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Original article

# Wood anatomy and properties of three species in the genus *Spondias lakonensis* (Anacardiaceae) found in Thailand

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ABSTRACT

The anatomy and properties of woods in the genus *Spondias* (Anacardiaceae) were investigated. Wood samples were collected from North and Northeast Thailand. Permanent slides of wood sections and tissue maceration were made. The specimens were observed under a light microscope and using scanning electron microscopy. The wood density, specific gravity and hardness were also investigated. It was found that the wood of all three species had indistinct growth rings and fine textured and straight grain. Kribs heterogeneous rays type I were found in *Spondias lakonensis* while Kribs heterogeneous rays type III were found in *Spondias pinnata* and *Spondias cytherea*. Radial canals were present in rays of all studied species. Prismatic crystals were found in the rays of *S. lakonensis* and *S. cytherea* but not in *S. pinnata*. Starch grains were also observed in *S. pinnata* and *S. cytherea*. The wood specific gravity of *S. pinnata, S. lakonensis and S. cytherea* was 0.45, 0.33 and 0.30; the wood density was 0.44, 0.33 and 0.27 g/cm$^3$ and the wood hardness was 2795.85, 1329.26 and 1059 N, respectively. The results from this study suggest that *Spondias* woods can be used for agricultural utensils but they are not suitable for heavy construction.
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## Introduction

The family Anacardiaceae comprises more than 70 genera and over 600 species which are mainly trees and shrubs growing in tropical, subtropical and temperate zones (Wannan, 2006). *Spondias* is a small genus consisting of 17 species, seven of which are native to the neotropics and 10 species are native to tropical Asia. Ten species of *Spondias* bear edible fruits (Chayamarit, 2010). Five species are found in Thailand—*Spondias bipinnata, Spondias cytherea, Spondias lakonensis, Spondias laxiflora* and *Spondias pinnata* (Morton, 1987; Hoyos, 1989).

Chayamarit (2010) studied the distribution and physical characteristics of *S. cytherea* Sonn. which is a typical tree native to the Pacific Islands and found in all South American countries. The tree is approximately 5–25 m in height. It is stately in appearance and has pinnate leaves (8–10 cm in length), opposite or sub-opposite, ovate-oblong or oblong leaflets (6–9 cm long) being apex acuminate or acute. The fruit is a fleshy drupe, up to 5 cm in diameter. This species is cultivated as a fruit crop in North and Northeast Brazil and is a very important component in jelly, juice and ice cream. Fermented fruits are used for making alcoholic beverages. Industrial glue can be made from the sticky resin released to make antiseptic solutions (Villegas et al., 1997). Its roots are commonly used for the treatment of fever, migraine and diarrhea (Abo et al., 1999). *S. pinnata* (L.f.) Kurz is found in India, Sri Lanka and other Southeast Asian countries (Anonymous, 1963). It is deciduous, all leaf parts are glabrous and the bark is gray and smooth. The tree is approximately 5–25 m in height. It is stately in appearance and has pinnate leaves (5–25 cm in length), elliptic or oblong leaflets (4–26 cm in long) with the apex acute or abruptly acuminate. The fruit is a fleshy drupe, up to 4.5 cm in diameter and contains a large stone seed (Chayamarit, 2010). The young leaf, flower and fruit are edible. The green fruit is pickled in brine and is commonly used in culinary preparations such as curries, jams and sherbet in countries where it grows naturally. Its bark contains large amounts of flavonoids, phenolic compounds and is high in antioxidant and free radical scavenging activities (Hazra et al., 2008). The wood is used for making match boxes, toothpicks and boxes (Development of Forest Products, 2005). *S. lakonensis* Pierre originated from Southern China, Lao and Vietnam and is abundant at an altitude of 200–500 m above sea level in North and Northeast Thailand (Chuakul, 1996). The tree is approximately 8–30 m in height. Young branches are pubescent. It is stately in appearance and has pinnate

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leaves (5.5–15 cm in length), opposite or elliptic, ovate or oblong (Chayamarit, 2010). The fruit is sour and astringent. Pricked young leaves are used for cloth staining.

Although the old trees are usually pruned and cut, the use of *Spondias* woods is not clear. Anatomical data of wood are important to evaluate the wood properties and can lead to suitable wood utilization. Furthermore, the anatomical characteristics support wood identification. At present, information on the wood anatomy in this genus is lacking and needs to be investigated.

## Materials and methods

### *Specimens collection*

Wood samples of *S. pinnata, S. lakonensis and S. cytherea* were collected from Nakhon Ratchasima, Ranong and Chiang Mai provinces, Thailand. Species identification was performed and examined with type specimens at the Forest Herbarium, Bangkok, Thailand. The wood samples were removed from the tree trunks at 1.3 m height from the ground.

### *Macroscopic study*

Each wood sample was trimmed into a 1 × 1 × 3 cm block and then was cut into sections of 120 μm thickness using a sliding microtome (SM 2010R; Leica, Wetzlar, Germany). The sections were observed under a light microscope (SZ30; Olympus, Tokyo, Japan).

### *Microscopic study*

#### *Permanent slides preparation of wood sections*

Wood samples were cut into sections in three dimensions (cross section, radial long section and tangential long section) using a sliding microtome (SM 2010R; Leica, Wetlar, Germany) with 20 μm thickness. The sections were stained with safranin T for 2 h and then were dehydrated with an ethyl alcohol series (30, 50, 70, 95 and 100%). The samples were placed in xylene for 6 h before being mounted with permount. The permanent slides were observed under the light microscope.

#### *Maceration of wood tissue*

Wood samples were cut into small pieces (toothpick size). Each specimen was boiled in a mixture of acetic acid and hydrogenperoxide (1:1) for 3 h, followed by washing three times with water. The macerated samples were stained with safranin T for 2 h and then were dehydrated with an ethyl alcohol series (30%, 50%, 70%, 95% and 100%). The samples were left in xylene for 6 h before mounting with permount.

### *Scanning electron microscopy*

Wood sections (120 μm thickness) and macerated cells were dehydrated with an ethyl alcohol series (30%, 50%, 70%, 95% and 100%), dried in a critical point dryer (K850; Emitech; Dubai, United Arab Emirates) and coated with gold particles (Ohtan et al., 1987; Schneider and Carlquist, 2001). The samples were observed under a scanning electron microscope (JSM 5600 LV; JEOL, Tokyo, Japan).

### *Wood property measurement*

#### *Wood density*

Wood samples were trimmed into 2 × 2 × 2 cm blocks. Each wood block was left for 1 wk at room temperature for air drying. The wood density was calculated using the formula in Equation (1):

$$D = \frac{M}{V} \quad (1)$$

where D is the density, M is the mass and V is the volume (Desch and Dinwoodie, 1996).

#### *Specific gravity*

The specific gravity was calculated using the formula in Equation (2):

$$S = \frac{Wo}{V} \quad (2)$$

where S is the specific gravity, Wo is the weight of wood (oven dry) and V is the weight of an equivalent volume of water (Brown et al., 1949).

#### *Hardness*

Wood samples were trimmed into 6 × 6 × 8 cm blocks. Each wood block was subjected to measurement in a hardness tester machine (Janka W-tester Type 5, Ludwigshafen, Germany).

## Results

### *Spondias pinnata (L.f.) Kurz (Thai name: Ma kok)*

#### *Macroscopic characters*

The wood is fine–textured with a light, fulvous color, no luster and is odorless. Growth rings are indistinct, the grain is straight, vessels are medium sized, visible to the naked eye, with yellow deposits (Fig. 1A).

#### *Microscopic characters*

The wood is diffuse-porous with more solitary pores and few multiple (2–6) pores. Vessels are round to oval shaped and are arranged in tangential bands and a diagonal pattern. There are 10 pores $mm^{-2}$ with 149 (102–206) μm diameter and 408 (209–591) μm length. Tyloses and gummy deposits were found in vessels (Fig. 1B). Vessels cover 14% of the cross section. The perforation plate is simple (Fig. 1C). Intervessel pits are 7 (5–10) μm in length, non-vestured, oval shaped and alternate in arrangement (Fig. 1D). Vessel-ray pits are 9 μm in length, oval shaped with much reduced borders to apparently simple (Fig. 1E). Septate fibers are usually observed (Fig. 1D), with 13 (8–18) μm diameter and 934 (627–1319) μm length. The fiber wall is very thin with 3 μm thickness. Axial parenchyma are vasicentric paratracheal or scanty paratracheal (Fig. 1B). Rays are 60 (34–84) μm or 2–4 cells in width and 480 (268–692) μm or 7–24 cells in height. Rays consist of several rows of procumbent cells and two rows of upright cells (Kribs heterogeneous type III). There are 4 rays/mm. Radial canals are present in rays with 44 (20–62) μm diameter (Fig. 1F). Starch grains are commonly observed in ray cells (Fig. 1G).

#### *Physical characters*

The wood is light weight with 0.45 specific gravity. The wood density is 0.44 $g/cm^3$ at 12% moisture content and hardness is 2795.85 N.

### *Spondias lakonensis Pierre (Thai name: Ma ho)*

#### *Macroscopic characters*

The wood is medium textured, with a light, lucescent color, no luster and is odorless. Growth rings are indistinct, the grain is straight and vessels are small sized, being visible to the naked eye (Fig. 2A).

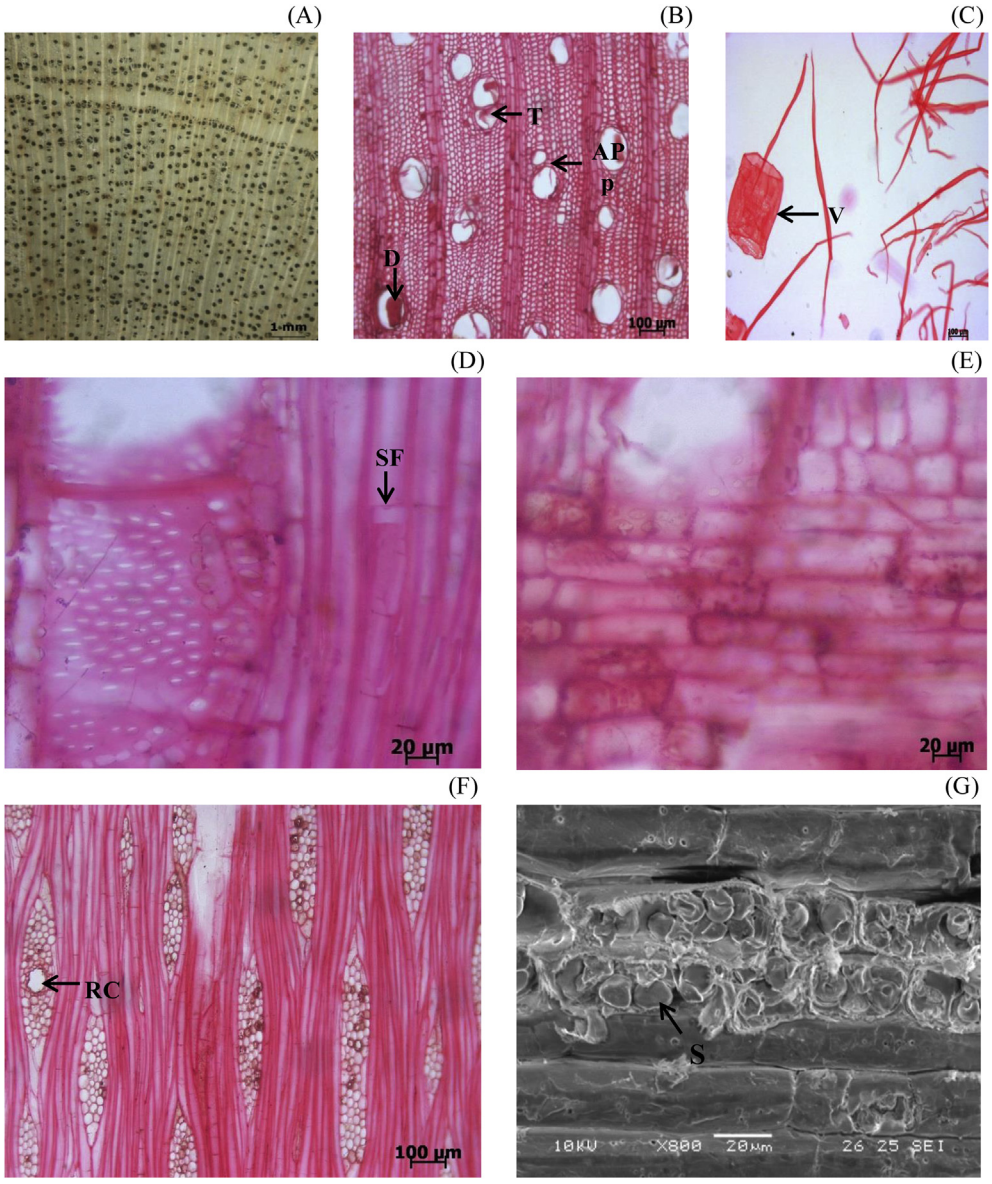


**Fig. 1.** *Spondias pinnata*: (A) Transverse section showing macroscopic characters; (B) Transverse section showing tylose, gummy deposit and axial parenchymas; (C) Macerated wood showing vessel and fibers; (D) Tangential long section showing intervessel pits; (E) Radial long section showing vessel-rays; (F) Tangential long section showing radial canals in rays; (G) Starch grains in ray cell observed by scanning electron microscopy (AP = Axial parenchyma, D = Deposit, RC = Radial canals, S = starch grains, SF = Septate fibers, T = Tylosis, V = Vessel.)

*Microscopic characters*

The wood is diffuse-porous with more solitary pores and few multiple (2–5) pores. Vessels are round to oval shaped and are arranged in tangential bands. There are 4 pores/mm$^2$ with 152 (119–182) µm diameter and 357 (196–575) µm length. Tyloses are found in vessels (Fig. 2B). Vessels cover 12% of the cross section. The perforation plate is simple (Fig. 2C). Intervessel pits are 10 (7–14) µm in length, non-vestured, oval shaped and alternate in arrangement (Fig. 2D). Vessel-ray pits are 12 µm length, oval shaped with much reduced borders to apparently simple (Fig. 2E). Libriform fibers are usually observed, with 18 (10–29) µm diameter and 937 (629–1418) µm length. The fiber wall is very thin with 2 µm thickness. Prismatic crystals are observed in fibers. Axial parenchyma are vasicentric paratracheal. Rays are 17 (7–29) µm or 1–2 cells in width and 306 (191–527) µm or 6–20 cells in height. Rays consist of several rows of procumbent cells and two rows of upright cells (Kribs heterogeneous type I). There are 4 rays/mm. Radial canals are present in rays with 18 (9–39) µm diameter (Fig. 2F). Prismatic crystals are commonly observed in procumbent and upright ray cells (Fig. 2G).

*Physical characters*

The wood is light weight with 0.33 specific gravity. The wood density is 0.33 g/cm$^3$ at 12% moisture content and the hardness is 1329.26 N.

*Spondias cytherea Sonn. (Thai name: Ma kok farang)*

*Macroscopic characters*

The wood is medium textured, with a light, fulvous color, no luster and is odorless. Growth rings are indistinct, the grain is straight and vessels are small sized (Fig. 3A).

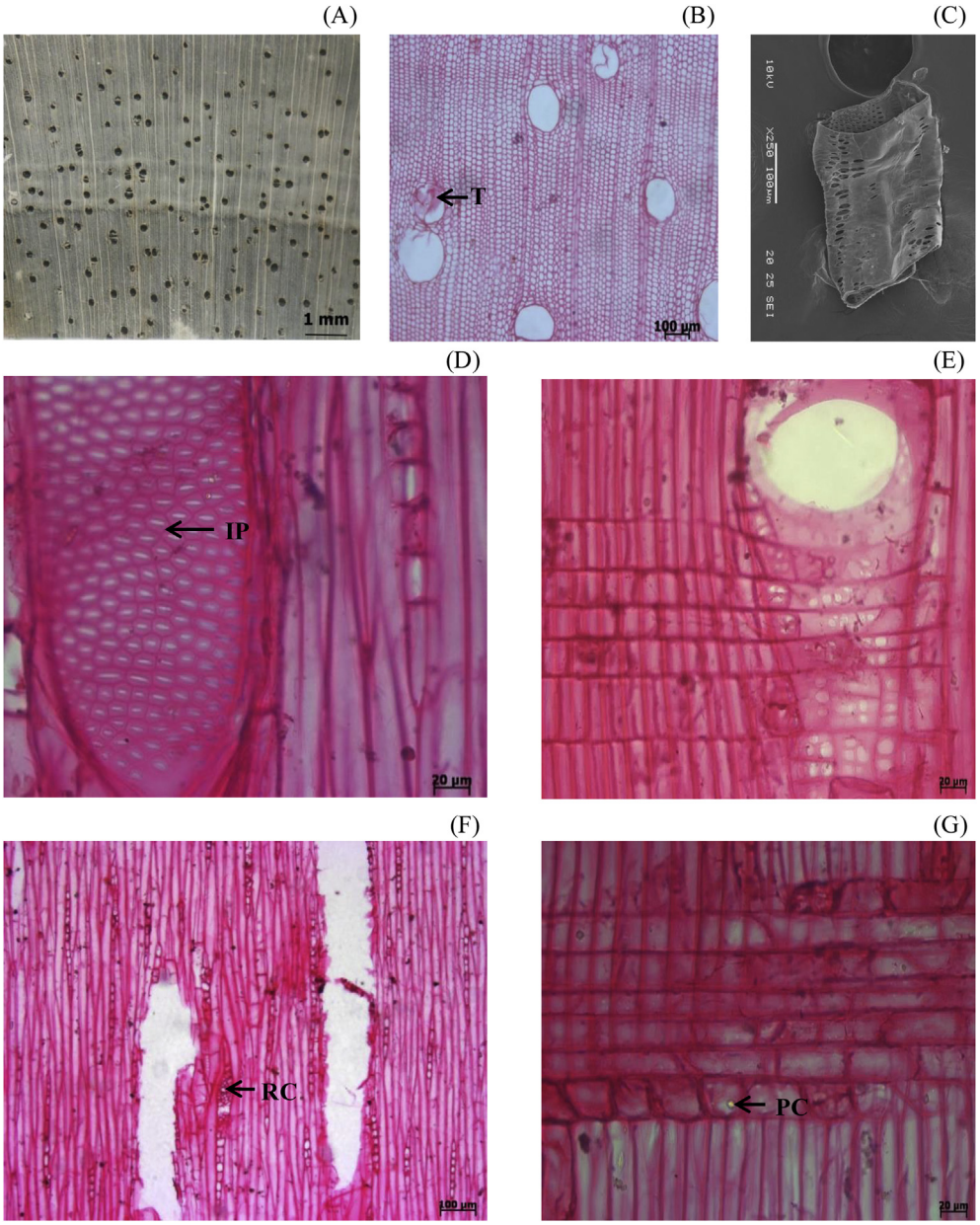


**Fig. 2.** *Spondias lakonensis*: (A) Transverse section showing macroscopic characters; (B) Transverse section showing tyloses; (C) Macerated vessel under scanning electron microscopy; (D) Tangential long section showing intervessel pits; (E) Radial long section showing vessel-rays; (F) Tangential long section showing radial canals in rays; (G) Primatic crystals in ray cell (AP = Axial parenchyma, IP = Intervessel pit, PC = Prismatic crystals, RC = Radial canals, T = Tylosis).

*Microscopic characters*

The wood is diffuse-porous with more solitary pores and few multiple (2–4) pores, cluster pores and oblique pores. Vessels are round to oval shaped and are arranged in a diagonal pattern. There are 9 pores/mm$^2$ with 155 (120–197) µm diameter and 370 (206–516) µm length. Gum and deposit are found in vessels (Fig. 3B). Vessels covered 14% of the cross section. The perforation plate is simple (Fig. 3C). Intervessel pits are 10 (7–15) µm in length, non-vestured, oval shaped and alternate in arrangement (Fig. 3D). Vessel-ray pits are 13 µm length, oval shaped with much reduced borders to apparently simple (Fig. 3E). Septate fibers are usually observed (Fig. 3F), with 15 (9–21) µm diameter and 906 (578–1225) µm length. The fiber wall is very thin with 3 µm thickness. Axial parenchyma are vasicentric paratracheal (Fig. 3B). Rays are 40 (28–55) µm or 1–4 cells in width and 376 (217–754) µm or 5–24 cells in height. Rays consist of several rows of procumbent cells and two rows of upright cells (Kribs heterogeneous type III). There are 5 rays/mm. Radial canals are present in rays with 37 (15–54) µm diameter (Fig. 3F). Prismatic crystals were observed in upright ray cells. Starch grains were found in procumbent and upright ray cells (Fig. 3G).

*Physical characters*

The wood is light weight with 0.30 specific gravity. The wood density is 0.27 g/cm$^3$ at 12% moisture content and the hardness is 1059 N.

## Discussion

*S. pinnata*, *S. lakonensis*, and *S. cytherea* have indistinct growth rings. As they grow in tropical areas, there is not much difference between soil water in summer and the rainy seasons. The xylem

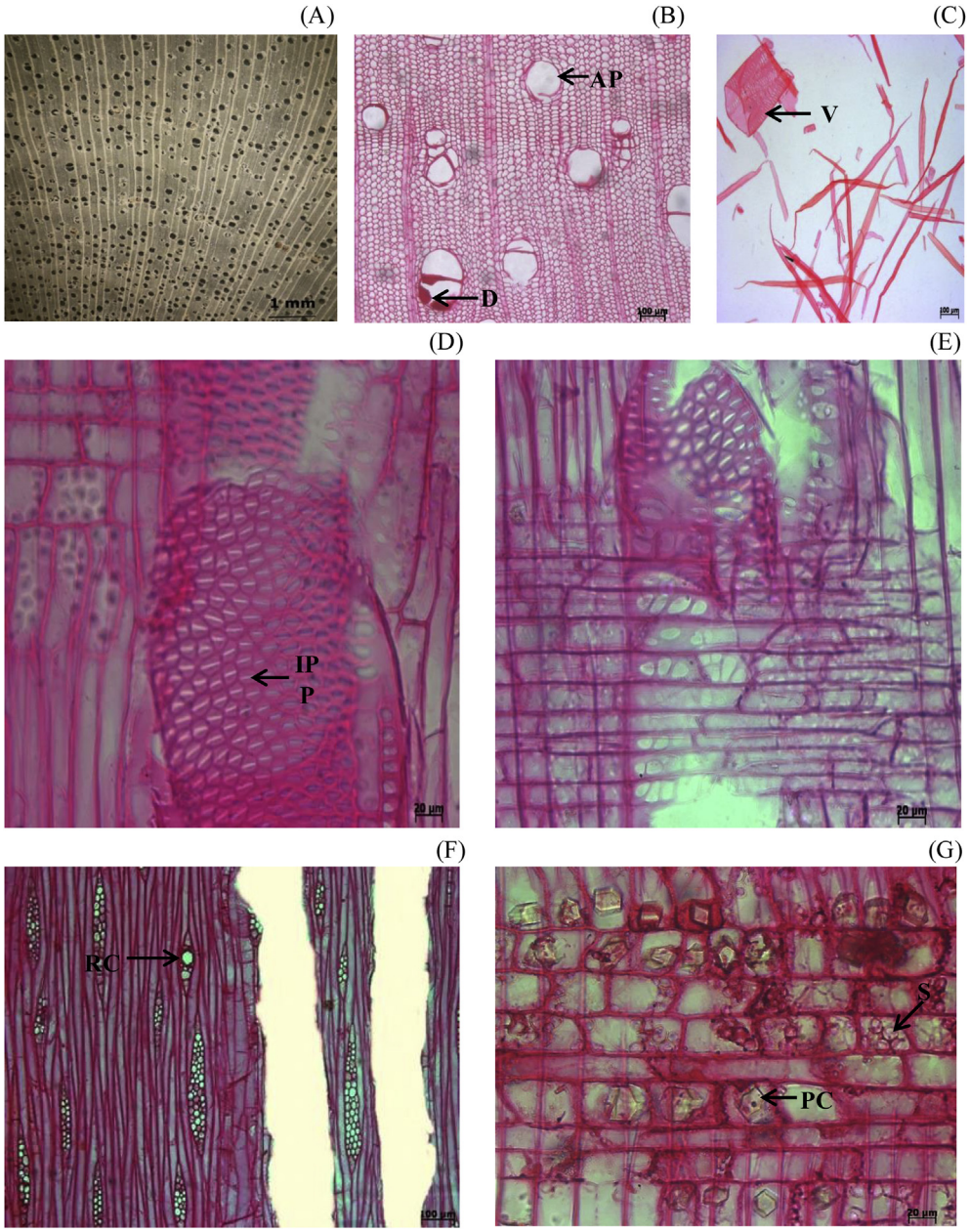


**Fig. 3.** *Spondias cytherea*: (A) Transverse section showing macroscopic characters; (B) Transverse section showing deposit and axial parenchymas; (C) Macerated wood showing vessels; (D) Tangential long section showing intervessel pits; (E) Radial long section showing vessel–rays; (F) Tangential long section showing radial canals in rays; (G) Prismatic crystals in ray cell (AP = Axial parenchyma, IP = Intervessel pit, PC = Prismatic crystals, D = Deposit, RC = Radial canals, S = Starch grains, V = Vessel).

shows regular growth year–round. The woods have straight grains. It has been proved that straight-grained wood has greater stress resistance than oblique–grained wood (Zhou and Shen, 2003). Wood texture depends on the vessel size; *S. pinnata* and *S. cytherea* have average vessel diameters of 149 and 148 μm and they are classified as fine textured woods while *S. lakonensis* has an average vessel diameter of 166 μm and is textured wood (Pastsabut, 1987). The vessels of all species are round and short classified as a medium with simple perforation. Wood which has this type of vessel shows highly efficient water transportation (Qi et al., 2012). The fiber wall of *S. cytherea* is thicker (3 μm) than in *S. pinnata* and *S. lakonensis* (1 μm); consequently, *S. cytherea* wood is harder and more dense than the other two species. Fiber wall thickness affects wood density and hardness (Chattaway, 1932). Tyloses were observed in this genus. Tylosis is the phenomenon whereby paratracheal parenchyma protrude into the lumen of a nearby vessel (Fahn, 1982; Esau, 1965). Fungi and injury may cause tylosis (Scheckler and Galtier, 2003). Generally, Anacardiaceae store starch in wood which is a food source of fungi and while tyloses can interrupt fungal invasion, in wood drying, tyloses are a disadvantage (Canny, 1997; Jaquish and Ewers, 2001). In this study, crystals were found in the rays of *S. cytherea*, while they were found in the rays and fibers of *S. lakonensis*. Crystal is a calciumoxalate compound and is occasionally found in living cells (Fahn, 1982). The types and occurrence of crystals have been used for wood identification (Chattaway, 1955). However, crystals were not observed in *S. pinnata*, similar to the report by Kryn (1952) but contrary to Dong and Baas (1993) who reported the presence of crystals in the rays of *S. pinnata* collected from India. Gupta and Agarwal (2008) found crystals in the rays and parenchyma strands of *S. pinnata* from China. Probably, environmental factors affect calciumoxalate metabolism.

Based on the wood density values, *S. pinnata*is classified as a light wood (density = 0.4–0.5 g/cm$^3$), while *S. lakonensis*. and *S. pinnata* are very light woods (density = 0.3–0.4 g/cm$^3$ (Pastsabut, 1987). Wood with a high density has a high weight and hardness (Zobel and Buijtenen, 1989). As *S. pinnata*, *S. lakonensis* and *S. cytherea* have low densities, their woods may not be suitable for heavy construction. However, Eiadthong (2007) suggested that *S. pinnata* wood can be used for skeleton structure and plywood. The data from this study suggest that *Spondias* woods can be used for agricultural utensils but they are not suitable for heavy construction.

Woods of the three *Spondias* species have indistinct growth rings, are fine-textured and have straight grain. *S. lakonensis* has Kribs heterogeneous type I rays while *S. pinnata and S. cytherea* have Kribs heterogeneous type III rays. Septate fibers, starch grains, gum and deposit were found in *S. pinnata* and *S. cytherea* but not in *S. lakonensis*. Prismatic crystals were found in *S. lakonensis* and *S. cytherea.* As the wood of this genus has low density and hardness, it may not be suitable for heavy construction.

## Conflict of interest

The authors declare that there are no conflicts of interest.

## Acknowledgment

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