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Semi-arid temporary lakes of Bahia, Brazil: anatomy of amphibious species of *Eleocharis* R. Br. (Cyperaceae)

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Abstract. *Eleocharis* is widely distributed and one of the most diverse genera of Cyperaceae. This family occurs from the tropics through Polar regions, with a high concentration of species in the Americas. In Brazil there are about 60 species, without, however, regional studies that point where within the country the highest diversity of this taxon occurs. In this scenario, morpho-anatomical studies have always been featured in taxonomic and phylogenetical approaches of the Cyperaceae. Andconsidering the genus *Eleocharis*, which is usually associated to water habitats and includes many species with an amphibious life form, few anatomical studies have been performed, especially for species found in temporary lakes. This work intends to describe the scape and root anatomy of five species of *Eleocharis* occurring in temporary lagoons of Bahia semiarid region in order to determine characters that could be useful for taxonomy and, especially, the ecology of the species studied. The taxa, in cross section of the scape, are similar, with the presence of a thick cuticle, a large number of fiber bundles, palisade and aerenchyma formed by dissolution of the anticlinal wall of cortical cells. Amongst the analised species, *Eleocharis acutangula* and *E. interstincta*, as well as *E. geniculata* and *E. minima* seem to be closer together. We believe that the formation of aerenchyma only at the root of the base of all species and not from the apex is an ecological attribute, as thickening pericycle would be a taxonomic feature.

Key words: Aquatic plants, monocotyledons, Northeast region

Resumo. **Lagoas temporárias do semiárido da Bahia, Brazil: anatomia de espécies anfíbias de *Eleocharis* R. BR. (Cyperaceae).** *Eleocharis* tem ampla distribuição sendo um dos gêneros mais diversos da família Cyperaceae ocorrendo desde os trópicos às regiões polares com grande concentração de espécies na América. No Brasil ocorrem cerca de 60 espécies, não havendo, contudo, estudos regionais que apontem onde está concentrada a maior diversidade do táxon no país. Mesmo diante deste cenário, estudos morfoanatômicos sempre tiveram destaque em abordagens taxonômicas e filogenéticas de Cyperaceae, e considerando o gênero *Eleocharis*, que tem hábito normalmente aquático e muitas espécies com forma de vida anfíbia, são escassos estudos anatômicos, sobretudo com espécies ocorrentes em lagoas temporárias. Assim, este trabalho visou descrever a anatomia do escapo e raiz de cinco espécies de *Eleocharis* ocorrentes em áreas de lagoas temporárias do semiárido baiano, a fim de levantar caracteres que possam ser úteis para a taxonomia e, principalmente, para a ecologia das espécies estudadas. Os taxa, em seção transversal do escapo, são muito semelhantes, principalmente quanto à observação de características como presença de cutícula espessa, grande número de feixes de fibra, parênquima paliçádico e aerênquima formados pela dissolução da parede anticlinal das células corticais. Das espécies analisadas, *Eleocharis acutangula* e *E. interstincta* assim como *E. geniculata* e *E. minima*, parecem ser mais próximas entre si. Consideramos que a formação de

aerênquima apenas na base da raiz de todas as espécies e não desde o ápice, seja um atributo apenas ecológico enquanto o espessamento do periciclo seria uma característica taxonômica.

Palavras-chave: Plantas aquáticas, monocotiledôneas, Nordeste

Introduction

The family Cyperaceae has a cosmopolitan distribution and includes around 120 genera and 4,500 species. In Brazil occur about 40 genera and 600 species (Souza & Lorenzi 2012). Among the most speciose genera of the family is *Eleocharis* R. Br with approximately 250 species that are usually aquatic and amphibious distributed from the tropics to the Polar regions with a high concentration of species in the American continent (Diego-Perez 1997).

According to Gil & Bove (2007), 60 species of *Eleocharis* are registered and more than 80 names have been published. Despite the large number of species that are reported, there is no study that deals specifically and significantly with the species of this genus. *Eleocharis* has an outstanding presence in floristic surveys, mostly of the time related to and restricted to works of flora and ecology of aquatic environments as observed in Pott & Pott (1994), Gil & Bove (2007), Trevisan & Boldrini (2008), Henry-Silva et al. (2010).

Anatomical works on aquatic genera of Cyperaceae are scarce compared to terrestrial genera (Prata *et al*. 2007, Leite e*t al.* 2009), and when they occur they are not exclusive to *Eleocharis* (Metcalfe 1971, Govindarajalu 1975, Soros & Dengler 1998, Rocha & Martins 2011) or address single species (Martins & Scatena 2015).

Eleocharis is amphibious, rarely submerged and it occurs on banks which are occasionally dry in lotic and lentic environments (Bove et al. 2003, Gil & Bove 2004, 2007). Lentic environments in the semi-arid regions occur in the form of lakes formed during the short rainy periods that usually do not last more than three months, while the drier period can last up to 11 months (Maltchik & Pedro 2001). Moreover, according to Maltchik & Pedro (2001), these water bodies exert an essential role in the supply of water and are a refuge for the biota of the region, thus contributing to the biological and landscape diversity. It is around these water bodies, even though they are temporary, that the local population is concentrated.

Eleocharis was selected for this research because it is among the dominant Cyperaceae and is present in various taxonomic lists (Gil & Bove 2004, 2007, Trevisan & Boldrini 2008). It is present primarily in the semi-arid region of Bahia (França *et al*. 2003) and plays an important ecological role, as it is often the only green substrate of the site. The genus is present almost all year round due to the amphibious habitat (Irgang *et al.* 1984) and its morphological capacity for stolon formation, which gives the possibility of perenial taxon (Haines & Lye 1983).

The *Eleocharis* species have as a remarkable feature the absence or reduction of the leaf blade and the scape is the main photosynthetic organ. More indepth anatomical studies with species of the genus have been presented in classic works (Metcalfe 1971, Govindarajalu 1975). More specialized and recent studies have been published by Roalson *et al*. (2010) and Martins & Scatena (2015) who evaluated the anatomical variety of the Kranz structure in vegetative organs with species of the genus under different environmental conditions.

Thus, the aim of this study was to investigate the occurrence of anatomical characteristics in *Eleocharis* species that occur in temporary lakes of the semiarid region which can, besides providing taxonomic information for the family, correlate with the environment in which they grow, mainly because they occur only in rainy periods or in wet soils but distant from water bodies.

Materials and methods

The samples selected for this study were collected randomly in different temporary lakes within the Semi-arid region in Bahia State, Northeastern Brazil, belonging to different populations, between localities of Ipirá and Irecê, formed during the rainy season in the region in low-lying areas. Vouchers were incorporated into the collection of Alexandre Leal Costa Herbarium of the Federal University of Bahia (acronym ALCB, according to Thiers 2016). Sampled species are *Eleocharis acutangula* (Roxb.) Schult. (Guedes, M.L. et al. 20635), *Eleocharis geniculata* (L.) Roem. & Schult. (Guedes, M.L. et al. 20658), *Eleocharis interstincta* (Vahl) Roem. & Schult. (Guedes, M.L. et al. 20661); *Eleocharis minima* Kunth (Guedes, M.L. et al. 20617); *Eleocharis* sp. (Guedes, M.L. et al. 20701).

Three individuals were collected in each population where the species occurred. For all

individuals collected, these were sectioned in the median region, from the base of the insertion of the scape.

For the anatomical analyses using light microscopy, fresh material of the species was collected in temporarily full lakes from the Northeastern semi-arid region of Bahia. Scapes of the individuals collected were fixed in FAA 50% and after twenty-four hours, stored in 70% ethanol (Johansen 1940).

In the laboratory, the middle region of the scapes was paradermically and transversely sectioned with the free-hand technique using a razor blade; the sections were clarified using 50% commercial sodium hypochlorite, subsequently, the sections were washed in distilled water, and stained with astra blue and safranin (modified from the technique by Bukatsch 1972 by Kraus & Arduin 1997), respectively, and mounted on semi-permanent slides with 50% glycerol.

Results and Discussion

The *Eleocharis* species that were analyzed are, according to the terminology used by Gil & Bove (2007), perennial herbs, aphyllous with a habit varying from cespitose–stoloniferous, cespitose and subwoody to absent rhizome or even elongated with short internodes. The scapes have different shapes varying from cylindrical, triangular, to quadrangular with or without septa. In the collection areas, they were observed growing always after the beginning of the rains while the soil is still damp, and/or very close to the water body, and often with the scape submerged. This was considered an amphibious habit (Irgang *et al.*1984) such as observed in other genera and species of the family by Leite *et al.* (2009, 2012).

Some convergent characteristics of the life form of the species studied such as thick cuticle, a large number of aerenchyma and xylem reduction were observed in all the materials analyzed. In cross sections (Fig. 1A-I), only E. acutangula (Fig. 1A-B) presents a triangular scape whereas the other species have a circular scape (Fig. 1C-I). The triangular type is also commonly observed in the Cyperaceae family. One point sout that even occurring in rainy periods, all the species presented thick cuticle and a predominant presence of long fibers just below the epidermis (Fig. 1B, F-H), sometimes interrupting this layer. This is related to the mechanical support that gives the erect posture of the scape. This organization is considered to be characteristic of species that belong to various different families of Poales (Jesus Junior *et al*. 2012, Daltin *et al*. 2015).

All the plants that were studied present a scape with two to three layers of palisade parenchyma (Fig. 1B, D) strongly compressed and with many chloroplasts forming the center of photosynthetic activity (Haines & Lye 1983). In this region, the palisade parenchyma, more internal in some species as for example in *E. geniculata*, is discontinuous due to the size and organization of vascular bundles (Fig. 1E). The palisade parenchyma occupies about one-third of the total scape area (Fig. 1C-F, H). Vascular bundles of collateral type and large air cavities were observed internally or in an interchangeable form adjacent to the palisade parenchyma (Fig. 1A-B, E, H).

In the species that have a slender scape as for instance *E. geniculata*, *Eleocharis* sp. and *E. minima* (Fig. 1E-F, H), there is reduction of the number of vascular bundles compared to the species *E. acutangula* and *E. interstincta* (Fig. 1A-D) in which the aerenchyma and the diaphragm are more evident. Also, it was observed that species with a smaller and more slender scape show a medullary region that is mainly filled with more compact parenchyma cells (Fig. 1E-F, H) while in species that show a more developed scape, there exists a predominance of brachyform parenchyma amidst the aerenchyma (Fig. 1A), forming the diaphragms that contribute to the mechanical support of the proper network of the scape of the aerenchyma giving mechanical support and avoiding its collapse of the organ as to the possibility of a lack of water in periods of drought when they are permanently emergent besides making the transport of atmospheric gases into the organ easier (Sorrell *et al.* 2002). This tissue was best observed in *E. acutangula* and *E. interstincta* cells have five to eight braciform extensions. *E. acutangula*, which shows triangular scape, has the largest number of air cavities and are delimited by only one row of cortical cells.

The air cavities in all the species are formed by the space between the cortical cells and must probably be of schizogenous origin (Fig. 1A, D-E, H-I) as referred in vegetative organs, such as the leaf and the scapet in other genera of Cyperaceae (Leite *et al.* 2009, 2012).

The pattern of schizogenous formation of the aerenchyma observed in the scape of the species that were studied here, as well as the pattern observed in aerial organs of other groups of aquatic species, seems to be associated with the effect of depth and level of gas transport of the organ in which aerial organs tend to absorb more atmospheric oxygen

transferring it to more basal regions, whereas submerged organs and organs located in a substrate with an excess of organic matter tend to concentrate more ethylene in their tissues causing the disruption of the cell wall and featuring the formation of lysigenous aerenchyma. Jung *et al*. (2008) state in their work that the schizogenous or lysigenous formation of aerenchyma depends on the format and the direction of formation of the aerenchyma. Regardless of which type is displayed, the process

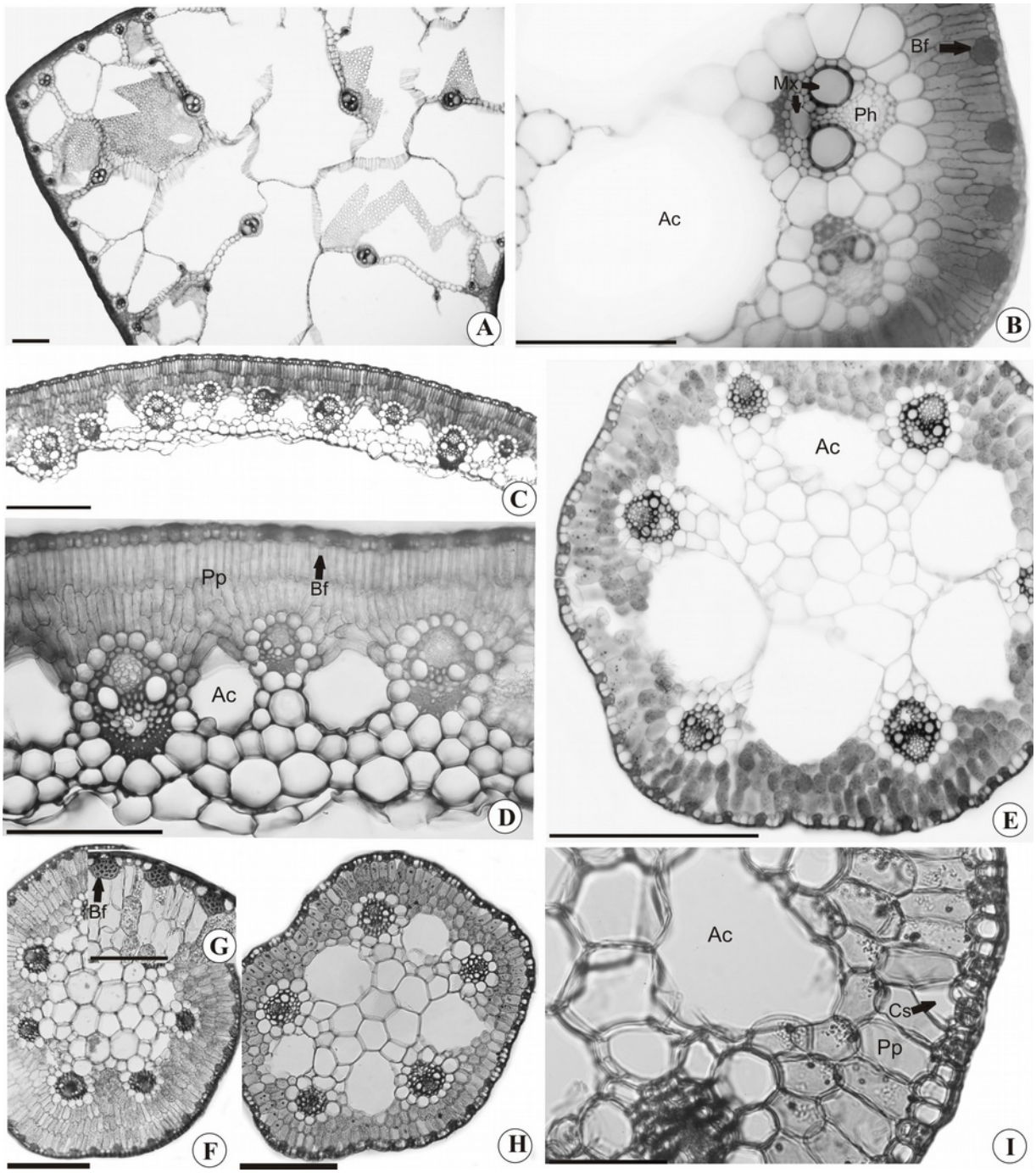

Figure 1. Anatomical aspects of transverse sections of scapes of *Eleocharis* species occurring in a semi-arid region, Bahia, Brazil. A-B. *E. acutangula*. A. General aspect with brachyform parenchyma forming the diaphragm. B. Detail of fibers and vascular bundle. C-D. *E. interstincta*. C. General aspect. D. Detail of parenchyma palisade and endodermis of the vascular bundle. E. *E. geniculata*. Detail of reentrance in the epidermis. F-G. *Eleocharis* sp. F. General aspects – organization of the vascular bundles. G. Detail of bundle fibers. H-I. *E. minima*. H. General aspect of vascular bundles and air cavities. I. Detail of air cavities and stomatal chambers. Ac = Air cavity; Bf = Bundle fibers; Cs = Stomatal chambers; Mx = Metaxylem; Ph = Phloem; Pp = Palisade parenchyma. Scale: A=250µm; B, D, E, G, I=100µm; C=300µm. F, H = 200µm.

through which these air chambers are formed is directly related to lowering of oxygen levels during the develpment of aquatic plants.

E. geniculata and *E. minima* have anatomical aspects that are very similar (Fig. 1E, H) from the epidermis to the region of denser cortical parenchyma, differing from *Eleocharis* sp. only by the difference in number of vascular bundles, five and eight, respectively. *E. acutangula* and *E. interstincta* were the most distinct of all the species; but were similar to each other. In these two species a large number of vascular bundles (around 65 for E. interstincta) were observed and a large amount of brachyform parenchyma. In the species that were studied, all the bundles were collateral and the species presented photosynthesis C3 as reported by Martins & Alves (2009) for various *Eleocharis* species of the northeast region of Brazil.

Several authors consider *Eleocharis* as a genus presenting high plasticity due to the presence of both Kranz anatomy and non-Kranz anatomy depending on the environmental conditions (Murphy *et al*. 2007; Martins & Scatena 2015). It was observed in our study that *E. minima* collected in areas of temporary lakes showed a non-Kranz anatomy, differing from those reported by Martins and Scatena (2015) who reported only the C_4 pattern for specimens collected in the southeastern region of Brazil in terrestrial and submerged conditions.

Besides the cross-sections, paradermal, sections were analyzed in all the species (Fig. 2AH). Elongated epidermal cells with thick walls were observed. They varied from highly sinuous in *E. acutangula* and *Eleocharis* sp. (Fig. 2A, H) to moderately sinuous in *E. interstincta*, *E. geniculata* and *E. minima* (Fig. 2D-E, G). The stomata presented dumbbell-shaped guard cells and subsidiary cells with parallel sides (Fig. 2B), distributed in longitudinal rows and interspersed by intercostal zones.

The differentiation of species was observed in the distribution of the stomata and the size of the epidermal cells that were elongated in *E. geniculata*, *E. minima*, and *Eleocharis sp*. (Fig. 2E, G-H) and short in *E. acutangula* and *E. interstincta* (Fig. 2A, D). Only *E. interistincta* had stomata forming blocks of two or three rows (Fig. 2F) whereas in the other species the rows were unique and without the formation of blocks (Fig. 2J). It was also possible

to note that these two species are the ones that show most stomata (*E. interistincta*, mainly), which may be explained by the fact that both are located more within lakes, thus having an increased supply of water and/or moisture compared to other species.

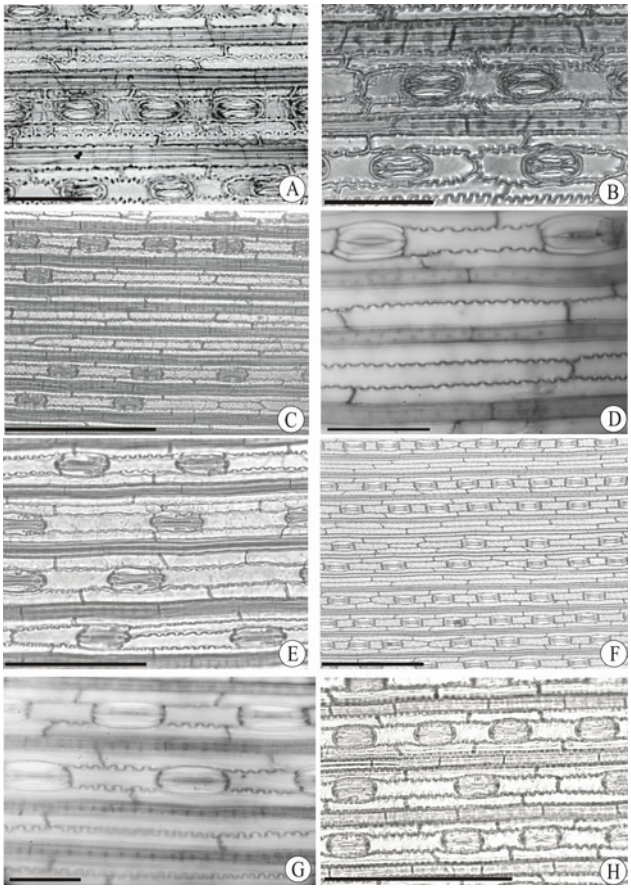

Figure 2. Anatomical aspects of paradermal sections of scapes of *Eleocharis* species ocurring in the semi-arid region, Bahia, Brazil. A-B. *E. acutangula*. A. General aspect. B. Detail of sinuous of cell walls. C-D. *E. minima*. C. General aspect with irregular distribution of stomates in costal zone. D. Detail of slightly sinuous cell walls. E. *E. geniculata*. General aspect of cell wall with regular distribution of stomata. F-G. *E. interstincta*. F. General aspect. G. Detail of slightly sinuous cell walls. H. *Eleocharis* sp. General aspect of sinuous cell walls. Scale: A-C-E, G = 100μm; F = 200 μm; H = 150 μm.

In the analysis of the cross-sections of the roots, five species showed well-organized uniserial epidermis and cortex (outer, median and inner) (Fig. 3A-F).

The species presented an exoderm with one to two layers of cells (Fig. 3A-F) ranging from globose (Fig. 3C) to polyhedral (Fig. 3A, D-F) thicker in *E. interstincta* and *E. geniculata* (Fig. 3D-E). The median cortex is the most evident tissue in all the species and the number of layers varies from seven (*E. minima*) to eleven (*E. interstincta*) layers of cells. In this tissue, the “lysis” of the anticlinal walls of the cells forming lysigenous aerenchyma could be

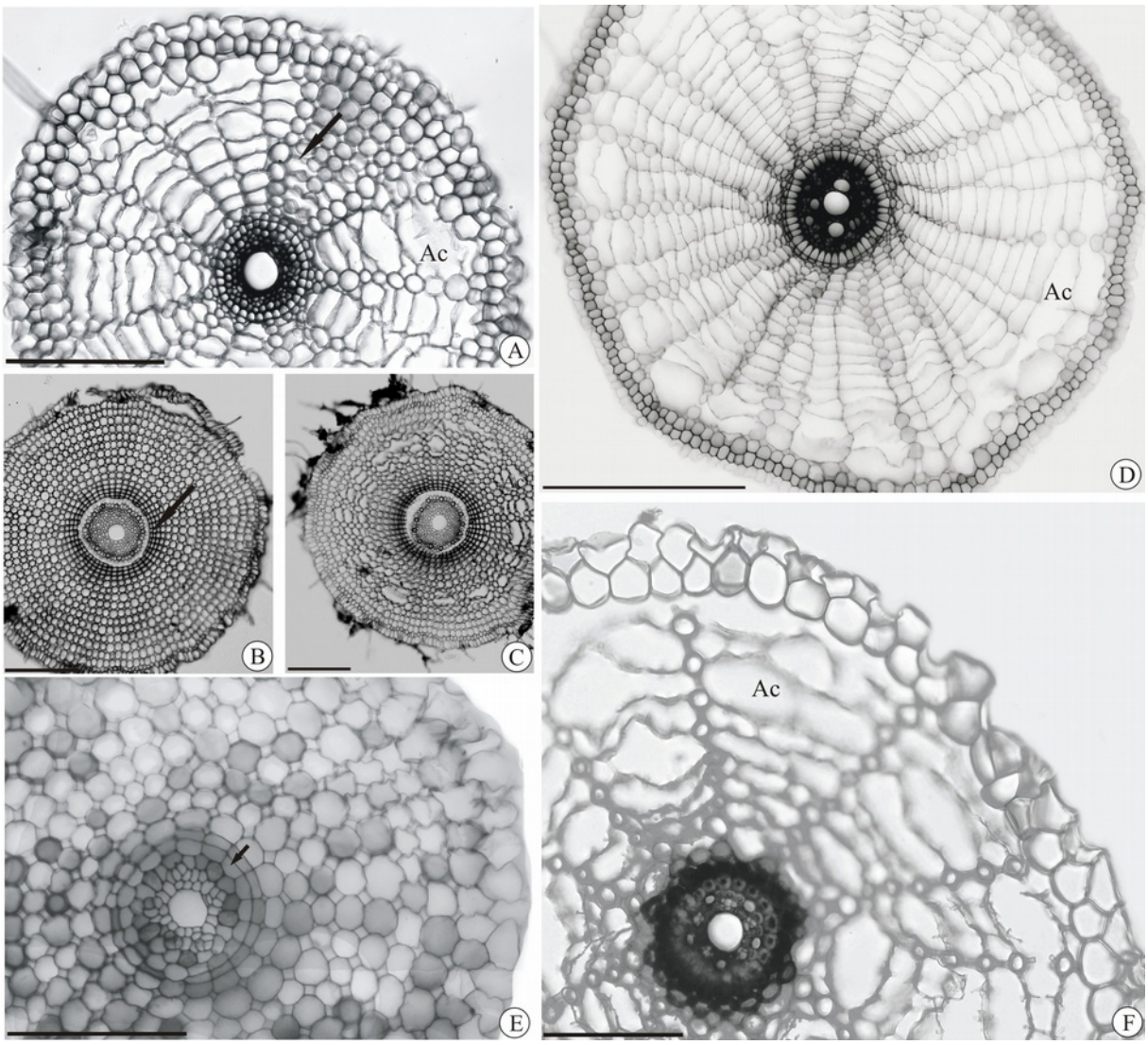

Figure 3. Anatomical aspects of transverse sections of roots of *Eleocharis* species ocurring in the semiarid region of Bahia, Brazil. A. *E. acutangula*. Detail of the region of cell wall lysis and air cavity formation (arrow); B-D. *E. interstincta*. B-C. Detail of the root section in apical and basal region, respectively, showed different stages. D. Air cavities arising from schizogenous to lysigenous processes. E. *E. geniculata*. Meristematic endoderm formation pattern (arrow). F. *Eleocharis* sp. Pericycle of sclerified cells. Ac = air cavity; Scale: A, C: 150µm, B: 250µm, D: 100µm; E: 200µm.

observed (Fig. A, C-D, F). During the study, the sections of the apex of the roots in development (region of the hood, or near it) showed an intact cortex region (Fig. 3B) while the sections made at the root base (Fig. 3C, F) showed the cortex with the aerenchyma well developed. The internal cortex presents thickening of the cells in "U" or in "O" (Fig. 3A, F respectively) and all of them present, as observed by Lima and Menezes (2008), the meristematic activity of the endodermis. The vascular cylinder presents uniserial pericycle in all the species and is strongly lignified only in *Eleocharis* sp. (Fig. 3F) and the number of xylematic poles is variable among the species.

Conclusion

Characteristics such as the formation of aerenchyma and xylem reduction by the plant body are typical of aquatic plants and it is important to note that these plants are adapted to two periods of stress during the year. In the dry period of the semi-arid region it was observed that aerenchyma formation does not occur from the apex and is greater at the base of the root. The mechanical support of the plant was derived only from the presence of few fibers in the scape, and for some species such as E. insterstincta and *Eleocharis* sp., the thickening of the pericycle was greater in the

root.

It is believed that the formation of the lysigenous and schizogenous aerenchyma in *Eleocharis* species with amphibious life form occurs due to the strong variability of rainfalls and difference of insolation in the region, which causes the plant to adapt rapidly to different ecological conditions.

It the field it was verified that *E. acutangula* and *E. interistincta* tend to live closer to the water body, towards the center of the lakes. These species have larger scapes and more evident spaces for gas circulation. The other species, with scapes of reduced size, were collected on the banks of the water bodies.

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