Conference Paper

Variation of Wood Density and Anatomical Characters from Altitude Differences: Case Study of Selected Fabaceae Trees in West Sumatra Secondary Forest, Indonesia

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Received: 19 February 2019
Accepted: 5 March 2019
Published: 16 April 2019

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICBSA Conference Committee.

Abstract

There are three tree species of Fabaceae used for furniture in the secondary forest of coastal to mountain areas in West Sumatra, Indonesia. Their wood samples were collected from secondary forests of altitude ranges. Wood density was calculated as dry weight divided by green volume. The anatomical characters are measured on transverse, radial and tangential sections. The results showed that *Senna sumatrana* showed moderately heavy of wood density at ≤600 m asl, *Gliricidia sepium* at >600 m asl, and *Pterocarpus indicus* at altitude 300 to 900 m asl. There are negative correlation between wood density and altitude on *S. sumatrana* (r = -0.967), negative correlation on *G. sepium* (r = +0.918) and *P. indicus* (r = +0.898). A ray height shows the positive correlation with the altitude for *S. sumatrana* (r = +0.957), *G. sepium* (r = +0.898), and *P. indicus* (r = +0.898), while other anatomical characters may exhibit positive or negative correlation. Based on analysis of multiple correlations that the wood density variables of *S. sumatrana, G. sepium* and *P. indicus* is determined by anatomical character variables with r -0.998, +0.987 and +0.993 respectively. This finding suggests that the relationship between wood density and anatomical characters of these three species can be described successfully using multiple regression equation models. The relative contribution of determinant for wood density value in *S. sumatrana* was determined by fiber, vessel and rays components, but *G. sepium* was determined by fiber and rays components, and *P. indicus* was determined by fiber only.

Keywords: wood density, anatomical characters, Fabaceae trees, altitude

1. Introduction

Biodiversity of Indonesian lowland forests has a serious threat due to greatest of damage, fragmentation and degradation of habitat, and over exploitation of resources [1]. The average annual loss of natural forests in Sumatra increased dramatically from

2000 to 2009 [2, 3]. In anticipating deforestation, the Indonesian government has involved the role of local communities to protect forests through a community timber plantation program called The Community Timber Plantation. Through the program, over 5 million hectares of new plantation has been established in 2016 [4]. Due to over-exploitation, high value timber is rarely found in natural forests, so the Community Timber Plantation tends to grow fast growing trees.

In generally, fast-growing tree species include the Fabaceae family. Syofyan et al. [5] have found 12 tree species of Fabaceae in the secondary forest of West Sumatra. Some tree species include fruit-producing trees for consumption, shade trees, and timber producers for furniture, house poles, and firewood for residents. *Senna sumatrana* Roxb., *Pterocarpus indicus* Willd. and *Gliricidia sepium* (Jacq.) Stud. are three tree species commonly used by residents for furniture and have the potential to be developed in Community Timber Plantation. *S. sumatrana* is one of the wood-producing trees that is less well known and used for furniture [6]. *G. sepium* has the potential to be a major lesser used species of timber and could substitute some economic species in Nigeria's timber market [7]. *P. indicus* has been developed for industrial processing in Papua New Guinea [8], introduced and cultivated in China because of their growth performances and ecological adaptabilities [9].

Wood quality is determined by wood density related to the physical properties of wood, and it can be determined by wood density. Wood density is affected by the growth site [10–13]. Wood density variation due to place can be caused by factors of edaphic categories [14], shade-tolerance [15], planting density [16], elevation [17, 18], and altitude gradient [19], adverse weather conditions [20], High or low wood density due to allocating biomass or C to stem development [21, 22].

Wood density is closely related to mechanical properties over a wide range of raw material types [23], longitudinal, radial, tangential, and volumetric shrinkage [24], modulus of elasticity and modulus of rupture [25]. The plant response to the altitudinal gradient is more focused on anatomical adaptations than morphological variation, it also species dependent [26]. Considering the spread of tree species of the Fabaceae tree found in the coastal areas to the mountains of West Sumatra, it has been conducted on the relationship between wood density and anatomical characters based on altitude gradients.

2. Materials and Methods

2.1. Collection of wood samples

Wood samples were collected from various secondary forest sites (Padang, Pesisir Selatan District, Pasaman District, and Solok District) of West Sumatra province, Indonesia. The location of secondary forest is grouped into four ranges of gradient altitude, i.e. 0-300 m asl, 300-600 m asl, 600-900 m asl and 900-1,200 m asl [26]. Wood samples ware taken at breast height (about 120 cm above ground from a minimal tree with a diameter of 20 cm). Four pieces of heartwood (20 cm from bark) sections 10 cm^3 were collected from four opposite sides of the stem with replications of three individuals per species.

2.2. Measurement of wood density

For wood density measurement, four wood pieces are provided with three individuals per species. The wood density was obtained by measuring a wet volume of the wood piece and its oven-dry weight. To measure the volume of wood pieces, a water-displacement method is used [27]. A volume of water equal to the volume of wood (at field moisture content) was weighed. Displacement was accomplished by immersing wood piece in a beaker of water. Wood samples were oven-dried at 85°C to constant mass. Wood density was calculated as dry weight divided by green volume [28]. Wood density classification is grouped according to Wong [29], i.e. light (<0.5 g/cm^3), moderately heavy (between 0.5 - 0.8 g / cm^3), heavy (between 0.8 - 1.0g cm^3) and very heavy >1.0 g/cm^3).

2.3. Measurement of anatomical characters

Wood samples with size 2x2x2 cm boiled in glycerin 30% until soft. The wood samples were sectioned by using a sliding microtome with a thickness of 15-20 μm in the transverse, radial and tangential fields. The sections were dehydrated in a series of alcohol solutions of 10%, 20%, 30% and 50% for 15 minutes respectively, and stained with 2% safranin solution in alcohol 50% for 3 hours, and excess color washed in 70% alcohol for 10 minutes. The section is further dehydrated in alcohol 90% and absolute, and is cleaned in xylol. The section was mounted on the surface of the object glass using the New Entelan [30]. The permanent slides were observed anatomical characters under the light microscope which included a vessel diameter, height and width ray.

For observing the characteristics of fiber, the samples were cut into small pieces (toothpick size). Small pieces macerated in fluid of aqueous nitric acid and aqueous chromic acid (1:1; v/v). Staining is done in 1% solution of Safranin in absolute alcohol [31]. From elements of macerated wood, fiber length, fiber diameter and wall thickness were measured using a micrometer.

2.4. Analisis data

Simple correlation and coefficient of determinant were computed between wood density and altitude, and between anatomical characters and altitude. Multiple regressions between wood density and anatomical characters so as to construct a prediction model for wood density, coefficient of determination R^2 was estimated to evaluate the relative contribution of anatomical character attributes (SPSS 25). Treatment means were compared using least significant different test at level 0.05.

3. Results and Discussion

3.1. Relationship between wood density and altitude

Wood density of *S. sumatrana* shows moderately heavy (0.54 ± 0.06 up to 0.61 ± 0.01) at ≤600 m but light (0.43 ± 0.01 up to 0.45 ± 0.03) at >600 m asl. On the contrary, the wood density of *G. sepium* shows moderately heavy (0.50 ± 0.03 up to 0.51 ± 0.01) at >600 m but the light is at ≤600 m asl, whereas *P. indicus* shows moderately heavy (0.55 ± 0.01 up to 0.55 ± 0.01) between >300≤900 m asl (Table 1). Table 2 and Fig. 1 shows that there is a significant negative correlation between wood density and altitude for *S. sumatrana* (r = -0.967), but positive correlation on *G. sepium* (+0.918) and *P. indicus* (r = +0.898).

This results showed that the value of wood density based on the altitude depending on the tree species of Fabaceae. Chave et al. [28] reported that the value of wood density shows significant decreases with increasing altitude and significant differences among low-altitude geographical regions. However, spruce (*Picea mariana*) has higher wood density in the sites forest located at lower altitudes [32], Scots pine is higher in intermediate altitude (700 m asl) compared to low altitude (250 m asl) and in high altitude (1200 m asl) [26]. *Fagus orientalis* growing in the altitude 400-600 m asl had

Table 1: Wood density variation of timber species of Fabaceae at different altitudes.

Species	Wood density and classification	Altitudes ranges			
		>0 up to ≤300 m asl	> 300 up to ≤600 m asl	>600 up to ≤900 m asl	>900 up to ≤1200 m asl
S. sumatrana	WD ($g.cm^{-3}$)	0.61±0.01	0.54±0.06	0.45±0.03	0.43±0.01
	Classification	Moderately heavy	Moderately heavy	Light	Light
G. sepium	WD ($g.cm^{-3}$)	0.43±0.02	0.46±0.01	0.50±0.03	0.51±0.01
	Classification	Light	Light	Moderately heavy	Moderately heavy
P. indicus	WD ($g.cm^{-3}$)	0.40±0.02	0.55±0.01	0.55±0.02	0.41±0.01
	Classification	Light	Moderately heavy	Moderately heavy	Light

Table 2: Correlation coefficient between wood density and altitude in commercial tree of Fabaceae.

Species	WD
S. sumatrana	-0.967*
G. sepium	+0.918*
P. indicus	+0.898*
* significant at 0.05 level	

the highest density values, and those in the altitude 0-200 m asl had the lowest density values [33].

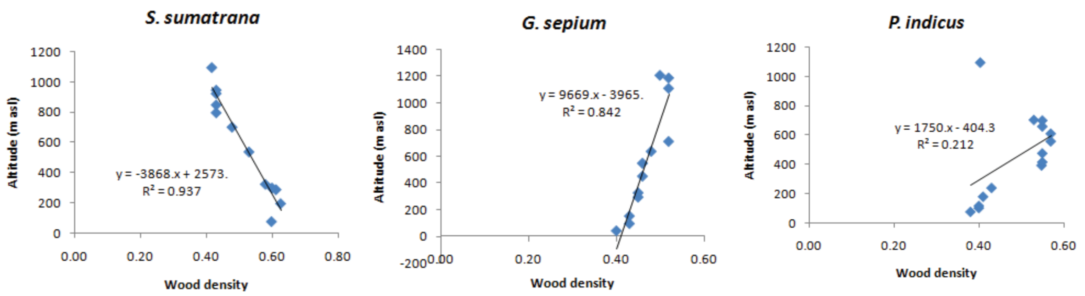


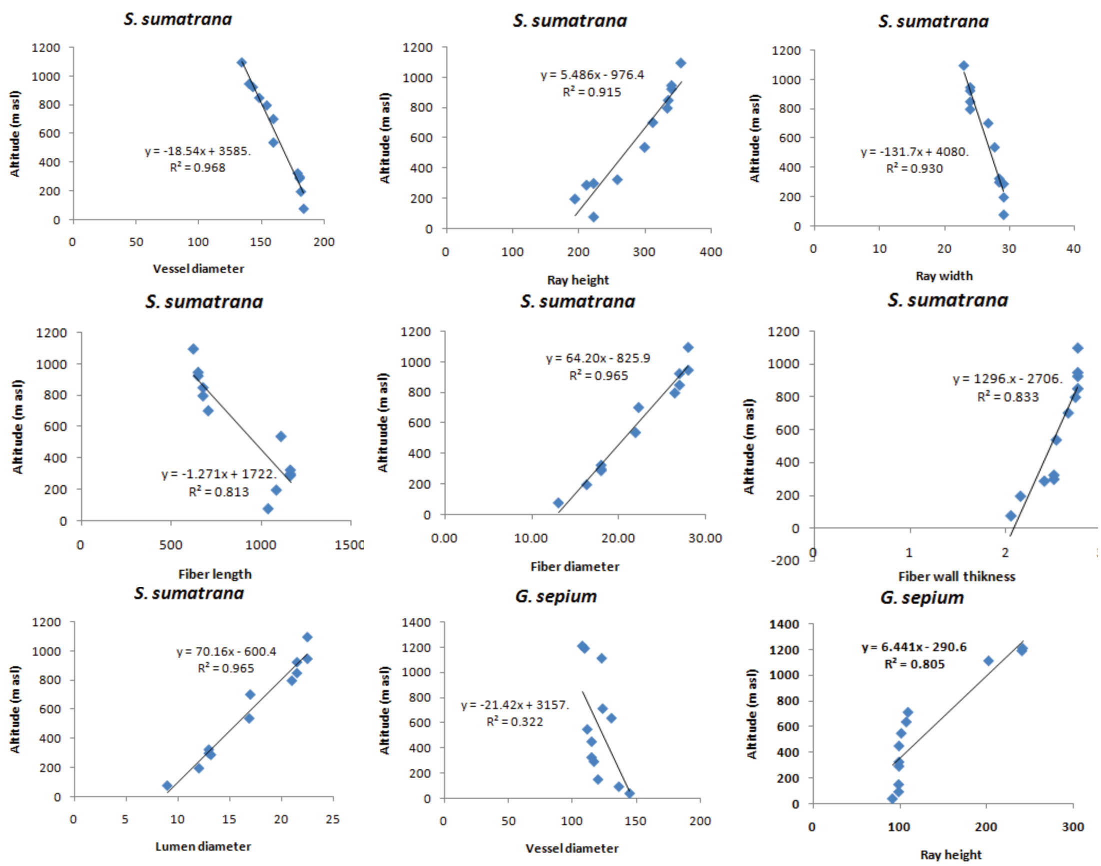
Figure 1: Regression between wood density and altitude in commercial tree of Fabaceae.

3.2. Relationship between anatomical characters and altitude

Fig. 2 and Table 3 shows regression and correlation between wood characters and altitude, respectively. Table 3 shows that the height ray has a positive correlation with the altitude for *S. sumatrana, G. sepium* and *P. indicus* denngan correlation coefficient (r), i.e. +0.957, +0.898 and +0.898 respectively). Ray width shows positive correlation with the altitude for *G. sepium* (r = +0.975) and *P. indicus* (r = +0.839), but significantly positive correlation on *S. sumatrana* (r = -0.964). Fiber length shows a positive correlation with the altitude for *G. sepium* (r = + 0.608) and *P. indicus* (r = +0.847), but significantly negative correlation in *S. sumatrana* (r = -0.902). Fiber diameter of *S. sumatrana* showed significantly positive correlation with the altitude (r = +0.875) and significantly negative correlation on *G. sepium* (r = -0.790).

Liang and Xin-Ying [34] reported that the height of the Lilac ray (*Syringa oblate* var. *giradii*) was gradually increased with the altitude. In *Gmelina arborea*, the altitude has a significant correlation with the number of cells at ray height, but the parenchyma is less stable because they are significantly affected by the altitude, latitude, longitude and precipitation [35]. The variation in ray height and ray width of *Albizia procera* with the site is significant that it is affected by locality and climate [36]. The ray width of *Alchemilla elongate* increased as elevation increased [37].

Respond of fiber quantitative character of each tree species of Fabaceae shows differences in gradient altitude (Table). Fiber wall thickness shows a positive correlation with the altitude for *G. sepium* (r = +0.925) and *P. indicus* (r = +0.949), but significantly negative correlation in S. sumatrana (r = -0.974). Lumen diameter of *S. sumatrana* showed a



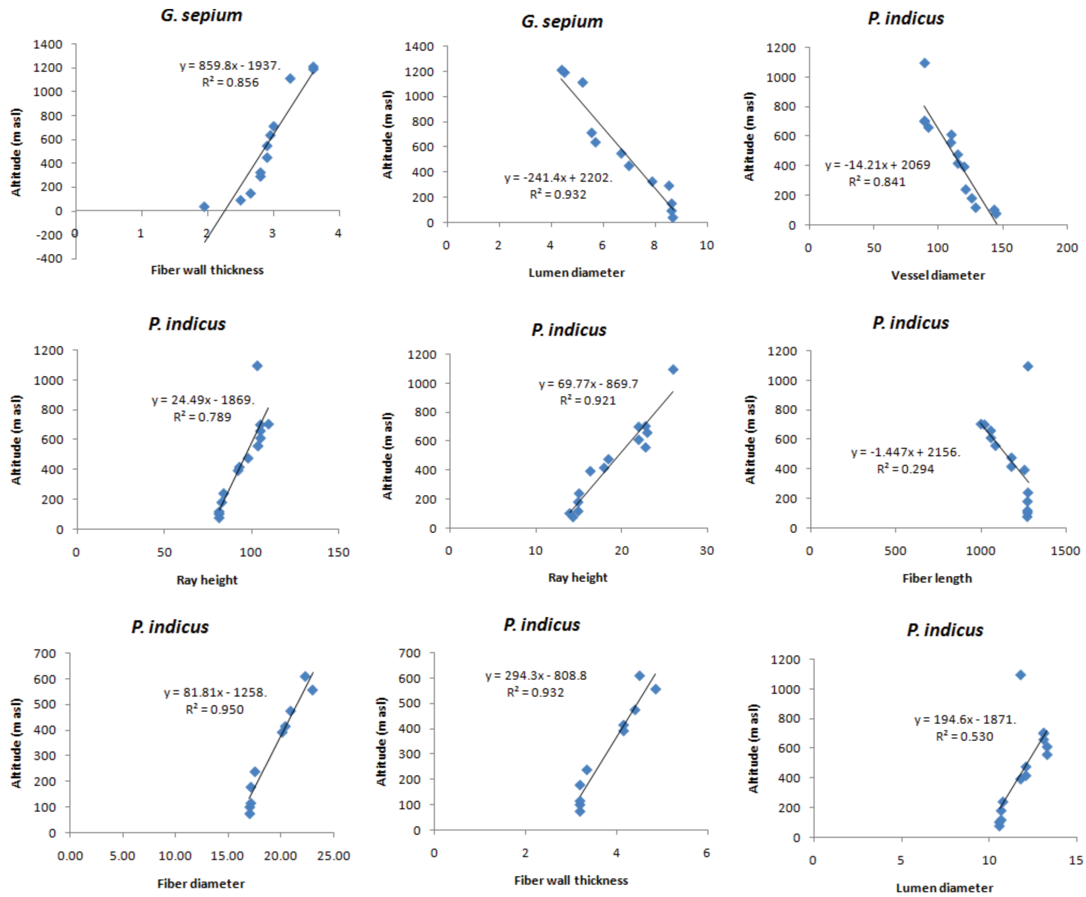


Figure 2: Regression between wood characters and altitude in selected tree of Fabaceae.

significantly positive correlation (r = +0.953), but significantly negative correlation on *G. sepium* (r = -0.966) and *P. indicus* (r = -0.980).

Table 3: Correlation coefficient between anatomical charaters and altitude of selected tree species of Fabaceae.

Species	**Anatomical characters**						
	Vessel diameter	**Ray height**	**Ray width**	**Fiber length**	**Fiber diameter**	**Fiber wall thickness**	**Lumen diameter**
S. sumatrana	-0.987*	+0.957*	-0.964*	-0.902*	+0.875*	-0.974*	+0.953*
G. sepium	-0.568^{ns}	+0.898*	+0.975*	+0.608*	-0.790*	+0.925*	-0.966*
P. indicus	-0.696*	+0.898*	+0.839*	+0.847*	-0.439^{ns}	+0.949*	-0.980*
* significant at 0.05 level, ns is non significant							

In *G. arborea*, length and diameter of the fiber and lumen show less affected by the altitude [35]. However, the significant effect on fiber components [38], where size of fiber length and fiber diameter of *F. orientalis* wood showed an increase of 0-400 m asl and decreased from 400-100 m asl, fiber wall thickness and lumen diameters show an increase from 0-400 m asl but fiber wall thickness does not vary and lumen diameter fluctuates from 400-100 m asl [33]. In *Q. fontica*, altitude was positively correlated with tracheid fiber wall thickness of [39].

Vessel diameter showed significantly negative correlation only with the altitude in *S. sumatrana* and *P. indicus* (r = -0.987 and -0.696 respectively). Strubbe (2013) reported that mean vessel area and vessel density did show significant correlation, respectively negative and positive with wood density. Decreasing growth rate with increasing altitude, the diameter of the vessels narrowed and the number of vessels in 1 mm increased [32]. The vessel lumen fraction is influenced by potential stem conductivity [40].

3.3. Relationship between wood density and anatomical characters

Based on analysis of multiple linear correlations that wood density variable of *S. sumatrana*, *G. sepium* and *P. indicus* were determined by anatomical character variables, correlation coefficient (r), respectively -0.998, +0.987 and +0.993 (Table 4). Result of multiple linear regressions showed that relative contribution of each anatomical character to predict wood density. The prediction equation was formulated as follow as equation (1), (2) and (3):

$$Y_{Ss} = 0.931 + 0.005X_1 - 0.010X_2) - 0.002X_4 - 0.001X_5) \quad (1)$$

$$Y_{Gs} = 0.059 + 0.011X_1 + 0.104X_2 + 0.001X_4 - 0.001X_5 + 0.006X_6 \quad (2)$$

$$Y_{Pi} = -1.143 + 0.031X_2 + 0.098X_3 + 0.002X_4 + 0.002X_5 - 0.020X_6 \quad (3)$$

Notes: Ss = *S. sumatrana*; Gs = *G. sepium*; Pi = *P. indicus*; Y = wood density; X_1 = fiber diameter; X_2 = fiber wall thickness; X_3 = lumen diameter; X_4 = vessel diameter; X_5 = ray height; X_6 = ray width

The relative contribution and the relative contribution of determinant for all anatomical character factors to the total variation in wood density values show differences in the three tree species of Fabaceae (Table 4). The relative contribution for all anatomical character factors in *S. sumatrana* explained 99.8% of the total variation in wood density value. Fiber length, fiber diameter, fiber wall thickness, lumen diameter, vessel diameter, height ray and ray width had the relative contribution of determinant of 0.89%, 0.65%, 0.58%, 0.81%, 0.93%, 0.96% and 0.95% respectively of the total wood density variance. In *G. sepium*, relative contribution for all anatomical character factors explained 97.4% of the total variation in wood density value. Fiber length, fiber diameter, fiber wall thickness, lumen diameter, vessel diameter, height ray and ray width had the relative contribution of determinant of 0.51%, 0.56%, 0.78%, 0.84%, 0.26%, 0.50% and 0.83% respectively of the total wood density variance. In *P. indicus*, relative contribution for all anatomical character factors explained 99.2% of the total variation in wood density. Fiber length, fiber diameter, fiber wall thickness, lumen diameter, vessel diameter, height ray and ray width had the relative contribution of determinant of 0.60%, 0.89%, 0.75%, 0.76%, 0.01%, 0.55% and 0.74% respectively of the total wood density variance.

TABLE 4: The relative contribution of all anatomical characters for predicting wood density value of selected Fabaceae trees using multiple linier regression analysis.

Species	Anatomical characters	R	r^2	Adjusted r Square	Std. Error of the Estimate	R	R^2	Adjusted R Square	Std. Error of the Estimate
S. sumatrana	FL	+0.942	0.887	0.876	0.03008	0.999	99.8%	99.5%	0.00580
	FD	-0.808	0.653	0.618	0.05279				
	FWT	+0.764	0.584	0.542	0.05790				
	LD	-0.901	0.811	0.793	0.03891				
	VD	-0.962	0.926	0.919	0.02435				
	RH	-0.982	0.964	0.960	0.01706				
	RW	+0.973	0.946	0.941	0.02073				
G. sepium	FL	+0.711	0.505	0.456	0.02949	0.987	97.4%	94.2%	0.00961
	FD	-0.750	0.563	0.519	0.02772				
	FWT	+0.882	0.778	0.755	0.01977				
	LD	-0.918	0.843	0.828	0.01658				
	VD	-0.512	0.262	0.189	0.03600				
	RH	+0.710	0.504	0.455	0.02950				
	RW	+0.912	0.832	0.815	0.01720				
P. indicus	FL	-0.777	0.603	0.570	0.05104	0.996	99.2%	98.5%	0.00961
	FD	+0.945	0.892	0.883	0.02658				
	FWT	+0.864	0.747	0.725	0.04058				
	LD	+0.873	0.762	0.742	0.03951				
	VD	0.078	0.006	-0.077	0.08037				
	RH	+0.743	0.552	0.514	0.05398				
	RW	+0.861	0.741	0.720	0.04121				

Notes: FL = fiber length, FD = fiber diameter, FWT = fiber wall thickness, LD = lumen diameter, VD = vessel diameter, RH = ray height, RW = ray width

The relative contribution of determinant for wood density value in *S. sumatrana* was determined by fiber, vessel and rays components, but but *G. sepium* was determined by fiber and rays components, and *P. indicus* was determined by fiber only. The high density wood is associated with thick fiber walls and large xylem vessels [41]. Fiber traits appear to be mayor determinants of wood specific gravity [42]. Wood density variation, mainly driven by fiber wall and lumen fraction [43, 44].

Vessel diameter, height and ray width factors tend to contribute negatively to wood density value of Fabacea tree species. *Eucalyptus nitents* wood with lower density tended to have higher vessel area, and lower fiber cell wall area, ring width, and latewood width [45].

4. Conclusions

Category of wood density of *S. sumatrana, G. sepium* and *P. indicus* are known variations based on altitude ranges. The relationship between wood density and altitude shows negative correlation on *S. sumatrana*, positive correlation on *G. sepium* and *P. indicus*. The length, diameter and lumen diameter of the fiber, the height and width of the pith radius increase with increasing altitude, while the vesel diameter decreases with increasing height. Diameter, wall thickness and fiber lumen diameter, and vesel diameter contribute significantly to the increase in wood density value.

Acknowledgments

The study was funded by a research grant from the Directorate General of Higher Education through the Research Center of Andalas University. Therefore, we would like to thank the Director of Directorate General of Higher Education and head of the Research Center of Andalas University.

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