

Comparative Anatomy of Two Mangrove Species, *Xylocarpus granatum* and *Xylocarpus moluccensis* (Meliaceae)

Boonyawee Chorchuhirun*, Ekaphan Kraichak and Prasart Kermanee

Department of Botany, Faculty of Science, Kasetsart University, Bangkhen Campus,
Ladyao, Chatuchak, Bangkok, 10900

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Abstract

Xylocarpus granatum and *Xylocarpus moluccensis* are true mangrove species, which are found in the central zone of mangrove forests. Anatomical character plays important roles to plant functions and adaptations to cope with certain environments. The plant samples were collected from the Sirinart Rajini Ecosystem Learning Center, Prachuabkirikhan province. Permanent slides of the samples were prepared using a paraffin method. The anatomical characters of root, stem, petiole, petiolule, rachis and leaf blade were examined and compared. The results showed that *X. granatum* and *X. moluccensis* shared their anatomical characters, i. e. , tanniferous cells and crystals are common in both species. However, there are some different characteristics such as primary xylem in root, shape of vascular bundle in petiole, petiolule and leaf blade including number of hypodermis and palisade layers. Overall of this study, the anatomical character can discriminate between the two species.

Keywords: anatomy; mangrove; *Xylocarpus granatum*; *Xylocarpus moluccensis*

1. Introduction

Mangroves are evergreen forests, which are found along coastlines, shallow- water lagoons, estuaries or rivers in tropical and subtropical areas. The mangrove ecosystem represents interphase between terrestrial and marine communities, which receive strong winds, sea tides and water salinity (FAO, 2007; Giesen *et al.*, 2007). Mangrove plants have several mechanisms of adaptation to an

anaerobic condition in saline water, including rooting system as morphological adaptation, pneumatophores as anatomical adaptation and water conservation as physiological adaptation (Göltenboth *et al.*, 2006).

The variation of salinity, elevation, wave exposure and tidal inundation lead to the zonation of mangroves. The mangrove zonation is classified into 4 main zones. The seaward zone is inundated by all high tides. A mid zone

is inundated by medium-high tide. The landward zone is inundated by the highest tides only. Brackish stream mangroves are found along brackish to freshwater streams (Giesen *et al.*, 2007; Waycott *et al.*, 2011). The landward zone is interesting for a study about mangrove plant adaptations because it is a transitioning ecosystem between mangrove and terrestrial communities. The outstanding true mangrove plants at the landward zone is *Xylocarpus*. This genus is important for traditional medicine. Which used fruits and seeds of *Xylocarpus granatum* J. Koenig and *X. moluccensis* (Lam.) M. Roem for treating diarrhea and bark decoction for treating cholera. Moreover, *X. granatum* woods are attractive and used for furniture making (Haron and Taha, 2010; Das *et al.*, 2014; Baba *et al.*, 2016).

X. granatum is a medium sized evergreen tree. Compound leaves have 1- 2 pairs of leaflets. Their leaflets are rounded and coriaceous. The trunk is smooth with light brown outer bark, which peels off with thin flakes, and red inner bark. Buttress roots, which are ribbon-like plank forms, are surrounded the trunk. Florets include 4 white petals and 4 yellowish-green sepals. Fruits are yellowish- brown globose up to 25 cm diameter (Haron and Taha, 2007; Haron and Taha, 2010; Das *et al.*, 2014; Ragavan *et al.*, 2014; Ragavan *et al.*, 2015).

X. moluccensis is a medium sized deciduous tree. Compound leaves, which arranged spiral or opposite, have 1-3 pairs of leaflets. The trunk is rough with dark brown outer bark, which peels in long narrow strips.

Pneumatophores are conical shape up to 30 cm tall. Inflorescence and florets are similar to *X. granatum*. Fruits are brownish green sub-globose up to 12 cm diameter. Both species have buoyant fruits and seeds (Haron and Taha, 2010; Das *et al.*, 2014; Ragavan *et al.*, 2014; Ragavan *et al.*, 2015).

Morphology and anatomy play important roles in adaptation to the stress environment in the mangrove forest, but there are a few pieces of knowledge about them (Das and Ghose, 1996; Haron and Taha, 2007; Rodriguez *et al.*, 2012). This research focused on anatomical characters of root, stem, petiole, rachis, petiolule and leaf blade in the genus *Xylocarpus* found in Thailand. The obtained data may support species identification and to understand the anatomical and physiological adaptations of *Xylocarpus*.

2. Materials and Methods

The specimens of *X. granatum* and *X. moluccensis* were collected from a mangrove forest at the Sirinart Rajini Ecosystem Learning Center in Pranburi, Prachuabkirikhan province. The six replicates of roots at 1 cm from the root tip, stem at 2-4 cm from shoot tip and mature leaves at 5th node from the apex were fixed in formalin acetic alcohol (FAA) solution. Permanent slides were prepared using the paraffin method (Johansen, 1940; Kermanee, 2008). The samples were dehydrated with tertiary butyl alcohol series, infiltrated in liquid paraffin, embedded in paraplast and sectioned into 10-15 microns thickness. The sections were

stained with safranin- T and fast green combination and then were mounted with permount. The specimens were examined with a compound light microscope (Zeiss; Axioskop 2, Germany) assembled with a camera (Zeiss; AxioCam MRc, Germany) and Zen 2 program.

3. Results

Six organs of *X. granatum* and *X. moluccensis* including root, stem, petiole, rachis, petiolule and leaf blade were examined. The anatomical characters were described as follows:

3.1 *X. granatum*

3.1.1 Root

The outer layer is epidermis which accumulates suberin (Figure 1A). There is a layer of exodermis beneath the epidermis. Cortex composes of parenchyma with air spaces. Tanniferous cells were observed in the cortex. A layer of endodermis with Casparian strip surrounds a stele. The stele is actinostele with 7 arches of primary xylem. The center of the root is pith with some tanniferous cells (Figure 1B).

3.1.2 Stem

The outer layer is periderm, consisting of several layers of phellem. The cortex contains parenchyma. A number of tanniferous cells and druse crystals were found in the cortex. Stele presents secondary phloem and secondary xylem. Gelatinous fibers were observed in phloem and xylem (Figure 1C and 1D).

3.1.3 Petiole

The outer layer is periderm which consists of phellem, phellogen and phellogen. Cortex composes of parenchyma with tanniferous cells and druse crystals (Figure 1E). The vascular bundles arranged in a semi-circular shape.

3.1.4 Rachis

The outer layer is the epidermis. Some epidermal cells deposit suberin. There is a layer of periderm beneath the epidermis. The cortex contains parenchyma which some cells contain tannin. Stele presents a ring of secondary phloem and secondary xylem (Figure 1F).

3.1.5 Petiolule

The outer layer is epidermis which accumulates suberin. Periderm presents beneath the epidermis. The cortex consists of parenchyma which stores druse crystals. The vascular tissues are collateral bundles which arrange in semi-circular shape (Figure 2A and 2B).

3.1.6 Leaf blade

Midrib composes of the upper and lower epidermis which are covered with thick cuticle ($2.66 \pm 0.29 \mu\text{m}$). The cortex consists of round- elliptic parenchyma. Abundant druse crystals are found in the cortex. Vascular bundles contain groups of collateral bundles in semi-circular shape (Figure 2C and 2D). The mature blade is bifacial, composes of upper and lower epidermis. There are 2- 3 layers of hypodermis under the epidermis (Figure 2E). Typical stomata are observed only on the lower epidermis (Figure 2F). Mesophyll composes of 2

types of modified parenchyma. Palisade mesophyll appears on the upper part of leaf blades, consisting of 2- 3 layers. Spongy

mesophyll presents in the lower part with large intercellular spaces. Druse crystals are found in

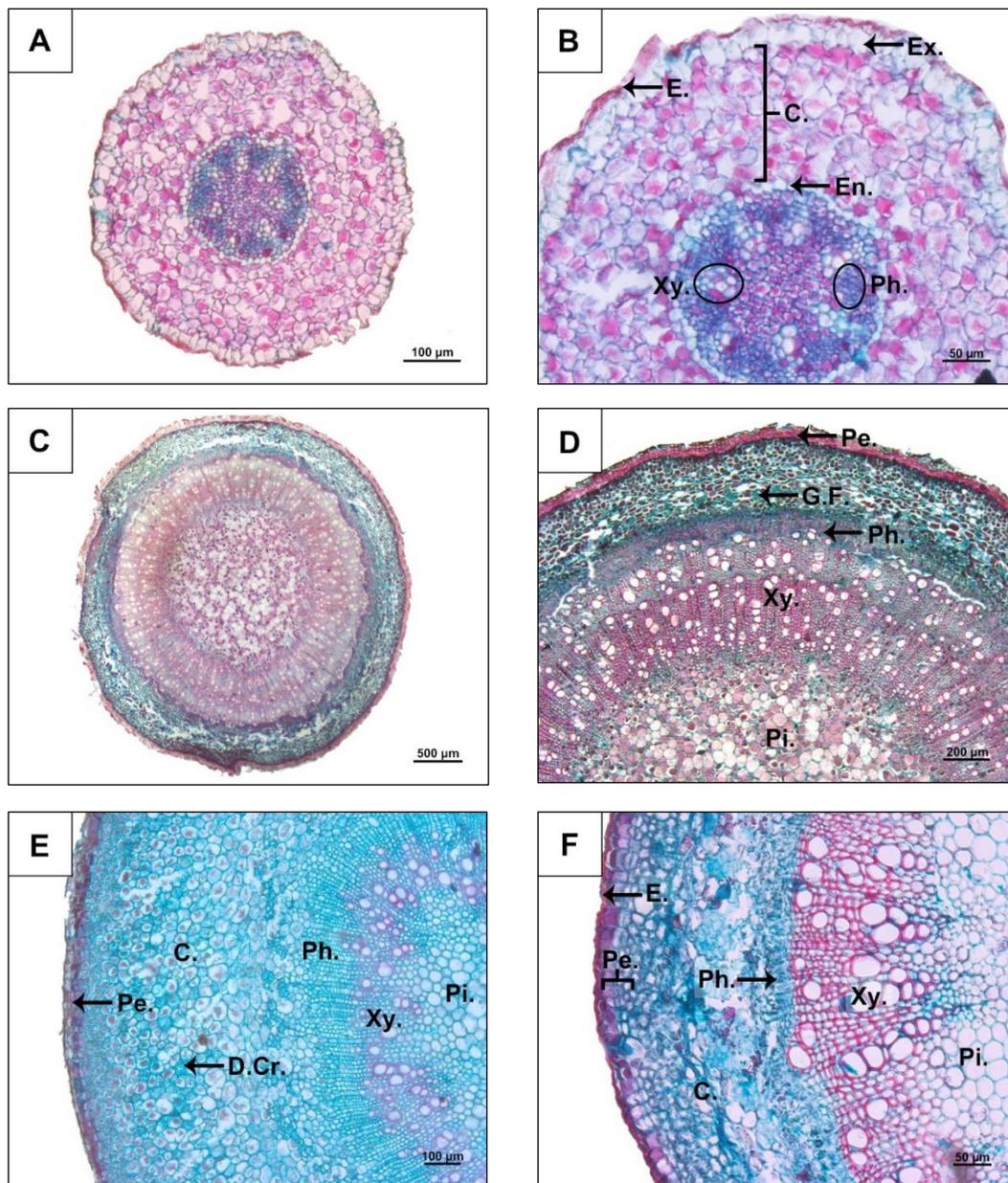


Figure 1 Transverse sections showing anatomical characters of *X. granatum*; (A) Root (B) Stele of root (C) Stem (D) Periderm, cortex, phloem, xylem and pith of stem (E) Petiole (F) Rachis (C. = cortex, D.Gr. = druse crystal, E. = epidermis, En. = endodermis, Ex. = exodermis, G.F. = gelatinous fiber, Pe. = periderm, Ph. = phloem, Pi. = pith, Xy. = xylem)

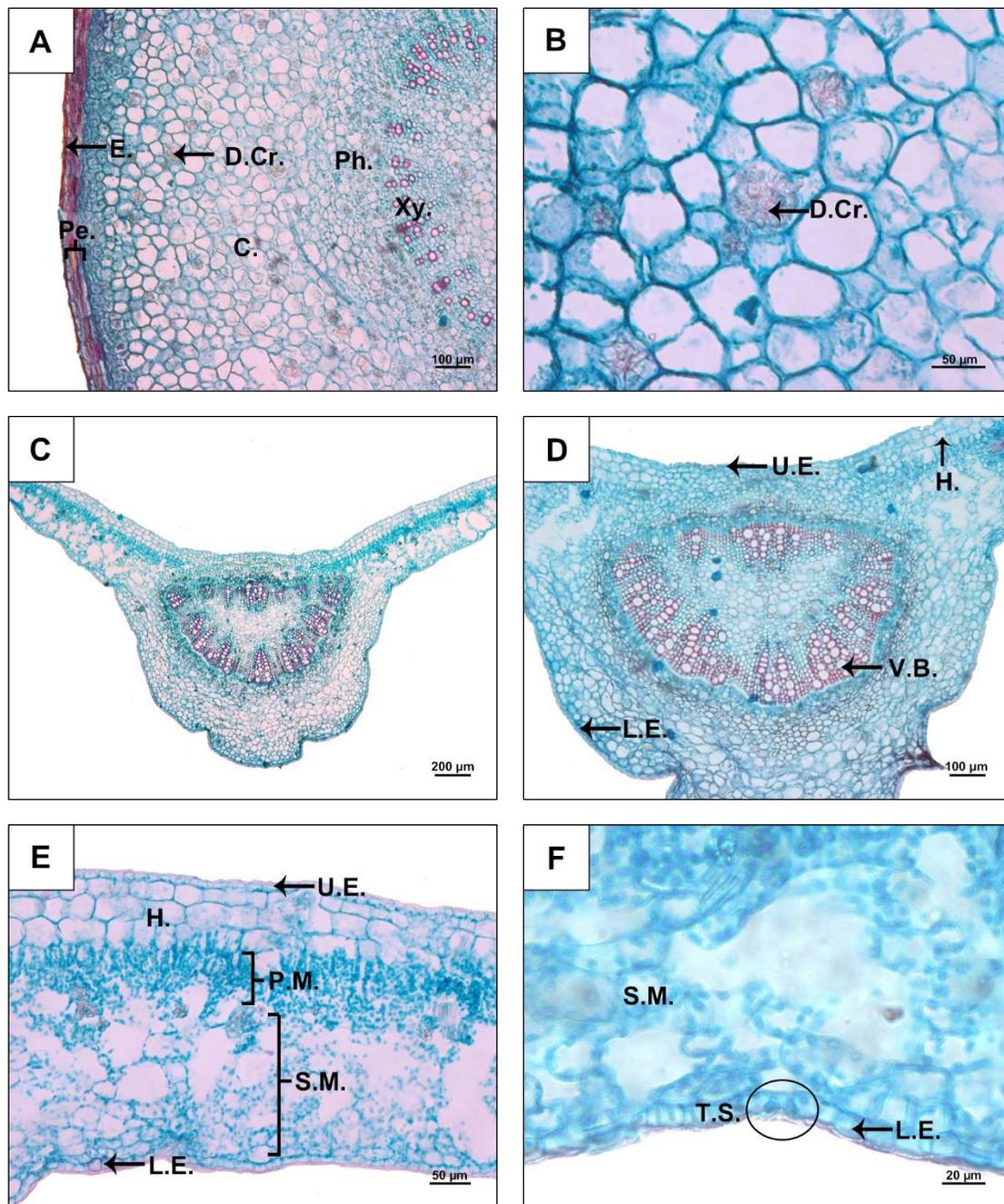


Figure 2 Transverse sections showing leaf blades anatomy of *X. granatum*; (A) Petiolule (B) Druse crystal in petiolule (C) Leaf blades (D) Midrib (E) Blade (F) Lower epidermis with typical stomata (C. = cortex, D.Cr. = druse crystal, E. = epidermis, H. = hypodermis, L.E. = lower epidermis, P.M. = palisade mesophyll, Pe. = periderm, Ph. = phloem, Pi. = pith, S.M. = spongy mesophyll, T.S. = typical stoma, U.E. = upper epidermis, V.B. = vascular bundle, Xy. = xylem)

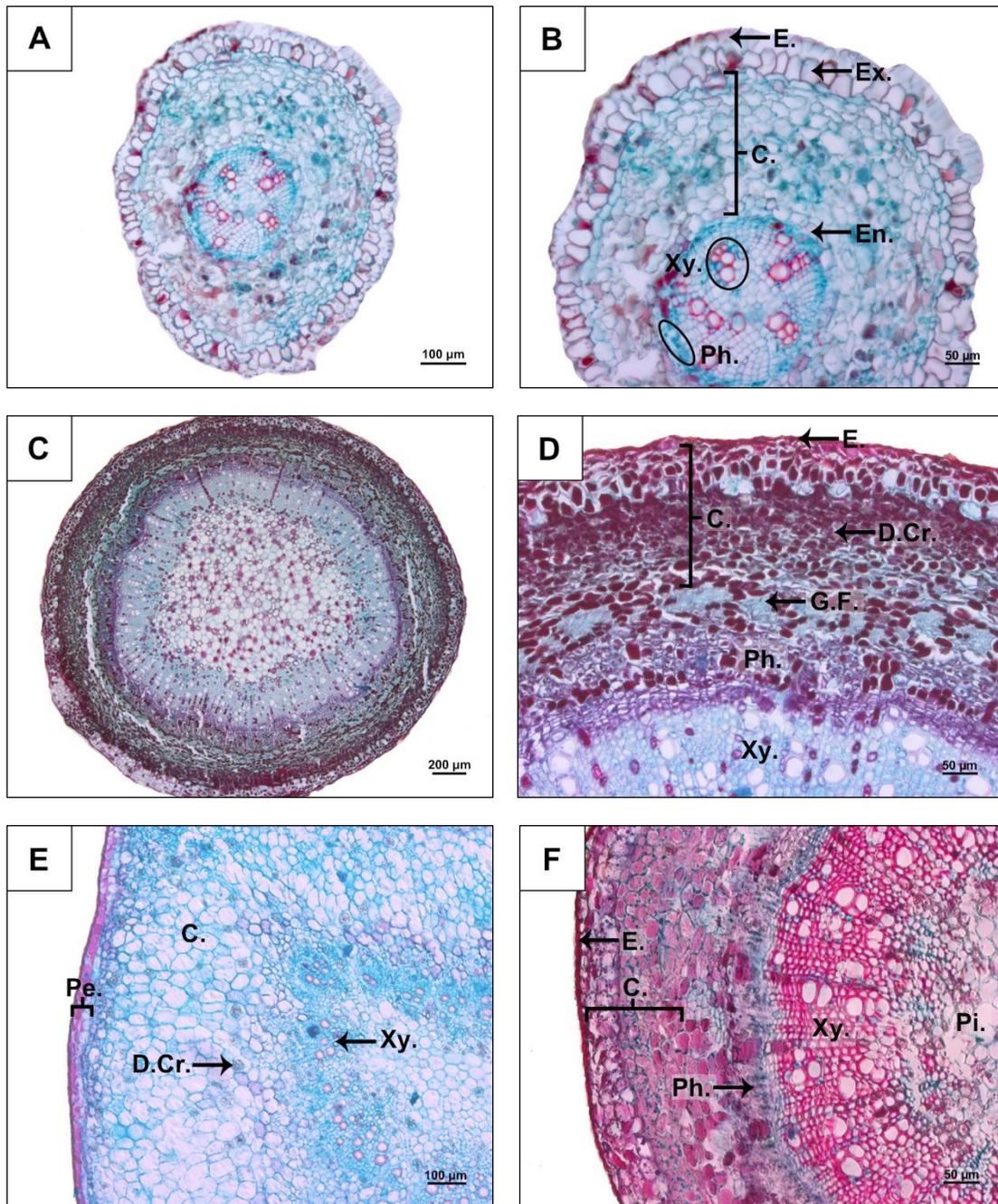


Figure 3 Transverse sections showing anatomical characters of *X. moluccensis*; (A) Root (B) Stele of root (C) Stem (D) Epidermis, cortex, phloem and xylem of stem (E) Petiole (F) Rachis (C. = cortex, D.Cr. = druse crystal, E. = epidermis, En. = endodermis, Ex. = exodermis, G.F. = gelatinous fiber, Pe. = periderm, Ph. = phloem, Pi. = pith, Xy. = xylem)

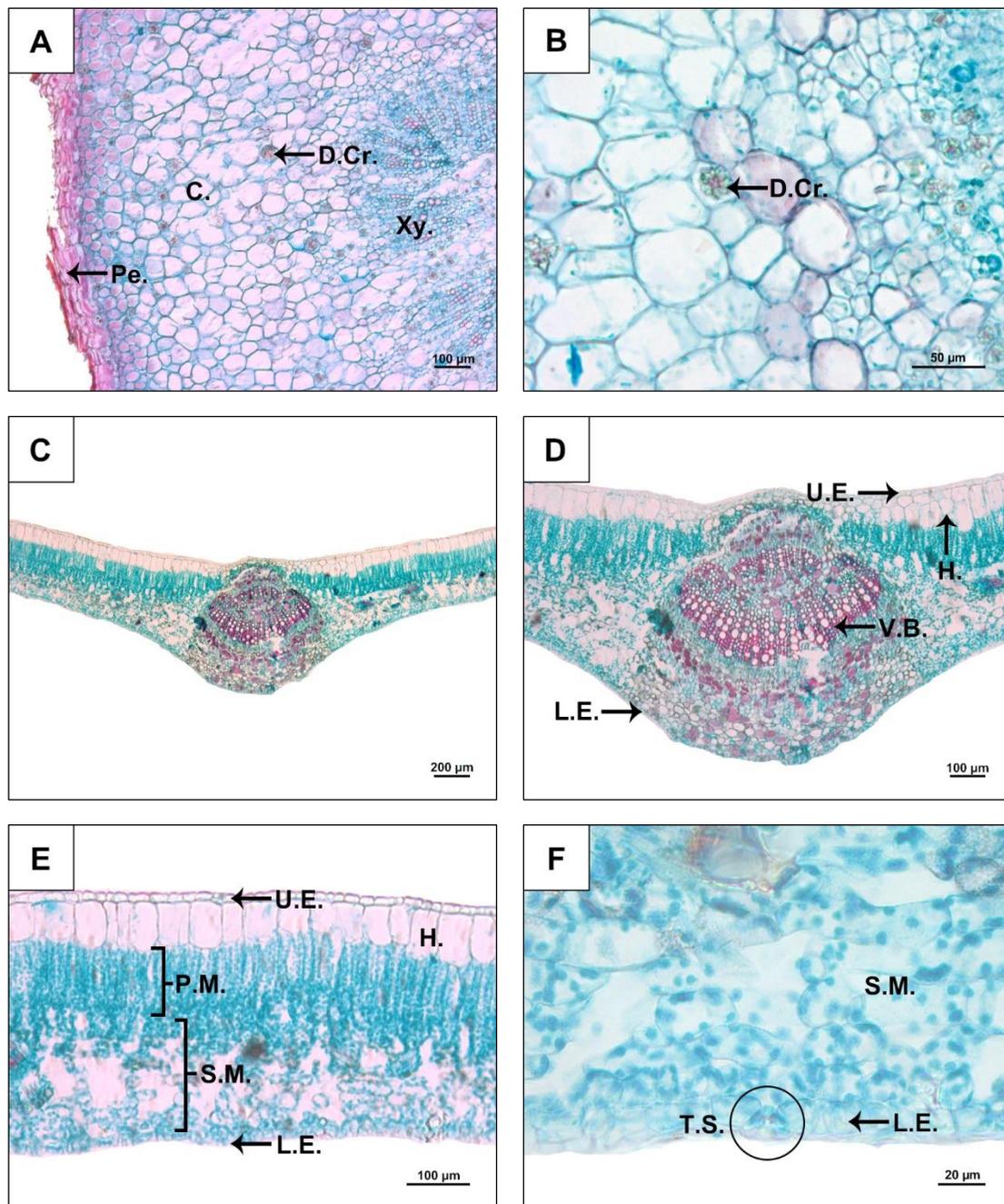


Figure 4 Transverse sections showing leaf blades anatomy of *X. moluccensis*; (A) Petiolule (B) Druse crystal in petiolule (C) Leaf blades (D) Midrib (E) Blade (F) Lower epidermis with typical stomata (C. = cortex, E. = epidermis, H. = hypodermis, L.E. = lower epidermis, P.M. = palisade mesophyll, Pe. = periderm, Ph. = phloem, Pi. = pith, S.M. = spongy mesophyll, T.S. = typical stoma, U.E. = upper epidermis, V.B. = vascular bundle, Xy. = xylem)

spongy mesophyll.

3.2 *X. moluccensis*

3.2.1 Root

The outer layer is epidermis which accumulates tannin (Figure 3A). The stele is actinostele with 4 arches of primary xylem. The center of the root is pith (Figure 3B). Exodermis beneath epidermis, cortex and endodermis with Casparian strip are similar to *X. granatum*.

3.2.2 Stem

The outer layer is epidermis which accumulates suberin. The cortex consists of two sizes of parenchyma. Tanniferous cells were observed in the cortex. Stele and gelatinous fibers present similar to *X. granatum*. (Figure 3C and 3D).

3.2.3 Petiole

The outer layer is periderm which consists of phellem, phellogen and phelloderm. Cortex composes of parenchyma with tanniferous cells and druse crystals. The vascular bundles arrange in cordate shape (Figure 3E).

3.2.4 Rachis

Suberin accumulation is observed in the epidermal layer. The cortex consists of two sizes of parenchyma. Tanniferous cells are observed. The stele is similar to *X. granatum* (Figure 3F).

3.2.5 Petiolule

The outer layer is periderm. Druse crystals are observed in the cortex. The vascular tissues are collateral bundles, which arrange in cordate shape (Figure 4A and 4B).

3.2.6 Leaf blade

Midrib cortex consists of round-elliptic parenchyma with druse crystals and tanniferous cells. Vascular bundles contain groups of collateral bundles arranging in oval shape (Figure 4C and 4D). The mature blade is bifacial, composes of the upper and lower epidermis with thick cuticle ($3.22 \pm 0.49 \mu\text{m}$). There is a layer of hypodermis under the epidermis (Figure 4E). Typical stomata are observed only on the lower epidermis (Figure 4F). Mesophyll composes long palisade mesophyll ($84.67 \pm 7.82 \mu\text{m}$) appears on the upper part of leaf blades, consisting of 1-2 layers. Spongy mesophyll presents large intercellular spaces which cells deposit druse crystals.

4. Discussion

4.1 Inclusion in *Xylocarpus*

Tanniferous cells are common in the genus *Xylocarpus*. Tannin is a derivative of phenolics (Alongi, 1987; Amarowicz, 2007) which plays an important role in preventing bacterial and fungal infestations (Giner-chavez, 1996) and alleviates damage in tissue caused by ion excess, salt or hydrogen sulfide toxicities (Kimura and Wada, 1989). Interestingly, the distribution of tanniferous cells in the two species is different. For instance, they were found in the root cortex of *X. granatum* but absent in *X. moluccensis* (Table 1). However, they were observed in the leaf tissue of *X. moluccensis*. This implied that the leaf of *X. moluccensis* is more susceptible to salt than root tissue.

Crystals are observed in most parts of

the species. Crystals are calcium oxalate compound which is derived from metabolic waste (Arnott and Pautard, 1970, Franceschi and Hornor, 1980). Their roles as making the plants inedible to predators and detoxification (Rasmussen and Smith, 1961; Finley, 1999).

4.2 Root

The primary roots of both species showed different characters. The primary xylem of *X. moluccensis* is tetrarch (4 arches of xylem) while *X. granatum* is polyarch (7 arches of xylem). This character can be used to discriminate between the two species. Roots of both species contain pith tissue in the stele. This is not found in normal eudicots. However, there are reports that found this character in other mangrove species, including *Rhizophora mangle* (Menezes, 2006), *R. apiculata*, *R. mucronata* (Thonglim, 2018) and *Bruguiera gymnorhiza* (Pornpromsirikul, 2017). The character was mentioned to aerial roots by Gill and Tomlinson (1977), these roots had an origin at the trunk or the other aerial roots (adventitious roots). This contrasts with *X. granatum* that its roots germinated from radicle (Das and Ghose, 2003). Polyarch xylem presented high vessel grouping and high vessel density, which were adapted to reduce the risk of air bubble formation in xylem sap (Baas *et al.*, 1983; Cochard, 2006; Robert *et al.*, 2009).

4.3 Stem

The epidermal layer of *X. moluccensis* stem deposited suberin while *X. granatum* developed a periderm layer. The major component of periderm is phellem tissue, which

contains suberin. Suberin is an insulating substance that can exclude salt from the environment to enter the plant body. The important function of periderm is the plants' tissue protection (Esau, 1965; 1977). Abundant gelatinous fibers were observed in the phloem (phloem fibers) and xylem (xylem fibers). Gelatinous fiber is a labriform fiber having protoplasm and lacks lignin on its cell wall. It possesses a flexible property. As *Xylocarpus* grows under windy areas, the gelatinous fibers can prevent stem breaking (Tomlinson, 2003; Pramod *et al.*, 2014).

4.4 Petiole and petiolule

Petiole and petiolule of both species present periderm, secondary phloem and secondary xylem. This means that they possess secondary growth like a stem. Vascular bundles of *X. granatum* arrange in semi-circular shape while the cordate shape is observed in *X. moluccensis*. This character would be support species identification.

4.5 Leaf blade

Xylocarpus leaves are covered with a thick cuticle. The cuticular layer can provide a hydrophobic barrier to water loss (Rotond *et al.*, 2003; Reef and Lovelock, 2015). Cortex at midrib of *X. granatum* composes of normal parenchyma, while *X. moluccensis* consists of parenchyma with tanniferous cells. Druse crystals were found in the midrib of both species. Vascular bundles of *X. granatum* is a semi-circular shape, while *X. moluccensis* is oval shape. Beneath the upper epidermis is a hypodermis, consisting of 2- 3 layers in *X.*

granatum, whereas *X. moluccensis* has only one layer. *Xylocarpus* grows under several stresses including saline water, strong wind and too much sunlight. The hypodermis is a xerophytic character. Its functions are water storage and infiltrate the excess light intensity (Saenger, 2002). Typical stomata are observed only on lower epidermis of both species which differs from a previous study of Haron and Taha (2010) that reported sunken stomata in *Xylocarpus* sp. This character responses to reducing water

evaporation in a rigid environment (Saenger, 2002). Palisade mesophyll consisting of 1-3 layers of chlorenchyma with less intercellular spaces. The palisade cells in *X. moluccensis* is longer ($84.67 \pm 7.82 \mu\text{m}$) than in *X. granatum* ($23.73 \pm 2.80 \mu\text{m}$). The long palisade cells of mangrove plants help to increase photosynthesis efficiency (Thonglim, 2018).

The comparison of distinct anatomical characters in *X. granatum* and *X. moluccensis* is summarized in Table 1.

Table 1 Comparison of distinct anatomical characters in *Xylocarpus granatum* and *Xylocarpus moluccensis*

Organs	Mangrove species	
	<i>X. granatum</i>	<i>X. moluccensis</i>
Root	Primary xylem with 7 arches	Primary xylem with 4 arches
	Tanniferous cells in cortex	No tanniferous cells in cortex
Stem	One zone of cortex	Two zones of cortex
Petiole	Semi-circular shape of vascular bundles	Cordate shape of vascular bundles
	Suberin accumulation in epidermis layer	Present periderm
Petiolule	Semi-circular shape of vascular bundles	Cordate shape of vascular bundles
Rachis	Present periderm	Absent periderm
Leaf	Semi-circular shape of vascular bundles in midrib	Oval shape of vascular bundles in midrib
	No tanniferous cells in cortex	Tanniferous cells in cortex
	2-3 layers of hypodermis	1 layer of hypodermis
	2-3 layers of palisade cells	1-2 layers of palisade cells

5. Conclusion

5.1 *X. granatum* and *X. moluccensis* share anatomical characters but there are some different characteristics such as primary xylem in the root, shape of vascular bundle in the petiole, petiolule and blade, number of hypodermis and palisade layers. These can be used to discriminate the two studied species.

5.2 Tanniferous cells and druse crystals are common in all parts of both species.

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and Promotion of Science and Technology Talents Project (DPST).

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