Influence of Planting Density on the Fiber Morphology and Chemical Composition of a New Latex-timber Clone Tree of Rubberwood (*Hevea brasiliensis* Muell. Arg.)

Harmaen Ahmad Saffian,[a] Paridah Md Tahir,[a] Jalaluddin Harun,[b] Mohammad Jawaid,[a,]* and Khalid Rehman Hakeem [c]

In this study, the fiber morphology and chemical constituents of a 4-year-old rubber tree (*Hevea brasiliensis* Muell. Arg.) from the RRIM 2000 clone series were evaluated. The effects of planting density on the fiber morphology and chemical compositions of the clone of rubber wood were also considered. It is clear that the fibers of the rubber wood samples grown under higher planting density were thicker, with a wider lumen diameter than those grown under lower planting density. There were significant interactions between planting density and the height of the tree from which the samples were taken for all measured fiber properties studied. The chemical composition of the clone of rubber wood was determined as per TAPPI standards. Each of the chemical constituents of the rubber wood displayed statistically significant (at the 95% confidence level) interactions with tree section (low, middle, or high) and planting density. Fiber morphology and chemical composition results showed that juvenile rubber trees could supply fiber to produce particleboard and medium density fiberboard. Compared to mature rubber trees (those more than 25 years old), the studied RRIM 2000 clone rubberwood trees were found to be as compatible for use in the wood industry.

Keywords: Rubberwood; Planting density; Fiber morphology; Chemical composition

Contact information: a: Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; b: Malaysian Timber Industry Board, Level 13-17 Menara PGRM, No.8 Jalan Pudu Ulu Cheras 56100 Kuala Lumpur, Malaysia; c: Faculty of Forestry, Universiti Putra Malaysia, Serdang-43400, Selangor, Malaysia;
** Corresponding author: jawaid@upm.edu.my; harmaen@upm.edu.my (A. S. Harmaen)*

INTRODUCTION

Currently, the main source of rubberwood is from old rubber trees that are no longer economically viable for use in latex production. It is expected that 41 more rubber farmers in Malaysia will switch to crops such as oil palm, bamboo and coir, and others due to the continued decline in rubberwood use in the near future. In light of this, the Rubber Research Institute of Malaysia (RRIM) has successfully bred latex timber clones (LTC) with high latex and timber yields. Planters in Malaysia have been encouraged to plant these clones to take advantage of their high latex and timber yields. In RRIM's Planting Recommendation Report (1995-1997), LTC is classified into two groups: Group I and Group II. Group I (Prang Besar (PB) and 900 series) consists of clones that have proven their performances for at least five years in large scale trials and in commercial plantings. Group II (900 and 2000 series) consists of selected clones currently undergoing small-scale trials based on their five-year yield record. Data regarding their performance in different climates, soils, and diseased environments are not yet available. Currently, the Malaysia Rubber Board (MRB) does not recommend planting clones on a large scale. Some of these clones seem to have better growth performance than those in Group I (PB 260 and PB 600 series). An example of a highly preforming clone is one from the RRIM 2000 series. These trees are planted under high planting density (more than 1000 trees/ha) in order to generate as much wood material as possible. If these planting practices turn out to be favorable, the system can be introduced to estate owners, and rubber trees can be harvested at an early age, benefitting the wood panel industry (Ong 2000).

Rubber trees from RRIM 2000 usually have a high wood volume with clear and straight trunks. They typically have a high latex yield. RRIM 900, RRIM 2000, and Prang Besar (PB) series clones can produce as much as 300% more timber than the current RRIM 600 series clones can, and they are harvestable just 12 to 15 years after they are planted. Rubberwood (RRIM 2020) is a new clone within RRIM 2000 series that has the potential for both high timber and high latex production. This clone has also exhibited better growth performance than rubber trees from the Prang Besar (PB) series and the RRIM 600 series (Najib *et al.*1997). In another related work, researchers carried out a study to determine the effects of clonal differences and planting density on growth rate and wood properties of rubber wood (Naji *et al.* 2012).

Rubberwood has become very important to the wood industry and is in ever-heightening demand. This is especially true for the wood panel product sector. Current declining trends in rubber replanting indicate that soon the supply of rubber wood may not be enough to meet the demand of the wood industry. It is imperative to establish an alternative source of rubber wood. Two possible approaches to meeting the growing demand for wood products would be to utilize rubberwood trees in their early growth stages and to implement a new planting system (*i.e.* one with high planting density). The trees grown in this type of plantation would not be tapped at all and would be harvested 15 years after they were planted. Both latex timber clones (LTC) and timber clones (TC) are suitable for growth in rubber plantations. The choice between the two depends on supply, product suitability, growth rate, yield, uniformity, and reliability of the selected clones.

Planting density is one of the methods of silviculture used to control tree growth. The MRB suggested that for solid wood production, tree spacing should be 4 x 4 m, yielding an initial planting density of 625 trees/ha. Lower density planting, of about 400 trees/ha, allows for better girth and cheaper planting materials. However, more pruning of branches and weed control are required. This planting density is suitable for latex production. The same practice could be suitable for planting clones from the RRIM 2000 series, which includes both LCs and LTCs. However, if these trees are planted for the chipboard and MDF industries, planting densities should be higher so that harvesting can be done earlier (5 or 6 years after planting, with tree diameters of about 15 cm). Silvicultural treatments applied to plantation trees during their early years can greatly affect their growth rates, but it is not well established how accelerated growth affects wood and fiber properties. Understanding this relationship is of vital and practical importance in maximizing fiber production without decreasing wood and fiber quality (Lei *et al.* 1997). Wood features (especially its anatomical properties) can be used as indicators of mechanical properties, densities, and final product characteristics (Norul and Sahri 2008; Pande and Singh 2005). Fiber length, an important aspect of fiber morphology, has a great effect on mechanical strength and longitudinal shrinkage

(Dinwoodie 1981). The specific gravity of wood influences most of its mechanical properties (Norul and Sahri 2008; Dinwoodie 1981).

The Malaysia Rubber Board has begun planting rubber trees for timber and latex production (*i.e.*, latex timber clone) using high planting densities between 1100 and 1666 trees/ha. In current practice, trees are planted using a 4 x 4 m planting distance. Both planting distances would give an initial planting density of 625 plants/ha. It is anticipated that during harvesting, 15 years after the date of planting, a density of 524 plants/ha will be achieved. The standard density for planting rubber is currently estimated to be 500 trees/ha irrespective of genotype, growth, morphological characteristics of the rubber clone, and environmental factors. This density will provide the space required by the mature rubber tree for its whole life span and will allow for the most favorable level of intra-species competition, resulting in the highest possible dry rubber yield per hectare. Under high densities, tree crowns can overlap, typically reducing the crown size (Makinan 1996). In addition, tree crowns become smaller under high densities due to self-pruning, affecting the interception of light (Pathiratna 2006; Cannell 1983). Under high tree densities, subterranean competition also can be high (Schroth 1999). In rubber trees, stress under high tree densities significantly reduces growth in girth and grams per tree per tapping yield (Obouayeba and Dian 2005; Webster and Paardekooper 1989). Under low densities, rubber trees grow faster, reach tappable girth earlier, and yield more wood on a per-tree basis (Westgrath and Buttery 1965). This is because trees grow faster during their immature phase under low densities (Rodrigo and Nugawela 1995). Growth of trees after the commencement of tapping is greatly reduced. The immature phase plays the most important role in determining the ultimate yields of rubber trees (Webster 1989). Despite the decrease in per-tree yield, higher tree densities have resulted in higher yields per hectare (Obouayeba and Dian 2005) and optimum planting densities have been determined. Other factors to consider are the cost of the plants themselves, of planting, of upkeep during the immature and mature phases, and of tapping and harvesting timber. Note that the costs of tapping and harvesting timber are high when large numbers of trees are managed under high tree densities.

In this study, the effects of planting density on the fiber morphology and the chemical constituents of four-year-old RRIM 2020 rubberwood clones were determined.

EXPERIMENTAL

Materials

A four-year-old RRIM 2000 series rubber tree clone was used for this study. The RRIM 2020 rubber tree clone was selected because it was planted for timber production. The site is located in the Northeast part of Malaysia at the Rubber Research Institute Mini Station (RRIMINIS) in Tok Dor, Besut, Terengganu (latitude of 4° 58′ 56.41″ N and longitude of 103° 09′ 08.67″ E). The RRIM 2020 rubber tree clone was planted at four different planting densities: 500, 1000, 1500, and 2000 trees/ha.

Methods

Cutting of wood samples

For each planting density, rubber trees were felled at 10 cm above the ground. The average tree height was 5 to 10 m, and the average diameter was 15 cm. Fifty-millimeter-thick discs were obtained from the top, middle, and bottom parts of the tree.

The discs were then covered with plastic bags, labeled, and brought to the laboratory for further processing. A total of 108 discs (3 trees x 3 height level x 4 planting densities x 3 repetition) were used.

Determination of fiber morphology

Each sample block was split into pieces of matchstick size and macerated into separate, labeled test tubes containing distilled water. Later, the water was replaced with a solution of equal parts glacial acetic acid and hydrogen peroxide (30 to 35%). The volume of the solution used in each test tube was 10 times the volume of the wood samples. During the maceration process, the test tubes were kept inside a water bath and maintained at 80 to 90 ºC for at least 8 h. About 5 mL of 10% glacial acetic acid and 1.5 g of sodium chlorite were added to the test tubes every 2 h to ensure that the wood samples' color became silvery-white. The chemicals were then washed away from the samples with distilled water by several consecutive washing steps. Solitary fibers were obtained within the suspension through gentle shaking. A pipette was used to transfer a drop of suspended fibers onto a slide before a cover slip was placed on top of the drop. Five slides were made for each sample of different planting density. Slides were then transferred to the slide warmer and dried at 60 ºC for an hour or more. Microscope images of the cross sections of each sample were collected using an image analyzer microscope (Quantimet 520, Cambridge Instruments). The fiber diameter, fiber wall thickness, and lumen diameters of 50 randomly selected fibers were measured by the image processing software. The software used a total magnification of 40X and was calibrated with a stage micrometer. From the data obtained, fiber length, fiber diameter, cell wall thickness, and lumen diameters were calculated.

Determination of chemical constituents

Discs from each tree were further cut into 5-cm-thick discs. The discs were ground and milled using a Willey Mill machine. The wood dust was sieved using British Standard (BS) 40 to 60 mesh. After grinding, the samples were kept in an airtight jar to maintain their moisture content. Alcohol-benzene (2:1) soluble extracts, hot water soluble extracts, and lignin and cellulose contents were determined using TAPPI T212 om-88, TAPPI T13 os-54, and ASTM 1104-56 (1978), respectively.

RESULTS AND DISCUSSION

Fiber Morphology

The mean values of fiber length, fiber diameter, fiber lumen diameter, and fiber wall thickness indicate that the young trees had lower quality wood than mature trees. Young wood's inferior fibers have shorter length, smaller lumens, and a thinner wall. Between young and matured woods, the latter always has longer fibers with thicker cell walls (Zobel and Kellison 1972). As was expected for RRIM 2020, the fiber lengths of 4-year-old rubberwood clone were shorter than those of the 25-year-old PB 260. Similar results were obtained by Bendsten and Senft (1986), Roslan (1998), Izham (2001), and Ashari (2002). They found that young wood has shorter fibers with thinner cell walls and larger lumen diameters.

The results are given in Table 1. Ashari (2002) showed that the average fiber length of two clones of rubberwood was 1.1 mm, while the fiber length of tropical hardwoods ranged from 0.8 and 1.6 mm.

Table 1. Analysis of Variance of the Effect of Planting Density and Tree Section on the Fiber Morphology of a RRIM 2020 Rubberwood Clone

		Fiber Length (mm)		Fiber diameter (µm)		Fiber Lumen Diameter(µm)		Fiber Wall Thickness(µm)	
Source Variance	DF	F value	Pr > F	F value	Pr > F	F value	Pr > F	F value	Pr > F
Planting density (P)	3	4.56	0.0037**	4.27	0.0055***	2.2	0.0876 *	2.91	0.034**
Tree Section (TS)	2	30.67	0.0001***	5.19	0.0001***	2.01	0.0437**	4.98	0.0001***
P*TS	6	3.53	0.0001***	2.08	0.0021***	2.41	0.0002***	2.39	0.0003***

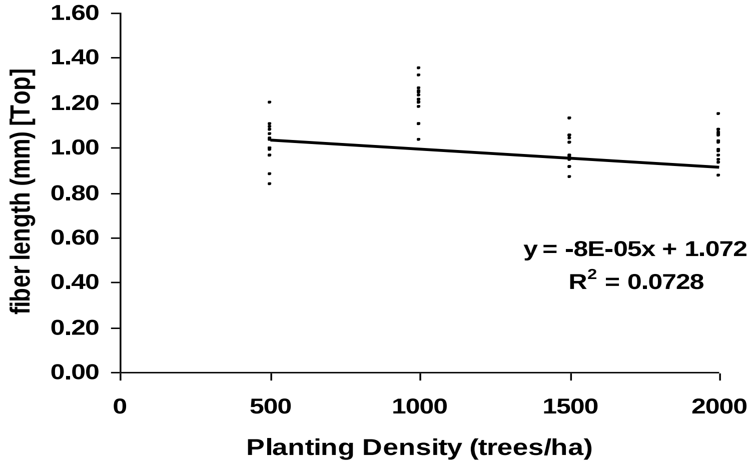
Note: ** - significant at $p \leq 0.05$ and *** - significant at $p \leq 0.01$

As shown in Table 1, there was significant interaction between the planting density and the tree height for all fiber properties studied. All of the following discussions are based on these interactions and not on the main effects themselves (planting density and tree section). These results are further illustrated in graph form in Figs. 1 through 4.

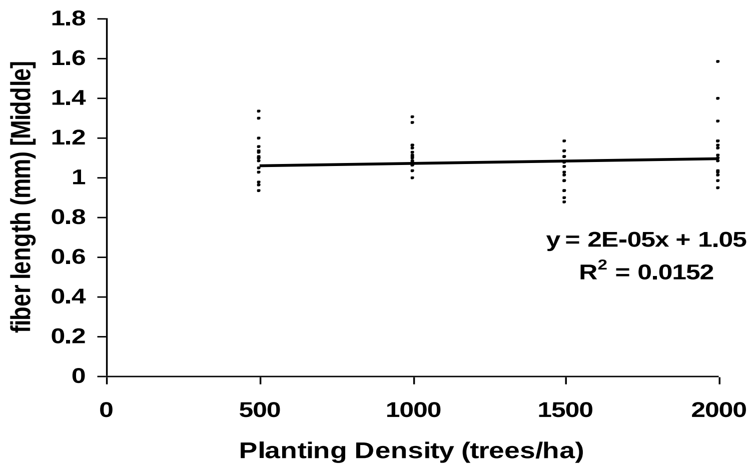
A summary of R^2 values and illustrations are given in Table 2 and Fig. 4, respectively. Fiber wall thickness was statistically significantly influenced by the planting density and tree height. Relationships were more prominent in wood obtained from the middle and top portions of the tree with R^2 values of 0.72 and 0.6, respectively. The effect was also significant for fiber lumen diameter in fibers taken from the middle section of the tree (R^2 value of 0.79).

Table 2. Summary of R^2 Values of Relationships between Planting Density and Tree Section on Fiber Length, Diameter, Lumen Diameter, and Wall Thickness

Section of Tree	Fiber Length (mm)	Fiber Diameter (µm)	Fiber Lumen Diameter (µm)	Fiber Wall Thickness (µm)
Top	0.07	0.31	0.32	0.60
Middle	0.02	0.15	0.79	0.72
Bottom	0.40	0.01	0.02	0.28



(a)



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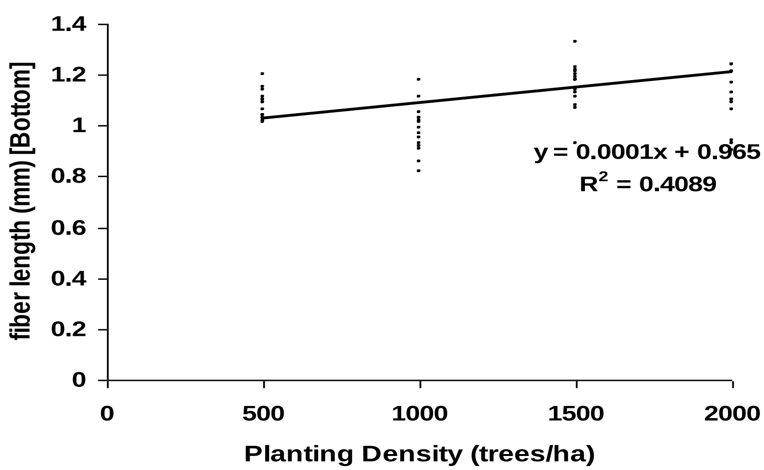


(c)

Fig. 1. Relationship between planting density and fiber length of fibers taken from different sections of the Rubberwood RRIM 2020 Clone; (a) Top, (b) Middle, and (c) Bottom

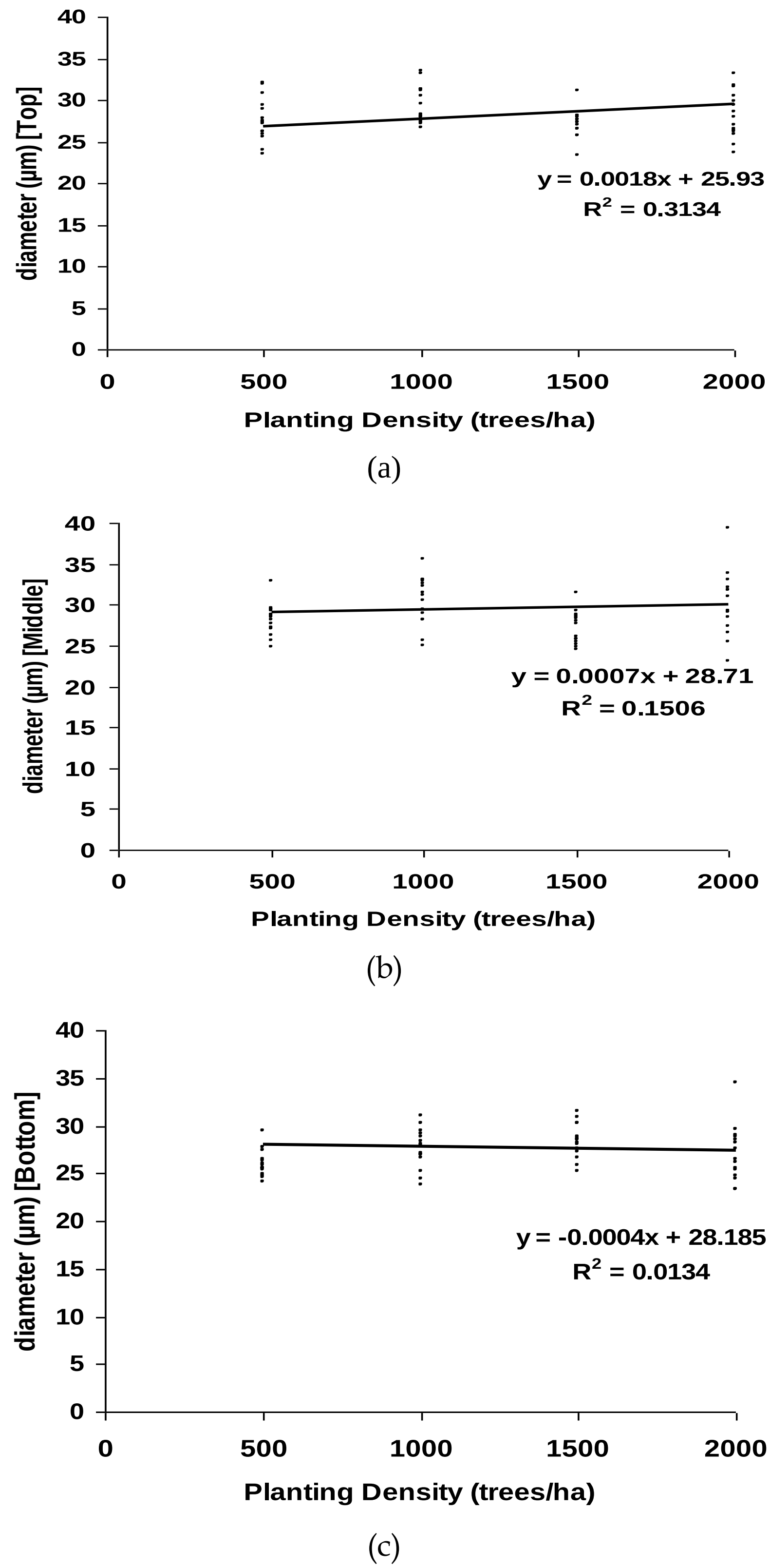
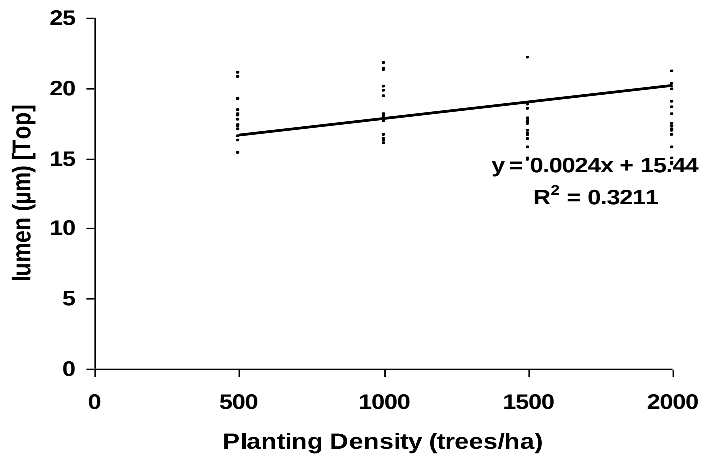


Fig. 2. Relationship between the planting density and the diameter of fibers taken from different sections of the Rubberwood RRIM 2020 Clone; (a) Top, (b) Middle, and (c) Bottom



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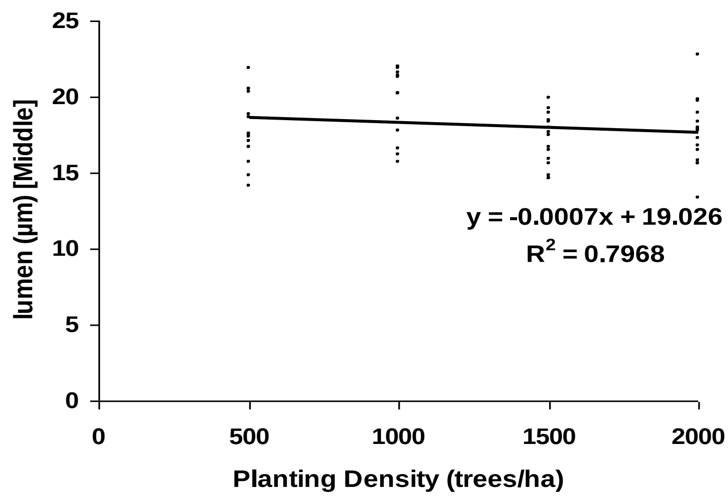

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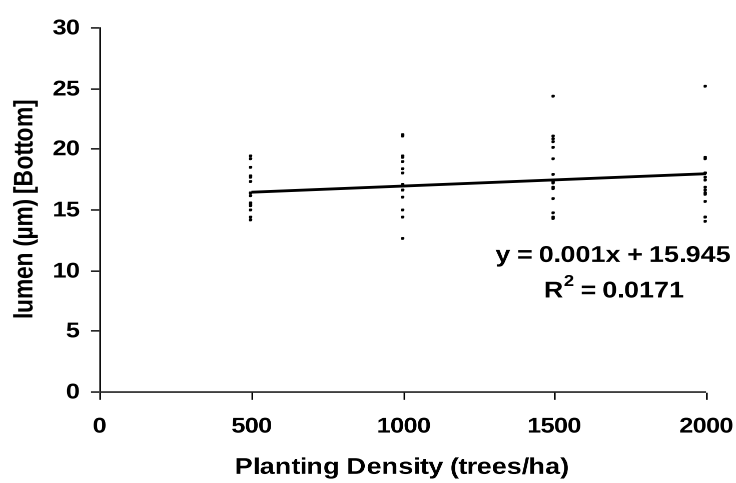
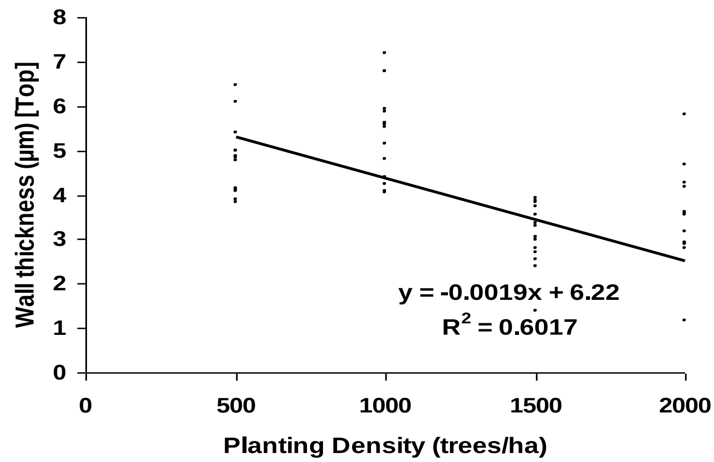
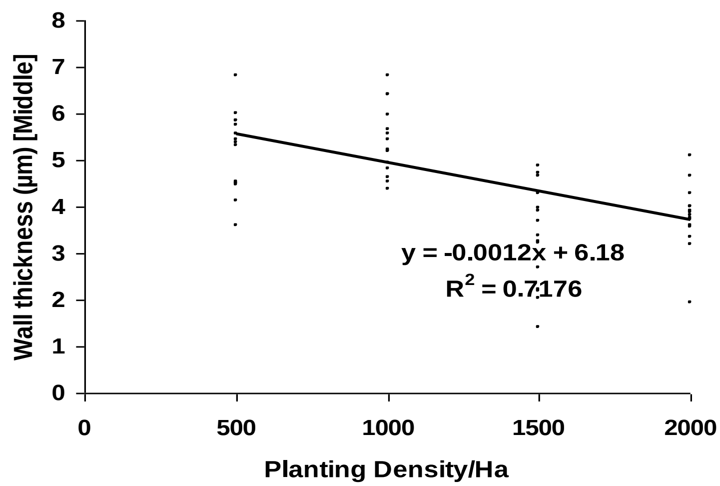


(c)

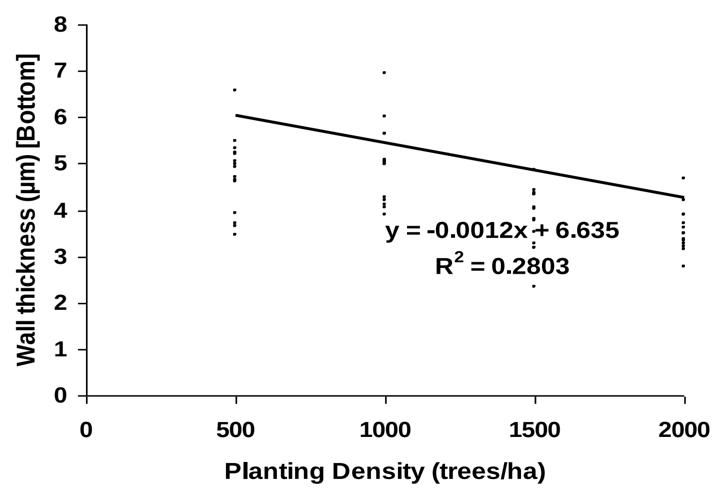
Fig. 3. Relationship between the planting density and lumen diameter of fibers taken from different sections of the Rubberwood RRIM 2020 Clone; (a) Top, (b) Middle, and (c) Bottom



(a)



(b)



(c)

Fig. 4. Relationship between the planting density and wall thickness of fibers taken from different sections of the Rubberwood RRIM 2020 Clone; (a) Top, (b) Middle, and (c) Bottom

The relationships between planting density and fiber diameter were weak, with R^2 values of 0.35 (top), 0.15 (middle), and 0.01 (bottom). It was found that the higher the planting density is, the wider the fiber is, particularly those located at the top of the tree (Fig. 2a, b, and c). The relationship between planting density and lumen diameter had R^2 values ranging from 0.01 to 0.80 (Fig. 3a, b, and c). Fiber lumen diameter from the middle portion of the tree affected planting density strongly as compared to other portions of the tree. This may be due to the fact that fiber dimensions were stable when growth rate increased at middle portion of tree as compared to lower and upper portion. This relationship had R^2 values of 0.32 and 0.02 for the top and bottom parts of the tree, respectively.

Results indicate that as the distance between trees was increased (*i.e.*, at lower planting density), the cell wall thicknesses of fibers from all sections of the tree decreased. This can be most clearly seen in the case of wood taken from the 500 trees/ha stand (Fig. 4). This phenomenon was irrespective of tree height.

In another study, rubberwood from a 25-year-old PB clone was used. Haifah (2002) reported that wood from the top portion of the tree had the longest fiber length compared to wood from the middle and bottom portions. Further, fibers at the bottom of tree had the thickest cell walls. The longest fibers were located in the sapwood (outer) region while those with the highest thicknesses, lumen diameters, and widths were located in the heartwood (inner) region. There was an increase in fiber wall thickness from the bottom to the top of the stem and a decrease in cell wall thickness from the outer to the inner parts of the radial zones due to mature-juvenile wood differences. Fiber with the thickest cell wall (4.6 µm) was located in the outer region, whereas fiber with the thinnest (4.5 µm) was located in the inner region of the bottom of the stem.

At higher planting density, there was significant change in lumen diameter. Figure 4 shows that cell wall thickness decreased as planting density increased from 500 to 1000 tree/ha. This effect was more prominent in fibers obtained from the top and middle parts of the tree (R^2 values of 0.60 and 0.72, respectively). In a denser planting arrangement, trees grew faster due to competition for sunlight. Hence, the cells grew faster, and their cell walls became relatively thinner. Such a trend is also apparent in this study (Fig. 4a and 4b).

Chemical Composition

The chemical components of the cell wall are normally inseparable without altering and degrading their structures (Janes 1969), making quantitative determination of their contents difficult. Therefore, separation and quantitative determination of each individual component was done in the laboratory through the use of solvent extraction and other techniques. The contents of chemical components in wood are widely variable due to the heterogeneity of the wood itself. Chemical differences in wood have been reported by many researchers such as Nikitin (1966) and Browning (1967). Experimental results for the chemical constituents, such as the extractives content, lignocellulosic material content, and ash content, of the juvenile RRIM 2020 rubberwood clone for different tree sections and planting densities are summarized in Table 3. There were significant interactions (at the 95% confidence level) in almost all properties studied. These effects were further analyzed using LSD and are summarized in Table 3.

Alcohol-Benzene Soluble Extractives

Wood extractives' components are a heterogeneous group of compounds, present in low concentration, that are important to wood formation (Stanley 1969). Extractives are also defined as the non-structural or secondary constituents of plants (Hillis 1970). Tables 3 and 4 show the differences in soluble extractives contents as functions of tree section and planting density. The highest extractive content was 2.63% in the bottom section and the lowest was 1.34% in the middle section of the tree. For a planting density of 1500 trees/ha, the highest extractive content was 2.63%.

Table 3. Analysis of Variance of Effect of Planting Density and Tree Height on the Extractive, Holocellulose, Alpha-Cellulose, Lignin, and Ash Contents of a RRIM 2020 Rubberwood Clone

		Alcohol:Benzene		Hot Water		Holocellulose	
Source Variance	df	F value	Pr > F	F value	Pr > F	F value	Pr > F
Planting density	3	36.94	0.0001***	16.68	0.0001***	6.68	0.0019***
Tree Height	2	14.78	0.0001***	126.52	0.0001***	2.69	0.0883*
P. density * T. height	6	5.52	0.0010***	2.67	0.0398**	6.83	0.0003***
		Alpha-cellulose		Lignin		Ash	
Source Variance	df	F value	Pr>F	F value	Pr>F	F value	Pr>F
Planting density	3	13.47	0.0001***	5.08	0.0073***	18.36	0.0001***
Tree Height	2	13.46	0.0001***	3.47	0.0474**	0.98	0.3887ns
P. density * T. height	6	0.8	0.5764 ns	1.26	0.3139 ns	2.87	0.0297**

Note: * - significant at p ≤ 0.1, ** - significant at p ≤ 0.05, *** - significant at p ≤ 0.01, and ns - not significant

The lowest extractive content of 1.34% was from the 500 trees/ha planting density. This study shows that under higher planting density, the wood contains relatively higher amounts of alcohol-benzene soluble extractives. This means that the wood samples may contain more waxes, fats, resins, and certain other ether-insoluble components such as wood gums.

Generally, the extractives content of Malaysian hardwoods varies between 0.6 and 11.6% of alcohol-benzene soluble, 0.1 and 14.4% of hot water soluble, and 2.6 and 24.5% of 1% alkali soluble (Khoo and Peh 1982). The amount of extractives in *Hevea brasiliensis* was between 6 and 10% (Hong 1994). Extractives make up between 4 and 10% of the dry weight of normal, temperate wood species but as much as 20% of tropical wood.

Extractives of tropical hardwood play important roles in decay resistance, termite resistance, creating resin spots on pulp sheets, and increases of paint curing time (Hong 1994; Yatagai and Takahashi1980; MacDonald and Franklin1969).

Table 4. Chemical Constituents of the Young RRIM 2020 Rubberwood Clone

	Tree Section	PB260 Harmaen *et al.* 2005	PD500	PD1000	PD1500	PD2000
Alcohol:Benzene Extractives (%)	Top	3.34	1.42e (0.09)	2.36ab (0.18)	2.27ab (0.17)	1.92dc (0.14)
	Middle		1.34e (0.10)	1.61de (0.31)	2.44ab (0.43)	1.46e (0.08)
	Bottom		1.67de (0.06)	2.41bc (0.08)	2.63a (0.14)	2.34ab (0.21)
Hot Water Extractives (%)	Top	6.55	3.55fe (0.320	3.30fg (0.51)	2.79hg (0.91)	2.25h (0.10)
	Middle		4.08de (0.22)	3.55bg (0.24)	3.12fg (0.49)	2.63hg (0.16)
	Bottom		5.77ba (0.13)	5.57bc (0.25)	5.88a (0.45)	4.52dc (0.43)
Holocellulose (%)	Top	66.86	73.75ced (0.72)	73.52cb (0.68)	74.47cbd (0.33)	73.20e (0.25)
	Middle		74.45cbd (0.16)	73.58ed (0.32)	74.15cedb (0.17)	74.55cbd (1.16)
	Bottom		75.11b (0.84)	74.95ed (0.39)	76.47a (0.45)	75.53ed (1.15)
α-Cellulose (%)	Top	44.00	53.17bac (1.12)	52.99bcd (0.65)	51.13e (0.54)	52.00ed (0.46)
	Middle		53.24ba (0.81)	54.15a (0.63)	52.13edc (0.35)	52.31bedc (0.47)
	Bottom		54.11a (0.31)	54.41a (0.23)	53.16bac (0.55)	53.31ba (0.21)
Lignin (%)	Top	23.00	13.55a (0.33)	11.56bc (0.09)	11.26c (0.57)	12.21bc (0.07)
	Middle		13.41ba (0.33)	12.12bc (0.39)	12.08bc (0.35)	12.13bc (0.62)
	Bottom		13.87c (0.31)	12.15c (0.52)	12.81c (0.73)	12.51c (0.11)
Ash (%)	Top	0.60	0.43a (0.03)	0.36fge (0.09)	0.44bc (0.01)	0.31g (0.09)
	Middle		0.47bcd (0.01)	0.35fg (0.01)	0.45becd (0.04)	0.39fgecd (0.02)
	Bottom		0.58ba (0.08)	0.38fged (0.02)	0.48fbecd (0.02)	0.44fbrcd (0.02)

Hot Water Soluble Extractives

Hot water soluble extractives from wood samples include components such as tannins, gums, sugars, coloring, starches, polysaccharides, inorganic salts, cyclitols, and some phenolic substances (Browning 1967). Consequently, the extractives soluble in organic solvents contain considerable material that is also soluble in water. Tables 3 and

4 show the significance levels of the relationships between water soluble extractives content and the two variables examined. The highest percentage of hot water solubles was 5.88% and the lowest was 2.25% in samples extracted from the bottom and top parts of the tree, respectively.

Holocellulose

Holocellulose is the total polysaccharide proportion of extractive-free wood. It includes cellulose and hemicelluloses. High holocellulose content indicates high levels of cellulose or hemicellulose (or both) (MacDonald and Franklin 1969). Tables 3 and 4 show that holocellulose levels were significantly affected both by planting density and by the section of the tree the wood was taken from. In this study, the highest percentage of holocellulose was 76.47%, obtained from the bottom part of the tree harvested from the 1500 trees/ha stand. The lowest was 73.20% at top of the tree harvested from the 2000 trees/ha stand. This range of holocellulose content is similar to that found by Hong (1994) and MacDonald and Franklin (1969) (between 65% and 78%). In general, hardwoods tend to possess higher holocellulose content than softwoods. Browning (1967) and Nikitin (1966) estimated the amount of holocellulose in softwood to be within the range of 70 to 75% and within 75 to 82% in hardwoods. However, the holocellulose content of Malaysian tropical hardwood was reported to vary more widely. It was within the range of 59.4 to 85.4% (Khoo and Peh 1982**)**.

Cellulose

Cellulose is the single most important component of the woody cell wall that contributes to the volume and characteristics of the wood. Approximately 40 to 45% of the dry mass of most wood species is cellulose, which is located predominantly in the secondary cell wall. Cellulose gives high tensile strength and is insoluble in most solvents due to its molecular structure and strong hydrogen bonding (Sjostrom 1981). The interaction effect on cellulose content was significant at the 95% confidence level. The highest cellulose level (54.41%) was found in wood from the bottom part of the tree, while the lowest (51.13%) was found in wood from the top of the tree. Cellulose content in wood is typically between 45 and 50% (Hong 1995). However, Khoo and Peh (1982) reported that most Malaysian hardwoods have alpha-cellulose contents in the range of 35.1 to 54.2%. In this study, the RRIM 2020 rubberwood tree clone had 44% cellulose content, which is similar to that of mature rubberwood (PB260), as shown in Table 4. The amount of hemicellulose as a fraction of the dry weight of wood is usually between 20 and 30%. Sjostrom (1981) reported a wider range of hemicellulose contents, between approximately 15 and 35%.

Lignin Content

There are various methods available for isolating lignin from wood. However, finding the ideal method of isolation is still considered a major problem in lignin chemistry (Polcin 1978).The lignin contents of the samples from various planting densities and tree sections were significantly different at the 95% confidence level. The results show that higher amount of lignin is located at the bottom part of tree as compared to top and middle part of tree (Table 4). Development of lignin is intimately associated with cellulose and hemicellulose; lignin penetrates the fibrils and strengthens the cell wall, which gives rigidity to the cell (Findlay 1975). Sjostrom (1981) found that normal softwood contains 26 to 30% lignin by mass while normal hardwood contains 20 to 28%

lignin. Sjostrom (1981) further reported that tropical hardwoods can have lignin contents exceeding 30% and that the lignin content in Malaysian hardwoods ranges from 12.7 to 34.2%.

Ash Content

Ash is an inorganic component of wood that does not burn even when heated to 575 ºC. Up to around 2% of wood, by mass, is ash. Silicate, one of the components of ash, is made up of silica; the silica content of most wood grown in the temperate zone is quite low compared to that of tropical woods, in which more than half of the ash weight is silica. Rubberwood planted at different planting densities showed significantly different ash contents. However, tree section had only a small effect on the amount of ash in the wood, especially in those planted at high planting density. The highest ash content (0.58%) was found at bottom part in trees planted at 500 trees/ha, and the lowest (0.31%) was at top part in trees from a planting density of 2000 trees/ha (Table 4). Usually, ash content is between 0.2 and 1% (Fengel and Wegener 1984).

CONCLUSIONS

1. The fiber morphology of 4-year-old RRIM 2020 tree clones was significantly affected by both planting density and the section of the tree from which samples were taken. Significant interactions were also found between the two factors. Using a high planting density (1500 and 2000 trees/ha) and taking samples from the bottom of the tree were found to have more dominant influences on the length and cell wall thickness of rubberwood fiber.
2. Wood taken from the top part of the tree had shorter fiber length compared to wood from the bottom part of the tree.
3. The levels of most of the chemical constituents in the RRIM 2020 rubberwood clone were significantly different at different planting densities and tree sections. However, the holocellulose and ash contents were not significantly affected by planting density.
4. In terms of the studied qualities, the new RRIM 2020 rubberwood clone is comparable to the natural timber species commonly used to make composite products.

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REFERENCES CITED

Ashari, A. J. (2002). "An investigation into the sap staining intrinsic properties of selected rubberwood (*Hevea brasiliensis*) clone," Ph.D thesis, Unpublished final year project report, University of Abertay, Dundee, U.K.

Bendtsen, A. B., and Senft, J. F. (1986). "Mechanical and anatomical properties in individual growth rings of plantation-growth eastern cottonwood and loblolly pine," *Wood Fiber Sci.* 18(1), 23-28.

Browning, B. L. (1967). *Methods of Wood Chemistry*, Vols. 1 & 2, John Wiley and Sons, New York.

Cannell, M. G. R. (1983). "*Plant Population and Yield of Tree and Herbaceous Crops*," P. A. Huxley (ed.), *Plant Res. Agroforestry*.

Dinwoodie, J. M. (1981). *Timber; Its Structure, Properties and Utilization*, Timber Press, USA.

Fengel, D., and Wegener, G. (1984). "*Wood: Chemistry, Ultrastructure, Reactions*," Walter de Gruyter, New York.

Harmaen, A. S., Paridah, M. T., Jalaluddin, H., Ali, R., Ismanizam, I., and Victor, L. S. (2005). "Fibre dimension and chemical constituents of rubber tree (*Hevea brasiliensis*) RRIM 2000 clone series," International Advanced Technology Congress 2005, Putrajaya. Malaysia.

Haifah, S. (2002). "Anatomical and fiber properties of hybrid *Acacia* grown in Sabah," Unpublished final year project report, Faculty of Forestry, Universiti Putra Malaysia.

Hillis, W. E. (1970). "The cellular distribution of lignin in tsuga wood," *J. Wood Sci. Technol.* 4(2), 122-139.

Hong, L. T. (1994). "*Proceeding of Processing and Utilization Rubberwood*," Kuala Lumpur, Malaysia.

Hong, L. T. (1995). "Rubberwood: Powering Malaysia's furniture and panel industry," *Asian Timber* 17(11), 17-22.

Izham, M. (2001). M.S. thesis, Unpublished final year project report, Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Janes, R. L. (1969). "The chemistry of wood and fibers," In: *Pulp and Paper Manufacture - The Pulping of Wood*, 2nd Ed., Vol. 1, R. G. MacDonald, and J. N. Franklin (eds.), McGraw-Hill, New York.

Khoo, K. C., and Peh, T. B. (1982). "Proximate chemical composition of some Malaysian Hardwoods," *Malays. For.* 45(2), 244-262.

Lei, H., Gartner, L. B., and Milota, M. R. (1997). "Effect of growth rate on the anatomy, specific gravity, and bending properties of wood from 7-year-old red alder (*Alnus rubra*)," *Can. Forest J. Resour.* 27(1), 80-85.

MacDonald, R. G., and Franklin, J. N. (1969). "*Pulp and Paper Manufacture: The Pulping of Wood*," 2nd Ed., Vol. 1, McGraw-Hill, New York.

Makinan, H. (1996). "Effect of inter tree competition on biomass production of *Pinus sylvestris* (L.)," *Forest Ecol. Manag*. 86 (1-3), 105-112.

Najib, L. A., Johari, M. H., Ghani, A. L., Mahdan, B., and Mahmud, A. W. (1997). "Viability of *Hevea* plantation for wood products. Seminar on commercial cultivation of teak, sentang, acacia and *Hevea* for timber," Forest Research Institute, Kepong, Malaysia.

Naji, H. R., Sahri, M. H., Nobuchi, T., and Bakar, E. S. (2012). "Clonal and planting density effects on some properties of Rubberwood (*Hevea brasiliensis* Muell. Arg)," *BioResources* 7(1), 189-202.
Norul, M. A., and Sahri, M. H. (2008). "Wood and cellular properties of four new *Hevea* species," FORTROP II International Conference, Kasetsart University, Thailand.
Nikitin, N. I. (1966). *The Chemistry of Cellulose and Wood*, Israel Program for Scientific Translation, Jerusalem.
Ong, E. L. (2000). "Characterization of new latex-timber clones of natural rubber," *J. Appl. Polym. Sci.* 78(8), 1517-1521.
Obouayeba, S., and Dian, K. (2005). "Effect of planting density on growth and yield productivity of (*Hevea brasiliensis* Muel. Arg). Clone PB 235," *J. Rubber Res.* 8(4), 257-270.
Pathiratna, L. S. S. (2006). "Management of intercrops under rubber (*Hevea*): Implication of competition and possibility for improvement," *Bull. Rub. Res. Institute of Sri Lanka* 47, 8-16.
Pande, P. K., and Singh, M. (2005). "Inter-clonal, intra-clonal, and single tree variations of wood anatomical properties and specific gravity of clonal ramets of *Dalbergia sissoo* Roxb.," *Wood Sci. Technol.* 39(5), 351-366.
Polcin, J. (1978). "Enzymic isolation of lignin from wood and pulps," *Wood Sci. Technol.* 12(2), 149-158.
Rodrigo, V. H., and Nugawela, A. (1995). "Effect of plant density on growth, yield and yield related factors and profitability of rubber (*Hevea brasiliensis* Muel. Arg)," *J. Rubber Res.* 76, 62-73.
Roslan. (1998). M.S. thesis, Unpublished final year project report, Universiti Putra Malaysia, Serdang, Selangor, Malaysia.
Schroth, G. (1999). "A review of below ground interactions in agroforestry, focusing on mechanisms and management options," *Agroforestry Syst.* 43 (1-3), 5-34.
Sjostrom, E. (1981). *Wood Chemistry – Fundamentals and Applications*, Academic Press, New York.
Webster, C. C., and Paardekooper, E. C. (1989). "The botany of the rubber tree," *Tropical Agriculture Series*, Chapter 2, Longman, U.K.
Westgrath, D. R., and Buttery, B. R. (1965). "The effect of density of planting on the growth, yield and economic exploitation of *Hevea brasiliensis*, Part 1. The effect on growth and yield," *Rubber Res. Institute of Malaya* 19, 62-73.
Yatagai, M., and Takahashi, T. (1980). "Tropical wood extractives' effects on durability, paint curing time, and pulp sheet resin spotting," *Wood Sci.* 12(3), 176-182
Zobel, B. J., and Kellison, R. C. (1972). "Wood properties of young loblolly and slash pines," Proceedings of the Symposium on the Effect of Growth Acceleration on Properties of Wood, Madison, WI.

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