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The effect of growth rate on wood density and anatomical characteristics of Rubberwood (*Hevea brasiliensis* Muell. Arg.) in two different clonal trails

Hamid Reza Naji[1,2], Mohd. Hamami Sahri[1], Tadashi Nobuchi[1] and Edi Suhaimi Bakar[1]

[1]Department of Forest production, Faculty of Forestry, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
[2]Department of Forestry, Faculty of Agriculture, Ilam University, Ilam, Iran

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ABSTRACT

The relationship between growth rate and wood properties has great importance in the management of forest plantation for wood and fiber production. Anatomical characteristics and wood density relationship in two different clones and planting densities as well as its variations from pith to bark were evaluated in this study. Eight trees of 9-year-old rubber tree (Hevea brasiliensis Muell. Arg.) plantation were taken as samples. Wood density of 0.65 and 0.54g.cm^{-3} were recorded in clone I, while clone II and respective planting densities revealed density values of 0.60 and 0.5g.cm^{-3}. Wood density and fiber features showed an increasing trend from pith to bark. Measuring vessel parameters also showed a direct relation with planting density. The properties of clone II were found to be comparatively better than clone I with longer fiber length and higher wood density.

Key words: growth rate, wood density, wood anatomy, clone, planting density.

INTRODUCTION

Rubberwood (*Hevea brasiliensis* Muell. Arg.) is one the most important hardwood for the forest-products industry in the tropical area especially in Malaysia. Until recently, the most important product from the rubber trees was its latex and efforts had been focused to increase the latex yield [1]. With the depletion of tropical forests, leading to a shortage of timber, attention has turned towards rubberwood as an alternative source of timber. Now, rubberwood is widely planted for production of timber[2]. In order for rubberwood industry to maintain its competitive position in global market, it must produce wood from intensively managed plantation with required quality to meet final products standards[3-4].

Planting at wide spacings stimulates rapid stem diameter growth early in the rotation which results in larger volumes of juvenile wood than occur in slower growing trees [5]. Silvicultural treatments applied to plantation trees during their early years greatly changed the growth rates, but it is not recognized how accelerated growth affects the wood and fiber properties. Understanding this relationship is of vital and practical importance in maximizing fiber production without decreasing wood and fiber quality[6]. Previous studies have been focused mostly on specific gravity and fiber length. The results of studies were often different for diffuse-porous species. In several studies, specific gravity and fiber length had a significant relationship to growth rate, but in some other studies there were no relationship between specific gravity and growth rate [7-8]. Anatomical variations in wood elements within and among the clones took the attention of wood anatomists for evaluating the wood quality [9].

Wood features especially anatomical properties can encompass the mechanical properties, density and predict final products characteristics [9-11]. Fiber length, as an important aspect of fiber morphology, has a great effect on mechanical strength and longitudinal shrinkage [10]. The specific gravity of wood is the single features which closely influence most mechanical properties of wood[10-11].

The objectives of this paper were to determine the effect of growth rate related to planting distance on some wood density and anatomical properties of clear wood of rubber trees (*H. brasiliensis*) in two different clones and two different planting densities.

MATERIALS AND METHODS

Two clones, namely RRIM2020 (Clone I) and RRIM2025 (Clone II) at age 9 years old were selected. The site is located in Tok Dor from Rubber Research Institute Mini Station (RRIMINIS) in Terengganu state under Malaysian Rubber Board in the Northeast part of Malaysia at a latitude of 4° 58′ 56.41″ N and longitude of 103° 09′ 08.67″ E. The average of precipitation during last three years was recorded 3752 mm [12].

Table 1 the mean statistics of stand features and tree growth of *H. brasiliensis*

Clone	No. of tree per hectare	Planting distance (m)	DBH mean (cm)	BH* mean (cm)
I	500 trees per hectare	5.0 x 4.0	20.22	467
	2000 trees per hectare	2.0 x 2.5	17.54	1023
II	500 trees per hectare	5.0 x 4.0	19.96	738
	2000 trees per hectare	2.0 x 2.5	15.07	1026

**BH: Bole height*

The planting densities in each clone were 5 x 4m and 2 x 2.5m (Table 1). From each planting density in each clone two trees were selected and felled down at 15 cm above the ground level. From each tree, a cross-sectional of approximately 5 cm in thickness was taken at diameter at breast height (DBH) levels. Discs were marked with the clone, planting density, and tree number. These discs were used for the determination of anatomical and physical properties. The discs were then wrapped in a plastic bag and labelled. All the wrapped discs were stored in a cold room (about 4°C) to prevent from moisture loss and fungal attack before further processing.

2.1 Wood density

Air-dried density at two opposite parts of pith [right-hand (+ symbol) and left-hand (- symbol) side] was measured. A radial segment was cut from bark in one side to bark in the other side. This segment was then cut to some precise blocks with 1.5 x 1.5 x 1.5 cm (longitudinally x tangentially x radius) dimensions from pith to bark with no interval between them. All blocks marked with number of clone, planting density and location from the pith. This method will show an uncut gradient in specific gravity from center to outer parts.

Natural rubber is obtained from bark of *H. brasiliensis*. This white or yellowish latex occurs in latex vessels in the bark, mostly outside the phloem[13-14]. Therefore, the wood density samples were nearly free of latex and samples didn't treat by a treatment such as dissolving by boiling to remove the extractive of the wood.

2.2 Anatomical properties

In this step, the fiber morphology (fiber length, fiber width, lumen diameter and wall thickness), and vessel features (vessel number, vessel diameter, vessel area and vessel proportion) from pith to bark were studied. For this purpose, each block that used to measuring specific gravity were converted to small blocks of 1.0 x 1.5 x 1.5cm. These new blocks were only taken in one side of disc. This shows a continuum cellular features changing from pith outward. Samples of thin sectional slides were prepared for anatomical assessment in terms of the Botanical Microtechnique [15].

2.3 Microscopic images and morphology measurements

From each sample, microscopic images of the cross sections were collected using an Image analyzer Microscopy (Leica QWin). The fiber diameter, fiber wall thickness, lumen diameters of 50 randomly selected fibers with a total magnification of 40X were measured by the image processing software calibrated with a stage micrometer. Additionally, with a total magnification of 10X the number of vessel elements was determined by counting the ones present within a field (approximately 994,011μm^2) and expressed as the number of vessels per square millimeter. With the data obtained, fiber cell wall thickness, lumen diameters, number of vessels per mm^2 (vessel frequency), mean vessel diameter (an average of radial and tangential vessel diameter), mean vessel area (mm^2), and percentage of the total area covered by vessels (vessel coverage) were calculated.

RESULTS AND DISCUSSION

3.1 Wood density

Average of air-dried density showed an increasing trend from pith to bark. For all discs lowest amount was near the pith (first block) and highest near the bark. A little decrease at last block near the bark was seen. This feature is found just at planting density I in both two clones (Fig.1). This trend may be related to the early maturity of trees in this planting density [9].

The mean air-dried densities for two different planting densities I and II of clone I were 0.59 and 0.53 $g.cm^{-3}$, and for clone II were 0.65 and 0.56 $g.cm^{-3}$, respectively. This showed a direct relationship between planting distance and wood density. This increasing at clone I was about

11% and at clone II about 16%. There was a positive correlation between spacing and wood density.

The results determined that there were significant differences between averages of air-dried densities in two different planting densities of clone I and II at probability of 95%. Based on some studies, there is no relationship between growth rate and wood density in diffuse-porous hardwoods[11]. However, some other studies have mentioned that growth rate has a little effect on wood density[16-17]. Generally, the density of diffuse-porous hardwoods is affected by growth rate, but results are variable[18]. It is also mentioned that the wood density increases from first rings, level off, and then decreases with ring number [17].

Table 2 the average air-dried densities at two opposite parts of discs (side + and -) for two different planting density and two clones of *H. brasiliensis*

Clone	Direction	500tr.ha^{-1}				2000tr.ha^{-1}		
		Blk* 1	Blk 2	Blk 3	Blk 4	Blk 1	Blk 2	Blk 3
I	Side +	0.58	0.61	0.62	0.59	0.50	0.53	0.55
	Side -	0.53	0.59	0.61	0.61	0.52	0.53	0.54
II	Side +	0.60	0.66	0.67	0.67	0.50	0.54	0.57
	Side -	0.64	0.65	0.64	0.66	0.54	0.59	0.60

** Blk=Block*

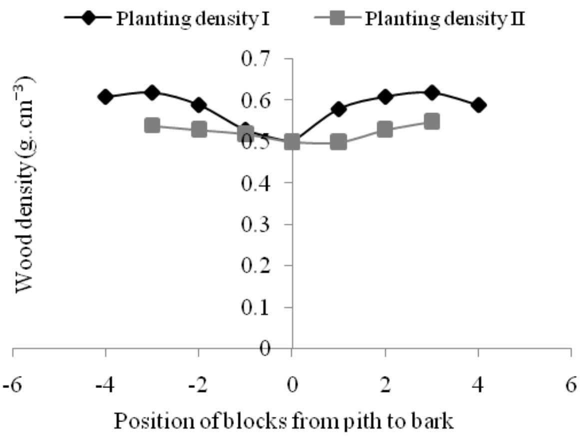
3.2 Anatomical Properties

The mean values of all anatomical properties for two planting densities at clone I and II are shown in Table 3 and 4.

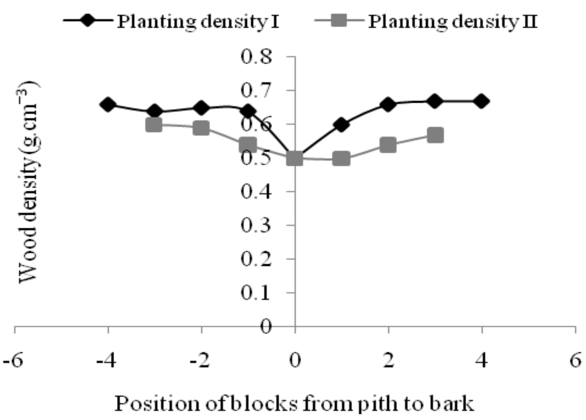
3.2.1 Fiber length

Fiber length from pith to bark increased in both planting densities and clones. The lowest amounts were in block 1 near the pith and highest amounts in outermost block (Tables 3 and 4 and Fig. 2). In clone I, the length of fibers near the pith at two planting densities was 1148 and 996 µm and near the bark were 1279 and 1385 µm, respectively. In clone II and block 1 for two planting densities the mean length of fiber were 1217 and 1133 µm and this amounts near the bark were 1438 and 1393 µm, respectively. Among two clones, the best situation was found at clone II, as in tables. There is a close relation between fiber length, mechanical properties and shrinkage. So, it could be considered as a great factor in determining wood quality [1, 10].

Data analyzing showed that there were significant differences between mean values of fiber length in two planting densities of clone I and also clone II at 5% level. Multiple comparisons of fiber length among two clones showed that there is a significant difference between planting density I at clone I on one hand with the same planting density at clone II on the other hand. There is no any difference between planting density I at first clone and planting density II at second clone. The difference between planting density II in clone I with two others planting densities in clone II is significant.



(1-a)



(1-b)

Figure 1 Wood density variations from pith to bark for two different planting densities of clone I (1-a) and II (1-b). Number 0 was considered as pith and 4 is outermost block near the bark. This status is distributed at both two opposite sides of discs (+,-).

Table 3 mean values of anatomical properties for two different planting densities at clone I of *H. brasiliensis*

Cell features	500 tr.ha^{-1}					2000 tr.ha^{-1}			
	Blk*1	Blk2	Blk3	Blk4	Mean	Blk1	Blk2	Blk3	Mean
Fiber length	1148	1239	1332	1279	1249	996	1179	1385	1187
F. diameter	24.67	29.48	30.16	30.02	29.63	27.78	26.62	34.70	27.26
F. lumen	17.32	20.17	20.39	23.25	20.28	17.01	17.05	19.33	17.32
F. wall thickness	4.63	4.75	4.97	5.16	4.88	4.08	4.79	5.38	4.97
Vessel No.	9.97	5.17	6.56	4.60	6.58	12.17	5.7	5.1	7.83
V. diameter	127	188	183	208	177	108	153	172	144
V. area	178482	175996	183655	166713	176211	161174	155801	132105	149693
V. tissue%	17.96	17.71	18.48	16.77	17.73	16.21	15.67	13.29	15.06

** Blk: Block*

Table 4 mean values of anatomical properties for two different planting densities at clone II of *H. brasiliensis*

Cell features	500 tr.ha^{-1}					2000 tr.ha^{-1}			
	Blk* 1	Blk2	Blk3	Blk4	Mean	Blk* 1	Blk2	Blk3	Mean
Fiber length	1217	1248	1457	1438	1340	1133	1266	1393	1276
F. diameter	26.55	32.77	29.16	31.71	28.54	27.78	32.84	34.70	31.78
F. lumen	16.43	22.29	19.78	20.94	18.92	20.01	25.13	26.56	23.90
F. wall thickness	4.19	4.39	4.84	5.39	4.71	3.89	3.96	4.10	3.98
Vessel No.	6.07	3.07	2.73	2.6	3.62	7.07	3.03	2.2	4.1
V. diameter	152	176	217	201	186	122	170	177	156
V. area	134218	100200	92992	84512	102980	114898	102909	70849	96218
V. tissue%	13.50	10.08	9.36	8.50	10.36	11.56	10.35	7.13	9.68

* *Blk: Block*

3.2.2 Fiber diameter

The values of fiber diameters from pith to bark increased, irrespective of clone and tree distance (Tables 3 and 4; Fig. 5). Fiber diameter ranged from 24.67 to 30.02 µm (21.7% increase) and 27.78 to 34.70 µm (24.9% increase) at clone I and two planting densities; and from 26.33 to 32.54 µm (23.6% increase) and 25.06 to 30.09 (20.0% increase) at clone II and two planting densities, respectively. The mean values of diameter of fiber at clone I and II and two planting densities related to them were: 29.63, 27.26 µm; and 28.54, 31.78 µm, respectively. Among two clones, the highest value of fiber diameter was found at clone II and planting density II. There were significant differences between mean values of fiber width at two planting densities in both clones at probability of 95%.

No significant difference between planting density I at clone I against clone II was revealed. While this showed a significant difference in planting density II at clones I and II. Fiber diameter has an effect on product quality. Most desire is to have long and narrow cells, but cell width has been little emphasized within species and choices among species are often influenced by the width and lumen size of cells[17]. There is a direct relationship between fiber diameter and wood density with strength properties of wood [1].

3.2.3 Fiber Lumen

The fiber lumen diameter showed an increase from pith to bark (Fig.4). Lumen diameter ranged from 17.32 to 23.25 µm (with a mean of 20.28 µm) and 17.01 to 19.33 (with a mean of 17.32) µm at clone I and two different planting densities, respectively; these values for clone II and its planting densities showed a range of 16.43 to 20.94 µm (with a mean of 18.92) and 20.01 to 26.56 µm (with a mean of 23.90). It was printed out that lumen diameter are in the range of 10.0-12.0 µm and 11.3-11.5 µm at rubber trees [11, 19]. Although the lumen diameter increased from pith to bark and this increasing is in spite of some studies, it has a direct relationship with fiber diameter. Increasing in value of fiber diameter is accompanied with an increasing in lumen diameter.

There were significant differences at mean values of fiber lumen between two planting densities in both two clones at difference level of 95%. No significant difference between planting density

I at clone I compared to clone II was recognized. While this showed a significant difference in planting density II at clones I and II.

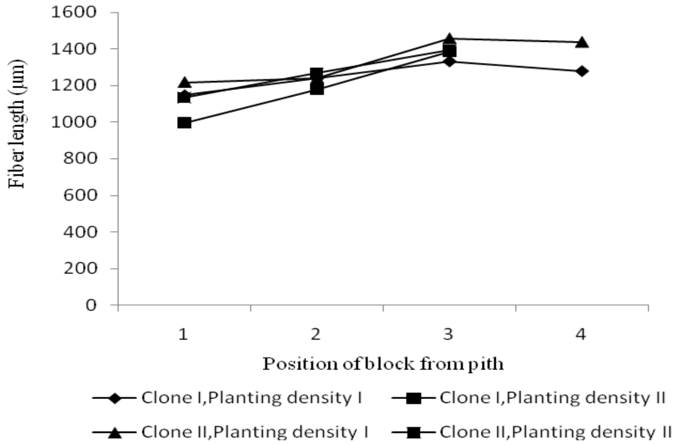


Figure 2 the changes of fiber length from pith to the bark.

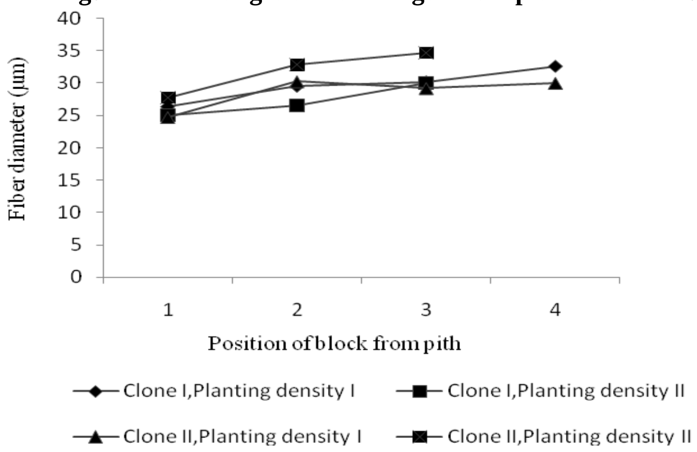


Figure 3 the changes of fiber diameter from pith to the bark

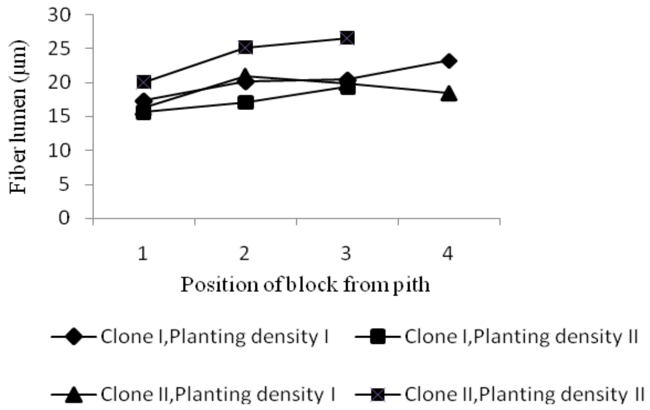


Figure 4 the changes of fiber lumen diameter from pith to the bark.

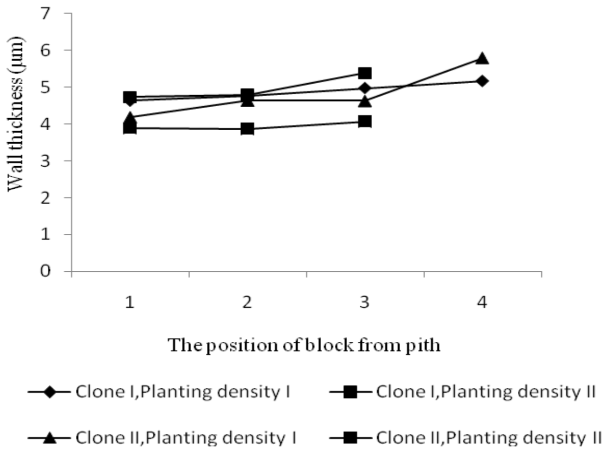


Figure 5 the changes of wall thickness from pith to the bark.

3.2.4 Wall thickness

In clone I, the wall thickness ranged from 4.63 to 5.16 µm (11.5% increase) with a mean 4.88 µm and 4.88 to 5.38 µm (10.3% increase) with a mean of 4.97 µm, respectively. These values in clone II were 4.19 to 5.39 µm (28.6% increase) with a mean of 4.71µm and 3.89 to 4.10 µm (5.4% increase) with a mean of 3.98 µm (Fig. 5). There was no significant difference in mean value of cell wall thickness between two planting densities of clone I. But, there is a significant difference in mean value of cell wall thickness between two planting densities at clone II. Among two clones, the multiple comparisons test showed that there is no significant difference between planting density I of clone I with same planting density of clone II. There is a significant difference between planting density II at clone I and clone II.

Cell wall thickness has a considerable effect on wood quality and this feature is greatly related to wood density. Any change in cell wall thickness leads to change in wood density [20]. Wall thickness largely changes within and between species and within a tree as well[17].

3.2.5 Variation in Vessel features

The variations of vessel features from pith to bark are tabulated in table 3 and 4. Vessel dimensions, viz. Number, diameter, and area were analyzed for the due to intra-clonal and inter-clonal variations. Statistical analysis revealed that vessel number was non-significant due to intra-clonal and inter-clonal differences at two different clones. Vessel diameter was significant at intra-clonal variation in both two clones and non-significant at inter-clonal between planting density I in clone I with two other planting densities in clone II and was significant between planting density II in clone I with just planting density I in clone II.

Vessel area was significant at intra-clonal comparisons in clone I and was non-significant at clone II and there was a significant difference due to inter-clonal comparisons.

The averages of vessel number, diameter, area and percent of vessel tissue at clone I for two planting densities were 6.58 and 7.83 per mm^2; 177 and 144 µm; 176211 and 149693 $µm^2$; 17.73% and 15.06%, respectively. These averages at clone II for two planting densities related were 3.62 and 4.1 per mm^2; 186 and 156 µm; 102980 and 96218 µm²; 10.36 and 9.68%, respectively.

Vessel number and diameter are important factors that reveal vessel proportion in the wood. High quantity of vessel number along with large vessel diameter leads to high amount of vessel proportion. The size and distribution of vessels in hardwoods have a major effect on wood quality and utility [17]. The mean vessel frequency for rubberwood was 3-4 vessel per mm^2 [21]. Moreover, the mean vessel frequency decreased from pith to bark[11]

CONCLUSION

All wood characteristics in *Hevea brasiliensis* studied, both the intra- and inter-tree variations are more or less influenced by tree spacings. A pattern of increasing wood cells along the radius direction demonstrated. Although all features showed an increasing trend from pith to bark and a difference value intra- and inter- clones, no significant differences was observed between some of them. In terms of wood density characteristics (viz., fiber length, cell wall thickness and vessel characteristics), compared to two clones and planting densities, planting density I in clone II show remarkably higher cell quality.

Although more information is needed, it is nonetheless clear that wood quality is affected by forestry practices. This factor should, therefore, be considered whenever product quality is significantly related to fiber length.

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