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Species identification of some *Castanopsis* (D.Don) Spach (Fagaceae) species from Northern Thailand using wood characteristics

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ABSTRACT

The anatomical characters of the wood of seven species of the genus *Castanopsis* (D.Don) Spach (Fagaceae) from northern Thailand were investigated. The specimens were sectioned using a sliding microtome. Tissue maceration was also performed using Franklin's solution. The samples of wood sections and macerated cells were observed under a light microscope and under scanning electron microscope. The wood anatomical data including presence of broad rays, vessel arrangement, presence of growth rings, occurrence of tyloses, shape of vessel-ray pits, and occurrence of prismatic crystals are helpful for identification of the species. From this study, a key to species based on wood anatomical characters was constructed.

KEYWORDS: Wood characteristics, *Castanopsis*, Fagaceae.

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INTRODUCTION

The genus *Castanopsis* (D.Don) Spach (Castaneoideae, Fagaceae) comprises about 120 species widely found in the tropics and subtropics of South Asia to near Australia, and also in south-western USA. *Castanopsis* is native to South-East Asia with 58 species (30 endemic) recorded in China (Chengjiu *et al.*, 1999); in Thailand, there are 33 species (Phengklai, 2008).

Several species are economic timber trees and important components of the ecosystem especially in the northern hemisphere (Shimaji, 1959; Cannon & Manos, 2003). Many species of *Castanopsis* provide edible nuts such as *C. diversifolia* (Kurz) King ex Hook.f., *C. acuminatissima* (Blume) A.DC., *C. argentea* (Blume) A.DC. and *C. echidnocarpa* (Hook.f. & Thomson ex A.DC.) A.DC.; *C. acuminatissima* is also used as a pioneer species for forest plantation (Phengklai, 2008). Woods of some *Castanopsis* are widely used for construction, furniture, flooring, firewood and mushroom culture (Lemmens *et al.*, 1995). Seven common species and many more useful species of northern Thailand were studied in this research.

Wood characteristics of *Castanopsis* were investigated by Metcalfe & Chalk (1957) within a generic survey of the wood anatomical characters of *Fagus* L., *Nothofagus* Blume, *Castanopsis*, *Castanea* Mill., *Lithocarpus* Blume and *Quercus* L. The wood anatomy of Japanese *Castanopsis* was reported by Shimaji (1959, 1962), whilst Hwang (1962) also described the anatomy of some important Taiwan woods and reported anatomical features of *Castanopsis*, *Lithocarpus* and *Quercus*. Pande *et al.* (2005) studied wood anatomical variations in the genus *Castanopsis* from different localities and examined in relation to altitude and latitude. Although there are many species of *Castanopsis* in Thailand, anatomical data on woods of this genus are rare. In addition, members of this genus show highly morphological variation and anatomical characteristics would supplement species identification based on morphological characters. Moreover, the

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data can be used to evaluate the properties of wood leading to suitable utilization of particular species.

MATERIALS AND METHODS

Seven species of *Castanopsis* woods were investigated as they are commonly used in northern Thailand (Table 1), and surveys and specimen collections were made in northern Thailand. Species identification was performed and examined with herbarium specimens at BK, BKF, KKU and QBG. The morphological data and localities were recorded. Wood samples were taken from mature trunks at 1.3 m height from the ground.

Macroscopic and microscopic characters

The woods were sectioned using a sliding microtome with a thickness of 60–120 µm. For microscopic characters, the samples were cut in three planes: transverse, tangential and radial long sections by a sliding microtome with 18–25 µm thickness and stained with 1% safranin. The excess stain was washed away with distilled water, dehydrated in 70% and 95% ethanol, then dehydration was completed with absolute ethanol, transferred to a mixture of equal parts of absolute ethanol and xylene, allowing at least 5–10 minutes in each. The stained samples were cleared with pure xylene for at least 15 minutes. Finally the wood sections were permanently mounted on microscope slides with permount.

Preparation of macerations

The wood specimens were cut into small pieces, then placed into Franklin's solution (10% Hydrogen Peroxide and 10% acetic acid 1:1) (modified from Franklin, 1945) and stained in 1% safranin for various times according to the species (6–12 hours). Excess stain was washed out in two changes of 70% ethanol, followed by dehydration with 95% ethanol and absolute ethanol. The samples were cleared with a mixture of equal parts of absolute ethanol and xylene, and then passed through pure xylene. The specimens were mounted on a slide with permount.

Scanning electron microscopy (SEM) analysis

The samples of wood sections and macerated cells were dehydrated, subjected to CPD and coated with gold particles prior to observation under a scanning electron microscope. Wood anatomical characteristics were described following the "IAWA List of Microscopic Features for Hardwood Identification" (IAWA Committee, 1989) with at least 25 measurements were made of each feature. The data and images were analysed using a Zeiss microscope assembled with an AxioCam MRc camera and Axioskop II Plus programme.

RESULTS

The anatomical features of the wood of the seven species of *Castanopsis* collected from northern Thailand are described as follows:

1. Castanopsis acuminatissima (Blume) A.DC.

Macroscopic characters

A tall tree up to 40 m high and 70–250 cm in girth. The wood is yellowish to light brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye.

Table 1. Some collected *Castanopsis* species from Northern Thailand

Species	Local Name	Collector Number	Locality	Habitat
C. acuminatissima	Ko dueai	P. Phromprasit 201	Chiang Rai	Ev, De, Gr
C. argyrophylla	Ko ti	P. Phromprasit 205	Chiang Mai	Ev
C. armata	Ko rang	P. Phromprasit 206	Chiang Mai	Ev, De
C. diversifolia	Ko paen	P. Phromprasit 210	Chiang Mai	Ev, De
C. echidnocarpa	Ko nam	P. Phromprasit 211	Chiang Mai	Ev, De, St
C. indica	Ko luang	P. Phromprasit 207	Phitsanulok	Ev, De, Ga
C. tribuloides	Ko bi lueam	P. Phromprasit 209	Chiang Mai	Ev, De, Gr

Ev = Everygreen forest, De = Deciduous forest, Gr = Granite to limestone bedrock, St = Near stream, Ga = Open grassland

Microscopic characters

Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal and radial pattern (Fig. 1A). Vessels 105±27 µm in diameter and vessel elements 403±257 µm in length. Vessel density is low with 12±3 vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 2.17±0.50 µm), round and alternate (Fig. 1D). Vessel-ray pits are with much reduced borders to apparently simple, rounded or angular and elliptic (Fig. 8C). Tyloses are absent. Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls (Fig. 8D). Fibres are non-septate, narrow, 4.6±1.86 µm in diameter and 1068.65 ±344.55 µm long. Fibre walls are 3.85±0.86 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically as diffuse, diffuse in aggregates and in narrow bands or lines two cells wide, 3 (2–6) cells per parenchyma strand. Rays are homocellular with procumbent cells (Fig. 1C) and heterocellular with body ray cells procumbent, one row of upright and/or square marginal cells. Rays are of have two distinct sizes. The narrow rays are uniseriate, sometimes biseriate, the larger rays are aggregate rays (Fig. 1B), commonly more than 20 seriate. The percentage of ray covering area is 65±0.21% (tangential surface), with 15±1.3 rays per mm^2. Prismatic crystals are present in chambered ray and axial parenchyma cells. Starch grains are present in both ray and axial parenchyma cells.

2. Castanopsis argyrophylla King ex Hook.f.

Macroscopic characters

A tall tree up to 30 m high and 120–200 cm in girth. The wood is brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad rays are absent to the naked eye.

Microscopic characters

Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal, radial (Fig. 2A) or dendritic pattern. Vessels 155±29 µm in diameter and vessel elements 277±128 µm in length. Vessel density is low with 11±1 vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 1.99±0.62 µm), round and alternate. Vessel-ray pits are with much reduced borders to apparently simple, rounded or angular and elliptic. Tyloses are present in vessels. Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls. Vascular tracheids are present near vessels. Fibres are non-septate, narrow, 3.60±1.37 µm in diameter and with 705.69±293.09 µm long. Fibre walls are 3.87±1.50 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically as diffuse, diffuse in aggregates and in narrow bands or lines one to two cells wide, 4 (3–7) cells per parenchyma strand. Rays are heterocellular with body ray cells procumbent (Fig. 2C), 1–2 rows of upright and/or square marginal cells. Rays are exclusively uniseriate (Fig. 2B), sometimes biseriate. The percentage of ray covering area is 31±0.24% (tangential surface), with 9±1.58 rays per mm^2. Prismatic crystals are present in chambered of axial parenchyma cells and ray cells (Fig. 2D). Starch grains are present in both ray and axial parenchyma cells.

3. Castanopsis armata (Roxb.) Spach.

Macroscopic characters

A tall tree up to 30 m high and 120–200 cm in girth. The wood is light brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye.

Microscopic characters

Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal, Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal, radial (Fig. 3A) or dendritic pattern. Vessels 157±52 µm in diameter and vessel elements 303±102.8 µm in length. Vessel density is low with 9±1vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 3.53±1.03 µm), round and alternate. Vessel-ray pits are with much reduced borders to apparently simple pits, elliptic. Tyloses are common in vessels (Fig. 3D). Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls. Vascular tracheids are present near vessel. Fibres are non-septate, narrow, 3.71±1.62 µm in diameter and 1067.36 ±295.83 µm long. Fibre walls are 3.48±0.83 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically as diffuse, diffuse in aggregates and in narrow bands

or lines two cells wide, 4 (3–10) cells per parenchyma strand. Rays are homocellular with procumbent cells and heterocellular with body ray cells procumbent (Fig. 3C), one row of upright and/or square marginal cells. Rays are of two distinct sizes. The narrow rays are uniseriate, sometimes biseriate, the larger rays are aggregate rays, commonly more than 5 seriate (Fig. 3B). The percentage of ray covering area are 16±0.02% (tangential surface), with 11±0.7 rays per mm^2. Prismatic crystals are present in chambered axial parenchyma cells. Starch grains are present in both ray and axial parenchyma cells.

4. Castanopsis diversifolia (Kurz) King ex Hook.f.

Macroscopic characters

A tall tree up to 30 m high and 120–200 cm in girth. The wood is light brown. Growth ring boundaries are distinct. Texture is fine, without lustre and odor. Broad rays are absent to the naked eye.

Microscopic characters

Wood diffuse porous.Vessels are mostly solitary and arranged in a diagonal, radial (Figs. 4A, 9A) or dendritic pattern. Vessels 109±36 µm in diameter and vessel elements 264±86 µm in length. Vessel density is low with 10±3 vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 2.22±1 µm), round and alternate (Figs. 8E). Vessel-ray pits are with much reduced borders to apparently simple, eliptic to vertical (palisade). Tyloses are common in vessels (Fig. 4D). Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls. Vascular tracheids are present near vessels. Fibres are non-septate, narrow, 4.14±1.84 µm in diameter and 1174.41±226.44 µm long (Fig. 4F). Fibre walls are 3.75±0.73 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically diffuse, diffuse in aggregates and in narrow bands or lines three cells wide, 4 (2–7) cells per parenchyma strand. Rays are heterocellular with body ray cells procumbent, one row of upright and/or square marginal cells (Fig. 4C). Rays are exclusively uniseriate, sometimes biseriate (Fig. 4B). The percentage of ray covering area are 50±0.01% (tangential surface), with 11±2.24 rays per mm^2. Prismatic crystals are present in chambered ray and axial parenchyma cells. Starch grains are present in both ray and axial parenchyma cells.

5. Castanopsis echidnocarpa (Hook.f. & Thomson ex A.DC.) A.DC.

Macroscopic characters

A tall tree up to 25 m high and 20–50 cm in girth. The wood is light brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye.

Microscopic characters

Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal, radial or dendritic pattern (Fig. 5A). Vessels 151±32 µm in diameter and vessel elements 319±30 µm in length. Vessel density is low with 10±1vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 1.44±0.92 µm), round and alternate (Fig. 5D). Vessel-ray pits are with much reduced borders to apparently simple pits, elliptic. Tyloses are absent. Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls. Vascular tracheids present near vessels. Fibres are non-septate, narrow, 2.58±0.70 µm in diameter and 1012.01± 153.76 µm long (Fig. 5F). Fibre walls are 4.25±0.92 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically as diffuse, diffuse in aggregates and in narrow bands or lines two cells wide, 4 (2–7) cells per parenchyma strand. Rays are homocellular with procumbent cells. Rays are of have two distinct sizes. The narrow rays are uniseriate, sometimes biseriates, the larger rays are aggregate rays (Fig. 5B), commonly more than 5 seriate. The percentage of ray covering area are 35±0.15% (tangential surface), with11±1.41 rays per mm^2. Prismatic crystals are present in chambered axial parenchyma cells (Fig. 5C). Starch grains are present in both ray and axial parenchyma cells.

6. Castanopsis indica (Roxb.) A.DC.

Macroscopic characters

A tall tree up to 30 m high and 120–200 cm in girth. The wood is light brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye.

Microscopic characters

Wood diffuse porous. Vessels are mostly solitary and arranged in a diagonal, radial (Fig. 6A) or dendritic

pattern. Vessels 105±32 µm in diameter and vessel elements 367±135µm in length. Vessel density is low with 15±1vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 2.80±1.74 µm), round and alternate. Vessel-ray pits are with much reduced borders to apparently simple, elliptic. Tyloses are common in vessels. Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls (Fig. 6D). Vascular tracheids are present near vessels. Fibres are non-septate, narrow, 2.82±0.91 µm in diameter and 900.80±277.42 µm long. Fibre walls are 3.48±0.93 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically as diffuse, diffuse in aggregates and in narrow bands or lines two cells wide, 4 (2–10) cells per parenchyma strand. Rays are homocellular with procumbent cells and heterocellular with body ray cells procumbent, one row of upright and/or square marginal cells (Fig. 6C). Rays are of have two distinct sizes. The narrow rays are uniseriate, sometimes biseriate; the larger rays are aggregate rays, commonly more than 5 seriates (Fig. 6B). The percentage of ray covering area are 41±0.24% (tangential surface), with 13±1.82 rays per mm^2. Prismatic crystals are present in chambered ray and axial parenchyma cells. Starch grains are absent in both rays and axial parenchyma cells.

7. Castanopsis tribuloides (Sm.) A.DC.

Macroscopic characters

A tall tree up to 40 m high and 80–150 cm in girth. The wood is light brown. Growth ring boundaries are indistinct. Texture is very fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye.

Microscopic characters

Wood diffuse porous. Vessel are mostly solitary and arranged in a diagonal, radial (Fig. 7A) or dendritic pattern. Vessels 93±32 µm in diameter and vessel elements 260±136 µm in length. Vessel density is low with 11±3 vessels per mm^2. Perforation plates are simple. Intervessel pits are minute (average 3.67±1.37 µm), round and alternate (Fig. 8F). Vessel-ray pits are with much reduced borders to apparently simple, rounded or angular and elliptic. Tyloses are common in vessels (Fig. 8G). Vasicentric tracheids are present with thick-walled, rounded bordered pits abundant on radial and tangential walls. Vascular tracheids are present near vessels. Fibres are non-septate, narrow, 4.02±1.08 µm in diameter and 706.48±297.33 µm long. Fibre walls are 3.33±1.1 µm thick. Fibres with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty. Apotracheal axial parenchyma, typically diffuse, diffuse in aggregates and in narrow bands or lines three cells wide, 4 (2–4) cells per parenchyma strand. Rays are homocellular with procumbent cells and heterocellular with body ray cells procumbent, one row of upright and/or square marginal cells (Fig. 7C). Rays are of have two distinct sizes. The narrow rays are uniseriate, sometimes biseriate, the larger rays are aggregate rays, commonly more than 25 seriates (Figs 7B, 8B). The percentage of ray covering area are 19±0.21% (tangential surface), with 9±0.71 rays per mm^2. Prismatic crystals are present in chambered axial parenchyma cells (Fig. 7D). Starch grains are absent in both ray and axial parenchyma cells.

KEY TO SPECIES BASED ON WOOD ANATOMICAL CHARACTERS

1. Broad rays absent
  2. Growth ring boundaries distinct — **4. C. diversifolia**
  2. Growth ring boundaries indistinct — **2. C. argyrophylla**
1. Broad aggregate rays present
  3. Tyloses not found in vessels
    4. Vessels arranged in diagonal, radial and dendritic patterns — **5. C. echidnocarpa**
    4. Vessels arranged in diagonal and radial patterns — **1. C. acuminatissima**
  3. Tyloses present in vessels
    5. Prismatic crystals found in only axial parenchyma
      6. Vessel-ray pitting only elliptic — **3. C. armata**
      6. Vessel-ray pitting round and elliptic — **7. C. tribuloides**
    5. Prismatic crystals found in axial parenchyma and rays — **6. C. indica**

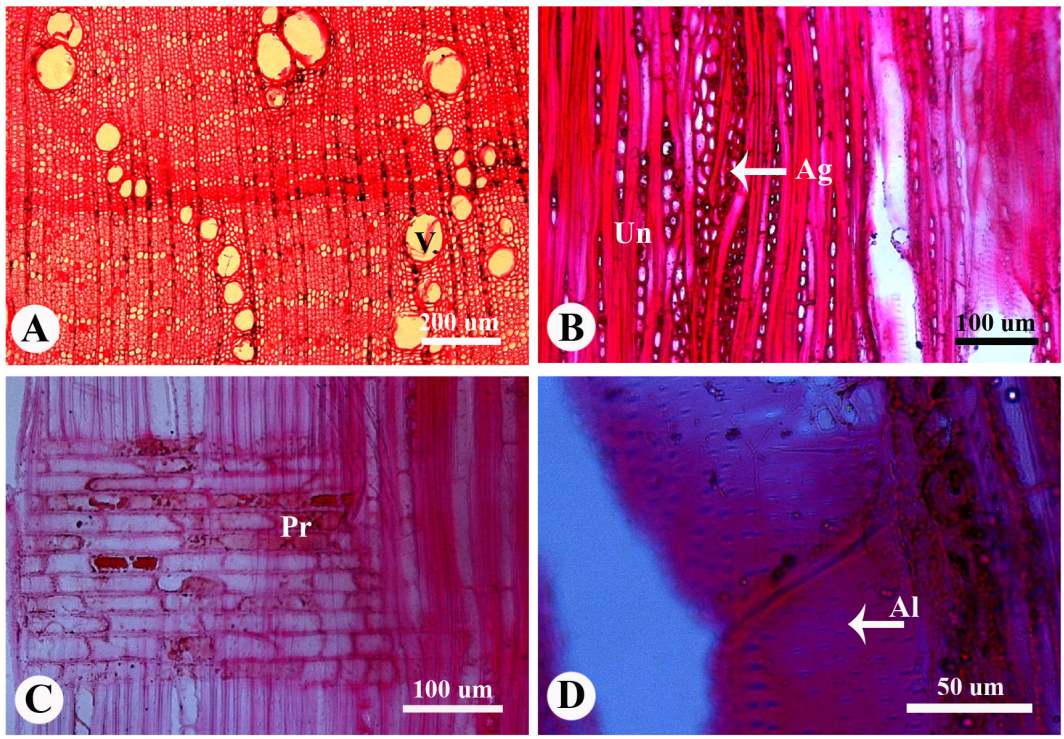

Figure 1. Wood anatomical features of *C. acuminatissima*: A. Transverse section, vessel diagonal and radial pattern; B. Tangential section, uniseriate and part of an aggregate ray; C. Radial section, procumbent ray cells; D. Tangential section, alternate pitting (V = Vessel, Ag = Aggregate ray; Al = Alternate pitting; Pr = Procumbent cells; Un = Uniseriate ray).

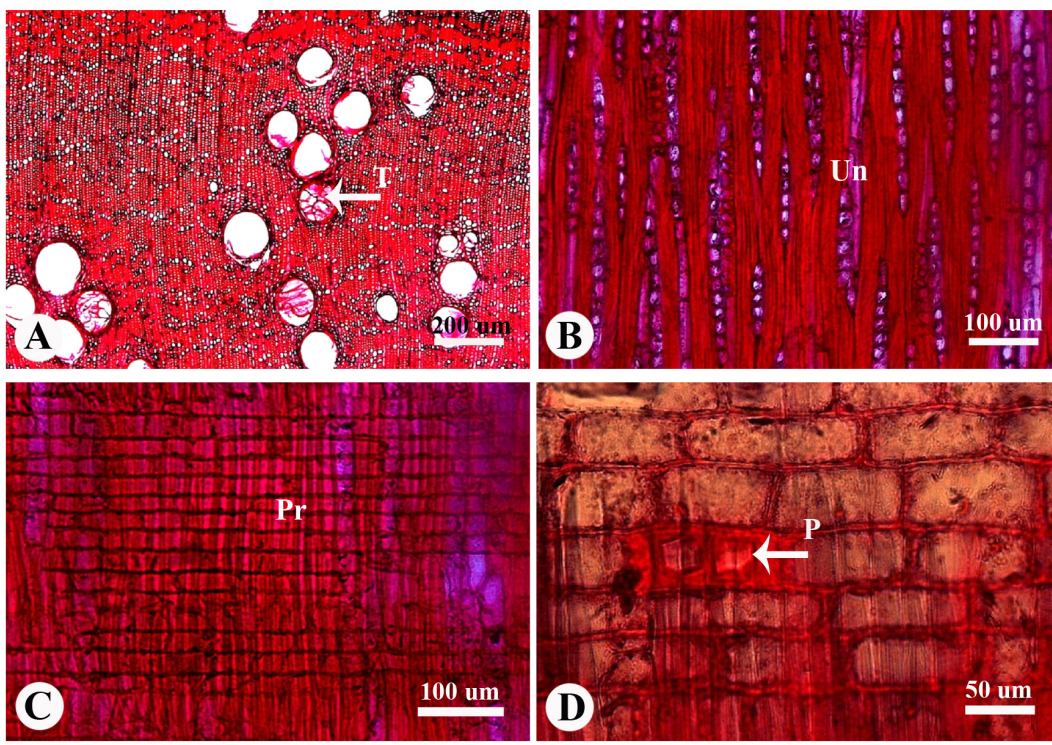

Figure 2. Wood anatomical features of *C. argyrophylla*: A. Transverse section, vessels in diagonal and radial pattern; B. Tangential section, uniseriate rays; C. Radial section, procumbent ray cells; D. Radial section, prismatic crystals (P = Prismatic crystals; Pr = Procumbent cells; Un = Uniseriate ray; U = Upright cells; T = Tyloses).

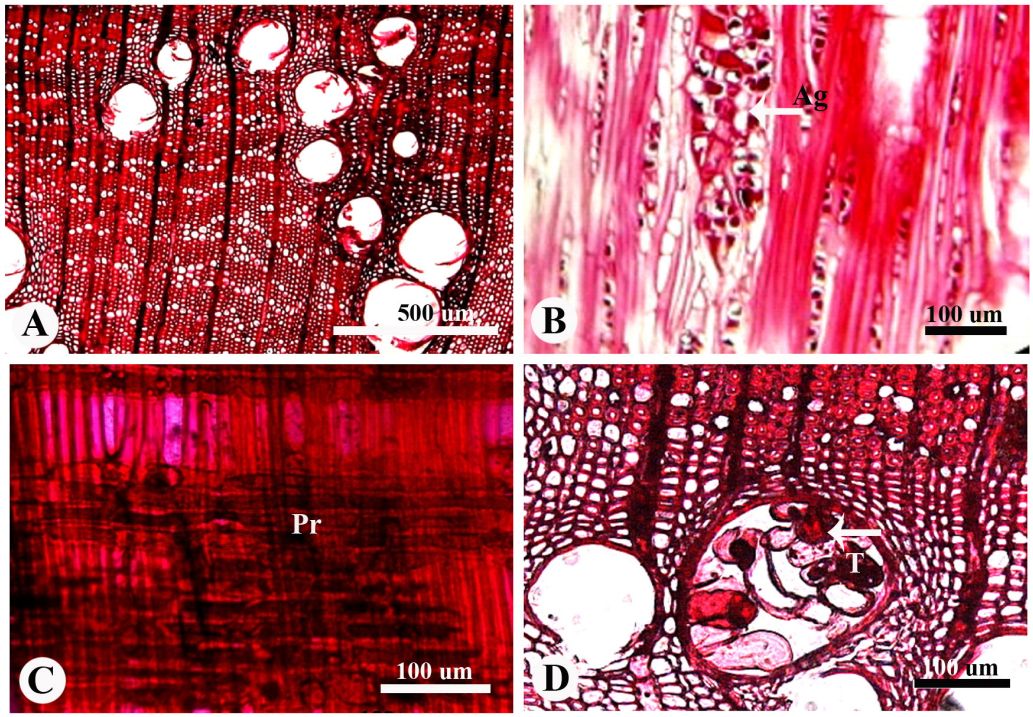

Figure 3. Wood anatomical features of *C. armata*: A. Transverse section, vessels in diagonal and radial pattern; B. Tangential section, uniseriate and part of an aggregate ray; C. Radial section, procumbent cells; D. Cross section, tyloses in one vessel (Ag = Aggregate ray; Pr = Procumbent cells; Un = Uniseriate ray; T = Tyloses).

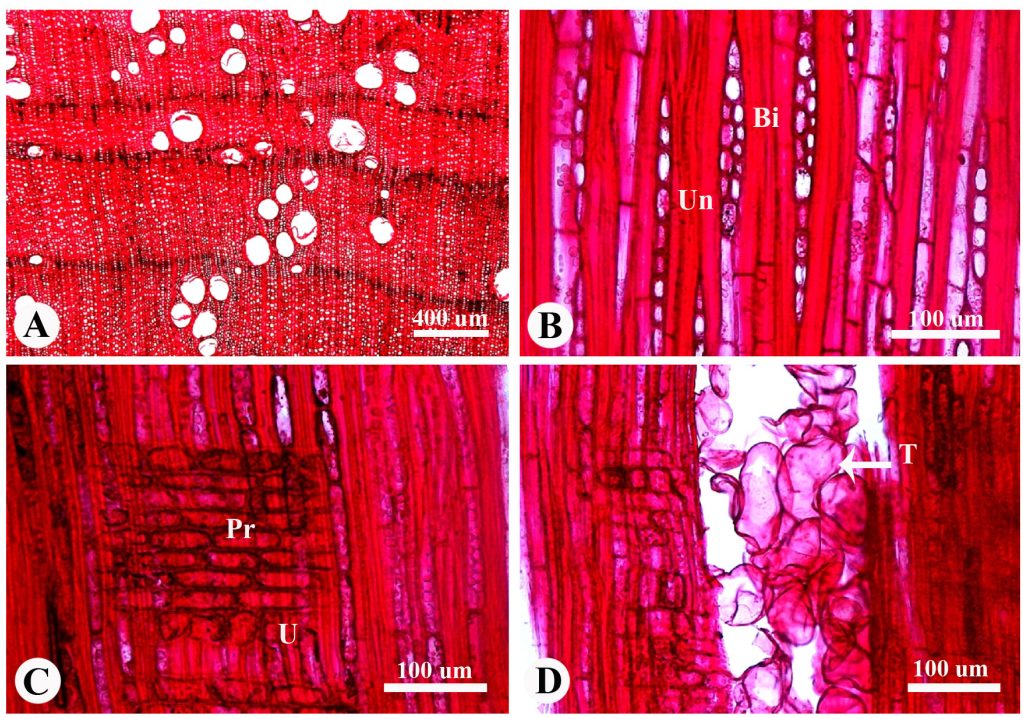

Figure 4. Wood anatomical features of *C. diversifolia*: A. Transverse section, vessels in diagonal and radial pattern; B. Tangential section, uniseriate and biseriate rays; C. Radial section, procumbent cells and one row of uprights; D. Cross section, tyloses (Bi = Biseriate ray; Pr = Procumbent cells; U = Upright cells; Un = Uniseriate ray; T = Tyloses).

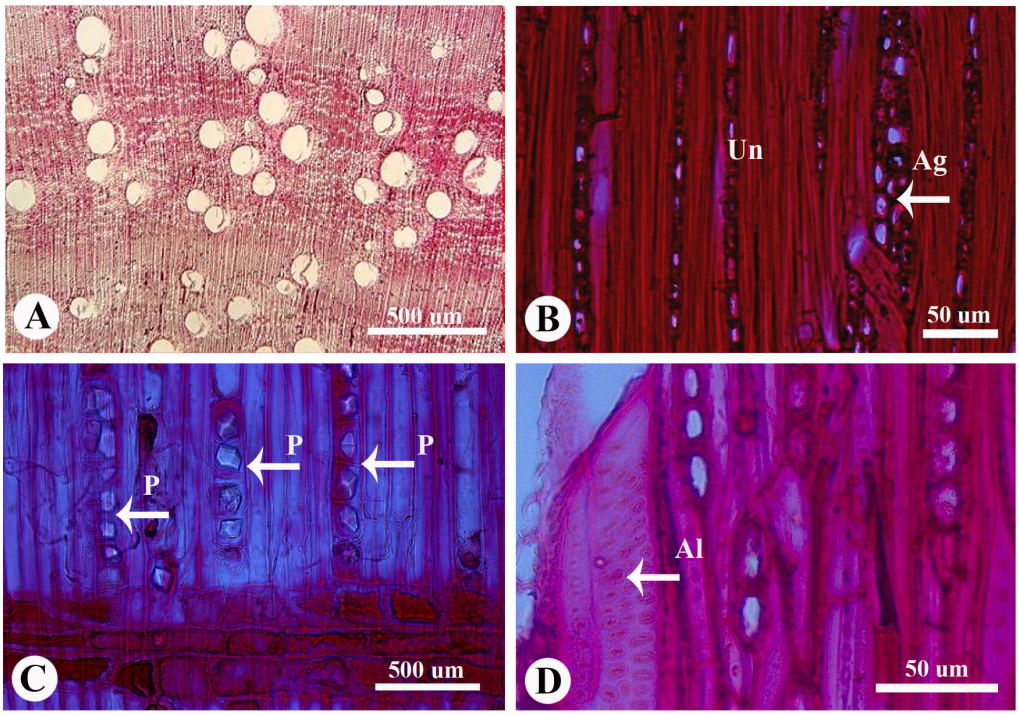

Figure 5. Wood anatomical features of *C. echidnocarpa*: A. Transverse section, vessels in a diagonal, radial or dendritic pattern; B. Tangential section, uniseriate and part of an aggregate ray; C. Radial section, procumbent cells, prismatic crystals; D. Tangential section, alternate intervessel pits (Al = Alternate pitting; Ag = Aggregate ray; P = Prismatic crystals; Un = Uniseriate ray).

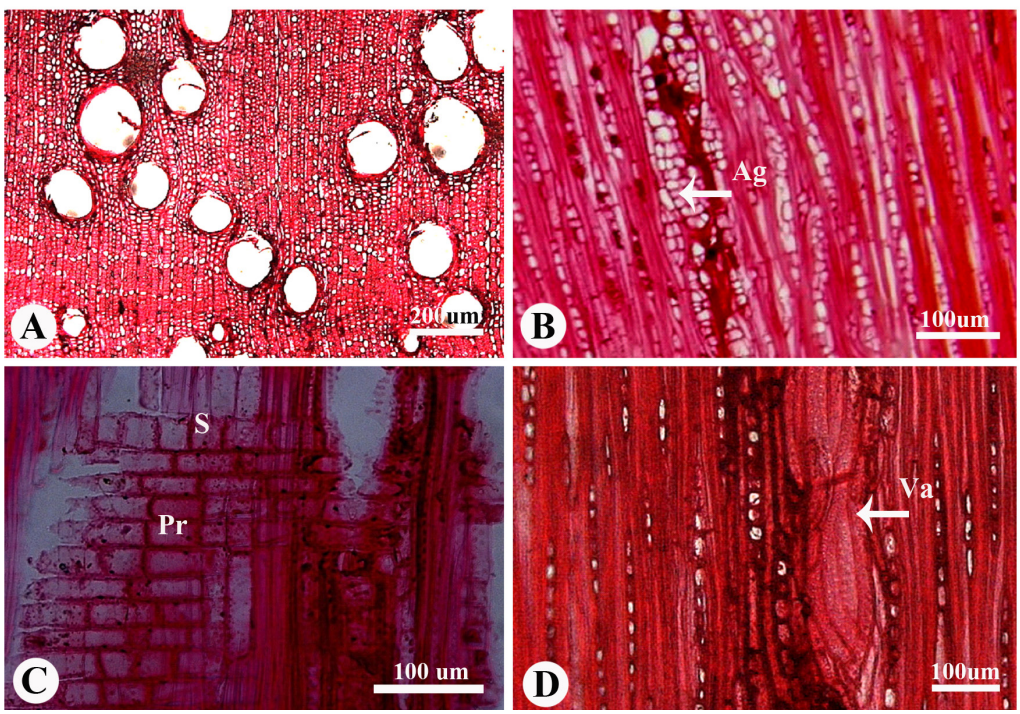

Figure 6. Wood anatomical features of *C. indica*: A. Transverse section, vessels in diagonal and radial pattern; B. Tangential section, uniseriate and part of an aggregate ray; C. Radial section, ray cells procumbent, one row of upright and/or square marginal cells; D. Tangential section, vasicentric tracheids (Ag = Aggregate ray; Pr = Procumbent cells; S = square cells; Va = Vasicentric tracheids).

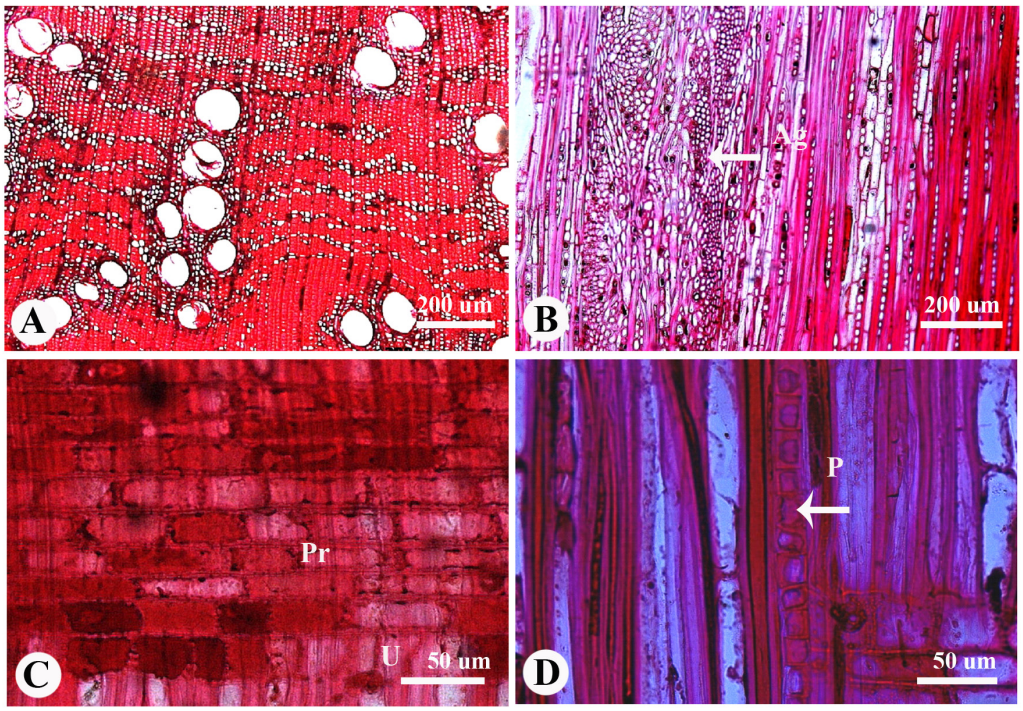

Figure 7. Wood anatomical features of *C. tribuloides*: A. Transverse section, vessels in diagonal and radial pattern; B. Tangential section, uniseriate and part of an aggregate ray; C. Radial section, procumbent cells and upright cells; D. Radial section, prismatic crystals in an axial parenchyma strand (Ag = Aggregate ray; P = Prismatic crystals; Pr = Procumbent cells; U = Upright cells).

DISCUSSION

The species of *Castanopsis* in this study can be identified using anatomical characteristics of their wood; presence or absence of broad rays and growth rings, occurrence of tyloses, shape of vessel-ray pits, vessel arrangement and occurrence of prismatic crystals. The qualitative, quantitative data and some anatomical features of *Castanopsis* species are summarized in the Table 2, 3. *Castanopsis* from SEM analysis are shown in Fig. 8. There are two distinct groups:

***Castanopsis* group A**: broad aggregate rays are present.

Species investigated were *C. acuminatissima*, *C. armata*, *C. echidnocarpa*, *C. indica* and *C. tribuloides*.

The general anatomical characters of woods are yellowish, basically brown to light brown. Growth ring boundaries are indistinct. Texture is fine, without lustre and odor. Broad aggregate rays are distinct to the naked eye. Rays are of two distinct sizes. The narrow rays are uniseriate, sometimes biseriate; the larger rays are aggregate rays commonly more than 25 seriate. These characters are similar to those described by Hwang (1962). Damayanti & Rulliaty (2010) reported that rays of two distinct sizes, exclusively uniseriate, sometimes biseriate, homocellular and aggregate are common in all the genera of Fagaceae.

***Castanopsis* group B**: broad rays are absent.

Species investigated were *C. diversifolia* and *C. argyrophylla*

The wood is brown to light brown. Growth ring boundaries are distinct in *C. diversifolia*. Grain, texture, lustre and odor are similar to *Castanopsis* group A, but broad rays are absent to the naked eye.

Almost all microscopic characters are the same as *Castanopsis* group A. On the other hand, rays are exclusively uniseriate, sometimes biseriate, as in the studies of Peng *et al.* (1988) who recorded rays of *C. argentea* as exclusively uniseriate and Pande *et al.* (2005) also reported that some species of *Castanopsis*

woods lack broad rays. Rays are exclusively uniseriate or 1–3 seriate such as some samples of *C. indica* but some specimens of the same species from different areas do have found broad rays. They also showed non-significant differences due to latitude. In the present study, a number of broad rays were found in *C. indica*, *C. armata* and *C. echidnocarpa* but are rare. A key to species of *Castanopsis* based on wood characters was constructed.

Role of wood characteristics and wood utilization

According to Lemmens *et al.* (1995), *Castanopsis* is suitable for medium to heavy construction under cover such as boat building, bridges, flooring, plywood,

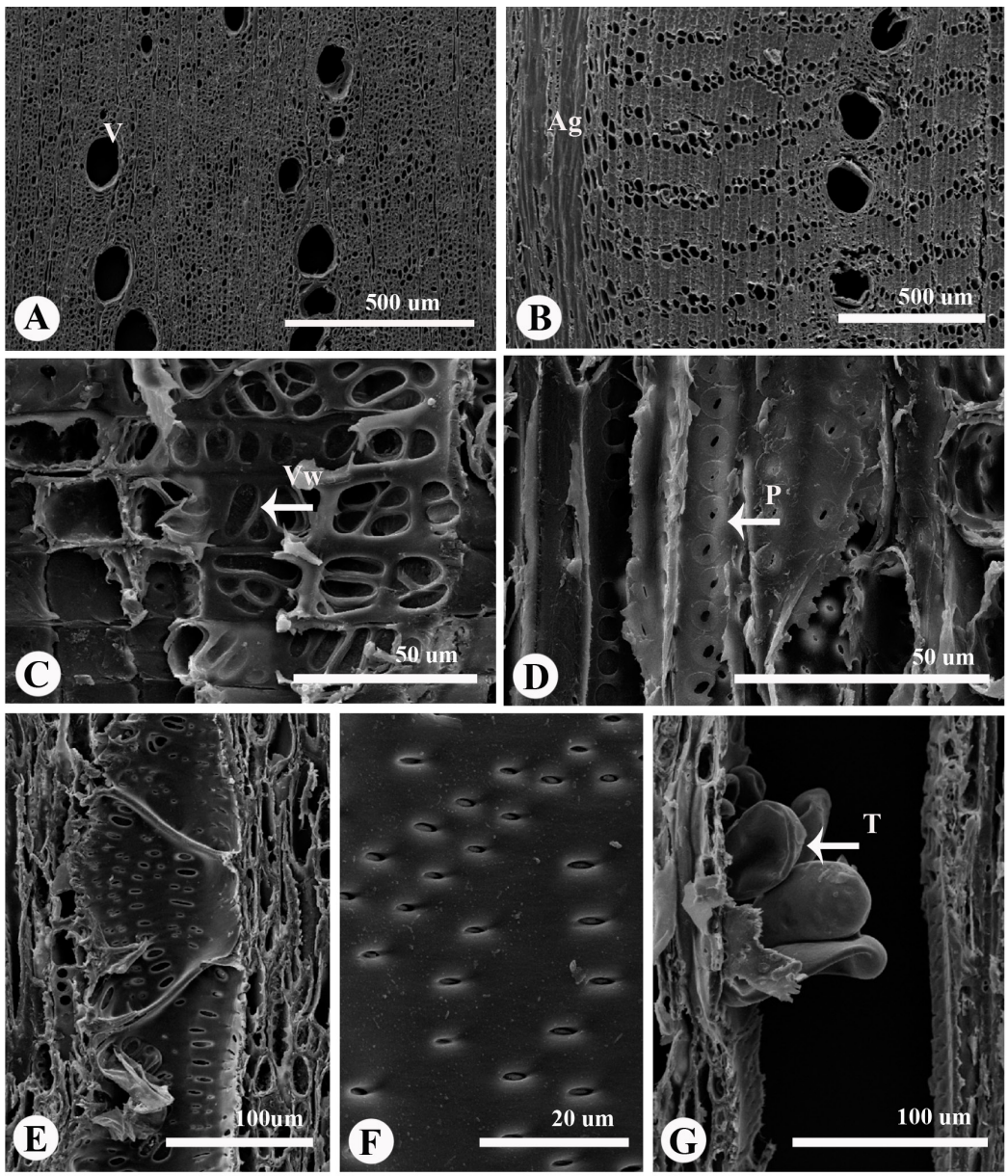

Figure 8. Castanopsis from SEM analysis: A. Cross section of *C. diversifolia*; B. Cross section of *C. tribuloides*, aggregate ray; C. Radial section of *C. acuminatissima*, vessel-ray pits with elliptic; D. Tangential section of *C. acuminatissima*, pit on secondary wall of vasicentric tracheids; E. Tangential section of *C. diversifolia*, alternate intervessel pits; F. Alternate intervessel pits of *C. tribuloides*; G. Tangential section of *C. tribuloides*, tylosis in vessel (Ag = Aggregate ray; V = Vessel; Vw = Vessel-ray pits with elliptic; P = Bordered pit; T = Tylosis).

Table 2. Some quantitative data and anatomical features of *Castanopsis* species

Species	Vessel (µm)		Fiber (µm)			Type ray
	Size	Length	Lumina size	Wall thickness	Length	
C. acuminatissima	105±27	403±257	4.6±1.86	3.85±0.86	1068.65±344.55	Un, Bi, Ag
C. argyrophylla	155±29	277±128	3.60±1.37	3.87±1.50	705.69 ± 293.09	Un, Bi
C. armata	157±52	303±102	3.71±1.62	3.48±0.83	1067.36±295.83	Un, Bi, Ag
C. diversifolia	109±36	264±860	4.14±1.84	3.75±0.73	1174.41±226.44	Un, Bi
C. echidnocarpa	151±32	319±300	2.58±0.70	4.25±0.92	1012.01±153.76	Un, Bi, Ag
C. indica	105±32	367±135	2.82±0.91	3.48±0.93	900.80±277.42	Un, Bi, Ag
C. tribuloides	93±32	260±136	4.02±1.08	3.33±1.10	706.48±297.33	Un, Bi, Ag

Un = Uniseriate, Bi = Biseriate, Ag = Aggregate

Table 3. The qualitative data based on IAWA List character numbers for each species

Species	Character numbers
C. acuminatissima	2 5 7 9 13 22 31 32 42 47 53 60 61 66 72 76 77 78 79 86 92 93 96 101 106 116 138 142 172 189
C. argyrophylla	2 5 7 8 9 13 22 31 32 42 52 56 60 61 66 71 76 77 78 79 86 92 93 96 106 115 138 142 172 189
C. armata	2 5 7 8 9 13 22 32 42 47 52 56 60 61 66 72 76 77 78 79 86 92 93 94 96 101 106 116 142 172 189
C. diversifolia	1 5 7 8 9 13 22 32 42 47 52 56 60 61 66 72 76 77 78 79 86 92 93 96 101 106 115 138 142 172 189
C. echidnocarpa	2 5 7 8 9 13 22 31 32 42 47 53 60 61 66 72 76 77 78 79 86 92 93 96 101 104 115 142 172 189
C. indica	2 5 7 8 9 13 22 32 42 47 53 56 60 61 66 71 76 77 78 79 86 91 93 94 96 101 106 116 138 142 172 189
C. tribuloides	2 5 7 8 9 13 22 31 32 41 47 52 56 60 61 66 7176 77 78 79 86 91 92 96 101 105 142 172 189

sliced veneer, packing cases, pallets, fence posts and firewood. In this study, broad rays were found in several species (more than 25 cells wide). Percentage of ray covering area up to 65%, with normally spaced to close (9–15 rays per mm^2). Wood with high percentage of ray results in low density and hardness.

Interestingly, abundant starch grains were observed in rays and axial parenchyma especially in *C. diversifolia*, *C. argyrophylla* and *C. acuminatissima*. As starch is a crucial food source for fungi, *Castanopsis* woods are widely used for mushroom cultivation in Thailand. In addition, plants with wood that contain starch grains have the advantage of being able to be propagated by stem cuttings.

Perforation plates are simple in all species, as reported in Damayanti & Rulliaty (2010), and discussed by Qi *et al.* (2012) who reported that simple perforation plate provided less resistance and, as a result, water transportation is good. However, tyloses that block water in vessels, are common in the vessels of *C. argyrophylla*, *C. armata*, *C. diversifolia*, *C. indica* and *C. tribuloides* as is often found in some Fagaceae

woods (e.g., Metcalfe & Chalk, 1957; Lemmens *et al.*, 1995; Damayanti & Rulliaty, 2010). However, the benefit of tyloses in white oaks for liquid storage is preferred in barrels, casks, and tanks, whilst red oak is avoided for such uses because this characteristic does occur (Shmulsky & Jones, 2011).

CONCLUSION

The wood characteristics of seven *Castanopsis* species from Northern Thailand were investigated. The generalized anatomical characters follow:

Growth ring boundaries are indistinct in all species except *C. diversifolia*. All species are without lustre and odor. Vessels are diffuse-porous with mostly solitary and arranged in diagonal, radial pattern or dendritic pattern except *C. acuminatissima* vessel arranged in diagonal and radial pattern. Tyloses are usually found in vessels of *C. argyrophylla*, *C. armata*, *C. diversifolia*, *C. indica* and *C. tribuloides*. Vasicentric tracheids presence in all species. Fibres are non-septate, with simple to minutely bordered pits. Axial parenchyma is paratracheal, typically vasicentric and scanty, typically diffuse, diffuse in aggregates and in narrow bands or lines. Rays are homocellular or heterocellular. Prismatic crystals are commonly present in chambered ray and axial parenchyma cells of *C. acuminatissima*, *C. argyrophylla*, *C. diversifolia*, *C. indica* while they are only in axial parenchyma cells of *C. armata*, *C. echidnocarpa* and *C. tribuloides*. Starch grains were found in rays and axial parenchyma cells of 5 species except *C. indica* and *C. tribuloides*.

The seven studied species of *Castanopsis* can be identified using the following anatomical characteristics: type of ray, occurrence of tyloses or prismatic crystals, shape of vessel-ray pits, occurrence of growth ring boundaries and vessel arrangements. The data from this study can be used to further evaluate wood utilization.

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REFERENCES

Buranachonnabot, B. (1999). Shiitake. 4th ed. Tankasetagum Press, Nonthaburi, Thailand.

Chengjiu, H., Yongtian, Z. & Bartholomew, B. (1999). Fagaceae, pp. 314–400. In Z. Wu and P.H. Raven, (eds.). Flora of China 4, Cycadaceae through Fagaceae. Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis.

Damayanti, R. & Rulliaty, S. (2010). Anatomical properties and fiber quality of five potential commercial wood species from Cianjur, West Java. Journal of Forestry Research 7(1): 53–69.

Desch, H.E. & Dinwoodie, J.M. (1996). Timber Structure, Properties, Conversion and Use.7th ed. Macmillan Press Ltd. London, UK.

Franklin, G.L. (1945). Preparation of thin sections of synthetic resins and wood-resin composites, and a new macerating method for wood. Nature 155: 51–59.

Forman, L.L. (1966). On the evolution of cupules in the Fagaceae. Kew Bulletin 18(3): 385–419.

Harlow, W.M. (1975). Inside wood masterpiece of nature. 3rd ed. The American forestry association. Washington D.C.

Hwang, S. (1962). The anatomy of some important Taiwan woods. Master of Forestry Thesis, The University of British Columbia, Canada.

IAWA Committee (1989). IAWA List of Microscopic Features for Hardwood Identification (E.A. Wheeler, P. Baas and P.E. Gasson, editors). IAWA Bulletin ns 10: 219–332.

Keating, W.G. & Bolza, E. (1982). Characteristics, Properties and Uses of Timbers South-east Asia, Northern Australia and the Pacific. Texas A&M University Press, Australia.

Lemmens, R.H.M.J., Soerianegara, I. & Wong, W.E. (1995). PROSEA: Plant resources of South East Asia 5(2): timber trees: minor commercial timbers. Pudoc Scientific Publishers, Wageningen, Netherlands.

Manos, P.S., Zhou, Z.-K. & Cannon, C.H. (2001). Systematics of Fagaceae: phylogenetic tests of reproductive trait evolution. International Journal of Plant Sciences 162: 1361– 1379.

Metcalfe, CR. & Chalk, L. (1957). Anatomy of the Dicotyledons: Leaves, stem and wood in relation to taxonomy with notes on economic uses. Vol 2. 2nd edn. Clarendon Press, Oxford, UK.

Pande, P.K., Chauhan, L. & Singh, M. (2005). Wood anatomical variations within the genus *Castanopsis*. Journal of Tropical Forest Science 17(3): 336–371.

Peng, L., Fang, C. & Jiaju, Y. (1998). Identification, Properties and uses of some Southeast Asian woods. Research Institute of Wood Industry. Chinese Academy of Forestry. Yokohama, Japan.

Phengklai, C. (2008). Fagaceae. In: T. Santisuk & K. Larsen (eds.), Flora of Thailand 9(3). pp. 179–410. The Forest Herbarium, National Parks, Wildlife and Plant Conservation Department, Bangkok.

Qi, C., Fang. X, Qin-lin, A. & Jiao-liao, C. (2012). Numerical simulation of water transport through vessel perforation plates. Applied Mechanics and Materials. 195–196: 645–650.

Shimaji, K. (1959). Anatomical studies on the wood of the Japanese Pasania, Castanea and *Castanopsis*. (with a key to the 22 Japanese Representative species of the Fagaceae). Bulletin of the Tokyo University Forests 55: 81–99.

_____. (1962). Anatomical studies on the phylogenetic inter-relationship of the genera in the Fagaceae. Bulletin of the Tokyo University Forests 57: 1–64.

Shmulsky, R. & Jones, P.D. (2011). Forest Products and Wood Science An Introduction. 6th edn. Wiley & Sons, Inc., UK.