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COMPARATIVE ANATOMICAL ADAPTATIONS OF *Cynodon dactylon* L. PERS. AND *Chloris barbata* Sw. IN SEMI-ARID HABITATS OF GUJARAT, INDIA

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ABSTRACT

Grasses (family Poaceae) are ecologically and economically important plants that exhibit remarkable adaptability to diverse environments, including arid and semi-arid regions. The present study investigated the comparative leaf and stem anatomy of *Cynodon dactylon* (L.) Pers. and *Chloris barbata* Sw., two dominant species occurring in Ahmedabad district, Gujarat, India. Field surveys were conducted during the summer of 2024 using the quadrat method, and plant materials were collected for anatomical analysis. Transverse sections of leaves and stems were prepared by free-hand sectioning and stained with safranin and fast green. Microscopic observations revealed several xeromorphic adaptations in both species, including V-shaped leaf blades, thick cuticles, bulliform cells, abundant sclerenchyma layers, and closed collateral vascular bundles. Notably, *C. dactylon* exhibited aerenchyma in its ground tissue, indicating adaptation to fluctuating soil moisture, whereas *C. barbata* displayed stronger sclerenchymatous reinforcement, suggesting enhanced structural rigidity. Stem anatomy showed thick epidermal walls, well-developed sclerenchyma cylinders, and numerous vascular bundles, features that support efficient transport and storage. These findings demonstrate that both species possess complementary structural strategies that enhance drought tolerance and ecological resilience in semi-arid habitats. The results highlight their potential application in grazing management, soil stabilization, and ecological restoration of stress-prone landscapes.

Keywords **:** Poaceae, Anatomy, *Cynodon dactylon* (L.) Pers., *Chloris barbata* Sw., Drought tolerance, Bulliform Cells.

Introduction

Grasses represent one of the most important groups of plants, providing food, fodder, and ecological stability for both humans and animals. The family *Poaceae* (Gramineae) is the fifth largest family of flowering plants, following *Asteraceae*, *Fabaceae*, *Orchidaceae*, and *Rubiaceae* (Gosavi, 2010). Members of this family range in size from tiny annual herbs less than an inch tall to giant bamboos reaching up to 40 m. Globally, *Poaceae* comprises an estimated 10,300 species across 898 genera (Tzvelev, 1989). In India, the family is represented by ~1,200–1,300 species belonging to 268 genera (Karthikeyan *et al.*, 1989; Moulik, 1997). The wide ecological amplitude of *Poaceae* allows its members to thrive under diverse and often extreme environmental conditions (Simpson, 1990). The name "grass" derives from the Old High German word *gras*, originally referring to forage for livestock. Fossil records indicate that grasses originated in the late Cretaceous period (Stromberg, 2011; Prasad *et al*., 2011). Today, grasslands cover about 24% of the Earth's vegetation, although prior to anthropogenic influences this figure may have been as high as 40% (Shantz, 1954). In Asia, grasslands occupy nearly 20% of land cover (Premadasa, 1990), and in India they form one of the major biomes. Within Gujarat, grasslands are most extensive in Saurashtra and Kachchh (Jadhav *et al*., 1998), with recent expansion into central and northeastern regions (Gandhi, 2018). Beyond their ecological roles, grasses have medicinal and aromatic value. For example, dried leaves of *Cynodon dactylon* (L.) *Pers.* are used for

their anabolic and antiseptic properties, *Setaria italica* has been traditionally employed to treat chicken pox in Pakistan, and *Chloris barbata Sw.* exhibits antibacterial activity (Gangwar *et al*., 2011; Ahmad *et al*., 2011; Natrajan *et al*., 2012). Anatomical investigations of *Poaceae* have further highlighted their significance in systematics, adaptation, and physiology (Ellis, 1979; Kellogg, 2015; Panizzo *et al*., 2017). Among these, *Cynodon dactylon (L.) Pers.* (Bermuda grass) is a rhizomatous perennial widely distributed across tropical and subtropical regions between 45°N and 45°S (Shi *et al*., 2012; Ling *et al*., 2015). It is tolerant to high temperature, drought, and salinity (Chen *et al*., 2015; Hu *et al*., 2015), attributes partly associated with its C4 photosynthetic pathway (Edwards *et al*., 2004; Carmo-Silva *et al*., 2008). C4 photosynthesis, highly successful in families such as *Poaceae* and *Cyperaceae*, provides a competitive advantage under arid and high- temperature conditions (Sage, 2004; Besnard *et al*., 2009). *Chloris barbata Sw.*, first described by Swartz in 1788, is another perennial grass belonging to the same subfamily (*Chloridoideae*). Morphologically, *C. dactylon* is characterized by creeping rhizomes, narrow linear leaves, and 2– 5 digitate spikes, while *C. barbata* is tufted, with 5–12 violet-purple spikes that turn straw-colored upon drying (Shah, 1978).

Comparative anatomical studies of grasses provide taxonomic markers and insights into ecological adaptations. Leaf and stem anatomy have been investigated across diverse species to highlight features such as vascular bundle arrangement, sclerenchyma distribution, bulliform cells, and epidermal traits, all of which play roles in stress tolerance and classification (Shaheen *et al*., 2012; Ahmad *et al*., 2011; Nazir *et al*., 2013; Rafique *et al*., 2021). Anatomical plasticity in response to climatic variation such as changes in vascular bundle number, xylem vessel size, and cortical layers has been shown to aid in species delimitation within *Poaceae* (Shamah *et al*., 2019; Makesh *et al*., 2022). Stress-related anatomical modifications in *C. dactylon* and related taxa include thickening of leaf mesophyll and cortex, enhanced sclerenchyma development, increased bulliform cell size, and accumulation of ions in parenchyma tissues, all of which contribute to salinity and drought tolerance (Hameed *et al*., 2010; Alvarez *et al*., 2008; Boughalleb *et al*., 2009; Geldner, 2013; Hameed *et al*., 2013). Additional adaptations such as leaf rolling, trichome proliferation, and micro-hair density reduce water loss and enhance salt tolerance (Balsamo *et al*., 2006; Hu *et al*., 2015; Noman *et al*., 2014; Qaderi *et al*., 2019). Such structural modifications underscore the resilience of these grasses and their importance in both ecological and applied contexts, including forage production and phytoremediation (Wu & Taliaferro, 2009; Shu *et al*., 2002; Sekabira *et al*., 2011; Tan *et al*., 2017).

Although the anatomical adaptations of grasses have been widely studied in other regions, comparative analyses of *C. dactylon* and *C. barbata* from Gujarat's semi-arid grasslands remain limited. The present study therefore aims to investigate the vegetative anatomy of these two species, with special focus on leaf and stem adaptations, to identify diagnostic traits that may contribute to their ecological success and taxonomic delimitation.

Materials and Methods

***Study Area and Selection of Site*:** The present study was carried out in Ahmedabad district, Gujarat, India (23.03°N, 72.58°E), which covers an area of 464 km² and is divided into eastern and western regions by the Sabarmati River. The district experiences a wide temperature range, from about 12 °C in winter to nearly 45 °C in summer, and supports vegetation such as scrublands, grasslands, and thorn forests. Field investigations were conducted during the summer of 2024 using the standard quadrat method, in which 1 × 1 m quadrats were randomly placed within the study area to systematically record and enumerate grass species. Representative specimens of *Cynodon dactylon* (L.) Pers. and *Chloris barbata* Sw. were then collected for anatomical analysis. For this purpose, freshly grown leaves, stems, and roots were sectioned freehand, subjected to serial dehydration in ethanol, and stained with safranin and fast green using the double-staining technique. Plant material was initially preserved in Formalin–Acetic Acid–Alcohol (FAA) fixative for 48 hours and later transferred to an acetic alcohol solution (25% acetic acid: 75% ethanol, v/v) for long-term storage.

Results

Leaf anatomical characteristics

The transverse sections of the leaf blades of *Cynodon dactylon* (L.) Pers. and *Chloris barbata* Sw. revealed a distinct V-shaped outline, with vascular bundles arranged in a single row running parallel to both the upper and lower epidermal surfaces.

Coastal regions

Upper Epidermis

In both studied species, the upper epidermis was composed of a single layer of spherical to oval cells with thickened outer walls, thinner inner walls, and covered by a prominent cuticle. In *Cynodon dactylon* (L.) Pers., the epidermal cells appeared papillary in

transverse section (Figure 1b), whereas in *Chloris barbata* Sw. the leaves bore numerous prickles (Figures 3b and 3c).

Ground tissue

In *Cynodon dactylon* (L.) Pers., the ground tissue consisted of aerenchyma, followed by two to three layers of chlorenchyma cells containing abundant chloroplasts and enclosed by thin cellulose walls (Figure 1b). In contrast, the ground tissue of *Chloris barbata* Sw. was composed of four to seven irregular, large parenchyma cells with thin cellulose walls and devoid of chloroplasts, succeeded by two to three layers of chlorenchyma cells containing chloroplasts (Figure 3c).

Vascular tissue

The vascular tissue in the leaves of both species consisted of oval, closed collateral bundles. Each bundle comprised xylem oriented toward the upper epidermis in a distinct V-shaped arrangement, with vessels possessing thick lignified walls and large cavities, and an inverted metaxylem occupying the tip of the V. The phloem, containing companion cells and sieve tubes, was positioned near the lower epidermis. Large vascular bundles were enclosed by a double-layered bundle sheath: the outer layer composed of parenchyma cells with thin cellulose walls and some chloroplasts, and the inner layer of small, thick-walled, lignified sclerenchyma cells. In all leaves, small vascular bundles were surrounded by a parenchymatous bundle sheath with chloroplasts (Figures 1b and 3b). Large vascular bundles were further connected to the lower epidermis through groups of lignified sclerenchyma cells, arranged in three to five layers in *C. dactylon* (Figure 1b) and in five to seven layers in *C. barbata* (Figure 3b).

Lower epidermis

The lower epidermis of both species resembled the upper epidermis in structure; however, prickles were absent in *C. barbata* (Figure 3b).

Inter coastal Regions

Ground tissue

In both species, the ground tissue consisted of three to four layers of chlorenchyma cells containing chloroplasts and bounded by thin cellulose walls. However, *C. dactylon* (Figure 1c) differed from *C. barbata* (Figure 3c) by the presence of aerenchyma.

Lower epidermis

The lower epidermis of both species was generally similar to the upper epidermis in its characteristics, but bulliform cells and a thick cuticle were absent in *C. dactylon* (Figure 1c) and *C. barbata* (Figure 3c).

Stem anatomical features

Cross-sectioned stems were circular in both *C. dactylon* (Figure 2a) and *C. barbata* (Figure 4a).

Epidermis

The stem epidermis in both species consisted of a single layer of spherical to elliptical cells with thick outer walls and thin inner walls, the outer surface being covered by a prominent cuticle in *C. dactylon* (Figure 2a) and *C. barbata* (Figures 4a and b).

Ground tissue

In *C. dactylon*, the ground tissue consisted of two to three layers of thin-walled parenchyma cells with chloroplasts, followed by three to five layers of sclerenchyma cells arranged in a cylindrical form connected to the external vascular bundle sheath. The remaining ground tissue was composed of parenchyma cells lacking chloroplasts and bounded by thin cellulose walls, with cell size gradually increasing toward the center of the pith and containing large intercellular spaces (Figures 2a and 2b). In *C. barbata*, the ground tissue was made up of three to four layers of chlorenchyma cells with thin cellulose walls and chloroplasts. Groups of three to four layers of lignified sclerenchyma cells were connected to the epidermis, followed by another three to four layers of sclerenchyma forming a cylindrical ring that linked to the vascular bundle sheath. The remaining ground tissue consisted of thin-walled parenchyma cells without chloroplasts, with cell size enlarging toward the pith center and interspersed with distinct intercellular spaces (Figures 4a and 4b).

Vascular tissue

In both species, the vascular bundles were scattered throughout the ground tissue, while the central region of the stem remained free of bundles. The bundles were closed collateral and oval in shape, consisting of xylem and phloem. The primary xylem included metaxylem vessels positioned at the tip of the V-shape, characterized by thick lignified walls and large cavities, while protoxylem vessels were replaced by air spaces or protoxylem cavities. The phloem, located toward the outer side, comprised sieve tubes and companion cells. Across both species, vascular bundles were distributed within the primary tissue and surrounded by a single layer of sclerenchyma cells forming the bundle sheath (Figures 2a and b; Figures 4a and b).

Discussion

Soil salinity and drought stress are among the most critical abiotic factors influencing plant growth worldwide, as they lead to physiological, biochemical, and anatomical modifications (Habib *et al*., 2016). Species of the Poaceae family, including *Cynodon dactylon* (L.) Pers. and *Chloris barbata* Sw., are known to exhibit considerable adaptive plasticity, expressed through structural and functional traits that enhance survival in challenging environments (Sridevi *et al*., 2012; Hameed *et al*., 2011). The present comparative anatomical investigation revealed several features in leaves and stems of both species that correspond to their ability to persist in the semi- arid conditions of Gujarat.

Both species exhibited V-shaped leaf blades with vascular bundles aligned in a single row, a characteristic previously reported in members of the Poaceae (Metcalfe, 1960; Doğan & Tosunoğlu, 1992; Mavi *et al*., 2011). Such leaf morphology reduces the exposed leaf surface area, thereby minimizing transpiration under high temperatures, while allowing for efficient absorption of minerals when water is available. In addition, the thick cuticular layer observed on the epidermis of both *C. dactylon* and *C. barbata* is a xeromorphic adaptation that reduces water loss, consistent with earlier reports (Carmo-Silva *et al*., 2009; Gangwar *et al*., 2011). The presence of stomata on both leaf surfaces and extensive intercellular spaces in mesophyll tissue indicates an efficient balance between gas exchange and internal aeration. Bulliform cells, observed in the upper epidermis, further enhance drought resistance by enabling leaf rolling under water stress, thereby reducing transpiration surface area (Alvarez *et al*., 2008; Grigore & Toma, 2017). Ground tissue anatomy showed interspecific differences with ecological implications. In *C. dactylon*, the presence of aerenchyma, in addition to chlorenchyma, may provide advantages in fluctuating soil moisture regimes, facilitating internal aeration under temporary waterlogging. By contrast, *C. barbata* lacked aerenchyma but exhibited larger parenchyma cells, which may serve as reservoirs for water storage. Both species showed chlorenchymatous layers with abundant chloroplasts, enhancing photosynthetic efficiency, while the presence of multiple layers of sclerenchyma contributed to leaf rigidity, mechanical strength, and grazing resistance (Noor *et al*., 2015). Vascular tissue organization in both species revealed closed collateral bundles with well-developed xylem and phloem. The presence of thick-walled metaxylem elements with wide cavities facilitate efficient water conduction, while bundle sheaths of parenchyma and sclerenchyma cells strengthen vascular tissues and regulate solute exchange. Notably, sclerenchyma strands connecting vascular bundles to the epidermis were more pronounced in *C. barbata* than in *C. dactylon*, suggesting enhanced structural reinforcement in the former. This difference may reflect species-specific strategies: while *C. dactylon* emphasizes aeration and flexibility, *C. barbata* invests more in rigidity and mechanical protection. Stem anatomy also showed adaptations associated with drought tolerance. The epidermis was thickly cutinized, and the ground tissue contained chlorenchyma layers followed by sclerenchyma cylinders connected to the vascular bundle sheath, providing both photosynthetic capacity and mechanical support. Large intercellular spaces in the central ground tissue, along with increasing parenchyma cell size toward the pith, indicated storage potential. The abundance of vascular bundles with well- developed metaxylem and phloem enhances water and nutrient transport, ensuring sustained metabolic activity under stress (Hameed *et al*., 2010).

Together, these findings highlight a suite of adaptive features that enable *C. dactylon* and *C. barbata* to persist in the arid and semi-arid regions of Gujarat. While both species share xerophytic traits such as thick cuticles, sclerenchyma reinforcement, and bulliform cells, *C. dactylon* demonstrates additional features such as aerenchyma, reflecting greater ecological flexibility in variable environments. Conversely, *C. barbata* shows stronger structural traits that provide rigidity and defense. These complementary strategies underscore the ecological success of both species, making them valuable components of natural grasslands and potential candidates for pasture improvement and ecological restoration in stress-prone habitats.

Conclusion

The present anatomical study of *Cynodon dactylon* (L.) Pers. and *Chloris barbata* Sw. revealed a series of adaptive features that support their survival under the arid and semi-arid conditions of Gujarat. Traits such as V-shaped leaves, thick cuticles, bulliform cells, sclerenchymatous reinforcement, and well-developed vascular tissues enhance drought tolerance and water-use efficiency, while interspecific differences such as the presence of aerenchyma in *C. dactylon* and stronger sclerenchymatous layers in *C. barbata* reflect distinct ecological strategies. These adaptations not only ensure persistence in stress-prone environments but also highlight their ecological importance as forage grasses, soil stabilizers, and candidates for grassland restoration. Understanding

such structural and functional traits provides valuable insights into the adaptive potential of Poaceae species and offers a basis for their sustainable utilization in agriculture and ecosystem management.

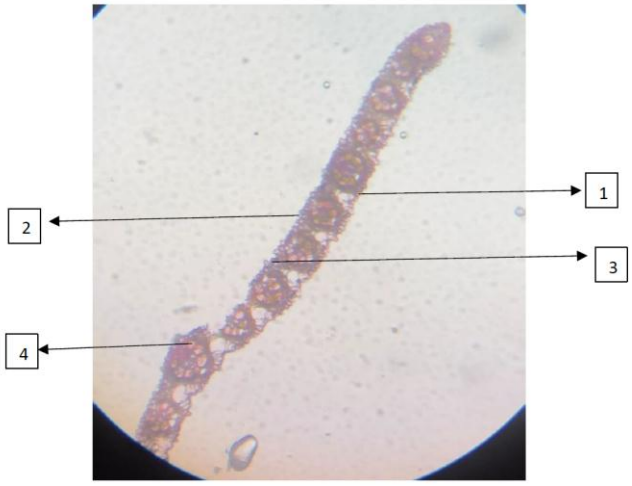

Figure 1 (a)

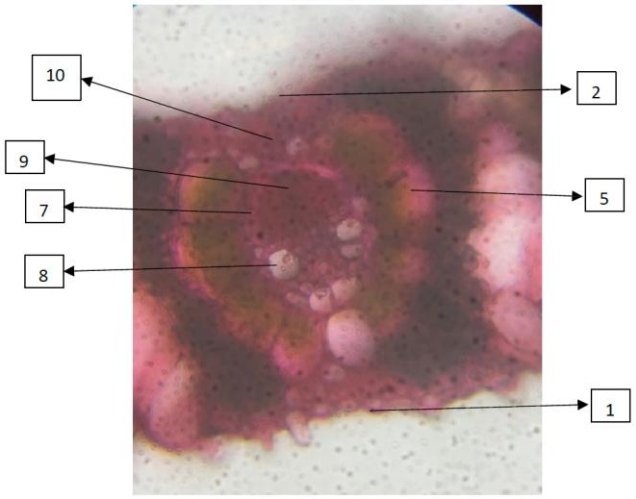

Figure 1 (b)

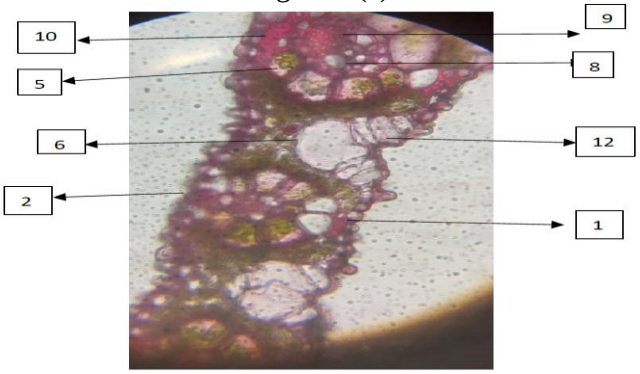

Figure 1 (c)

Fig. 1 : Cross sections of the C. dactylon (L.) Pers. (leaf). a-Blade shape, b-Coastal region, c- Intercostal region, 1-Upper epidermis, 2-Lower epidermis, 3 Intercoastal region, 4-Coastal region, 5-Parenchyma shealth, 6-Aerenchyma, 7-Sclerenchyma shealth, 8-Xylem, 9-Phloem, 10-Sclerenchyma cells, 11-Chlorenchyma tissue and 12-Bulliform cells.

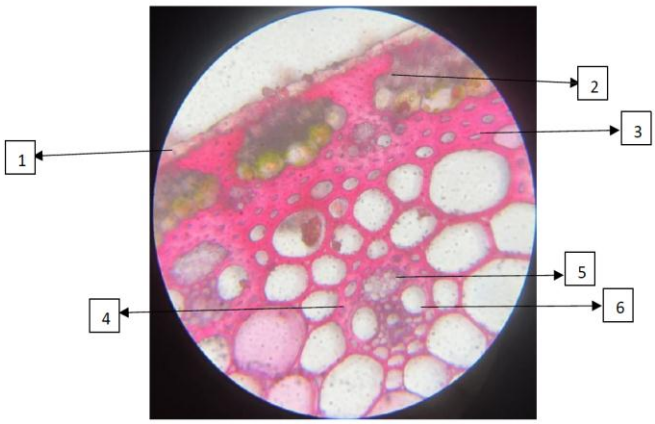

Figure 2 (a)

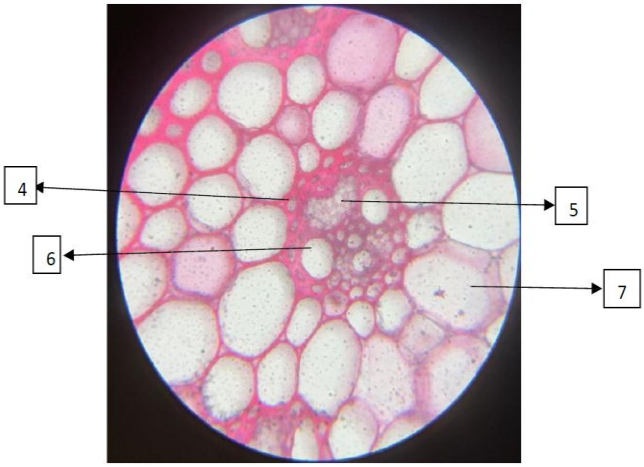

Figure 2 (b)

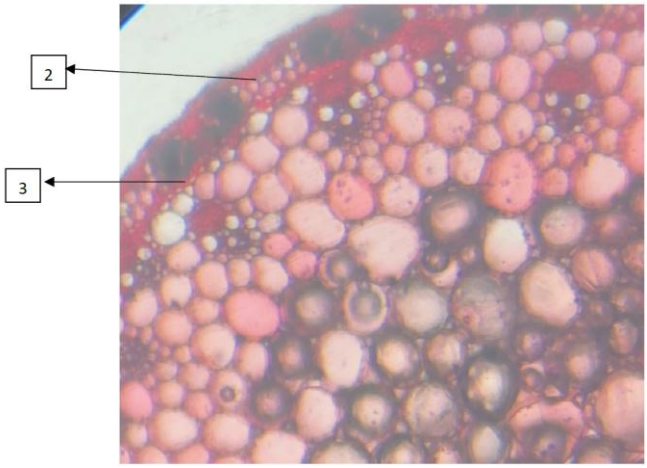

Figure 2 (c)

Fig. 2 : Cross sections of C. dactylon (L.) Pers. (Stem). a 200×, b-400×, c.200×. 1-Epidermis, 2-Chlorenchyma tissue, 3 Sclerenchyma cells, 4-Schlerenchyma shealth, 5-Phloem, 6 Xylem and 7-Parenchyma cells

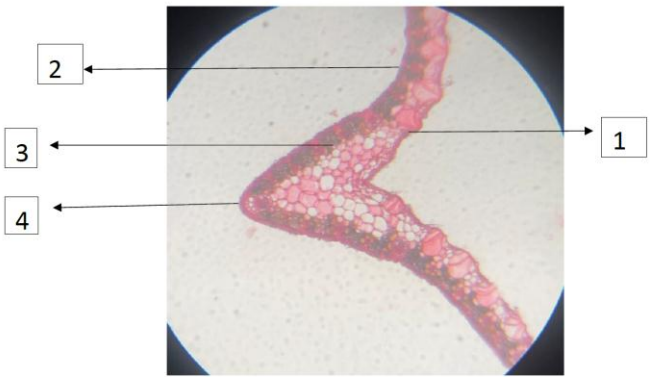

Figure 3 (a)

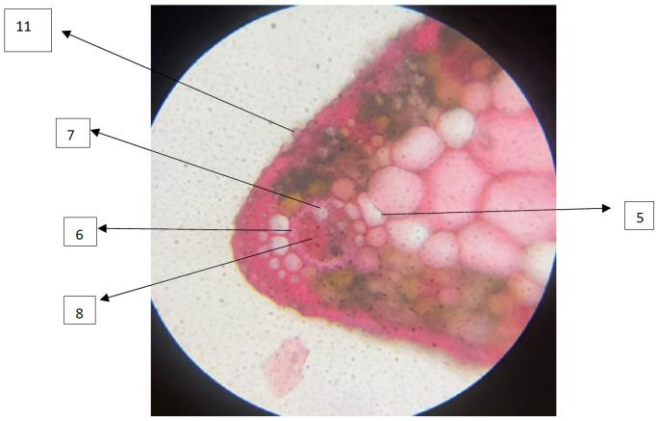

Figure 3 (b)

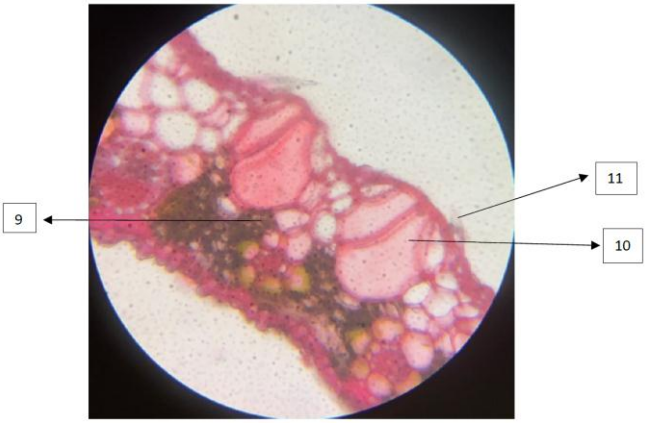

Figure 3 (c)

Fig. 3 : Cross sections of C. barbata SW. (leaf). a-Blade shape in leaf and coastal regions 200×, b-Vascular bundles in coastal regions 400×, c-Intercoastal region 200×, 1-Upper epidermis, 2 Lower epidermis, 3-Intercoastal region, 4-Coastal region, 5 Parenchyma shealth, 6-Schlerenchyma shealth, 7-Xylem, 8 Phloem, 9-Chlorenchyma tissue, 10-Bulliform cells and 11 Prickles.

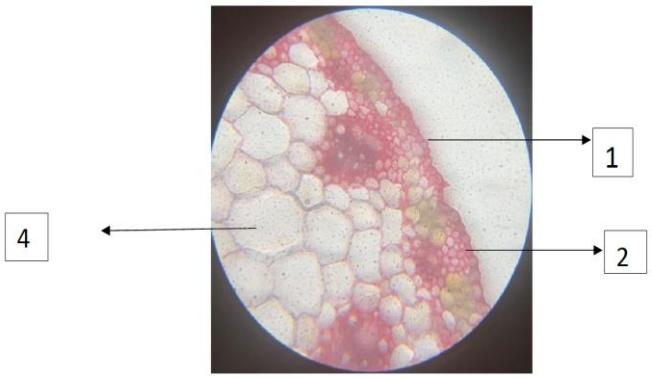

Figure 4 (a)

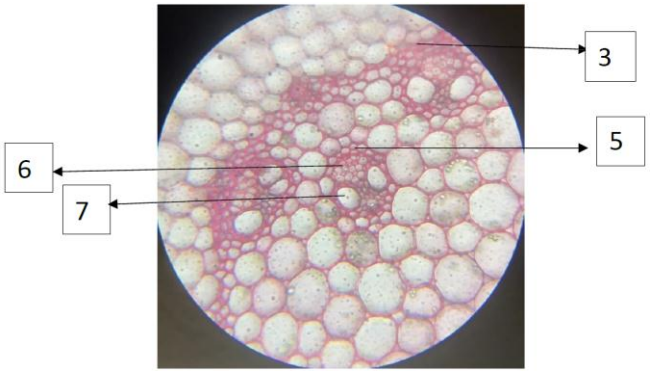

Figure 4 (b)

Fig. 4 : Cross sections in C. barbata SW. (Stem). a-100×, b-400×. 1-Epidermis, 2-Chlorenchyma tissue, 3-Sclerenchyma cells, 4-Parenchyma cells, 5-Sclerenchyma shealth, 6-Phloem, 7-Xylem.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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