Comparative Morphology and Anatomy of Few Mangrove Species in Sundarbans, West Bengal, India and its Adaptation to Saline Habitat

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Abstract

Mangroves cover large areas of shoreline in the tropics and subtropics where they are important components in the productivity and integrity of their ecosystems. High variability is observed among the families of mangroves. Structural adaptations include pneumatophores, thick leaves, aerenhyma in root helps in surviving under flooded saline conditions. There is major inter- and intraspecific variability among mangroves. In this paper described morpho-anatomical characters helps in identification of family and genus and species of mangroves. Most of the genus have special type of roots which include Support roots of *Rhizophora,* Pnematophores of *Avicennia, Sonneratia,* Knee roots of *Bruguiera*, *Ceriops,* Buttress roots of *Xylocarpus.* Morpho-anatomically the leaves show xerophytic characteristics. This morphological and anatomical response to local conditions may allow the trees to maximize their photosynthetic efficiency Most of the species are now endangered species due to environmental effects and human activities.

1. Introduction

The term “mangrove” refers to grouping of tropical trees and shrubs that grows in the intertidal zone. Mangroves include approximately 16 families and 40 to 50 species (depending on classification). According to Tomlinson (1986), the following criteria are required for a species to be designated a “true or strict mangrove”: Complete fidelity to the mangrove environment, major role in the structure of the community and has the ability to form pure stands. These plants possess morphological and physiological adaptation to their habitat. They should be isolated taxonomically from terrestrial relatives. Thus, mangrove is a non-taxonomic term used to describe a diverse group of plants that are all adapted to a wet, saline habitat. Mangrove may typically refer to an individual species. Terms such as mangrove community, mangrove ecosystem, mangrove forest, mangrove swamp, and mangal are used interchangeably to describe the entire mangrove community.

1.1. Distribution

Mangrove distribution is circumglobal with the majority of populations occurring between the latitudes of 30° N and S (Tomlinson, 1986). At one time, 75% of the world’s tropical coastlines were dominated by mangroves. Unfortunately, mangrove extent has been significantly reduced due to human activities in the coastal zone. There are two centers of mangrove diversity: the Eastern group (Australia, Southeast Asia, India, East Africa, and the Western Pacific) where the total number of species is approximately 40 and the Western group (West Africa, Caribbean, Florida, Atlantic South America, and Pacific North and South America) where the number of species is only 8.

The Sundarbans- World largest delta and continuous mangrove forest, covering about 10200 m^2 of land and water within the Ganga, Bramhaputra and Meghna delta, with some approximately 6000 km of reserve forest located in Bangladesh and the rest aprroximately 4200 m^2 reserve forest in West bengal, India. The flora of the Indian Sundarban includes 26 true mangrove species, 29 mangrove associates, and 29 back mangrove species of 40 families and 60 genera (Naskar and Guha Bakshi, 1995).

An overview of tropical mangrove community ecology, based primarily on Australian Work, can be found in Robertson and Alongi (1992). Li and Lee (1997) reviewed much of the Chinese mangrove literature published between 1950 and 1995. Ellison and Farnsworth (2001) have recently published a general review of mangrove ecology.

There is major inter- and intra-specific variability among mangroves. For example, physiological differences have been identified between West African and Western Atlantic *Avicennia germinans* (Saenger and Bellan, 1995) and distinct chemotypes have been described for *A. germinans* and *Rhizophora* (Corredor et al., 1995; Dodd et al., 1995; Rafii et al., 1996). Variability may result from genotypic differences or from phenotypic responses to local environments. Mean leaf area of *Rhizophora mangle* in Mexico, for example, is positively correlated with annual precipitation and negatively correlated with latitude. This morphological response to local conditions may allow the trees to maximize their photosynthetic efficiency (Rico-Gray and Palacios-Rios, 1996a). Similarly, leaf area indices can be used to differentiate *Rhizophora mangle* from basin and dwarf forest types in southeast Florida, USA (Araujo et al., 1997).

1.2. Ecological significance

With a low productivity, most ecologists today view them as highly productive, ecologically important systems. Major roles of mangrove swamps are mentioned:

- It contribute to soil formation and help to stabilize the system
- It act as filters for upland runoff.
- The systems serve as habitat for many marine organisms such as fish, crabs, oysters, and other invertebrates and wildlife such as birds and reptiles.
- It produces large amounts of detritus that may contribute to productivity in offshore waters.
- Mangrove forests serve as protection for coastal communities against storms such as hurricanes.
- It also serves as nurseries and refuge for many marine organisms that are of commercial or sport value. Areas where widespread destruction of mangrove has occurred usually experience a decline in fisheries. Many threatened or endangered species reside in mangrove forests.
- Mangrove forests are also important in terms of aesthetics and tourism. Many people visit these areas for sports fishing, boating, bird watching, snorkeling, and other recreational pursuits.

1.3. Physiological adaptation

Mangrove species use two major methods of internal ionic regulation. Salt excluding species do not take salt water internally. The red mangrove is a salt excluder separating fresh water at the root surface by making a type of non-metabolic ultrafiltration system. Transpiration at the leaf surface creates negative pressure in the xylem. This causes a type of "reverse osmosis" to occur at the root surface. The salt concentration of xylem sap in the red mangrove is about 1/70 the salinity of surrounding seawater, but this is l0 times higher than in normal plants. Black and White mangroves regulate ionic concentration by excreting salt through glands on the leaf surfac. This temperature sensitive enzymatic process involves active transport with energy expended. Xylem sap is 1/7 concentration of salt water. This is l0 times the concentration of the salt excluders. All three species exhibit to a small degree a combination of both methods of salt regulation. The Red mangrove stores and disposes of excess salt in the leaves and fruit. Black and White mangroves are capable of limited salt exclusion in the roots. Lenticels and spongy tissue in roots and modified branches facilitates gaseous exchange. In Black mangroves, spongy pneumatopphores (up to l0,000 per tree) extend up to 20 cm above the sediment. Prop roots in the Red mangrove possess many lenticels which allow O_2 diffusion with passage to underground roots by means of open passageways (aerenchyma). In the White mangrove, lenticels in the lower trunk obtain O_2 for aerenchyma. Peg rootsand pneumatophores may be present when found in oxygen deprived sediments.

Five species of mangroves (*Bruguiera gymnorrhiza, Excoecaria agallocha, Heritiera fomes, Phoenix paludosa* and *Xylocarpus granatum*) were investigated with respect to their photosynthesis rate, chlorophyll content, mesophyll conductance, specific leaf area, stomatal conductance and photosynthetic nitrogen use efficiency under saline (15-27 PPT) and non-saline (1.8-2 PPT) conditions (Nandy et al., 2007). In this study, it was found that elevated assimilation rate coupled with increased chlorophyll content, more mesophyll and stomatal conductance and higher specific leaf area in nonsaline condition indicates that these mangroves can grow well even with minimal salinity in soil.

It has been documented that xylem anatomy and leaf tissue of *Laguncularia racemosa* appeared to be modulated by salinity, which led to a coordinated decline in hydraulic properties as salinity increased. Therefore, these structural changes would reflect functional water use characteristics of mangrove leaves under salinity (Sobrado, 2007).

High salinity levels (400 mM NaCl) reduces photosynthesis in leaves of *Bruguiera parviflora*, primarily by reducing diffusion of CO_2 to the chloroplast, both by stomatal closure and by changes in mesophyll structure, which decreased the conductance to CO_2 within the leaf, as well as by affecting the photochemistry of the leaves (Parida et al., 2004).

Morpho-anatomy play important role in adaptation in mangroves, but few studies have been undertaken. The present paper illustrates the morphological, anatomical variations in root, stem, leaf, which help in identification of families and species and to understand leaf physiological processes.

2. Materials and Methods

A survey has been made recently to study mangrove vegetation in the Indian Sundarban area, a region of great diversity. We studied morphology and anatomy of few species of mangroves in relation to adaptation to saline habitat. Leaves, stems, roots of different families of mangrove materials were collected from the Sunderban area of West Bengal (Mangrove Ecological Park, Calcutta Wildlife Society) during August 2011 and put in a polythene bag containing water. Thin sections were cut by using a sharp razor blade. The sections were immersed in water to avoid the formation of air bubbles. Sections were stained with Safranine. Excess of stain was washed with water. Then, sections were stained with fast green solution and the excess of stain was washed with water. Thereafter, sections were mounted in Glycerol and covered with cover slip and observed under microscope.

3. Results and Discussion

Some of the mangrove families show different morphological and anatomical characters. Morphologically they differ in root, stem, and leaf. Most of the mangroves have leathery type leaves and sunken stomata. The dominant families and halophytes represented in the coastal area of Sunderban are mainly Avicenniaceae , Rhizophoraceae, and Lythraceae (Sonneratiaceae), among others. All the species have thick cuticle. The average value for cuticle thickness is much greater in mangrove plants studied presently compared with other mesophytes and some of the causal factors that effect cuticular features are identified (20-21). The enlarged cell layers of hypodermis and mesophyll greatly contribute towards the increase of succulence. The salt content of the soil is the chief factor that causes succulence in shore plants and halophytes. The water storage tissue plays an important function in regulating the water loss and the transpiration process is very significant in understanding the ecophysiological relationships in mangrove (Li et al., 2009).

3.1. Morphological Characters

Mangroves are well adapted to the coastal environment (different mangroves in Plate 1-3). They mostly exhibit respiratory roots, extensive support roots, buttress roots, knee roots, salt-excreting leaves, and viviparous water-dispersed propagules. These characters may different in different taxa as follows:
Support roots- *Rhizophora*
Pnematophores- *Avicennia, Sonneratia*
Knee roots- *Bruguiera*, *Ceriops*
Buttress roots- *Xylocarpus*

The specialized roots are important sites of gas exchange for mangroves living in anaerobic substrata. The exposed surfaces of roots may have numerous lenticels (loose, air-breathing aggregations of cells (Tamlinson, 1986). *Avicennia* possesses lenticel – equipped pneumatophores (upward directed roots) through which oxygen passively diffuses. *Sonneratia, Avicennia, Xylocarpus, Bruguiera,* and *Ceriops* exhibit a system of air-filled cable roots.

Mangrove leaves are almost leathery with obscure leaf veins (there are no vein sheaths). The cuticle is thick and smooth with small hairs, giving the plant a glossy appearance. The leaves are of moderate size and are arranged in a modified decussate (bijugate) pattern with each pair at an angle less than 180° to the preceding pair. This arrangement reduces self-shading and produces branch systems that fill space in the most photosynthetically efficient way (Tomlinson, 1986). The leaves generally show dorsiventral symmetry though isolateral leaves are also found in *Kandelia candel*, *Sonneratia apetala* and *Phoenix paludosa* (Das et al., 1996).

The mangrove plants exhibit several xeromorphic characters. The leaves are succulent. Sometimes stems also become succulent. Some of the families' leaves characters are given in Table 1.

3.2. Anatomical Characters

3.2.1. Root Anatomy

It consists of epidermis, cortex, and vascular bundles (Plates 4-5). Epidermis is single layered; the cork consists of suberized cells. The cork layer remains consists of alternating layers of suberized and ordinary pharenchymatous cells in the aerial portion. Cortex is thick and containing abundant, large, intercellular spaces, arranged radially around the stele. Cortex is divided into two parts, primary cortex and secondary cortex. The primary cortex is broad and lacunar. The secondary cortex is found beneath the cork. The cells which are present in primary cortex help in mechanical support. Idioblast cells also present in cortex. The endodermis is not clear. Numerous secretory cells are found in pericycle region. Xylem is lignified. Oil cells are present in the pith region.

The lenticels may be closed, partially opened or fully opened, depending on environmental conditions (Ish-Shalom-Gordon and Dubinsky, 1992). The spongy pneumatophores are generally short (<30 cm), but grow much larger and become more numerous in *Avicennia marina* living in anaerobic and oil-polluted conditions. This phenotypic response apparently increases surface area for gas exchange (Saifullah and Elahi, 1992). In *Sonneratia*, the pneumatophores may be 3 m long and stout from heavy secondary thickening (Tomlinson, 1986). In *Rhizophora*, the roots become thinner and form "capillary rootlets" with a simple diarch stele and a narrow cortex (Tomlinson, 1986).

There is great development of aerenchyma in pneumatophore

Table 1. Leaf characteristics of different mangrove species

Family	Species	Leaf characters
Avicenniaceae	*Avicennia officinalis*	Leaves are leathery, shiny, and medium size; Opposite and deccasate orientation; Ovate shape; Lamina elliptic and oblong; Rounded apex; Upper surface is glabrous; Midrib and viens are prominent; Small petiole with semi terrate; and Exstipulate
	Avicennia alba	Dark green leaves. Leaves are somewhat leathery. oblong linear shape. Opposite leaves. Lamina linear. Acute apex, Mid rib somewhat swollen. Small petiole. Exstipulate
	Avicennia marina	Leaves are leathery, Medium size leaves. Opposite. Ovate shape, Lamina. Elliptic oblong. Somewhat rounded apex. Upper surface is glabrous. Midrib is prominent. Small petiole with exstipulate
Rhizophoraceae	*Bruguiera sexangula*	Simple. Thick leathery leaves. Medium size. Opposite. Ovate shape. Lamina elliptical oblong. Acute apex. Prominent midrib. Exstipulate.
	Bruguiera gymnorrhiza	Leathery leaves. Medium size. Opposite. Ovate shape. Lamina elliptical oblong. Acute apex. Upper surface glabrous. Prominent midrib. Exstipulate.
	Bruguiera cylindrica	Simple. Leathery leaves. Medium size. Opposite. Ovate shape. Lamina elliptical oblong. Acute apex. Prominent midrib. Exstipulate.
	Ceriops decandra	Fleshy, more leathery leaves. Medium size. Opposite leaves. Ovate shape. Oblong margin. Somewhat rounded apex. Prominent midrib. Exstipulate.
	Rhizophora apiculata	Thick, fleshy leathery leaves. Opposite leaves. Surface glabrous. Ovate shape. Lamina elliptical oblong. Acute apex. Prominent midrib. Exstipulate.
	Rhizophora mucronata	Simple. Leathery leaves. Medium size. Opposite. Ovate shape. Lamina elliptical oblong. Acute apex. Prominent midrib. Exstipulate.
Lythraceae (Sonneratiaceae)	*Sonneratia caseolaris*	Simple. Thick medium size leaves. Opposite. Ovate shape. Rounded apex. Somewhat rounded lamina. Midrib is swollen at base. Exstipulate.
	Sonneratia griffithii	Oblong leaves. Opposite. Rounded apex. Short petiole with exstipulate
Acanthaceae (Halophytes)	*Acanthus vulubilis*	Fleshy, leathery leaves. Opposite. Glabrous surface. Ovate shape. Rounded apex. Lamina elliptical. Prominent midrib. Weak petiole with exstipulate.
	Acanthus ilicifolius	Fleshy, leathery leaves. Opposite. Glabrous surface. Oblong shape. Dentate margin with spines. Small petiole with exstipulate
Meliaceae	*Xylocarpus granatum*	Smooth, oblong leaves. Medium size. Opposite. Acute apex. Lamina elliptical oblong. Midrib prominent. Short petiole with exstipulate.
	Xylocarpus mekongensis	Oblong leaves. Medium size. Opposite. Acute apex. Lamina elliptical oblong. Midrib prominent. Short petiole with exstipulate.

of Avicennaiceae and Lythraceae, when comparing with other families. In Lythraceae members, the cork cells composed of three layers, differ in shapes. Sclereids are present in Rhizophoraceae, but absent in Lythraceae. Oil cells are absent in pith cells of Lythraceae. Fibrous patches are present in pericycle of Lythraceae. Secretory cells are present in pericycle of Rhizophoraceae. High content of lignin is present in Rhizophoraceae members.

3.2.2. Anatomy of Leaf

Leaf anatomy is related with assimilation rate through its effects on light and CO_2 acquisition and leaf nitrogen concentrations (Nandy et al., 2007).

The leaves of mangrove species had common features of structure with lesser epidermis cell, hypodermis structure, settle of stomata, abundant palisade tissue, and vascular bundle in midrib (Plate 6-9). The leaves are usually dorsiventral. Hairs are mostly unicellular with thick or thin walls. The cuticle is well developed and often quite thick on both the leaf surfaces. Cork-warts occur as small black spots on the lower side of the leaf. The epidermis is single layered and consists of rectangular

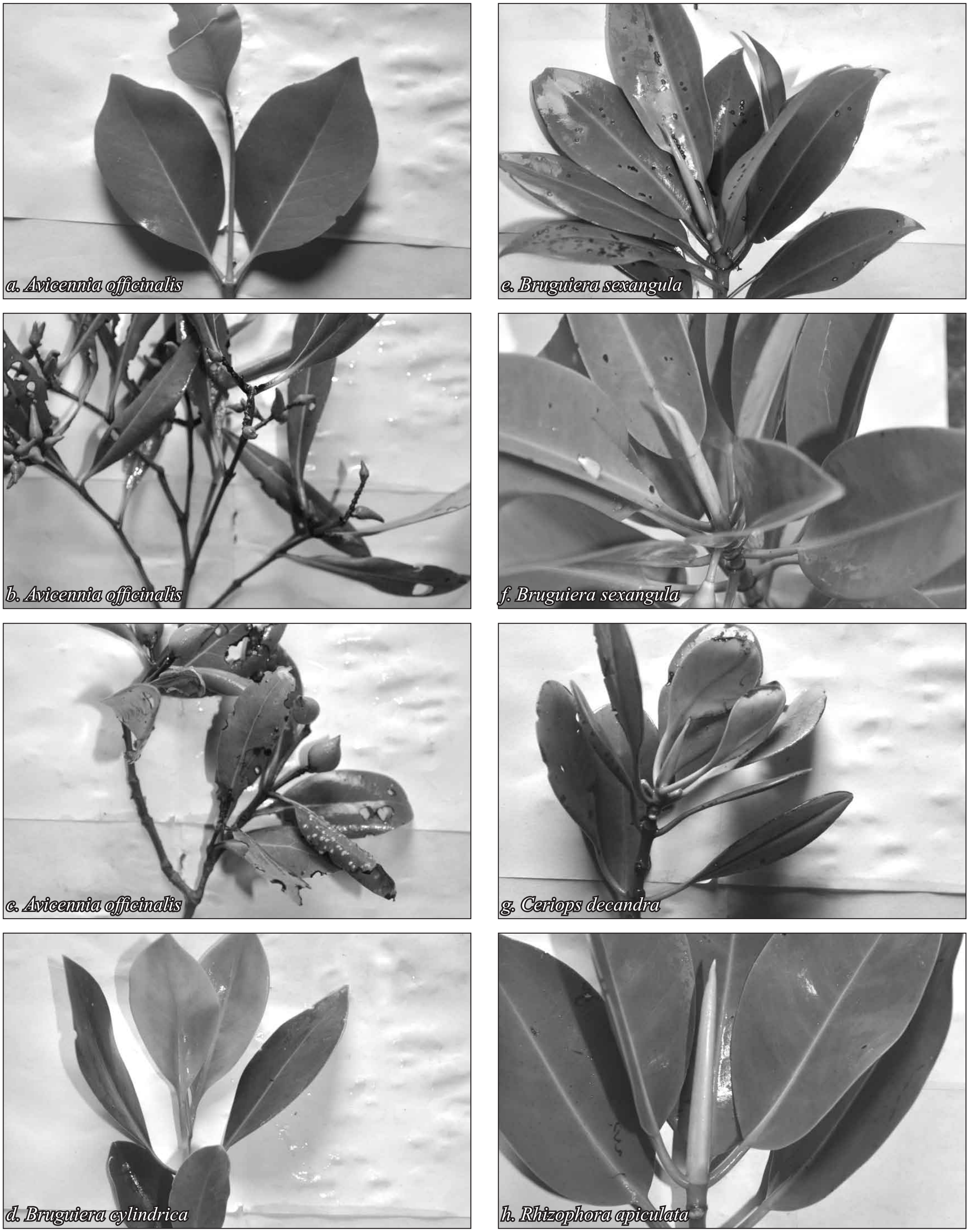

Plate 1: Leaf morphology of a. *Avicennia officinalis*; b. *A. alba*; c. *A. marina*; d. *Bruguiera cylindrica*; e&f. *B. sexangula*; g: *Ceriops decandra*; h: *Rhizophora apiculata*

Plate 2: a. *Rhizophora mucronata*; b. *Xylocarpus granatum;* c. *Xylocarpus mekongensis*; d. *Sonneratia caseolaris*

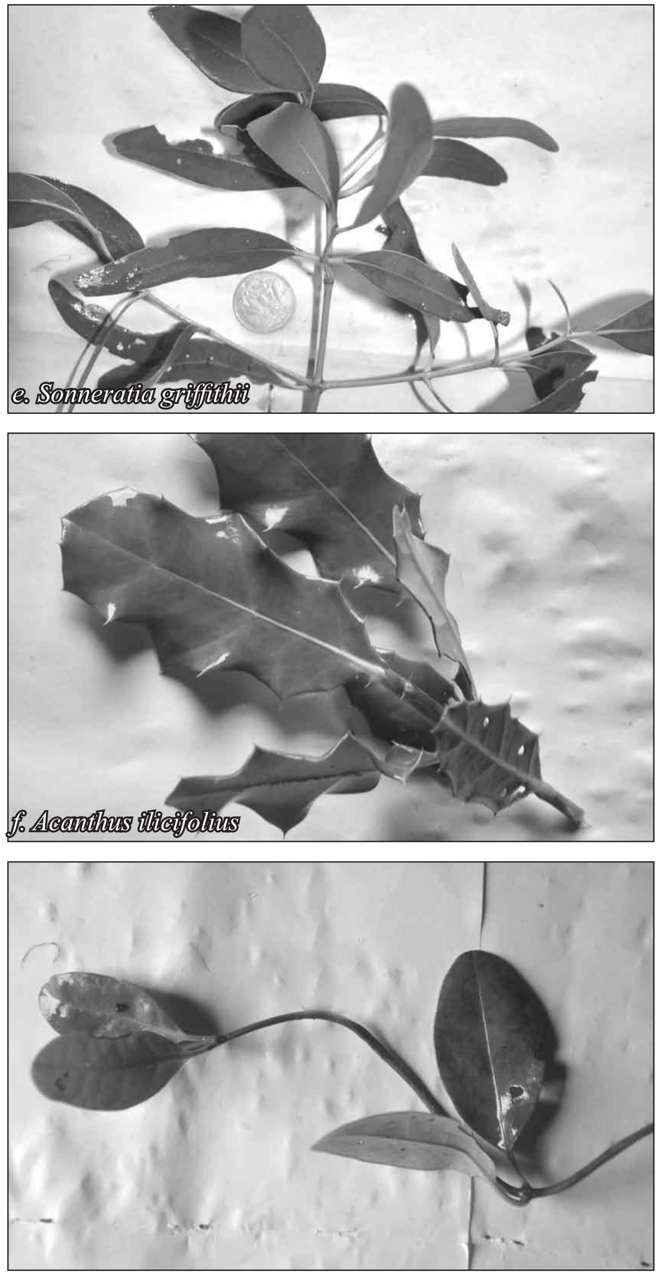

Plate 3: e. *Sonneratia griffithii*; f: *Acanthus ilicifolius*; g: *Acanthus volubilis*

cells. The cells of upper epidermis possess some rod shaped and cubical crystals of calcium oxalate. The hypodermis towards the upper surface is 2 or more layered. The stomata are confined to the lower surface. They are depressed and often provided with a front cavity. The mesophyll consists of palisade and spongy tissue. Palisade tissue consists of 1 to 4 layers. Spongy tissue usually possesses large intercellular spaces. Aqueous tissue and mucilage cells are also present beneath the upper epidermis. H-shaped sclerenchymatos idioblasts occur in the palisade tissue and variously branched one in the spongy mesophyll.

Mangrove leaves have specialized idioblast cells including tannin cells (Rhizophoraceae), mucous cells (*Rhizophora*, *Sonneratia*), crystalliferous cells (Rhizophoraceae), oil wells (*Osbornia*) and laticifers (*Excoecaria*) (Tomlinson, 1986). Branched sclereids are abundant and well developed in *Aegiceras*, *Rhizophora*, *Sonneratia* and *Aegialitis*.

Yoshihira et al. (1992) studied the distribution of pigments in mangrove leaves. They found that different species concentrated the pigments in different parts of the leaves. In *Aegiceras corniculatum*, the highest concentration of carotenoids and chlorophylls was in the light-harvesting complex. In *Rhizophora apiculata*, however, chlorophyll was concentrated in the chloroplast reaction center. The chlorophyll-binding proteins (including the functional cytochrome B 6/f complex and the protein kinases) were found in the thylakoid membranes in *Bruguiera gymnorrhiza* and *Kandelia candel.*

Leaf thickness is different from species to species. Within the Avicenniaceae members, the range is 327.83 μm to 666.60 μm (Yuanyue et al., 2009). Mostly stomata are preset on lower surface, but in Sonneratiaceae, have stomata on both surfaces of the lamina. The average number of stomata per given area, and the average leaf area was different from species to species (Yuanyue et al., 2009).

Heritiera fomes has deeply sunken stomata covered by trichomes. The leaves in this species also have a palisade-spongy ratio that is small compared to other halophytes (Das et al., 1995). Species of *Lumnitzera* and *Excoecaria* accumulate salts in leaf vacuoles and become succulent (Tomlinson, 1986)

Variation in leaf anatomy (Transverse Section, TS) and key characters for identification and its adaptative functions are tabulated below (Table 2):

Excoecaria agallocha

Transverse section of leaf shows thick cuticle, compactly arranged hypodermis above the lower epidermis in the region of veins, half moon shaped vascular tissue

Scyphiphora hydrophyllacea

Transverse section of leaf shows thick cuticle, more or less uniformly distributed palisade and spongy tissue, half moon shaped vascular tissue

Solanum trilobatun - Leaf

Transverse section of leaf shows thick cuticle, compactly arranged long palisade tissue.

Ipomoea pes-caprae - Leaf

Uniformly distributed mesophyll tissue, and it is not very well differentiated in to spongy and palisade tissue

Phoenix paludosa **-** Leaf

Elongated hypodermis occupies more than half of the portion in TS. Mesophyll is confined below the hypodermis. The sclerenchyma tissue is arranged in the patches just above the lower epidermis.

Tamarix troupii - Root TS

Considerable amount of secondary growth, uniformly distributed secondary xylem vessels and prominent secondary phloem in root TS are the characteristic features.

Salicornia brachiata: oblong in outline of TS of leaf, long palisade tissue and thick cuticle.

Aegialitis rotundifolia - Leaf TS

Shows vacuoles with crystals in mesophyll, thick cuticle, vascular bundles at middle vain are arranged in rows; mesophyll is not distinguished in to spongy and palisade tissue.

Lumnitzera racemosa - Leaf TS

Shows widely spread parenchyma tissue between upper and lower epidermis, bi-layered palisade below the upper epidermis, spongy tissue above the lower epidermis.

Aegiceras corniculatum - Leaf TS

Thick lower epidermal cells and cuticle, multilayered hypodermis, two central vascular cylinders surrounded by high amount of sclerenchyma.

Merope angulata - Leaf TS

Shows thick cuticle, long compactly arranged palisade tissue, big central vascular tissue.

Pneumatophore

cork covers the outer surface, Cork cambium is clearly distinguished, air chamber in cortex.

Azima tetracantha- Leaf TS

Highly thick cuticle, large hypodermal cells, medium long palisade cells, and spongy tissue, 3-5 layer cells are grouped below the veins, ovoid central vascular cylinder.

Manikara hexandra- Leaf TS

Thick cuticle, 2 layered compactly arranged palisade cells, uniformly distributed air chamber in spongy tissue, big circular central vascular tissue, and compactly arranged collenchyma below the vein.

The association between hydraulic conductance of stems and functional water use characteristics of leaves could contribute to the ecological success of mangroves in general as well as of other halophyte species (Sobrado, 2007).

3.2.3. Stem Anatomy

The details are depicted in Plate 9-13.

3.2.3.1. Epidermis

The epidermis is composed of variously shaped cells appearing

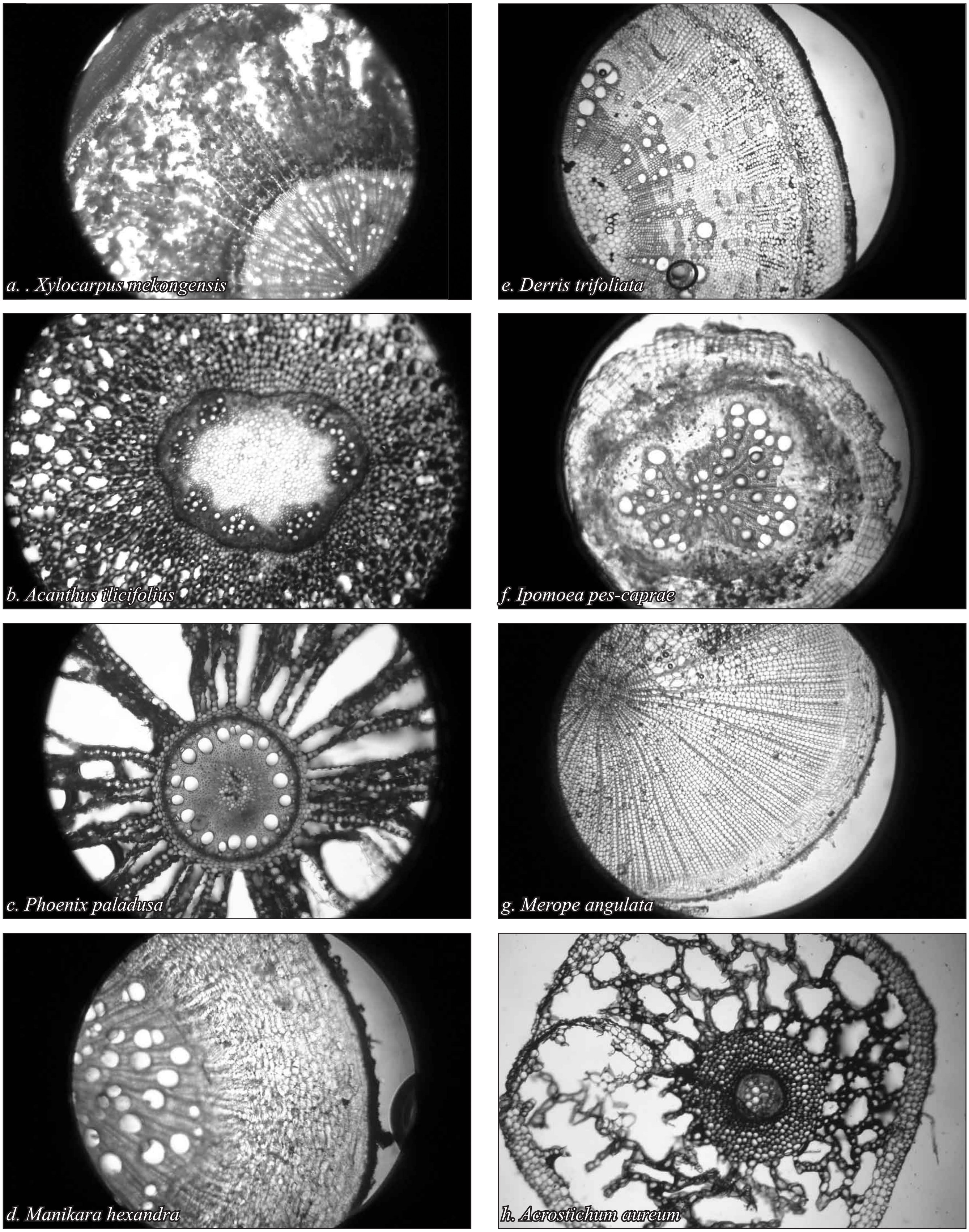

Plate 4: Root transverse section of some mangrove species

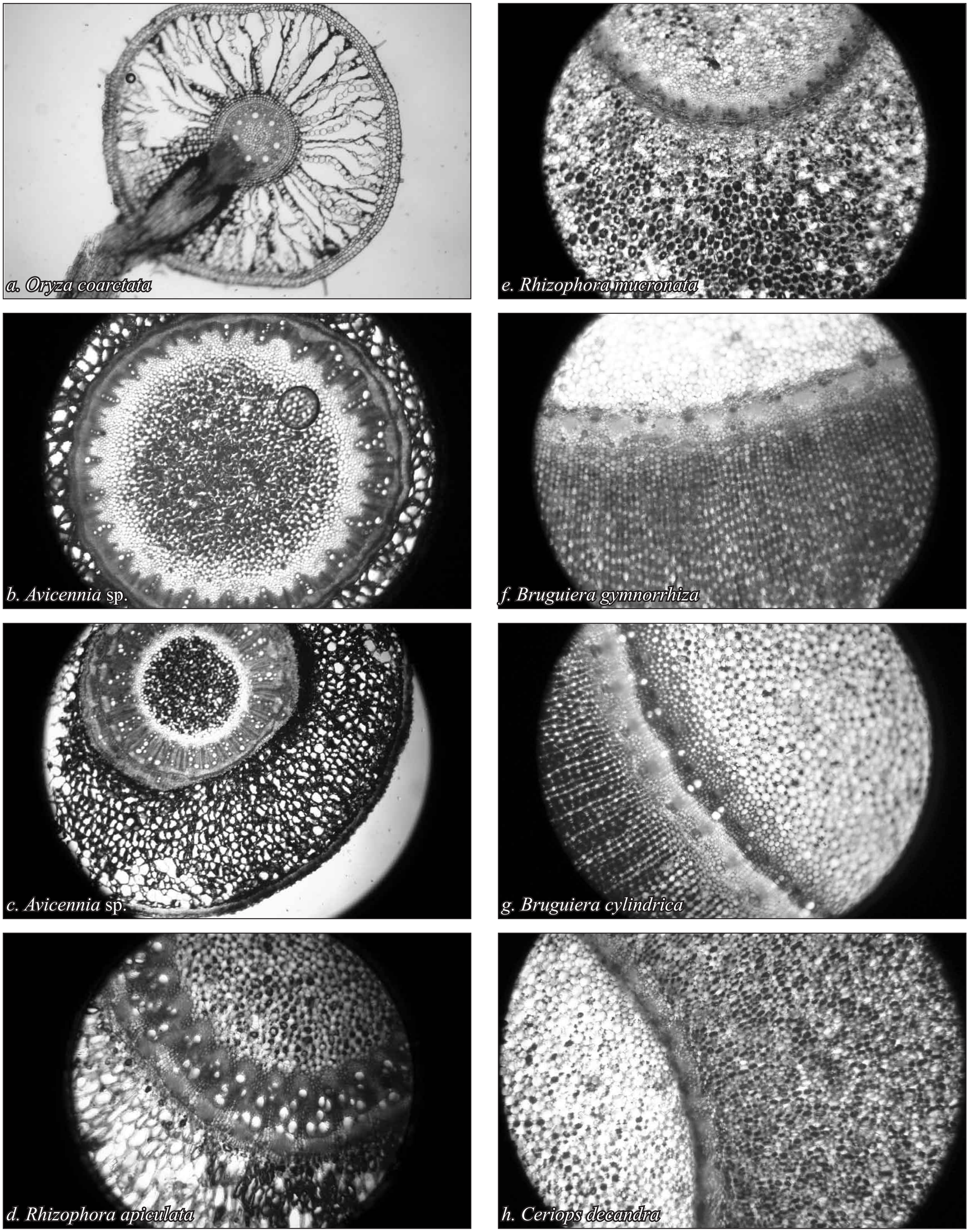

Plate 5: a: Root transverse section; b-h: Pneumatophore transverse section

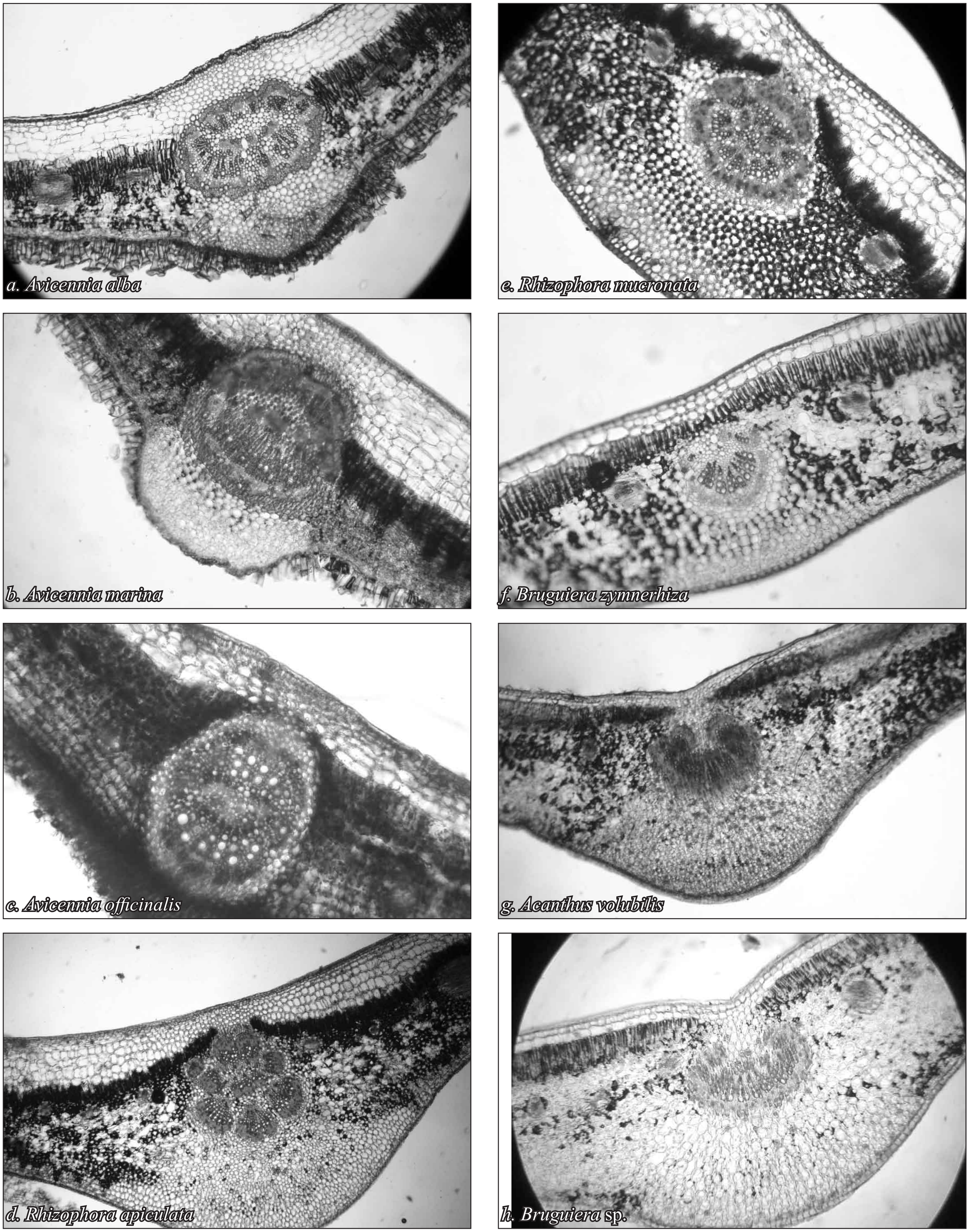

Plate 6: *Leaf transverse section*

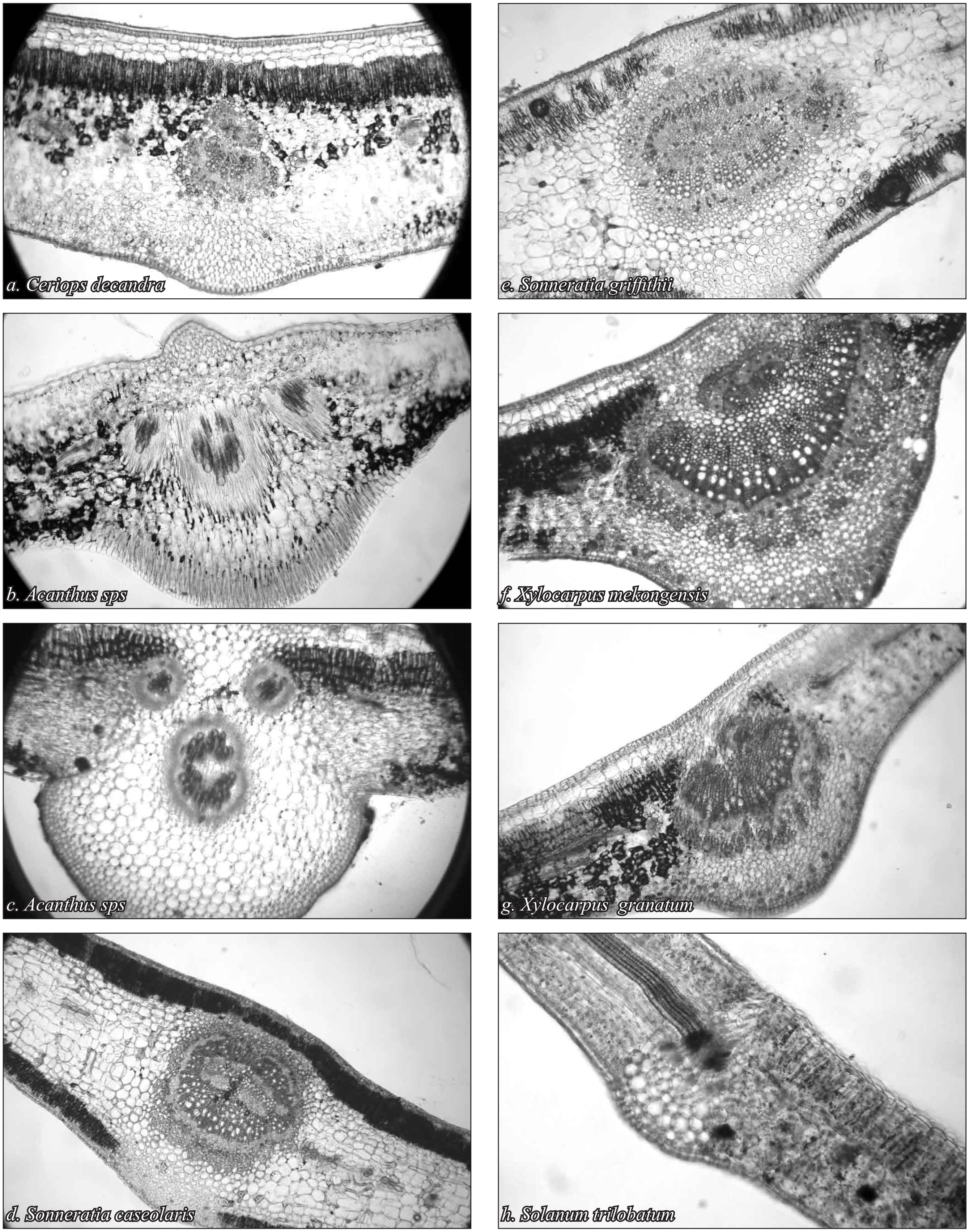

Plate 7: Leaf transverse section

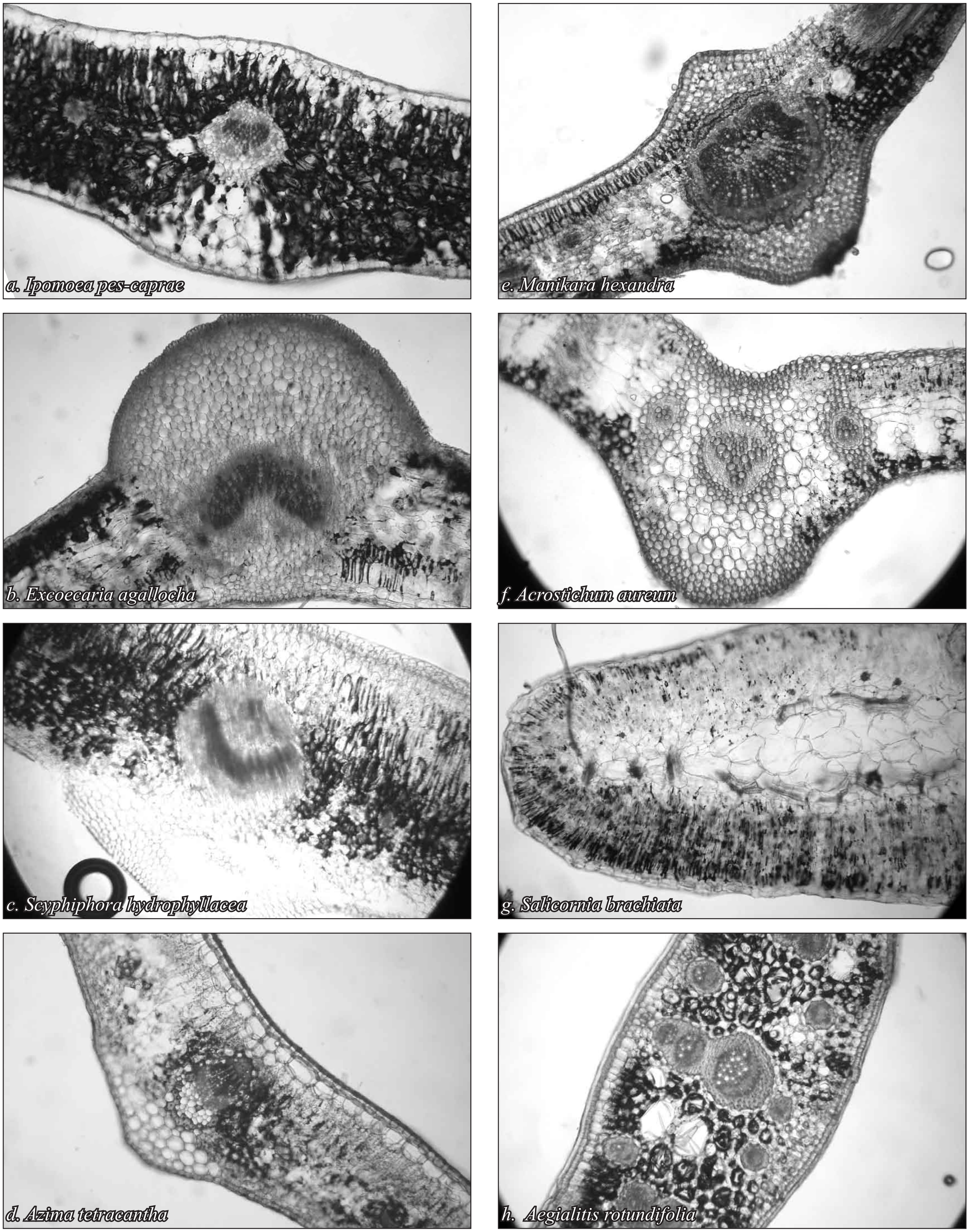

Plate 8: Leaf transverse section

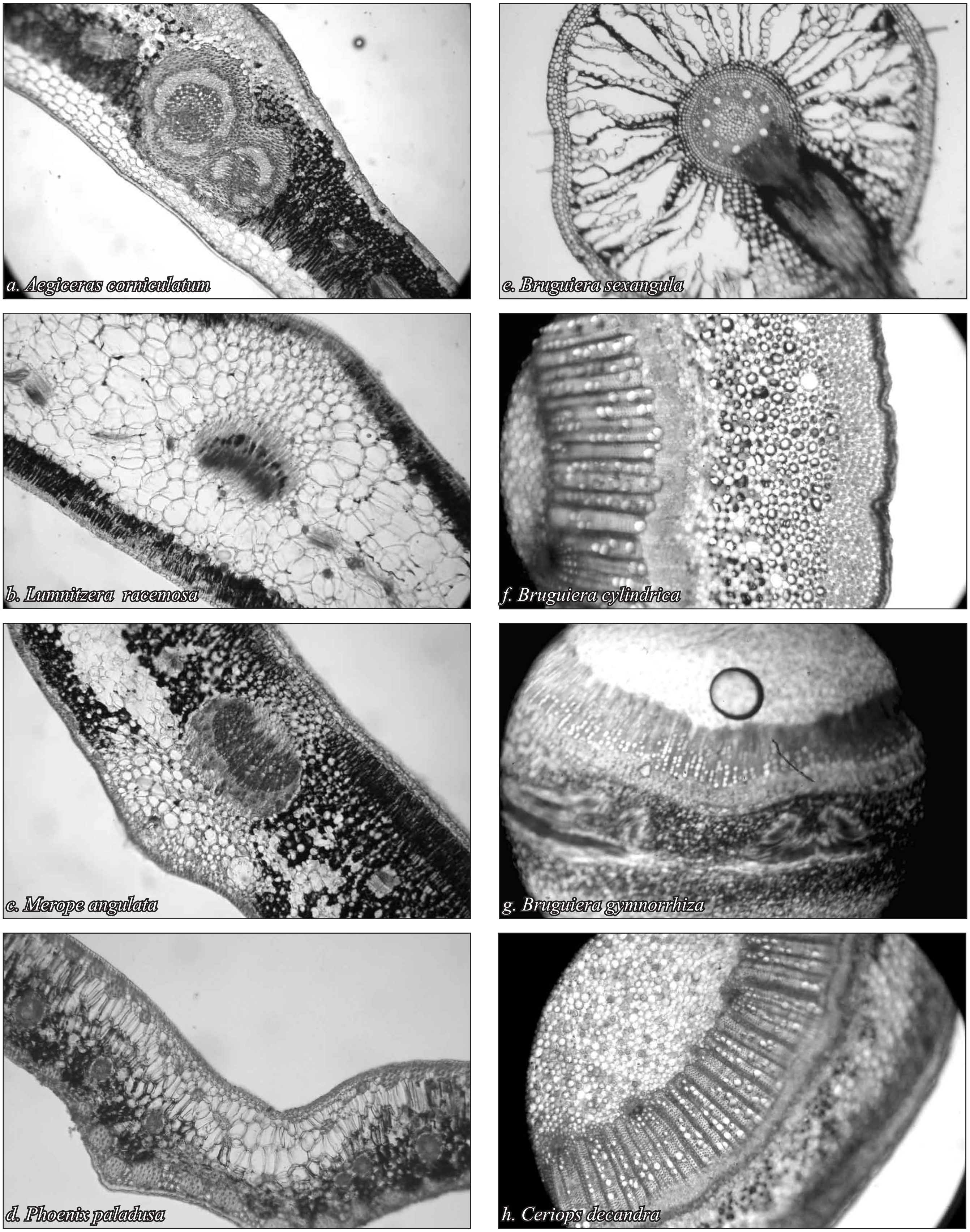

Plate 9: a-d: Leaf transverse section; e: Fruit transverse section; f-h: Stem transverse section

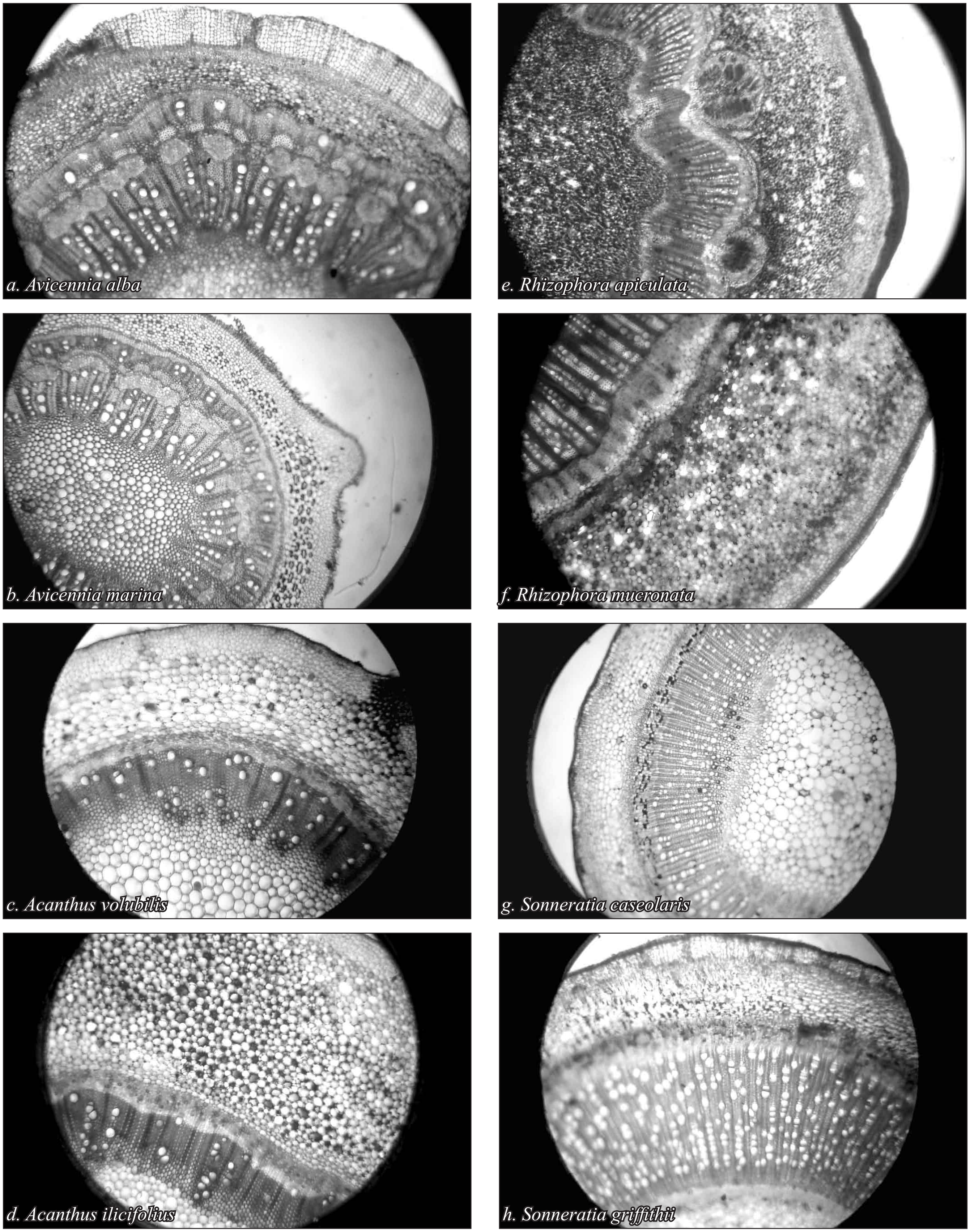

Plate 10: Stem transverse section

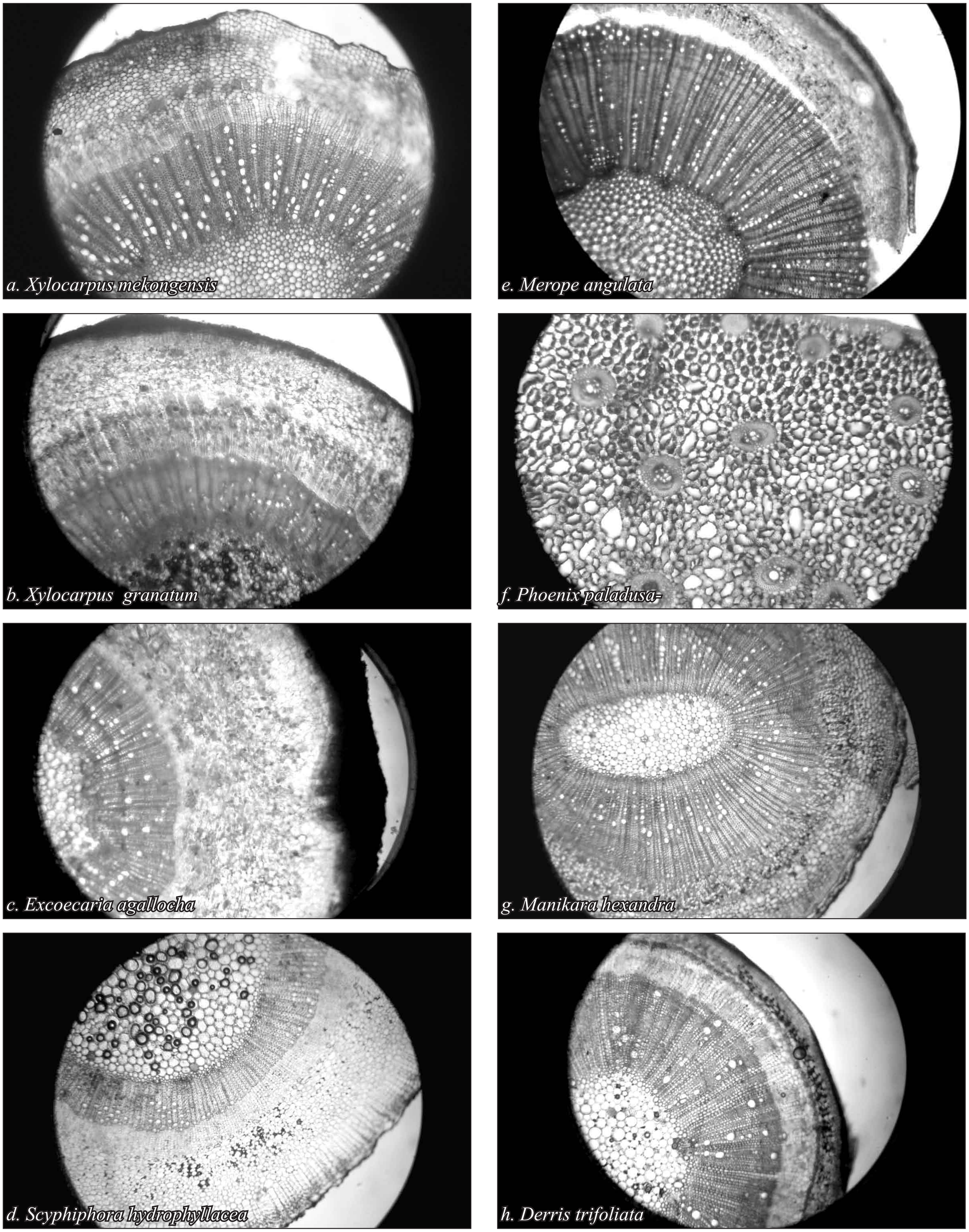

Plate 11: Stem transverse section

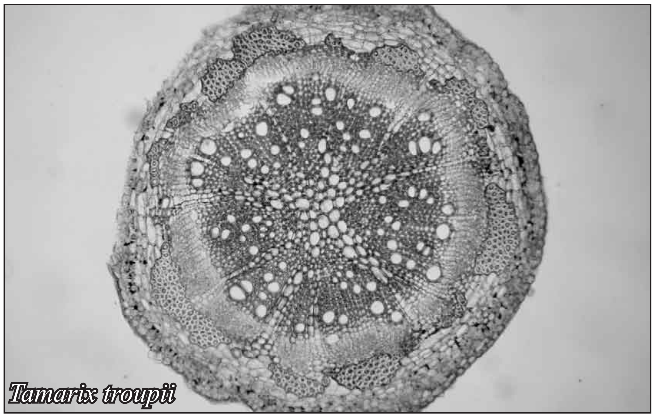

Plate 12: Stem transverse section

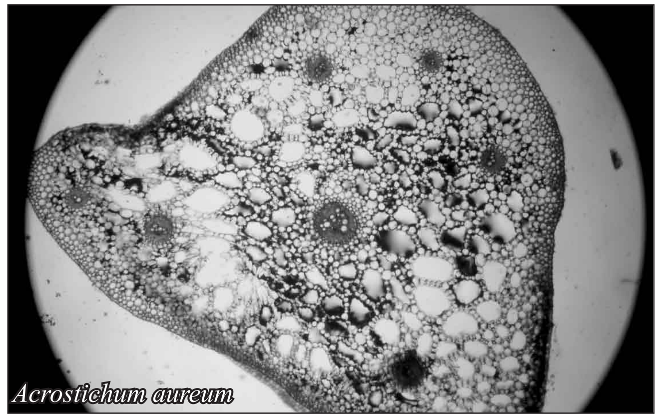

Plate 13: Petiole transverse section

conical in transverse sections. The epidermis often consists of more than one layer, but a true hypodermis of 3 to 7 layers is also common. The cork in young stems generally arises superficially, usually in hypodermis. The young stem has a very thick cuticle.

3.2.3.2. Cortex

The primary cortex is lacunar. S-shaped sclerenchymatuos idioblasts. The cells of cortex posses pitted walls and are full of tannin and oil. Calcium oxalate crystals are also present. The inner cortex has groups of branched sclereids which give mechanical strength to the lacunate cortex. The sclereids are lignified thick walled cells with narrow lumina. The endodermis is conspicuous. The endodermal cells possess starch grains.

3.2.3.3. Pericycle

It consists of s sub-continuous composite ring of sclerenchyma consisting of 3 to 4 layers of cells.

3.2.3.4. Vascular bundles

The vascular bundles are conjoint, collateral, endarch and open.

3.2.3.5. Xylem

The xylem is traversed by rays of 2 to 3 cells wide in *Rhizophora mucronata*. The vessels possess scalariform perforation plates.

3.2.3.6. Crystals

The crystals are generally clustered.

3.2.3.7. Secretory elements

Vertically elongated secretory cells containing tannin and or oil present in the cortex and the pith. The wood of most mangroves is diffuse-porous. Water conduction depend on size of vessel.

According to Mullan (1933), crystals in vertical rows of special cells in the secondary phloem of (wood) *Sonneratia* species. The wood anatomy of *Sonneratia* consists of secretory cells in the phloem and in intraxylary phloem. Sclernchymatous pericycle is present in the wood of Lythraceae. Density of vessels is different among the genus. The wood of most mangroves is diffuse-porous, but *Aegialitis rotundifolia* has ring-porous wood (Das and Ghose, 1998).

Variation in stem anatomy (Transverse sections, TS) and key

Table 2: Variation in leaf anatomy

Family: Avecenniaceae			
Genus: *Avicennia*	Species		
	alba	*marina*	
Stem TS	Circular in outline	Consist of grooves	
Xylem vessels	Smaller in size	Large in size	
Root TS	Circular in outline	Circular in outline	
Aerenchyma	Well distributed in cortex	Well distributed in cortex	
Genus: *Bruguiera*	Species		
	cylindrica	*gymnorrhiza*	*exangula*
Stem TS	Circular with grooves	Uniform circular	Uniform circular
Epidermis	Thick epidermis and cuticle	Thick epidermis and cuticle	Medium thick
Cavities	Highly distributed	Very less in number	Distributed in cortex
Genus: *Rhizophora*	Species		
	apiculata	*mucronata*	
Bark	Highly thick bark	Moderately thick	
Cavities	Moderately distributed	Highly distributed	
Family: Acanthaceae			
Genus: *Acanthus*	Species		
	ilicifolius	*ebracteatus*	
Hypodermis	7-8 layers	5-6 layers	
Cortex	High content	Low content	

characters for identification are described below:

Phoenix paludosa- Stem: sclerecnchymatous hypodermis, scattered vascular bundles, aerenchyma in the cortical cells.

Phoenix paludosa- Root: cortex consists of large aerenchyma, central circular stele.

Salicornia brachiata - Petiole*:* Transverse section shows aerenchyma distributed in mesophyll; the mesophyll is not differentiated into spongy and palisade tissue, and vascular bundles are distributed in mesophyll.

4. Conclusion

Lot of variability is observed among the families of mangroves. Structural adaptations include pneumatophores, thick leaves, aerenchyma in root helps in surviving under flooded saline conditions.

Above morpho-anatomical characters described helps in identification of family and genus and species of mangroves. Most of the species are now endangered species due to environmental and human activities. Mangroves serve as a critical nursery for young marine life and therefore play an important role in the health of fisheries. The ecosystem is also considered as most productive and biodiversity providing significant functions in the coastal zones as buffer against erosion, storm surge and tsunamis.

5. Reference

Araujo, R.J., Jaramillo, J.C., Snedaker, S.C., 1997. LAI and leaf size differences in two red mangrove forest types in south Florida. Bulletin of Marine Science 60(3), 643-647.

Corredor, J.E., Morell, J.M., Klekowski, E.J., Lowenfeld, R., 1995. Mangrove genetics: III. Pigment fingerprints of chlorophyll-deficient mutants. International Journal of Plant Sciences 156(1), 55-60.

Das, P.K., Chakravarti, V., Dutta, A., Maity, S., 1995. Leaf anatomy and chlorophyll estimates in some mangroves. The Indian Forester 121(4), 289-294.

Das, S., Ghose, M., 1996. Anatomy of leaves of some mangroves and their associates of Sunderbans, West Bengal. Phytomorphology 46(2), 139-150.

Das, S., Ghose, M., 1998. Anatomy of the woods of some mangroves of Sunderbans, West Bengal (India). In: International Symposium on Mangrove Ecology and Biology, April 25-27, 1998, Kuwait, 10.

Dodd, R.S., Fromard, F., Rafii, Z.A., Blasco, F., 1995. Biodiversity among West African, *Rhizophora*: Foliar wax chemistry. Biochemical Systematics and Ecology 23(7-8), 859-868.

Ellison, A.M., Farnsworth, E.J., 2001. Mangrove communities. In: Bertness, M.D., Gaines, S.D., Hay, M.E. (Eds.), Marine Community Ecology. Sinauer Associates, Sunderland, MA, USA, 423-442.

Ish-Shalom-Gordon, N., Dubinsky, Z., 1992. Ultrastructure of the pneumatophores of the mangrove *Avicennia marina*. South African Journal of Botany 58(5), 358-362.

Li, M.S., Lee, S.Y., 1997. Mangroves of China: a brief review. Forest Ecology and Management 96, 241-259.

Li, Y., Li, Z., Lin, P., 2009. The Study on the Leaf Anatomy of Some Mangrove Species of China. In: International conference on Environmental Science and Information Application Technology, 2009. ESIAT 2009, Wuhan, China, 11-14.

Nandy, P., Das, S., Ghose, M., Spooner-Hart, R., 2007. Effects of salinity on photosynthesis, leaf anatomy, ion accumulation and photosynthetic nitrogen use efficiency in five Indian mangroves. Wetlands Ecology and Management 15, 347-357.

Naskar, K., Guha Bakshi, D.N., 1995. Vegetation pattern of the Sundarbans. Mangrove Swamp of the Sundarbans- and Ecological perspective. Nayaprakash. Calcutta, India, 27-174.

Parida, A.K., Das, A.B., Mittra, B., 2004. Effects of salt on growth, ion accumulation, photosynthesis and leaf anatomy of the mangrove, *Bruguiera parviflora*. Trees 18, 167-174.

Rafii, Z.A., Dodd, R.S., Fromard, F., 1996. Biogeographic variation in foliar waxes of mangrove species. Biochemical Systematics Ecology 24, 341-345.

Rico-Gray, V. and Palacios-Rios, M. 1996. Leaf area variation in *Rhizophora mangle* L. Rhizophoraceae) along a latitudinal gradient in Mexico. Global Ecology and Biogeography Letters 5(1), 30-35.

Saenger, P., Bellan, M.F., 1995. The mangrove vegetation of the Atlantic coast of Africa: A review. Universite de Toulouse Press, Toulouse, France, 96.

Saifullah, S.M., Elahi, E., 1992. Pneumatophore density and size in mangroves of Karachi, Pakistan. Pakistan Journal of Botany 24(1), 5-10.

Sobrado, M.A., 2007. Relationship of water transport to anatomical features in the mangrove *Laguncularia racemosa* grown under contrasting salinities. New Phytologist 173, 584-591.

Tomlinson, P.B., 1986. The Botany of mangroves. Cambridge University Press, Cambridge, U.K., 413.

Yoshihira, T., Shiroma, K., Ikehara, N., 1992. Profiles of polypeptides and protein phosphorylation in thylakoid membranes from mangroves, *Bruguiera gymnorrhiza* (L.) Lamk. and *Kandelia candel* Druce. Galaxea 11(1), 1-8.

Yuanyue, L., Zhongbao, L., Peng, L., 2009. The study on the leaf anatomy of some mangrove species of China. In: International conference on Environmental Science and Information Application Technology 3, 47-51.