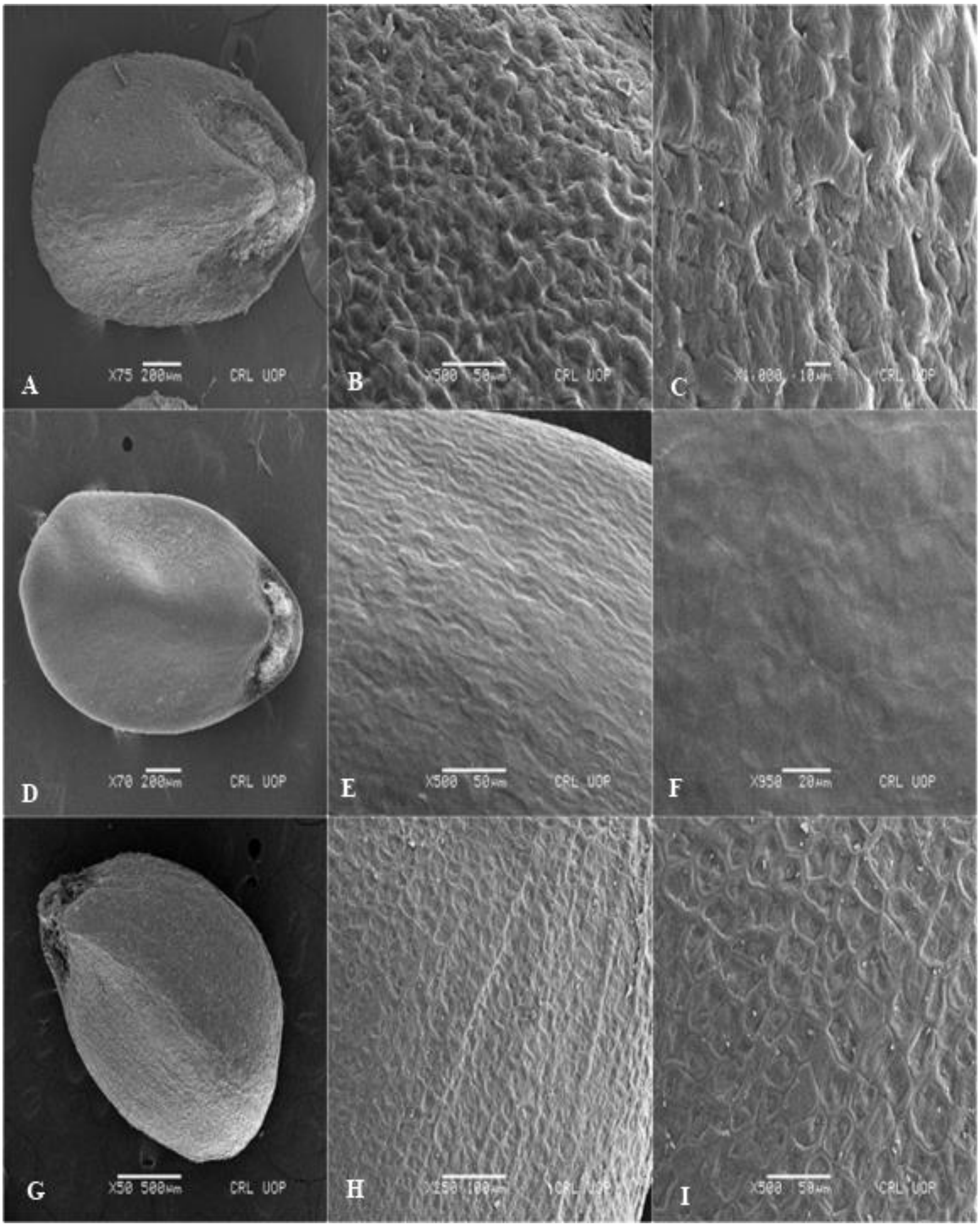

Plate. 94. Scanning electron micrographs of the *Nepeta* seed micromorphology; (A-C) *N. distans* (A) Rough texture (B) Sinuate wall (C) Verrucate (D-F) *N. discolor* (D) Smooth texture (E) Smooth reticulate (F) Polygonal epidermal cells. (G-I) *N. erecta* (G) Acute apex (H) Reticulate (I) Evenly thickened.

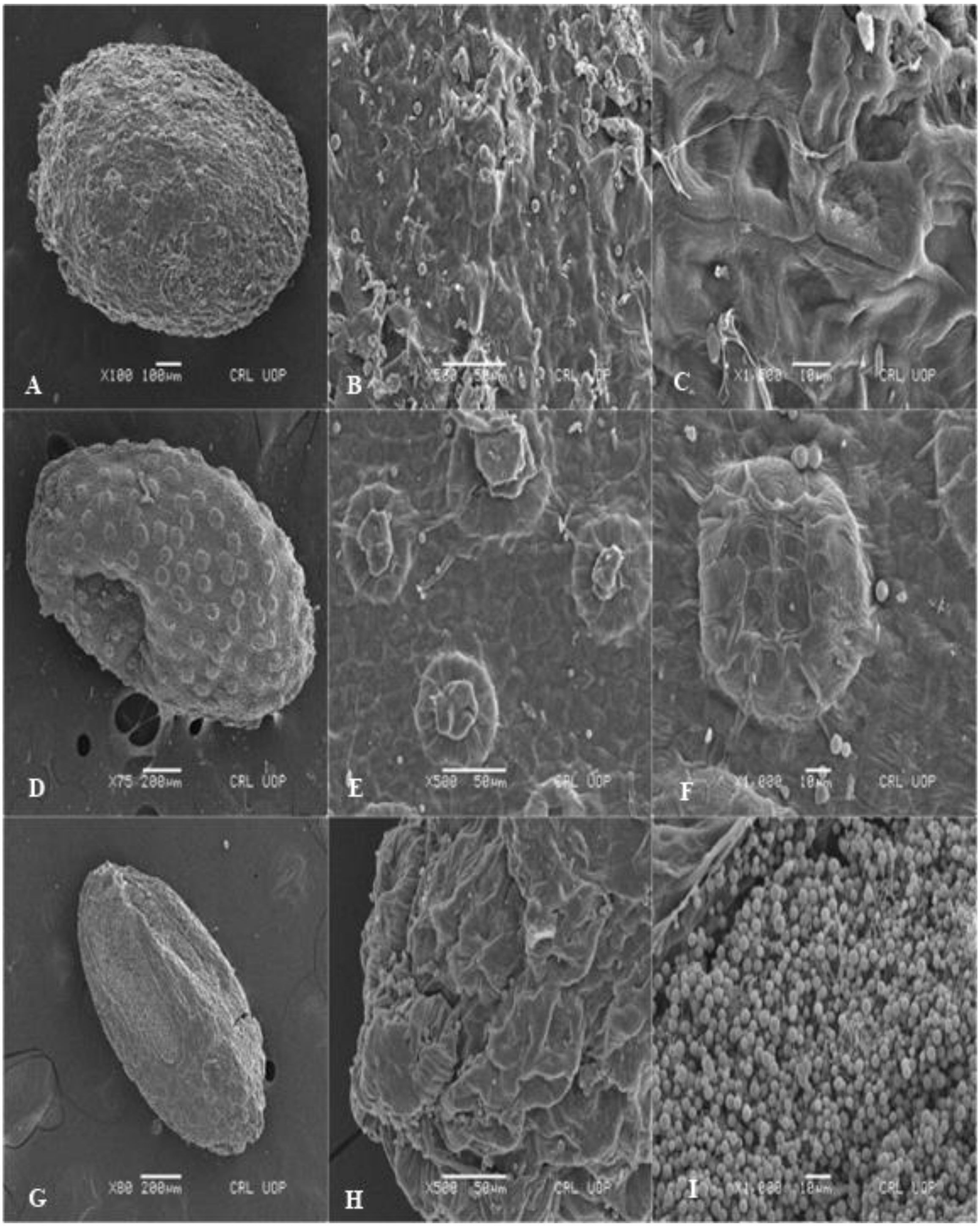

Plate. 95. Scanning electron micrographs of the *Nepeta* seed micromorphology; (A-C) *N. graciliflora* (A) Rough texture (B) Irregular epidermal cells (C) Verucate and pitted. (D-F) *N. griffithii* (D) Subterminal hilum (E) Pitted surface (F) Irregular epidermal cells. (G-I) *N. hindostana* (G) Oblong (H) Buttressed wall(I)

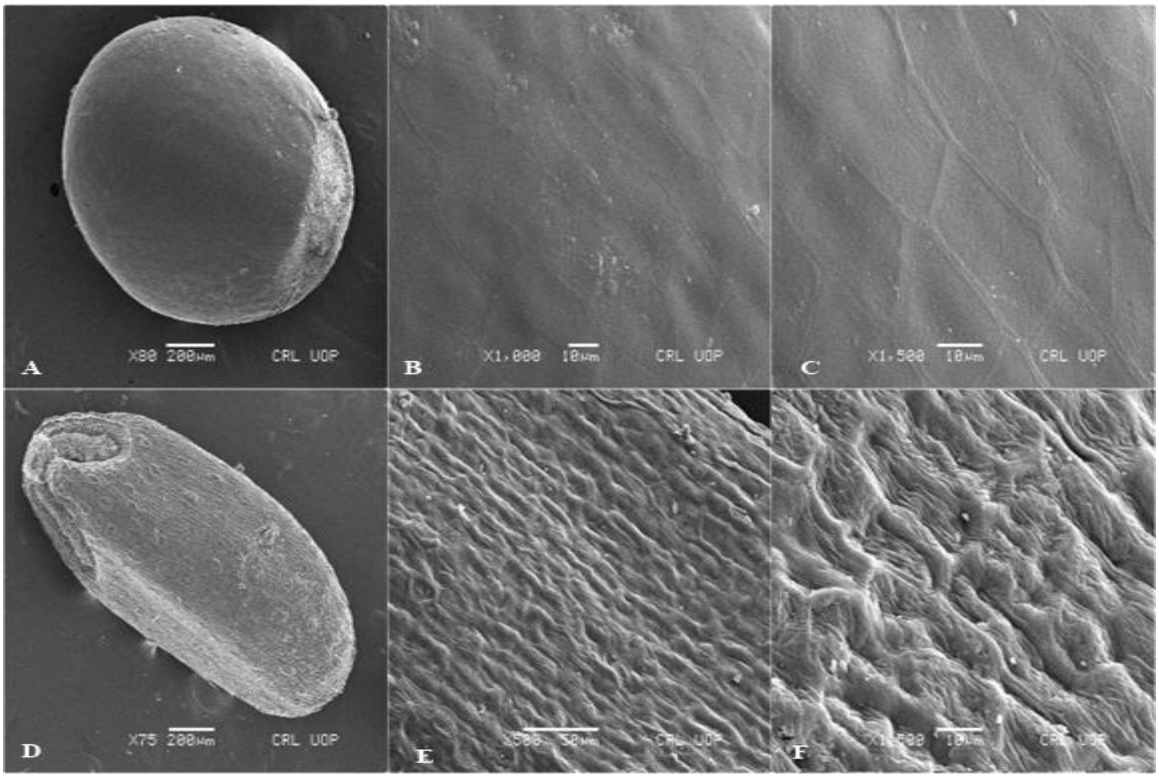

Plate. 96. Scanning electron micrographs of the *Nepeta* seed micromorphology; (A-C) *N. lavigata* (A) Smooth (B) Reticulate (C) Polygonal epidermal cells. (D-F) *N. praetervisa* (D) Oblong shape (E) Striate surface (F) Irregular epidermal cells.

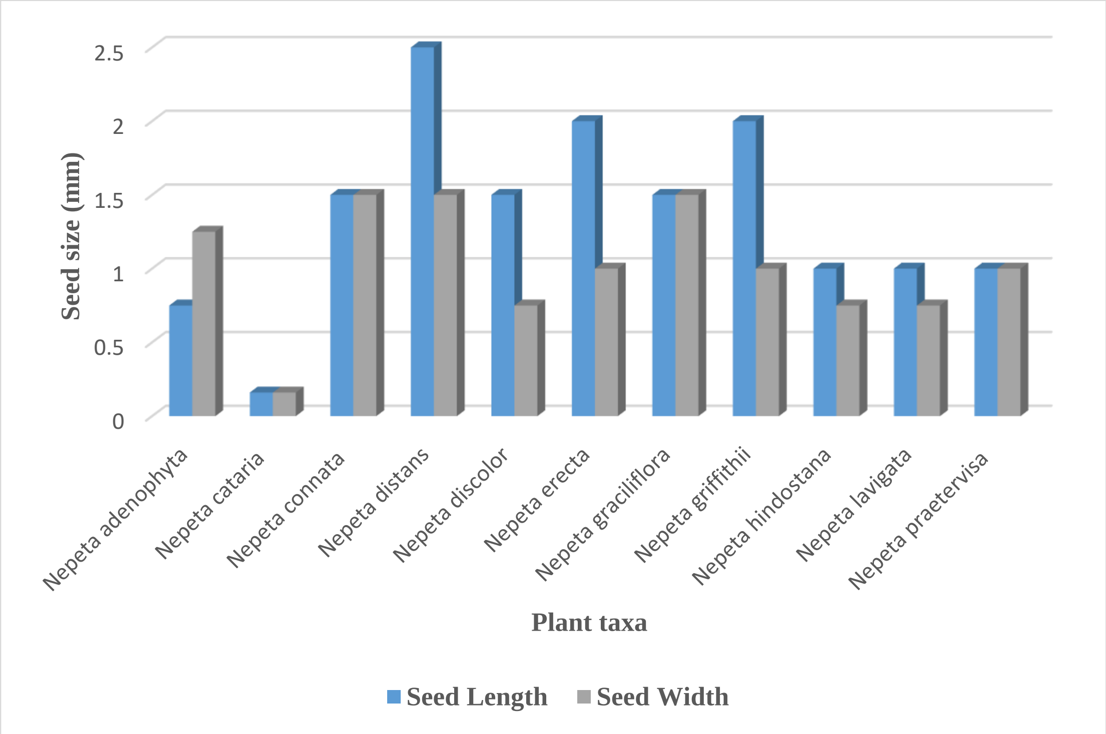

Fig. 63: Variation in seed length and width of *Nepeta* taxa

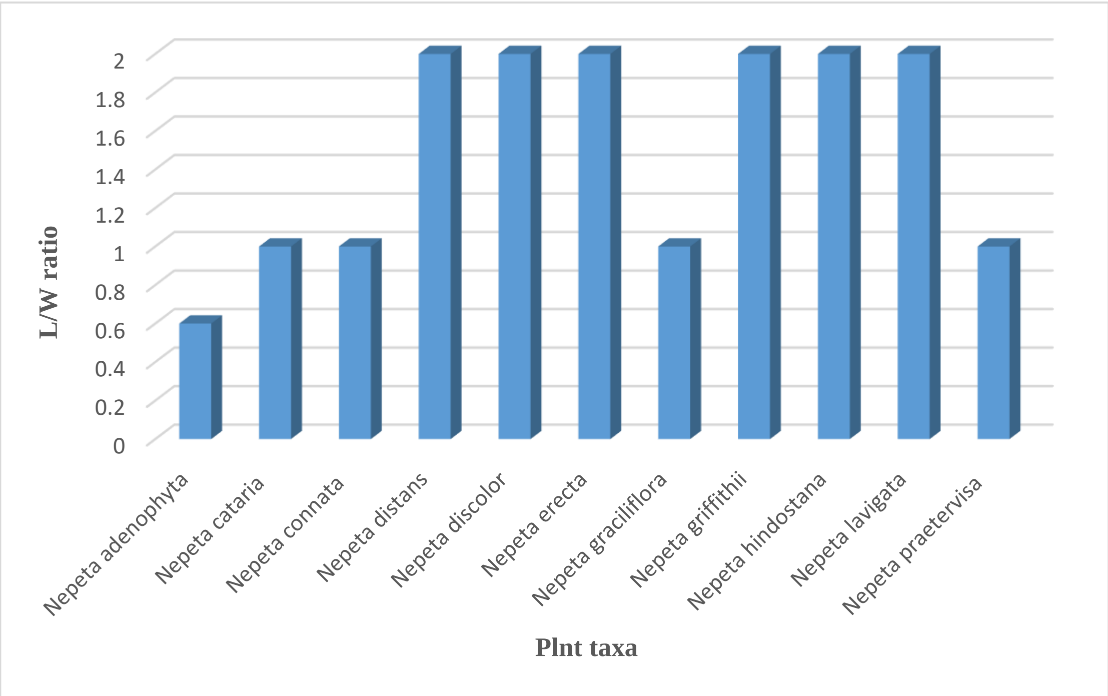

Fig. 64: Variation in seed length/width ratio of *Nepeta* taxa

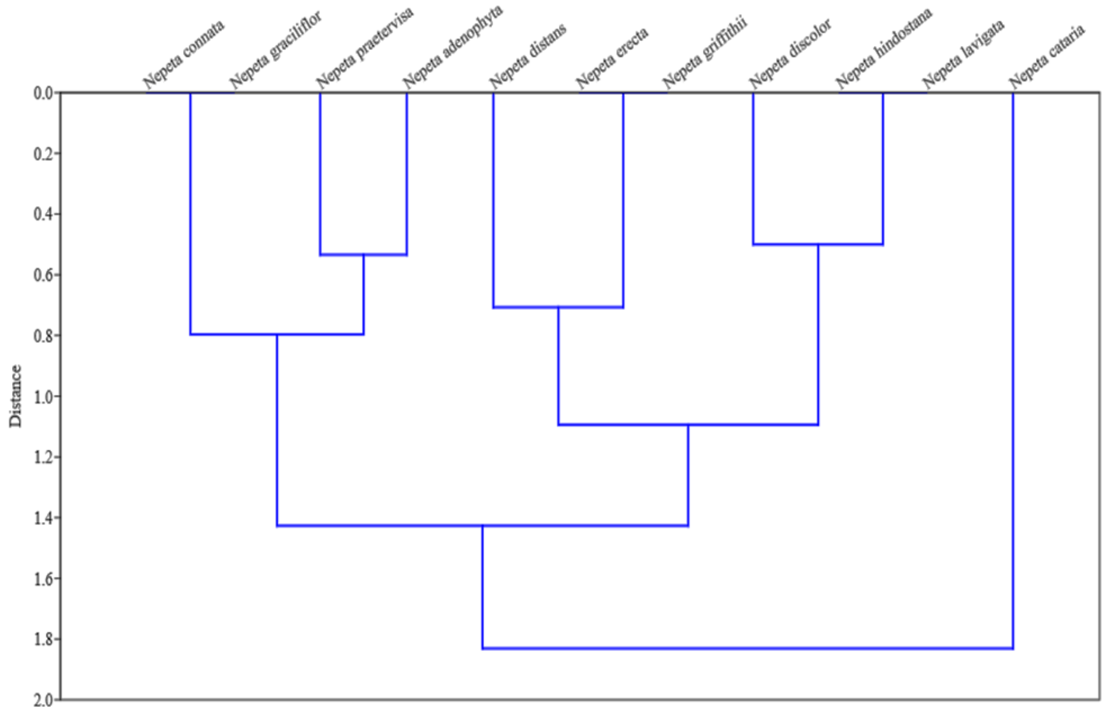

Fig. 65: Clusters analysis shows the similarity index among the Genus *Nepeta* taxa based on quantitative seed micromorphological characteristics.

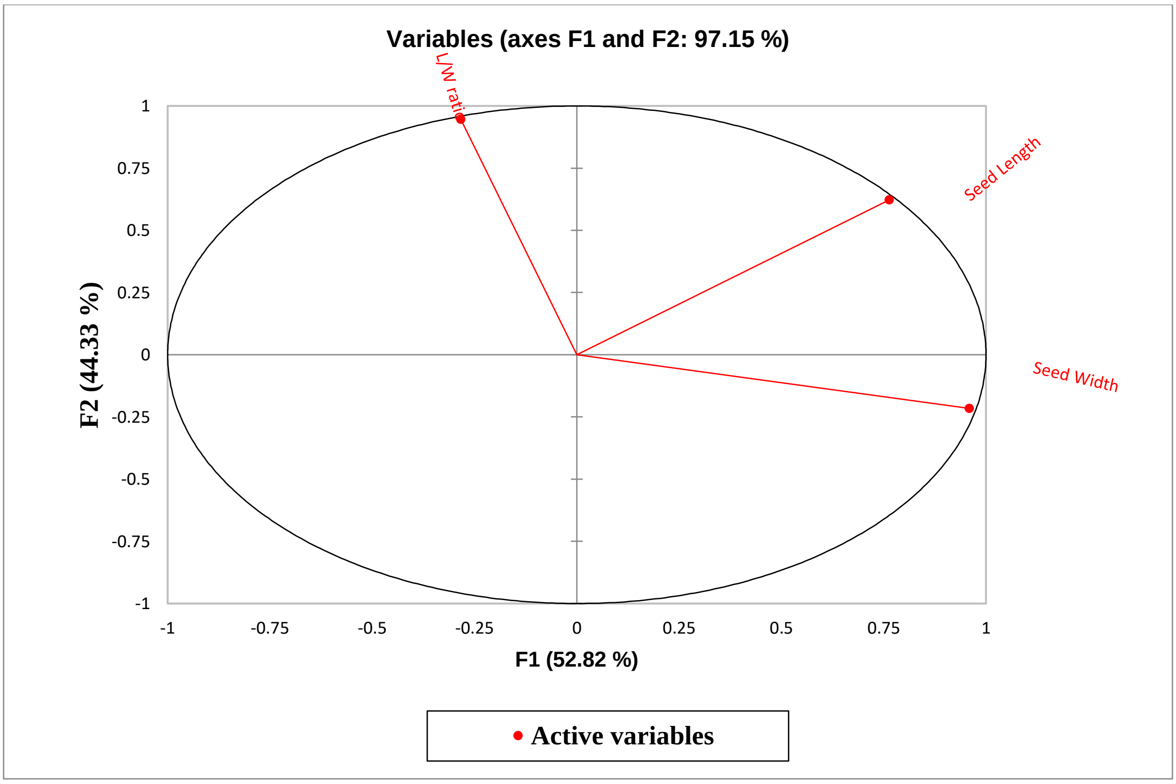

Fig. 66: Active variables of PCA biplot of seed.

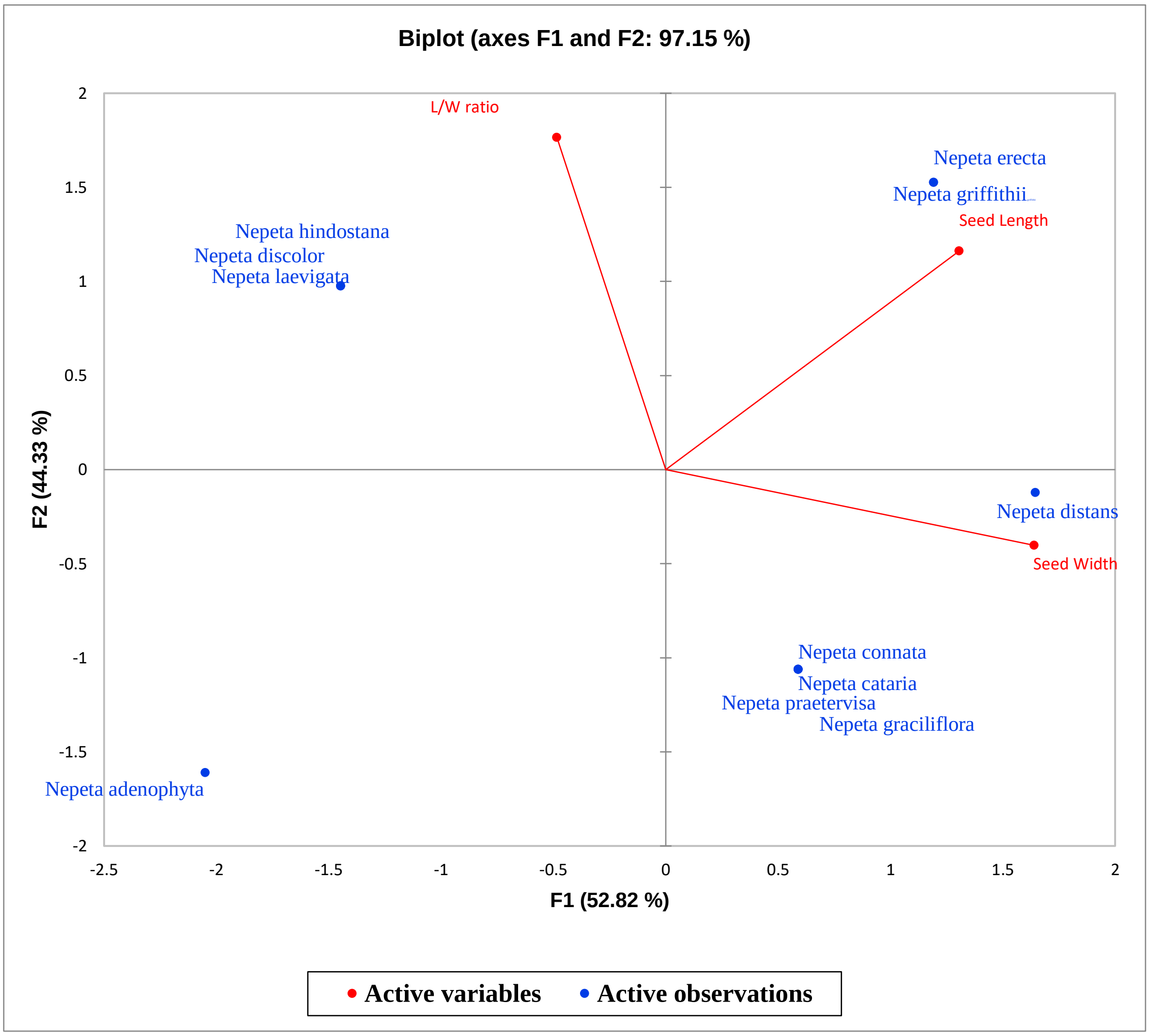

Fig. 67: Matric variables of PCA biplot of Nepeta taxa based on seed quantitative traits

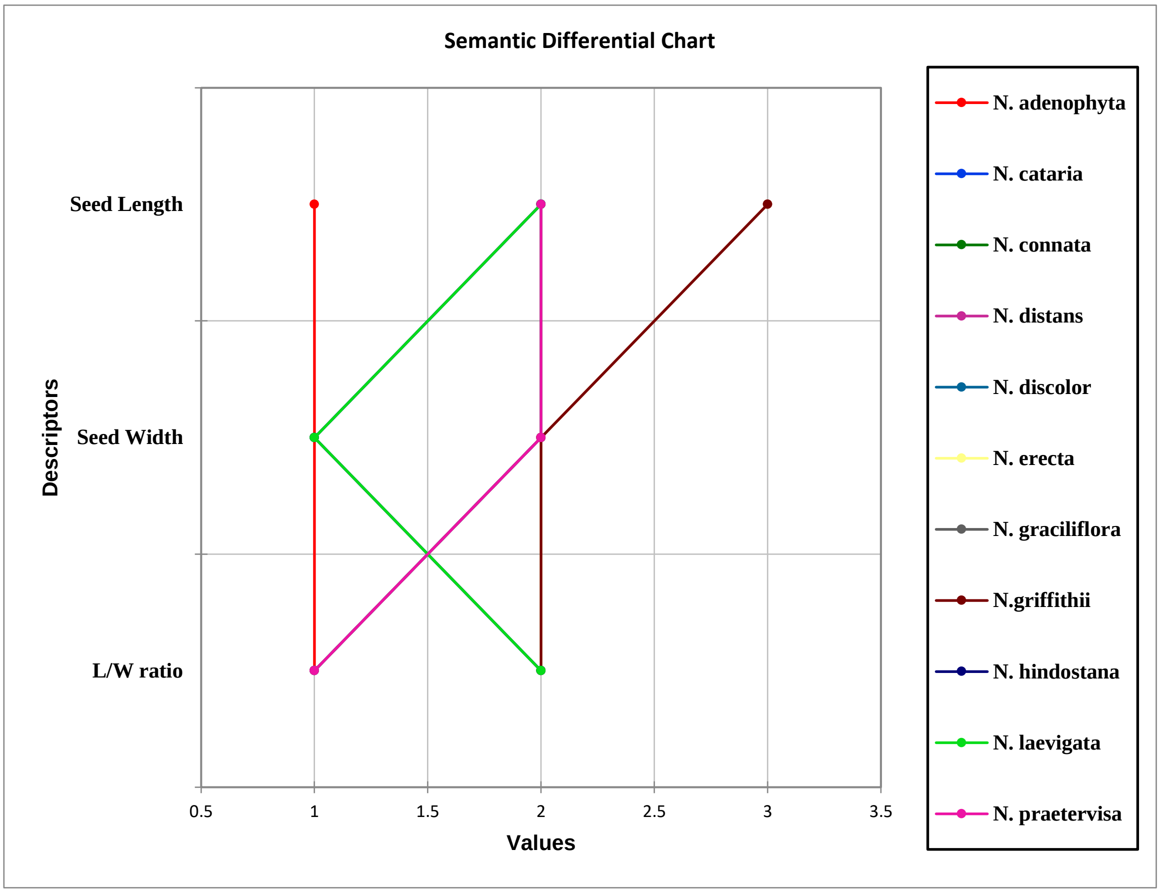

Fig. 68: Semantic Differential Chart of seed micromorphology of Genus Nepeta

3.10 Seed Micromorphology of Genus Salvia

The seed characteristics of ten Salvia species were investigated. macro and micromorphological features such as color, shape, hilum, texture, seed outline, ornamentation of wall, anticlinal wall pattern, periclinal wall pattern, epidermal cell shape and margin were found to be quite variable within Salvia L. (Table 29 and 30). SEM micrographs of all taxa studied are shown in Plates 97 and 98.

3.10.1 Seed Color and Texture

One of the diagnostics and taxonomically relevant features is seed colour. Seeds of various colours were observed in the taxa investigated, from black, dark brown to light brown and yellow. Seed colour is black in *S. aegyptiaca*, *S. cabulica* and *S. santolinifolia*; brown in *S. coccinea*, *S. lanata*, *S. moorcraftiana* and *S. splendens*; and light to dark brown in *S. officinalis*, dark brown in *S. plebia* and yellow in *S. reflexa* (Plates 97,98). Five seed textures were observed in studied taxa: scabrate in *S. aegyptiaca*, *S. cabulica*, *S. coccinea*, *S. plebia* and *S. splendens*, rough in *S. lanata*, smooth in *S. moorcraftiana*, rough to slightly smooth in *S. officinalis* and smooth pitted in *S. reflexa* (Plates 97,98).

3.10.2 Seed Shape, Hilum Position and Level

There were large variations in seed shape of the studied taxa. Six different shapes were observed. Seed shape is obovate in *S. aegyptiaca*, *S. coccinea* and *S. plebia*, (Plates 97 B and H, 98 E), spheroid in *S. moorcraftiana* and *S. officinalis* (Plates 97 N, 98 B), oblong in *S. santolinifolia* and *S. splendens* (Plate 98 K and N). In *S. cabulica* seeds are spherical (Plate 97 B), elliptic in S. reflexa (Plate 98 H) and broad elliptic in *S. lanata* (Plate 97 K). In all studied taxa, the hilum was visible and terminal in position, while its level was either raised or depressed. Hilum level was raised in *S. aegyptiaca*, *S. coccinea*, *S. lanata* and *S. reflexa*, and depressed in, *S. cabulica*, *S. moorcraftiana*, *S. officinalis*, *S. plebia*, *S. santolinifolia* and *S. splendens* (Table 29, Plates 97,98).

3.10.3 Seed Size

Seed size shows great variability among the studied taxa of the genus *Salvia*. Seed length ranges from.40(0.30-0.50) ±.031 (mm) maximum in *S. cabulica* to minimum

0.02(0.01-.01) ±.000 (mm) in *S. plebia*. (Fig. 69). Seed width ranges from .34(0.30-0.40) ±0.024 (mm) maximum in *S. cabulica* to minimum 0.01(0.01-0.02) ±.002 (mm) in *S. plebia*. (Fig 1) Length to width ratio ranges from 2.1 to 1 in *S. coccinea* and *S. plebia* respectively (Fig. 70).

3.10.4 Surface Sculpturing of Seed

The surface sculpturing of the Salvia genus showed remarkable diversity. Seven sculpturing patterns were observed: colliculate, rugulate, papillae, rugose, reticulate, negative reticulate and granular (Table 30, Plates 97, 98). The nutlet surface patterns are described below.

3.10.5 Nutlet Surface Patterns are Described using Technical Terms.

Terms	Explanation
Colliculate	having little hill-like eminences or circular wide elevations that are evenly distributed and cover the entire nutlet surface
Rugulate	Fine, wrinkled in an uneven pattern
Papillae	The protuberances that arose from the testa cells were known as papillae.
Rugose	Wrinkled, with uneven elevations moving largely in one direction that makes up the wrinkles.
Reticulate	The seed surface consists of a reticulum or net and interspaces are characterized by raised walls. OR made up of polygonal cells that are generally concave and are bordered by anticlinal wall thickening that is continuous.
Negative reticulate	made up of polygonal cells that are usually convex. Concave linear anticlinal wall thickening distinguishes each cell.
Granular	consisting of or covered with very minute grains or granules.

Within species of the same genus, seed surface sculpturing pattern varied. Colliculate seed sculpturing was found in *S. aegyptiaca* (Plate 97 C) and *rugulate in both S. cabulica and S. plebia* (Plates 97 F, 98 F). *Papillae sculpturing was found in S*. coccinea

(Plate 97 I), rugose in *S. lanata* (Plate 97 L), reticulate in *S. officinalis* and *S. moorcraftiana* (Plates 98 C, 97 O), and granular in *S. splendens* (Plate 98 O). Negative reticulate surface sculpturing with regular epidermal cells was found in both *S. reflexa* and *S. santolinifolia* (Plate 98 I, L).

3.10.6 Anticlinal and periclinal wall pattern

There were six types of anticlinal wall pattern in the studied taxa. The anticlinal wall pattern is buttressed in *S. aegyptiaca* and *S. officinalis* (Plates 97 C, 98 C), while it is irregularly thickened in *S. cabulica*, *S. coccinea*, *S. lanata* and *S. plebia* (Plates 97 F, I and L, 98 F, respectively). The anticlinal wall is thickened in *S. moorcraftiana* (Plate 97 O), rounded in *S. reflexa* (Plate 98 I), smooth and angular in *S. santolinifolia* (Plate 98 L) and slightly undulate in *S. splendens* (Plate 98 O). The periclinal wall is concave, concave to slightly concave or convex. Convex in *S. reflexa*, *S. santolinifolia* and *S. coccinea* (Plates 98 I, L, 97 I, respectively), concave in *S. aegyptiaca*, *S. lanata*, *S. moorcraftiana*, *S. officinalis* and *S. plebia* (Plates 97 C, L and O, 98 C, F, respectively). The periclinal wall is slightly concave in *S. cabulica* and *S. splendens* (Plates 97 F, 98 O).

3.10.7 Principal components analysis of Salvia Seed as a Statistical Tool

In the PCA of the studied Salvia species, *S. santolinifolia*, *S. aegyptiaca* and *S. reflexa* are more correlated than other species of the genus. *S. cabulica* and *S. plebeia* had isolated positions because of their habitat and, possibly, because of differences in seed size. The seed size of *S. cabulica* was .40(.30-.50) ±.031, which is the largest of the studied taxa, while *S. plebeia* was 0.02(.01-.01) ±.000mm, which is the smallest seed size in the studied taxa. *S. coccinea* also had an isolated position, with the highest length to width ratio (2.1). PC1 accounted for 95% of the overall variation in quantitative data, followed by 4% for PC2, which contributed 99% of total variance (Table 28, Fig. 71). This means that there is less variance between seed length and width. The quantitative characteristics with dominant scores that helped in the formation of observed groups in the PCA were seed length and width. Qualitative characteristics, such as seed shape, color, texture, hilum, cell outline, surface sculpturing, anticlinal wall pattern, periclinal wall pattern and epidermal cell arrangement, were significant in the present study.

3.10.8 Taxonomic Key Based on Seed Macro and Micromorphological Characters of the Salvia Species.

1	a	Seed black, obovate, scabrous, colliculate surface, and irregular epidermal cells	*S. aegyptiaca*
	b	Seed shape spherical, rugulate surface, anticlinal wall pattern irregularly thickened	2
2	a	epidermal cells wavy pentagonal and hexagonal…………	*S. cabulica*
	b	Seed colour brown, seed outline random, surface sculpturing papillae	3
3	a	Anticlinal wall pattern irregularly thickened, epidermal cells irregular	*S. coccinea*
	b	Seed shape broad elliptic, seed texture rough…………………….	4
4	a	cell outline slightly random-raised, surface sculpturing rugose………	*S. lanata*
	b	Seed shape spheroid, seed texture smooth, cell outline in rows flattened	5
5	a	Anticlinal wall pattern thickened; surface sculpturing cellular/reticulate	*S. moorcraftiana*
	b	Seed colour is light brown -dark brown, seed texture slightly rough-smooth	6
6	a	Surface sculpturing reticulate, anticlinal wall pattern buttressed	*S. officinalis*
	b	Seed shape obovate, seed colour dark brown………………………	7
7	a	cell outline random and protuberant, surface sculpturing regulate……	*S. plebia*
	b	Seed shape elliptic, seed colour yellow, seed texture smooth pitted…	8
8	a	Cell outlines random and depressed, surface sculpturing negatively reticulate	*S. reflexa*
	b	Seed shape oblong, seed colour black, anticlinal wall pattern smooth and angular	9
9	a	Epidermal cell arrangement regular, pentagonal to hexagonal……	*S. santolinifolia*
	b	Seed shape oblong, seed texture scabrous…………………………	10
10	a	surface sculpturing granular, anticlinal wall pattern slightly undulate	*S. splendens*

Table 28. Multivariate principal component-scatter analysis

Principal component	Eigenvalue	% Variance
1	0.0174242	95.127
2	0.00089249	4.8726

Table 29: Seed micromorphological features of Salvia taxa examined from Pakistan.

Sr. no	Plant taxa	Seed shape	Seed color	Seed texture	Seed apex	Seed base	Hilum occurrence	Hilum Position	Hilum Level	Seed length Mean (min-max) ±SE (mm)	Seed width Mean(min-max) ±SE (mm)	L/w ratio
1.	*Salvia aegyptiaca* L.	Obovate	Black	Scabrous	Oval	Round	Visible	Terminal	Raised	.20(.10-.30) ±.031	.12(.10-.20) ±.020	1.6
2.	*Salvia cabulica* Benth.	Spherical	Black	Scabrous	Round	Round	Visible	Terminal	Depressed	.40(.30-.50) ±.031	.34(.30-.40) ±.024	1.1
3.	*Salvia coccinea* Buc'hoz ex Etl.	Obovate	Brown	Scabrous	Oval	Round	Visible	Terminal	Raised	.34(.30-.40) ±.024	.16(.10-.20) ±.024	2.1
4.	*Salvia lanata* Roxb.	Broad elliptic	Brown	Rough	Obtuse	Round	Visible	Terminal	Raised	.24(.20-.30) ±.024	.20(.10-.30) ±.031	1.2
5.	*Salvia moorcroftiana* Wall. Ex Benth.	Spheroid	Brown	Smooth	Obtuse	Round	Visible	Terminal	Depressed	.26(.20-.30) ±.024	.14(.10-.20) ±.024	1.8
6.	*Salvia officinalis* L.	Spheroid	Light brown to dark brown	Slightly rough to smooth	Slightly obtuse	Round	Visible	Terminal	Depressed	.22(.10-.30) ±.037	.16(.10-.20) ±.024	1.3
7.	*Salvia plebeia* R.Br.	Obovate	Dark brown	Scabrous	Oval	Round	Visible	Terminal	Depressed	0.02(.01-.01) ±.000	0.01(.01-.02) ±.002	1
8.	*Salvia reflexa* Hornem.	Elliptic	Yellow	Smooth, pitted	Obtuse	Round	Visible	Terminal	Raised	.20(.10-.30) ±.031	.12(.10-.20).020	1.6
9.	*Salvia santolinifolia* Boiss.	Oblong	Black	Slightly smooth	Acute	Obtuse	Visible	Terminal	Depressed	.16(.10-.20) ±.024	.10(.10-.10) ±.00	1.6
10.	*Salvia splendens* Sellow ex Schult.	Oblong	Brown	Scabrous	Oblong	Oblong	visible	Terminal	Depressed	.30(.20-.40) ±.031	.22(.10-.30) ±.037	1.3

Table 30: SEM Seed qualitative findings of Salvia taxa examine.

S.no	Plant Taxa	Cell outline	Wall ornamentation	Surface sculpturing	Anticlinal wall pattern	Periclinal wall pattern	Epidermal cell arrangement
1.	*Salvia aegyptiaca* L.	Random	Very thick and raised	colliculate	Buttressed	Concave	Irregular
2.	*Salvia cabulica* Benth.	In rows	Thick	Rugulate	Irregularly thickened	Slightly concave	Wavy, pentagonal to hexagonal
3.	*Salvia coccinea* Buc'hoz ex Etl.	Random	Very thick	papillate	Irregularly thickened	Convex	Irregular
4.	*Salvia lanata* Roxb.	Random, slightly raised	Thick	Rugose	Irregularly thickened	Concave	Irregular
5.	*Salvia moorcroftiana* Wall. Ex Benth.	In rows, flattened	Thick	Cellular/ reticulate	Thickened	Concave	Irregular
6.	*Salvia officinalis* L.	Random	Thick	Reticulate	Buttressed	Concave	Irregular, sunken
7.	*Salvia plebeia* R.Br.	Random and protuberant	Thick	Rugulate	Irregularly thickened	Concave	Irregular
8.	*Salvia reflexa* Hornem.	Random and depressed	Thin to slightly thick	Negative reticulate	Rounded	Convex	Regular, pentagonal to hexagonal
9.	*Salvia santolinifolia* Boiss.	In rows	Thin	Negative reticulate	Smooth and angular	Convex	Regular, pentagonal to hexagonal
10.	*Salvia splendens* Sellow ex Schult.	In rows, slightly raised	Thick	Granular	Slightly undulate	Slightly concave	Irregular, pentagonal to hexagonal

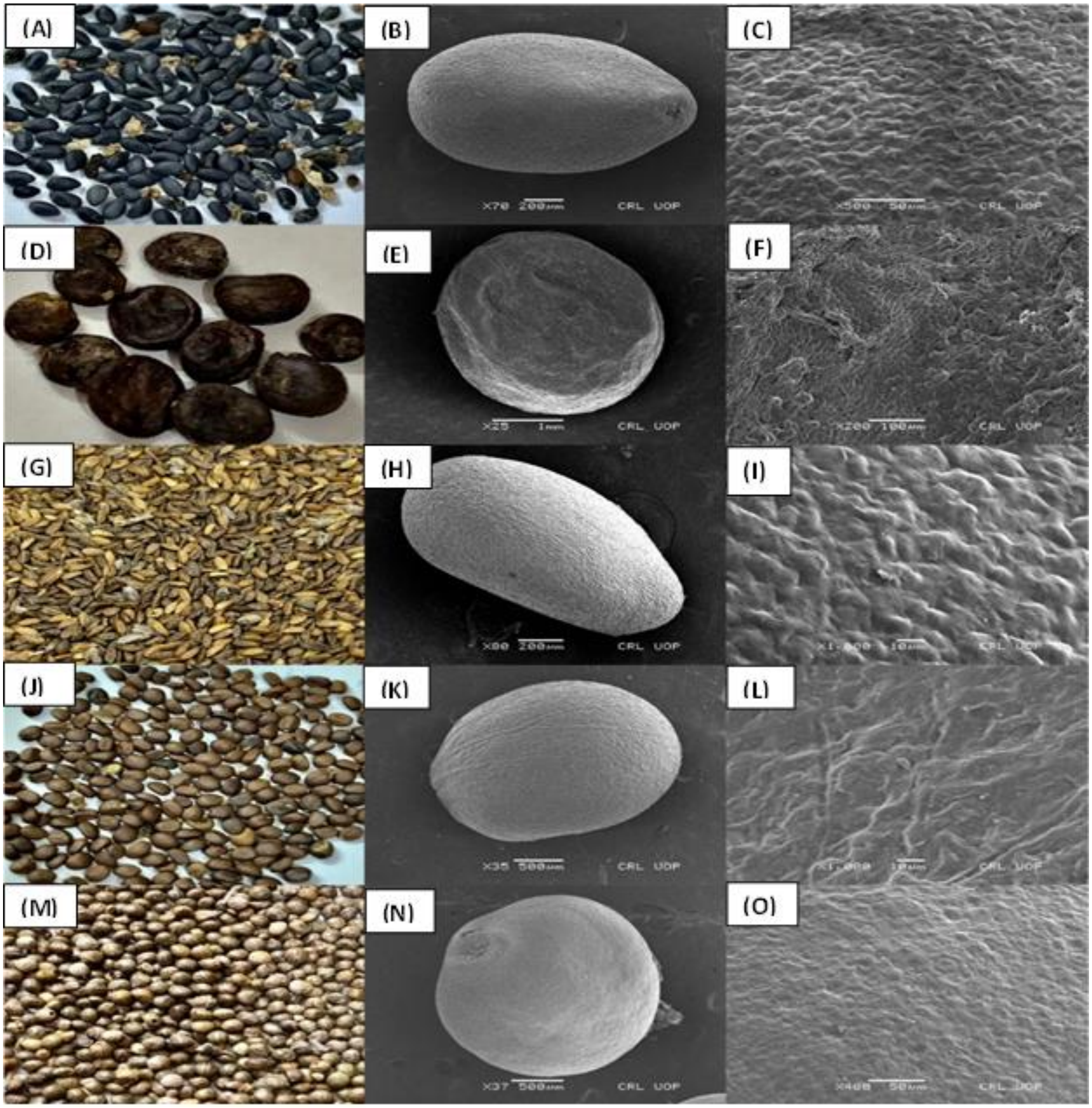

Plate 97: (SEM) Scanning electron micrographs of seed morphology of *Salvia* genus (**A, B, C**) *S.aegyptiaca* obovate seed with colliculate surface sculpturing;(**D, E, F**) *S.cabulica* spherical seed with rugulate surface sculpturing;(**G, H, I**) *S. coccinea* obovate seed with papillae surface sculpturing;(**J, K, L**) *S.lanata* with broad elliptic seed and rugose surface sculpturing;(**M, N, O**) *S.moorcraftiana* spheroid seed with cellular/reticulate surface sculpturing.

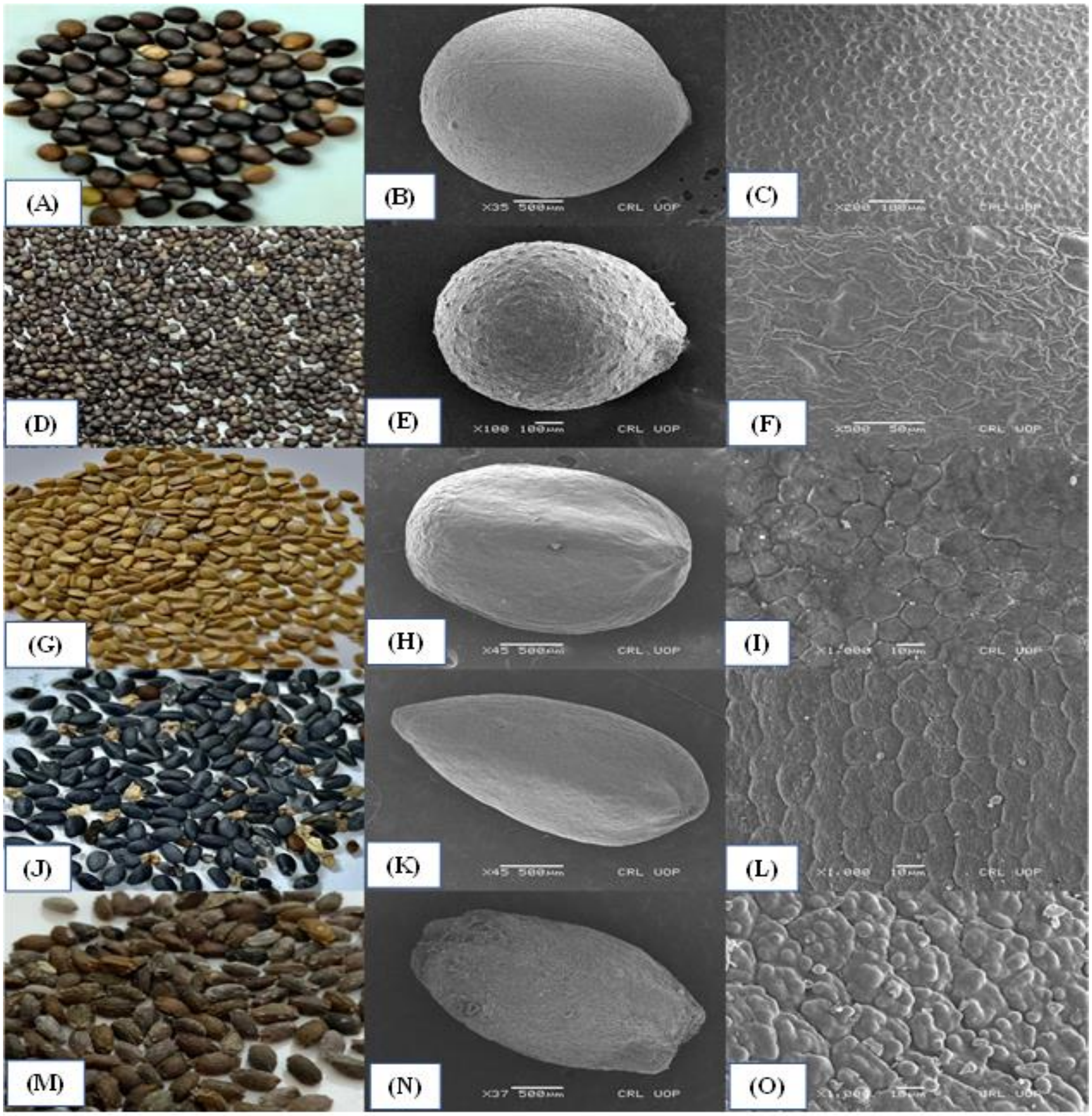

Plate 98: (SEM) Scanning electron micrographs of seed morphology of *Salvia* genus (**A, B, C**) *S. officinalis* spheroid seed with reticulate surface sculpturing;(**D, E, F**) *S.plebia* obovate seed with rugulate surface . Sculpturing;(**G, H, I**) S.reflexa elliptic seed with regular pentagonal to hexagonal epidermal cells ;(**J, K, L**) *S.santolinifolia* oblong seed with regular pentagonal to hexagonal epidermal cells;(**M, N, O**) *S.splendens* oblong seed with granular surface sculpturing.

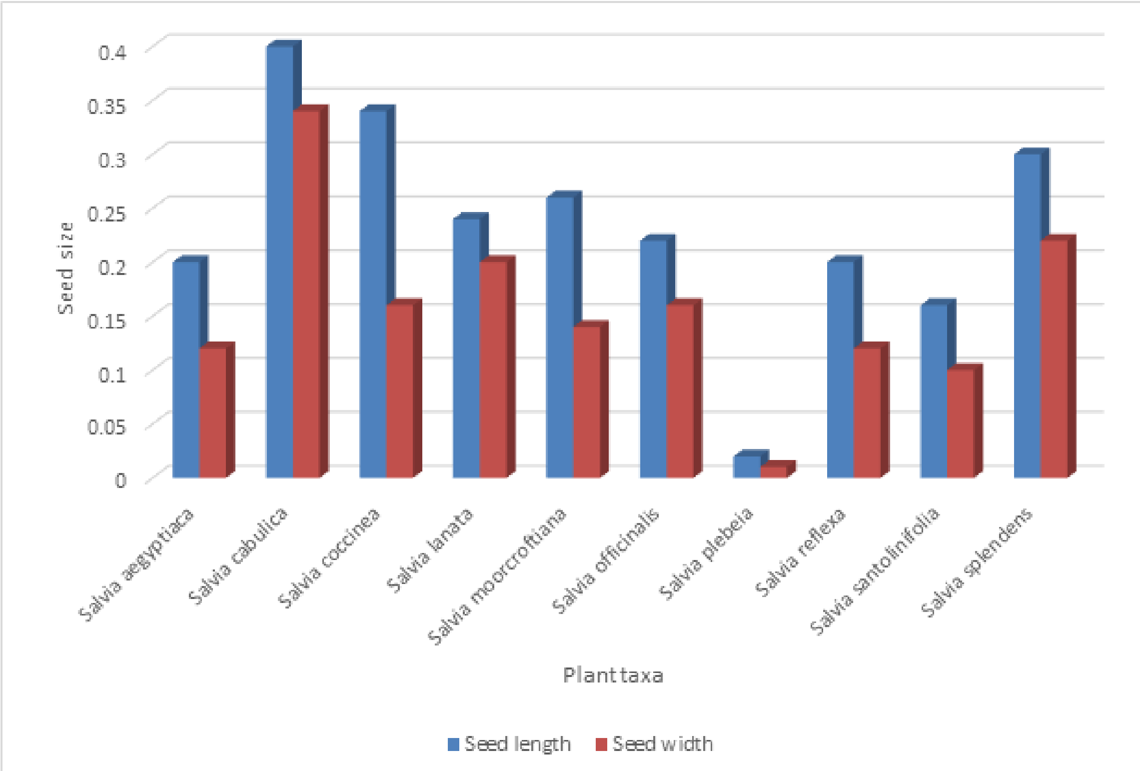

Fig. 69. Graph showing variation in seed length and width of genus Salvia L.

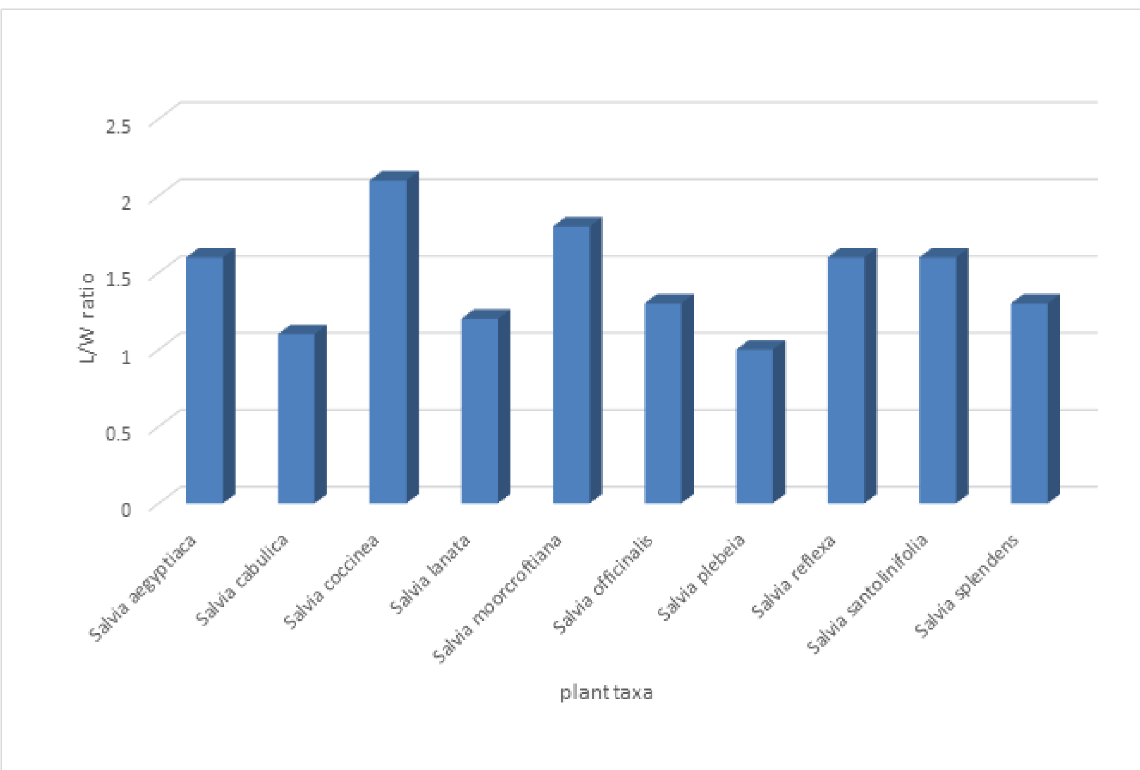

Figure 70: L/W ratio of various species of seed of genus Salvia L.

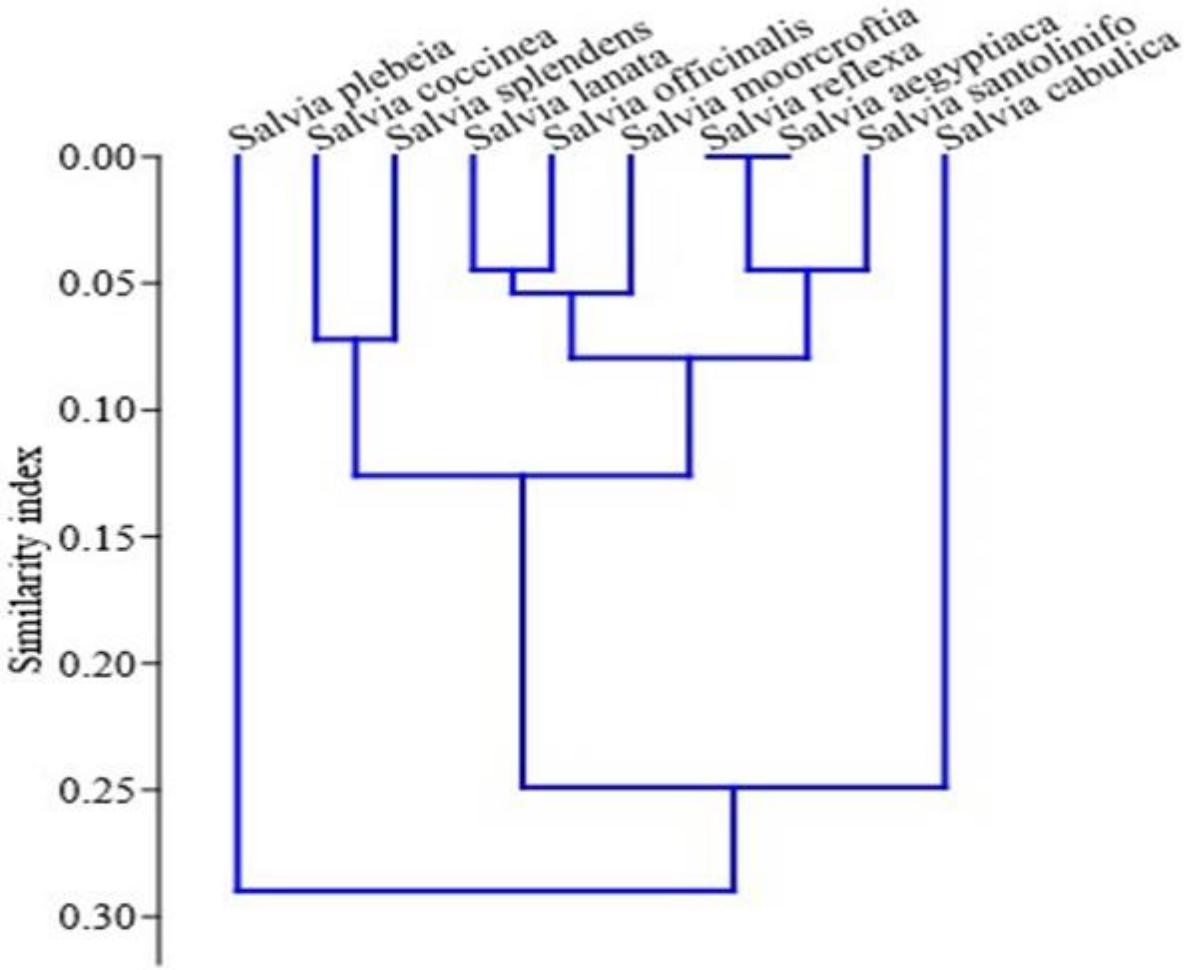

Figure 71: Cluster analysis showing the similarity index of Salvia taxa based on quantitative seed micromorphological characteristics; (a) *Salvia.aegyptiaca*, (b) *S.cabulica*, (c) *S.coccinea*, (d*) S.lanata*, (e*) S.moorcraftiana,* (f) *S.officinalis*, (g) *S.plebia,* (h) *S.reflexa*, (i) *S. santolinifolia*, (j) *S.splendens*

.

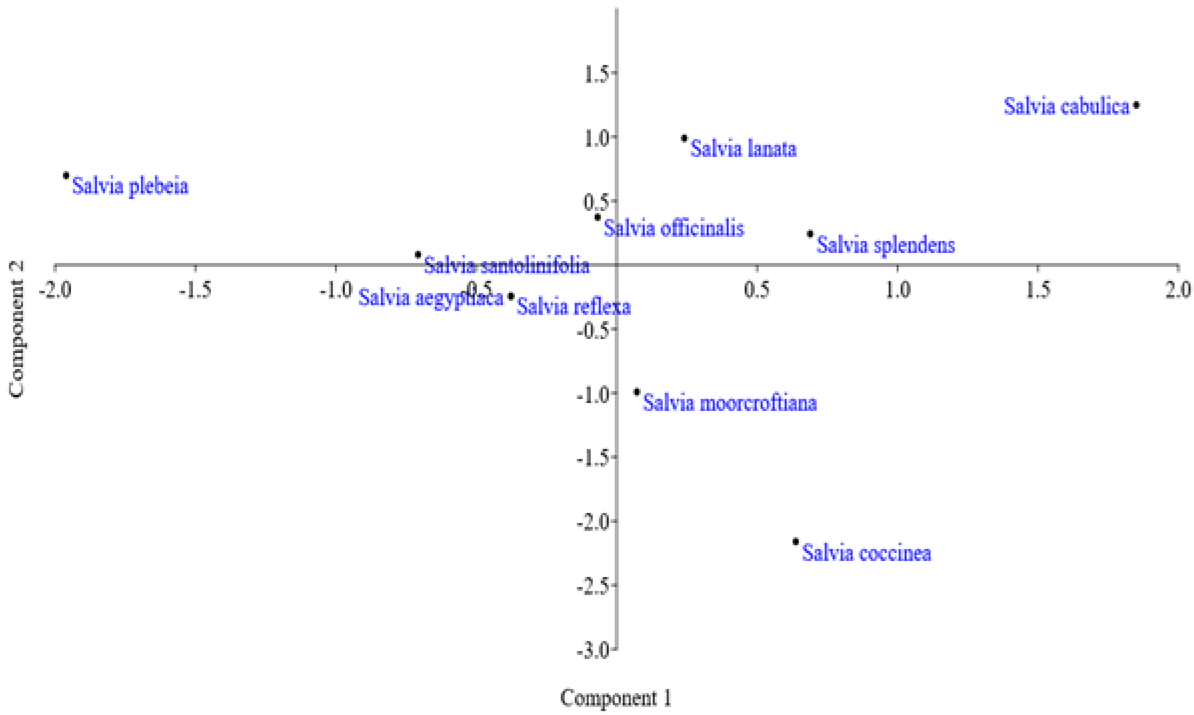

Figure 72: PCA (Principle component analysis) using PAST based on the quantitative micromorphological seed features reported in Tables 29 and 30.

Discussion

We studied the seed macro- and micromorphological characteristics by means of a stereomicroscope and SEM. The use of SEM as a tool for studying micromorphological variation has gained attention in recent years in plant systematics because, despite the difficulty of sample preparation, the observed data are highly accurate. At different taxonomic levels, seed micromorphology of genus Salvia revealed significant variation in distinct features. The screening of seed coats revealed much micromorphological variation which could be useful in the correct identification of species, using several novel micromorphological features relevant to Salvia taxonomy. Within Salvia, seed form, color, hilum, anticlinal wall thickness, cell surface, epidermal cell shape, border, length, breadth and length:width all differed significantly. Even with this limited selection of Salvia species, it is obvious that seed sculpturing aids in infrageneric classification.

The colour, shape, size and sculpturing of the seed surface varied greatly. Seed morphology is important, especially micromorphological characteristics, which has previously been proven useful in Lamiaceae, including genus Salvia (Buyukkartal et al. 2011; Kahraman et al. 2010; Mousavi et al. 2013; Ozkan et al. 2009; Polat et al. 2017). Mature seeds of Salvia species are usually brown (Ozkan et al. 2009), blackish (Buyukkartal et al. 2011), or brown, black (Kahraman et al. 2011). Seeds of the studied species varied in color from light brown, yellowish to dark brown, as found in previous research in Salvia. According to Ozkan et al. (2009), some Salvia seeds can be distinguished based on color alone, e.g., *S. aethiopis*, *S. candidissima* and *S. cryptantha* have pale-surfaced seeds; however, the variation in shape and size of seeds demonstrates the taxonomic importance of Salvia seed morphology.

This is the first report of seed micromorphology for the genus Salvia from Pakistan. Obovate seeds were the dominant seed shape, followed by spherical, spheroid, broadly elliptic, elliptic, and oblong. Brown was the most common seed colour, followed by black, light brown to dark brown and yellow. Seed textures were mostly scabrous, followed by rough, slightly rough-smooth, smooth, and smooth-pitted. Hilum was mostly visible in the terminal position, either raised or depressed. The largest seed length was in *S. cabulica* and the largest width was also in *S. cabulica*; the lowest length and width was in *S. plebia* (Table 29). The cell outline was random, in rows (flattened), random (protuberant), random slightly raised or randomly raised in rows. Ornamentation varied from thick to thin. Surface sculpturing varied from colliculate, rugulate, rugose, reticulate, negatively reticulate, papillate to granular. The anticlinal walls were mostly irregular thickened, buttressed, thickened, rounded, smooth and angular or slightly undulate. The periclinal wall was dominantly concave to convex. Epidermal cell arrangement was irregular, wavy pentagonal to hexagonal, regular pentagonal to hexagonal. This study showed that analysis of seed features, especially at the species level, might yield much taxonomic information.

Cluster analysis produced a species similarity index based on the examined quantitative traits, revealing a high degree of similarity between *S. lanata* and *S. officinalis*, while *S. moorcraftiana*, *S. reflexa* and *S. aegyptiaca* which were distantly related (Fig. 72). *S. lanata* and *S. officinalis* were two closely related species with less variation. *S. moorcraftiana*, *S. reflexa* and *S. aegyptiaca* were more similar than *S. santolinifolia* and *S. cabulica* which were distantly related species. *S. reflexa*, *S. aegyptiaca* and *S. santolinifolia* were more similar than *S. coccinea* and *S. splendens* but less than *S. officinalis* and *S. moorcraftiana*.

Earlier studies on Lamiaceae seeds found less diversity in seed surface sculpturing compared to the Salvia genus (Husain et al. 1990), and no other genus, although is as diverse and has a vast distribution as the genus Salvia. Marin et al. (1996) suggested that comprehensive research on Salvia species seed microcharacters will be critical for infrageneric categorization and a clearer understanding of the evolutionary origins of this unique genus. Hedge (1970) already mentioned the taxonomic relevance of seed features within the genus Salvia discovered a vast variety of seed morphologies, along with several kinds of mucilage produced when seeds are wet.

Marin et al. (1996) investigated 13 Salvia species from different sections and subgenera and found that the seed surface of *S. glutinosa* and *S. officinalis* were similar, with slight differences; while the seed surface of S. sclarea, *S. viridis*, *S. austriaca*, *S. jurisicii*, *S. nemar*osa, *S. nutants* and *S. pratensis* had irregular protuberances with undulating ridges. The seed surface of *S. lyrata* is papillate; the surface of *S. verticillata* has a distinctive irregular, reticulate pattern, with papillae of varied sizes. The *S. coccinea* nutlet surface had hexangular or pentangular cells (papillae). Sphaeropapillose shapes were found in seed of *S. splendens*. In the present study, three Salvia species were similar in both our and the above studies, i.e., *S. officinalis*, *S. coccinea* and *S. splendens*, with differences in seed surface from a previous study, i.e., *S. coccinea* had a papillate surface, *S. splendens* had a granular surface (Plates 98 I, O). Only *S. officinalis* had a similar seed surface, namely a sunken reticulate surface. When we summarize the results of Marin et al. (1996), the results of the present study show a lot more variation in seed surface sculpturing.

The seeds of 12 Turkish Salvia species were studied by Ozkan et al. (2009) and characterized as black, dark brown or pale brown, like our findings, except for *S. reflexa* which is yellow. Seed shapes according to Ozkan et al. (2009) is spheroidal to prolate spheroidal, unlike our investigation, except for *S. cabulica*, *S. moorcraftiana* and *S. officinalis* (spherical, and spheroidal, respectively; Table 29), and surface ornamentation also differs from our results, except in *S. officnalis* with reticulate surface sculpturing (Plate 98 C). Mousavi et al. (2013), studied nutlets of ten Salvia species from Iran and found that they were round, prolate-spheroidal, spheroidal, black, dark brown or light brown, which partially resembles our findings (Table 29), except for *S. reflexa* which is yellow, and shape of seed is spherical in *S. cabulica* and spheroidal in *S. moorcraftiana* and *S. officinalis*. Moon et al. (2009), studied 13 Salvia species with psilate (*S. eremostachya* and *S. polystachya*), negatively reticulate (*S. reflexa*), reticulate (*S. glutinosa*) and papillae (*S. nilotica*, *S. pratensis* and *S. sclarea*) surface ornamentation, which is similar to some of our studied Salvia species, i.e., reticulate in *S. officinalis*, negatively reticulate in *S. reflexa* and *S. santolinifolia*, and papillate in *S. coccinea*. *S. reflexa* surface sculpturing is similar in both studies. Hassan & AlThobaiti (2015) only studied *S. officinalis*, stating it has round, dark brown, and oscillating surface sculpturing; where seed shape and colour are similar to our results, but surface sculpturing is dissimilar. Kahraman et al. (2010) studied seed micromorphology of *S. macrochlamys* with a rounded-trigonous shape and protuberances ornamentation, which is dissimilar to our results. Kahraman et al. (2010) also studied *S. ballsiana* which is broadly ovate with a rounded outline, rounded hilum, brown, surface is glabrous with pentagonal to hexagonal papillae. The colour and shape of this seed is similar to our species but dissimilar in surface ornamentation.

Kahraman et al. (2011) studied 13 Salvia species from Turkey that had brown-black seeds with colliculate, verrucate and reticulate surface sculpturing, while in present study, seed colour was similarly brown, dark brown, black, except *S. reflexa*, which is yellow. Surface sculpturing in present study is reticulate in *S. officinalis* and colliculate in *S. aegyptiaca*, similar to Kahraman et al. (2011). Buyukkartal et al. (2011) studied three Salvia species with a blackish colour from east Turkey where surface sculpturing was colliculate in all three. The anticlinal wall had straight channels and undulate channels in *S. hedgeana*, *S. rosifolia* and *S. huberi*, while the periclinal wall was convex with small holes in all three species. The colour and surface sculpturing were similar to our investigated Salvia species, i.e., *S. aegyptiaca*, with convex periclinal walls in *S. reflexa* and *S. santolinifolia*, but no straight anticlinal walls in the presented study. According to

Ya'ni et al. (2018), *S. schimperi* had rounded trigonus and greenish brown seeds, with a smooth surface, which is dissimilar to our investigation. Akcin & Camili (2018) reported that mature seeds are ovate with pentagonal to hexagonal colliculate surface sculpturing, unlike our investigation but with similar seed colour: dark brown. According to Botanica (2009), seeds of Lallemantia L. are black and oblong, which is similar to our investigation, but seed surface sculpturing was verrucate-regulate, which is different from our studied taxa. According to El Rabiai et al. (2021), seed shape of *S. viridis* is obovate and brown in colour, with reticulate surface sculpturing, like our studied taxa.

When we compare all the above studies, there is a parallelism in seed colour but a huge variation in surface sculpturing and size within the Salvia genus. However, the combination of different morphological features in seeds may aid in species categorization and identification. The shape, size, and surface sculpturing of seeds varied greatly between species within the genus. The value of seed screening as a research tool is determined by the degree of variability observed within the genus and species.

4. Conclusion

This is the first detailed report of taxonomic studies of Lamiaceous taxa by using light microscopy (LM) and scanning scanning electron microscopy (SEM). A total of 104 Lamiaceous taxa were collected from Northern region of Pakistan. From the above study it is concluded that anatomical, palynological and seed micromorphological characteristics are very helpful in the identification and separation of Lamiaceous taxa.

Palynology

- The pollen traits of 97 Lamiaceous species from Northern Pakistan were significant in the differentiation and separation of taxa at a genus and species level, using light and scanning electron microscopy. This finding was further supported by the unique documentation and visualization.
- The variations in polarity, shape, number and arrangement of apertures, Amb, both polar and equatorial views, exine sculpturing, aperture surface showed sufficient for the taxonomic identification of the species was the subject of the inquiry.
- Different exine sculpturing was shown i.e., reticulate, bireticulate and reticulate perforate, microreticulate, mega reticulate echinate, fine reticulate, coarsely reticulate, verrucate, granulate, Foveolate and scabrate.
- By providing access to the variation in different pollen traits, the taxonomic key finally determines the species boundaries required for precise taxonomic identification.
- The utilization of multivariate analysis techniques, including PCA, dendrogram and correlation plot, yielded additional comprehensive insights into the species characteristics.

Anatomy

- Foliar epidermal anatomy of 60 Lamiaceous taxa growing in Northern region of Pakistan divulge that the anatomical characteristics i.e., the variety of epidermal cells, stomatal variations and trichome morphology are potentially helpful to separate the Lamiaceous taxa at the genus and species level.
- Foliar epidermal investigation was carried out on 27 Lamiaceous taxa followed by subfamiliy Nepetoideae (33 species).

- Lamiaceous species can quickly differentiated due to their shape of epidermal cells i.e., irregular, regular, polygonal, isodiametric.
- Through the creation of PCAs, dendrograms, and diagnostic features for species identification, the quantitative data analysis identified significant trends in the data set.
- It is summed up that scanning electron microscopy (SEM) for identification of characters of Lamiaeous species were helpful in classification.

Seed Micromorphology

- The taxonomic importance of seed micromorphology in the identification of Lamiaceous species has been observed.
- The current research investigates the ultrastructure of 43 Lamiaceous seed collected from Northern Pakistan. The Nepeta genus was dominant with (11 seeds) followed by Salvia (10 seeds), and 22 general Lamiaceae seeds.
- Identification of micro seed images through SEM shown important taxonomic varieties among different species and provide helpful data on seed ornamentation in the phylogenetic view.
- Seeds were mostly minute and small, larger than one millimeter in some taxa. Anticlinal wall pattern can be divided into different types: convex, thin, and straight, thick, and depressed, slightly thickened, convex, and depressed and others.
- The variables in seed ultra structure among Lamiaceous species were very useful for accurate identification and classification and shows that micromorphological attributes have significant taxonomic application.

5. Future Recommendations

- It is recommended that advance analytical tools should be used in future studies for phylogenetic studies for better understanding the placement of Lamiaceous taxa in the evolutionary tree.
- The medicinal aspects of Lamiceous species in pharmaceuticals industry using advanced chromatographic, spectroscopic, and molecular techniques is recommended.

- Many Lamiaceous taxa can be cultivated and commercialized to gain economic benefits via exporting them.
- The medicinal Lamiaceous species may be incorporated in development of valuable drugs that will lead to the strengthening of local industries.
- The family and genus-based DNA markers can be employed on these Lamiaceous species for accurate identification using advanced molecular taxonomic tools.

Chapter 04

References

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PUBLISHED PAPERS

QUAID-I-AZAM UNIVERSITY

DEPARTMENT OF PLANT SCIENCES

Subject: **Publication of W – Category Miss. Shaista Jabeen (Ph.D. Scholar)**

This is in reference to a circular regarding the publication requirement for Ph.D. scholars in the Department of Plant Sciences, Faculty of Biological Sciences. It is certified that **Miss. Shaista Jabeen** has published research papers in W-Categories as given below:

S. No.	Paper Title	Year	Impact Factor
1.	Jabeen, S., Zafar, M., Ahmad, M., Althobaiti, A. T., Ozdemir, F. A., Kutlu, M. A., ... & Majeed, S. (2023). Ultra-sculpturing of seed morphotypes in selected species of genus Salvia L. and their taxonomic significance. *Plant Biology*, *25*(1), 96-106.	2023	3.87
2.	Jabeen, S., Zafar, M., Ahmad, M., Ali, M. A., Elshikh, M. S., Makhkamov, T., ... & Rahmatov, A. (2024). Micrometer insights into Nepeta genus: Pollen micromorphology unveiled. *Micron*, *177*, 103574.	2024	2.4

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RESEARCH ARTICLE

Ultra-sculpturing of seed morphotypes in selected species of genus *Salvia L.* and their taxonomic significance

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Keywords
Cluster analysis; micromorphology; *Salvia*; SEM; surface sculpturing.

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ABSTRACT

- The taxonomic importance of macromorphological and micromorphological seed characteristics was investigated using SEM of ten species of the *Salvia* genus from Pakistan. The aim was to identify diagnostic seed ultrastructural features that could aid in species delimitation, correct identification and phylogenetic position. The ultrastructure of *Salvia* varies greatly, and a wide range of unique micromorphological features have been observed.
- Seed micromorphological features were explored by SEM, including seed shape, colour, texture, cell outline, surface sculpturing, epidermal cell arrangement, anticlinal, and periclinal wall pattern.
- Seed shapes were categorized as obovate, spherical, spheroid, broadly elliptic, elliptic and oblong, mostly with a terminal hilum. Seed colours were black, light brown, dark brown, brown and yellow. Exo-morphological characters, *i.e.* epidermal cell arrangements, included irregular, wavy pentagonal-hexagonal, regular pentagonal-hexagonal. Cluster analysis was used to assess similar and distinct species within *Salvia* with a feasible explanation. Taxonomic keys were made based on micromorphological qualitative features that help to delimit species and identify them quickly within the *Salvia* genus.
- Seed morphology of ten *Salvia* species was described and investigated, and the diagnostic significance of features evaluated using SEM. This study analysed seed features, especially at the species level, which might provide much new taxonomic information. The results revealed that, in seed morphology, using SEM can help with taxon identification, especially at the genus and species levels.

INTRODUCTION

Seed micromorphology includes features that indicate morphological importance in inferring phylogenetic and evolutionary relationships, as well as species identification (Attar *et al.* 2007; Johnson *et al.* 2004). The variability of form, size and colour of seeds can aid in taxonomic identification (Ninkaew *et al.* 2017). Seed morphology and anatomical traits were previously thought to be conservative, indicating their taxonomic significance. Seed characteristics have been revealed as a useful tool for distinguishing species at the family level and their grouping at the level of genus (Speta 1998). At intraspecific and intrageneric levels, seed ultrastructural traits, especially seed surface and cell shape, are thought to be key differentiating features (Kubitzki *et al.* 2013). The direct relationship with nutritional reserves was reported to be seed size, leading to earlier seedling development (Veloso *et al.* 2017).

Salvia L. (Lamiaceae: tribe Mentheae) is a genus with about 1000 species, each with a unique form of growth, pollination biology, secondary chemicals and floral appearance. *Salvia* has spread across continents, with 500 species in Central and South America, 200 species in Western Asia and 100 species in Eastern Asia (Walker & Sytsma 2007). Lamiaceae is the sixth largest angiosperm family and the largest family in the Lamiales order, with over 230 genera and over 7000 species (Group *et al.* 2016; Harley *et al.* 2004; Olmstead 2005). The Lamiaceae has seven subfamilies, the largest being Nepetoideae, and three tribes: Elsholtzieae, Mentheae and Ocimeae. Based on the latest classification of Harley *et al.* (2004), Salviinae, Menthinae and Nepetinae are the three subtribes of Mentheae. Based on their classification, genus *Salvia* belongs to the Salviinae subtribe. *Salvia* species differ from other genera in the Mentheae tribe by having two posterior stamens and an extended connective that connects the thecae of these stamens (Walker *et al.* 2004).

A number of studies have addressed the genus *Salvia* using various data: morphology (Hedges 1982), anatomy

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Micrometer insights into *Nepeta* genus: Pollen micromorphology unveiled

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A B S T R A C T

This study provides a comprehensive pollen micromorphology within the *Nepeta* genus, revealing intricate details about the pollen grains' structure and characteristics. The findings shed light on the evolutionary and taxonomical aspects of this plant genus, offering valuable insights for botanists and researchers studying *Nepeta* species. The pollen grains of 18 Nepeta species were studied using scanning electron microscopy (SEM) and light microscopy (LM) in Northern Pakistan. At the microscale, pollen quantitative measurements, qualitative traits, and diverse sculpturing patterns were reported and compared. Significant differences in pollen size, shape, ornamentation, and sculpturing patterns were discovered among the Nepeta species. Our data show that exine sculpturing is quite diverse, with most species exhibiting a reticulate perforate pollen pattern. *Nepeta connata, Nepeta discolor, Nepeta elliptica,* revealed a distinct bireticulate perforate exine stratification. Hexazonocolpate pollen is the most common. Furthermore, the surface membrane attributes of the colpus varied greatly, ranging from rough, scabrate, psilate, to sinuate patterns. Principal Component Analysis (PCA) was used to discover the key factors influencing pollen diversity. PCA results showed that polar and equatorial diameters, colpi size, and exine thickness were the most influential pollen features between *Nepeta* species. This study adds to our understanding of pollen morphology in the *Nepeta* genus, offering information on the vast range of characteristics found in this economically important group. The extensive characterization of pollen features provides useful insights for the categorization and differentiation of *Nepeta* species, adding to the Lamiaceae micromorphology.

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