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RESEARCH ARTICLE

WOOD ANATOMY OF THE FABACEAETREE SPECIES IN TROPICAL RAINFOREST, WEST SUMATRA, INDONESIA

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ABSTRACT

The wood anatomy of Fabaceae tree species was studied in four locations of tropical rainforest West Sumatera Province, Indonesia using survey method. Samples were collected from trees having minimum diameter 20 cm, and parts of stem about 120 cm above soil surface. Permanent slides were prepared using sliding microtome and stained with Safranin 2% in ethanol 70%. Description of qualitative characters of wood anatomy referred to IAWA list and category of quantitative characters referred to Atlas of Indonesian Wood. The grouping of wood anatomy was based on quantitative characters of wood anatomy using Paired Group at PAST Program. Results showed that 12 tree species of Fabaceae generally had diffuse vessels with solitary-multiple groups, except *Parkia speciosa*, *Adenanthera malayana* and *Dalbergia sisso* had multiple vessels. Parenchyma types varied greatly, i.e. diffuse apotracheal, scanty, vasicentric, confluent and aliform paratracheal. All species studied had homocelluler type of ray cell composition, and the composition of rays varied, i.e, uniseriate, combination of uniseriate-multiseriate, and multiseriate. The character of ray height could be used as key character to categorize wood anatomy of the Fabaceae tree species.

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INTRODUCTION

Indonesia has tropical rainforest which is rich of various trees. However, most of tree species have limited population due to illegal logging (Venburg and van Eijk-Bos, 2003; Harrison and Swinfield, 2015). The impact of the illegal logging is the tree spesies with highly economic value have become extinct and the ones with moderate economic value, one of them is family of Fabaceae have been limited. Tree species of Fabaceae are usually known as fast growing plants distributed widely in various habitats, and have highly adaptation capability in degradated lands due to their ability in fixing nitrogen directly from air (Lioret and Martinez, 2005). Tree species of Fabaceae are generally found in natural and public forests in Indonesia, specifically in West Sumatera. Their habitats were widely distributed from sea shore up to mountains, and from dry to wet locations. However, due to great changes in land use function for agriculture and dwellings, the population of tree of Fabaceaeis reducing in nature. The quality of Fabaceae tree wood is very variable, from durable class to strong class, I-IV class.

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Wood of Johar (*Senna siamea*) in South Asia is a hard wood and heavy enough with specific gravity ranges from 0.6-1.01 and categorized as durable class I (Gutteridge, 1997). Wood of merbau (*Intsia palembanica*) distributed in Nusantara islands up to Papua, is categorized as heavy wood with specific gravity 0.63-1.04 and strong class I-II (Soerianegara and Lemmens, 2002). Sonokeling (*Dalbergialatifolia*) found in Central and East Jawa forests are categorized as hard wood with specific gravity 0.77-0.86 and resistant against termites (Soerianegara and Lemmens, 2002). Wood of Jeunjing (*Paraserianthes falcataria*) growing in Maluku and Papua is categorized as light wood with specific gravity 0.33, strong class IV-V and durable class IV-V (Martawijaya *et al*., 2005). The use of wood is generally based on its specific gravity, strength, and durability. In wood processing and using, wood anatomical structure should get a major attention. Characters of wood anatomy can be used to predict wood quality (Martinez-Vilalta *et al*., 2002), because characters of wood depend much on anatomical structure. Therefore, introduction to wood anatomy is a basic thing for policy in using type of wood in natural and production forests. Looking at the condition of reducing the population of tree species in family of Fabaceae in West Sumatera, a study has been conducted on anatomical characters of tree wood which are usefull in assisting characteristic state and their potential for development.

MATERIALS AND METHODS

Collection of wood samples

Wood samples were collected from four locations in natural and public forests in West Sumatera, Indonesia using survey method. The locations were Padang area, and Pesisir Selatan, Solok and Pasaman districts. Samples were collected from trees having minimum diameter 20 cm, and parts of stem about 120 cm above soil surface. The size of wood sample was 2x2x2 cm^3, and they were stored temporarily in alcohol 70%.

Preparation of anatomical slides

Permanent slides were prepared from cuts of wood samples which were boiled until soft in glycerin 30%, then they were sliced using sliding microtome with a thick of 15-20 µm at transverse, radial and tangential sections. The slices were soaked in series of ethanol 50, 30, 20, 10% and distillated water and then stained with Safranin 2% in ethanol 70% for six hours. Then, the slices were dehydrated in ethanol 30, 50, 70, 90 and 100%, and at last they were cleared in xylol slices were placed on object glasses and dripped with Entellan New before they were covered with cover glasses (Sass, 1958).

Characterization of wood anatomy

Observations at transverse section were characterized arrangement, grouping, diameter and category of vessel, and parenchyma types. At radial section was describe dray cell composition, and at tangential section were measured height and width of rays, and composition of ray cell. Description of the qualitative characters referred to International Association of Wood Anatomists (IAWA) list (Wheeler *et al.,* 1989) and the quantitative one referred to Atlas of Indonesian Wood (Martawijaya *et al.,*2005).

Grouping of quantitative wood anatomy

Grouping of wood anatomy was based on quantitative characters selected from anatomical characters of stem wood i. e. vessel diameter, height and width of rays, using Paired Group at PAST Program (Hammer *et al*., 2001). As comparison of wood anatomy studied, four other species were taken as out group in which their anatomical data and wood quality had been known. The four species were *Scorodocarpus borneoensis* (class I), *Intsia bijuga (*class II-III), *Lophopethalum javanicum (*class III-IV), and *Parasianthes falcataria* (class IV-V) (Martawijaya *et al.,* 2005).

RESULTS

Characteristics of wood anatomy

Observation on transverse section (Table 1 and Fig. 1- 4) indicated that 12 tree species of Fabaceae generally had diffuse vessel with solitary-multiple groups, except on *Parkia speciosa, Adenanthera malayana* and *Dalbergia sisso* had multiple vessels. Generally, the species had rather small diameter of vessel with an average of 103±11.39 µm to 157±19.87 µm. Small vessel diameter were found on *Archidendron bubalinum* (92±32.63 µm) and *D. sisso* (98±8,24 µm). Types of parenchyma are varied greatly i.e. diffuse apotracheal, scanty, vasicentric, confluent and aliform par tracheal. *Pithecellobium ellipticum*, *Dialium procerum* and *Milletia unifoliata* had diff use type of parenchyma, *A. bubalinum* was scanty, *P. speciosa*, *Archidendron jiringa* and *D. sisso* had vasicentric type. *Sennasumatrana* had aliform type, *Pelthophorum dasyrhachis* and *Pterocarpus indicus* had confluent type. Mixed form between vasicentric and aliform was found in *A. malayana* and between aliformand confluent was found in *Gliricidium sepium.*

Observation on radial section (Table 1 and Fig. 5-7) indicated that all species studied showed homocelluler type of rays composed of *procumbent cells*. On tangential section, composition of rays varied i.e. uniseriate, combination of uniseriate-multiseriate, and multiseriate. Average height of rays was incredibly short with the shortest one was 96±11.49 µm found in *P. indicus* and the longest was 306±52.35 µm found in *P. dasyrhachis.* Composition of uniseriate rays was found in *A. jiringa, A. bubalinum*, *G. sepium, P. indicus* and *D. sisso.* In this composition, average width of rays was very narrow, which was found in *A. bubalinum* and *D. sisso*. The narrow ones were found in *A. jiringa, G. sepium*and*P. indicus*. Combination of uniseriate-multiseriate was found in *P. ellipticum, P. dasyrhachis* and *M. unifoliata.* In this composition, average width of rays was found incategoriesn arrow and rather wide. Narrow category was found in *M. unifoliata*, while the ones with rather widewas found in*P. Ellipticum and P. dasyrhachis*. Composition of multiseriate ray was found in *P. speciosa, A. malayana*, *D. procerum* and *S. sumatrana,* with width of rays belonged to narrow and rather narrow categories. Narrow category was found in *A. malayanaand S. sumatrana,* while rather narrow one was found in *P. speciosa* and *D. procerum*. Very narrow width of ray was found in *A. bubalinum* (10±0.81 µm) and the one with rather wide was ound in *P. dasyrhachis (*82±21.97 µm).

Group of wood anatomy

Based on results of cluster analysis using vessel diameter, height and width of rays there were three groups of wood anatomy found (Fig. 8A). In first group there was only one species, *D. procerum*. In second group there were eight species; *A. malayana, S. sumatrana, P. ellipticum, P. speciosa, P. dasyrhachis, D. sisso, A. jiringa and M. unifoliata*. In third group there were three species; *A. bubalinum, G. sepium* and *P. indicus.* If grouping which used vessel diameter and of ray height or without vessel height, group of species does not change (Figure 8B).Grouping which based only on ray height showed that the group was the same as the former two characters (Fig. 8C). Therefore, ray height could be used as character key to catagorize tree wood anatomy of Fabaceae. Based on height of ray in 12 species of Fabaceae studied and four out group species there were four groups of wood anatomy found (Fig. 9). Group A was found in one species of outgroup, *S. borneoensis*, which belonged to strong class I. Group B was found in five species, *M. unifoliata, A. jiringa, A. bubalinum, G. sepium* and *P. indicus*, the same class as outgroup species of *P. falcataria* which belonged to strong class IV-V. In group C there were six species, *A. malayana*, *S. sumatrana,* *P.*

Table 1. Anatomical characters of wood in some tree species of Fabaceae

Sub family	Spesies	Tangential Section					Radial Section	Tangential Section				
		Vessel				Parenchyma type	Ray cell composition	Rays				
		Arrange ment	Grouping	Diameter (µm)	Category			Height (µm)	Category	Width (µm)	Category	Composition
Mimosoideae	*P. speciosa*	Diffuse	Multiple	155±33.58	Rather small	Vasicentric	Homocellular	250±47.77	Incredible short	40±10.20	Rather narrow	Multiseriate
	A. jiringa	Diffuse	Solitary - Multiple	123±19.49	Rather small	Vasicentric	Homocellular	185±16.03	Incredible short	16±5.03	Narrow	Uniseriate
	P. ellipticum	Diffuse	Solitary - Multiple	125±12.55	Rather small	Diffuse	Homocellular	242±55.76	Incredible short	52±19.08	Rather wide	Uniseriate, Multiseriate
	A. bubalinum	Diffuse	Solitary-Multiple	92±32.63	Small	Scanty	Homocellular	141±11.80	Incredible short	10±0.81	Very narrow	Uniseriate
	A malayana	Diffuse	Multiple	145±19.81	Rather small	Vasicentric;Aliform	Homocellular	327±28.58	Incredible short	29±1.91	Narrow	Multiseriate
Caesalpinioideae	*P. dasyrhachis*	Diffuse	Solitary - Multiple	111±19.44	Rather small	Confluent	Homocellular	269±44.31	Incredible short	82±21.97	Rather wide	Uniseriate, Multiseriate
	D. procerum	Diffuse	Solitary - Multiple	103±11.39	Rather small	Diffuse	Homocellular	427±52.10	Incredible short	52±7.60	Rather narrow	Multiseriate
	S. sumatrana	Diffuse	Solitary - Multiple	156±22.85	Rather small	Aliform	Homocellular	306±52.35	Incredible short	27±2.59	Narrow	Multiseriate
Faboideae	*G. sepium*	Diffuse	Solitary - Multiple	125±7.87	Rather small	Aliform; Confluent	Homocellular	144±64.61	Incredible short	20±13.03	Narrow	Uniseriate
	P. indicus	Diffuse	Solitary - Multiple	111±20.29	Rather small	Confluent	Homocellular	96±11.49	Incredible short	20±4.88	Narrow	Uniseriate
	D. sisso	Diffuse	Multiple	98±8.24	Small	Vasicentric	Homocellular	261±37.83	Incredible short	14±3.13	Very narrow	Uniseriate
	M. unifoliata	Diffuse	Solitary - Multiple	157±19.87	Rather small	Diffuse	Homocellular	203±38.01	Incredible short	26±11.61	Narrow	Uniseriate, Multiseriate

dasyrhachis, D. sisso, P. ellipticum and *P. spesiosa,* the same class as outgroup species*, L. javanicum* which belonged to strong class III-IV. In group D there was only one species found, *D. procerum*, the same class as outgroup species *I. bijuga* belonged to strong class II-III.

DISCUSSION

Twelve species of trees of Fabaceae in tropical rainforest, West Sumatra, Indonesia studied had arrangement of diffuse porous vessel with multiple-solitary and multiple groups. Multiple vessels were found in two species, *P. speciosa* and *A. malayana* from sub family of Mimosoideae*,* and one species from sub family of Faboideae, *D. sisso* (Table 1). According to Fengel and Wegener (1989), generally species of hard wood in moderate climate areas have arrangement of diffuse vessel.

Diffuse porous vessel was found in other species of Fabaceae, *Cyathostegia mathewsii* in Papilionoideae (Gasson and Wray, 2001), *Canavalia* in Fabaceae (Rajput, 2003), 10 genus in sub family of Caesalpinioideae (Melandri and de Pernia, 2009), *Swartzioxylon naraense* and most species in tribe of Podalyrieae in Papilionoideae (Stepanova *et al*., 2013; Kloster*et. al*., 2015), *Sophora linearifolia* in subfamily of Faboideae (Pujana *et al*., 2013), seven species in tribe of Crotalarieae Fabaceae (Oskolski *et al*., 2014), two species of *Butea* in Caesalpinioideae (Sahney and Vibhasa, 2015) and wood fossil *Itaquixylon heterogenum* from Pleistocene in Brazil (Benicio *et al*., 2016). However, they were different from four indigenous species of Faboideae in New Zealand (Patel, 1995), wood fossil of Mimosoideae from the early Paleocene of Patagonia, Argentina (Brea *et al*., 2008), and species in genus *Albizia procera* of Mimosaceae (Meena and Gupta, 2014) have type of vessel from diffuse-porous to semi-ring-porous.

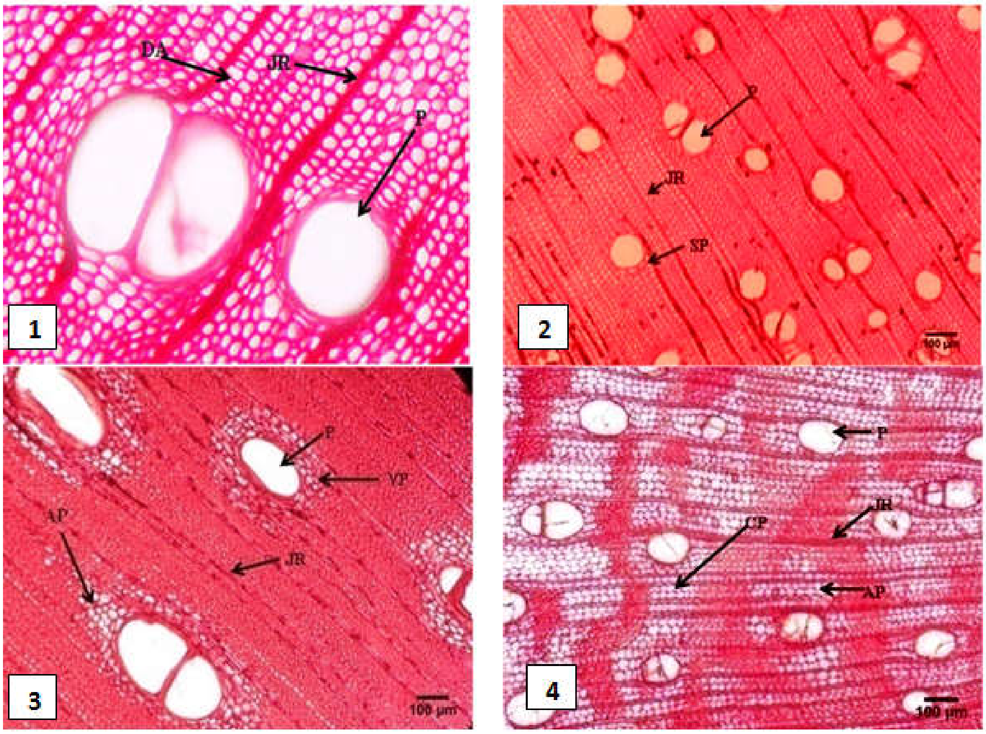

Fig. 1-4. Type of parenchyma on traverse wood section of Fabaceae trees: 1. diffuse in *M. unifoliata*; 2. scanty in *A. bubalinum*; 3. vasicentric in *A. malayana;* and 4. aliform and confluent in *G. sepium.* Notes: JR = rays; DA = diffuse parenchyma; P = pore (vessel); SP = scanty parenchyma; AP = aliformparenchyma; CP = confluent parenchyma.

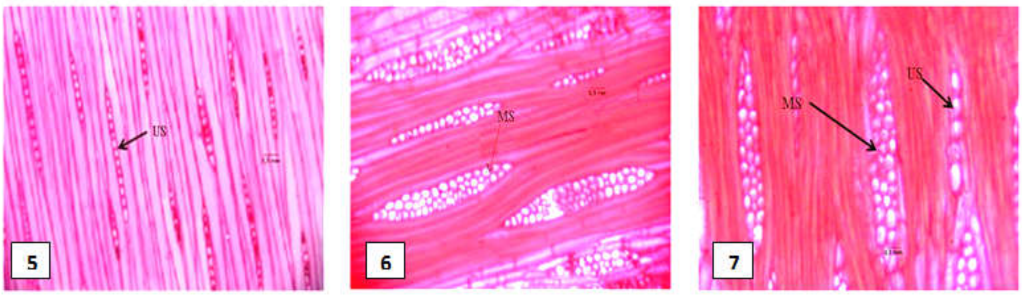

Fig. 5-7. Rays Composition on tangential wood section of Fabaceae trees: 5. uniseriate in *D. sisso*; 6. multiseriate in *P. speciosa*; and 7. uniseriate and multiseriate in *M. unifoliata.* Notes: US = uniseriate; MS = multiseriate

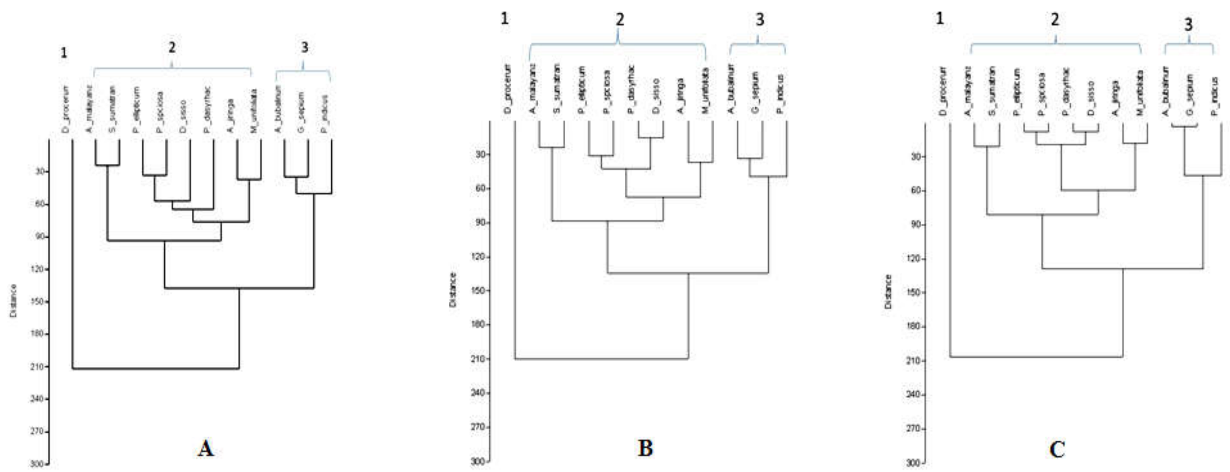

Fig.8. Dendogram of anatomical wood group of 12 spesies of Fabaceae: A. cluster analysis based on vessel diameter, height and width of rays; B. cluster analysis based on vessel diameter and height of ray; and C. cluster analysis based only on height of ray

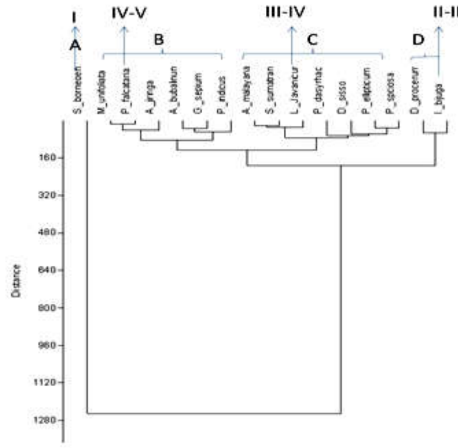

Fig. 9. Dendogramof anatomical wood group based on height of ray of 12 species of Fabaceae trees and 4 out group species, *S.borneoensis, P. falcataria, L. javanicum*and*I.bijuga*

According to Carlquist (1989), seven species *of Cercidium* (Fabaceae) can be said to be semi-ring porous because growth rings are present. In most species, grouping of vessel were multiple-solitary and only several species had multiple vessel (Table 1). Kloster *et al.* (2015) reported that *Zygiaxylonam azonicum* (Mimosoideae), *S. naraense* (Papilionoideae) and *Tachigalia ubl* of Fabaceae (Reis *et al.,* 2011) showed multiple-solitary vessel, while solitary vessels were reported in *Cyathostegia mathewsenii* of Papilionoideae (Gasson and Wray, 2001), *Canavalia* of Fabaceae (Rajput, 2003), wood fossil of Mimosoideae (Brea *et al*., 2008), genera from sub family of Caesalpinioideae (Melandri and de Pernia, 2009), *Sophora liniearifolia* of Faboideae (Pujana *et al*., 2013) and wood fossil of *Itaquixylon heterogenum* (Benicio *et al*., 2016).

Type of parenchyma of 12 species of Fabaceae observed in West Sumatera varied greatly, diffuse apotracheal, scanty, vasicentric, confluent and aliform paratracheal. Five species in subfamily of Mimosoideae had various axial parenchyma, diffuse apotracheal, vasicentric, scanty, and mixed vasicentric-aliform paratracheal (Table 1). Mundotiya *et al*. (2016) reported that three species of *Acacia,* five *species* of *Albizia, Dichrostachy scinerae, Parkia timoriana, Pithecellobium dulce and Xylia xylocarpa* (Mimosoideae) growing in different parts of Pakistan had vascicentric, aliform and confluent parenchyma. Wood fossil of *Paracacioxylon frenguellii* (Mimosoideae) from the early Paleocene of Patagonia, Argentina had diffuse apotracheal, vasicentric and confluent axial parenchyma (Brea *et al*., 2008).

Benicio *et al.* (2016) reported that *I. heterogenum* (Mimosoideae) as wood fossil from the Touro Passo Formation (Pleistocene) in the north western part of Rio Grande do Sul State, Brazil had scanty type and vasicentric parenchyma. Three species of wood in subfamily of Caesalpinioideae had different type of axial parenchyma, diffuse apotracheal, aliform or scanty paratracheal (Table 1). In general, the species of wood in sub family of Caesalpinioideae in Venezuela have aliform and confluent and some vasicentric or scanty parenchyma (Melandri and de Pernia, 2009). *Butea monosperma,* native of tropical South Asia and *B. superb,* native of Thailand (Caesalpinioideae) have two types of axial parenchyma, vasicentric and banded (Sahney and Vibhasa, 2015).

Four species of subfamily of Faboideae had various axial parenchyma, diffuse apotracheal, vasicentric, confluent, and mixed aliform-confluent paratracheal (Table 1). Type of axial parenchyma in Faboideae observed in West Sumatera is more various than the one reported by Patel (1995), that *Sophora*, indigenous Faboideae in New Zealand only had confluent forming irregular bands. Wood of *Cyathostegia mathewsii* (Papilionoideae; Faboideae) in Ecuador and Peru had scanty paratracheal and diffuse parenchyma, occasionally winged aliform and confluent (Gasson and Wray, 2001).Two endemic species to Argentina, *Sophora linearifolia* and *S. rhynchocarpa* (Papilionoideae; Faboideae) had scanty paratracheal to vasicentric parenchyma (Pujana *et al*., 2013). Some species of Cyclopia (Papilionoideae; Faboideae), sub endemic to the Cape Floristic Region of South Africa had scanty paratracheal to vasicentric parenchyma, rarely confluent (Stepanova *et al*., 2013). Oskolski *et al.* (2014) reported that tribe of Crotalarieae (Faboideae) had various parenchyma types, vasicentric and aliform to confluent in *Aspalathus* sp; diffuse, vasicentric and confluent in *Calobata* sp and in *Rafinia* sp; scanty and vasicentric in *Crotalaria* sp; vasicentric to confluent in *Leobordea* sp; scanty, vasiccentric to confluent in *Lotonis*sp; vasicentric in *Wiborgia* sp and *Wiborgiella* sp.

All species studied had homocelluler type of ray composed of procumbent cells (Table 1). This result is similar to the one reported by Mundotiya *et al*. (2016) in 11 species of Mimosoideaein Pakistan having homocellular rays. However, it is different from the species in sub family of Caesalpinioideae in Venezuela having homocellular rays with typically procumbent cells to heterocellular upright and/or square marginal cells (Melandri and de Pernía, 2009). *Cyathostegiamathewsii* (Papilionoideae; Faboideae) mostly has homocellular type of ray, composed of procumbent ray cells, but some have heterocellular with procumbent, square and upright cells mixed throughout the ray (Gasson and Wray, 2001). *S. linearifolia* in Faboideae (Pujana *et al*., 2013), tribe Crotalarieae from Faboideae (Oskolski, 2014) and *Buteamonosperma* in Caesalpinioideae (Sahney and Vibhasa, 2015) always show heterocellular composed of procumbent, square and upright cells mixed through the ray. Composition of ray cells in Faboideae is generally uniseriate and only one species shows mixed uniseriate-multiseriate. In Mimosoideae, composition of ray cells are generally uniseriate and multiseriate, one species with mixed uniseriate-multiseriate, while two species of Caesalpinioideae have multiseriate rays, and one species with mixed uniseriate-multiseriate (Table 1). Some species of Cyclopia of the tribe Podalyrieae (Papilionoideae; Faboideae) have uniseriate rays (Stepanova *et al*., 2013). Vascular rays in seven species *of Cercidium* (Caesalpinioideae) (Carlquist. 1989), and *Cyathostegiamathewsii* (Papilionoideae; Faboidea) (Gasson and Wray. 2001) are both multiseriate and uniseriate. *Buteamonosperma* and *B. superb* (Caesalpinioideae) mostly have multiseriate and rarely uniseriate rays (Sahney and Vibhasa, 2015). Most species of *Sophora* (Papilionoideae; Faboideae) (Patel, 1995) and *Sophoralinearifolia* (Papilionoideae; Faboideae) (Pujana *et al.,* 2013) have multiseriate rays. Based on Paired group at PAST program on three quantitative characters (vessel diameter, width and height of rays) it was found that height of rays could be used as key character to catagorize tree wood anatomy of Fabaceae (Fig. 8C).

Size and distribution of rays have been reported to be specific to climate as well as locality and the anatomical character are very significant parameter in Albiziaprocera (Meena and Gupta, 2014). The grouping of quallitative and quantitative wood anatomical characters for Araucaria Forest were influenced by rays height and width (Soffiati *et al*., 2016). According to von Arx *et al*. (2016), ray parenchyma is an essential tissue for tree functioning and survival. This living tissue plays a major role for storage and transport of water, nutrients, and non-structural carbohydrates, thus regulating xylem hydraulics and growth. The parenchyma rays are usually strongly lignified (Rana *et al*., 2009).

Conclusion

In general, 12 species of Fabaceae trees in tropical rainforest, West Sumatra, Indonesia showed arrangement of diffuse vessel with multiple-solitary groups, except in *P. speciosa, A. malayana* and *D. sisso* having multiple vessels. Types of parenchyma varied greatly, diffuse apotracheal, scanty, vasicentric, confluentand aliformparatracheal. All species studied had homocelluler ray cell composition, but composition of ray varied, uniseriate, combination of uniseriate-multiseriate, and multiseriate. Based on quantitative anatomical characters using Paired group at PAST program, it was shown that height of ray could be used as a key character to categorize wood anatomy of Fabaceae.

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