Wood Density Variations of Tropical Wood Species: Implications to the Physical Properties of Sawdust as Substrate for Mushroom Cultivation

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Abstract

The physical properties of sawdust including particle size distribution, particle density, porosity and water retention of tropical wood species were examined taking sixteen different wood densities users into consideration. Sawdust of each wood species was prepared using a milling machine (type CE TUV, made in Germany) with thickness of band saw size of 2 mm. Particle size of sawdust was classified into 3 classes; Over Size (OS) < 24 mesh (<710 µm); Coarse Particle Size (CPS = 350µm~710 µm) and Fine Particle Size (FPS = 177 µm~250 µm). In relation to the physical properties analysis, OS particle was excluded due to high variation in the particle size distribution but significant lowest in the proportion comparing to the FPS and CPS. Although statistical analysis showed that different wood density revealed relatively weak relationship with particle size distribution however wood density had positively correlated with the particle density. High of wood density tended to make higher particle density of sawdust. In addition, comparison between CPS and FPS for each wood species generally showed that CPS was significantly higher in porosity but lower in particle density and water retention than that FPS. Further, a comparison between different wood species in porosity and water retention showed different pattern, increasing wood density was negatively correlated with the porosity in CPS and also FPS; however the different wood density not showed significant relationship with the water retention.

Key words: Tropical sawdust, wood density, physical properties, substrate, mushroom cultivation.

Introduction

The output of sawmill industries from tropical wood-processing industries in East Kalimantan, Indonesia can be categorized as sawn timber (53% of total raw material), sawdust (14%), and solid waste (33%) (MFor 2007). Utilization of this sawdust is an urgent problem because the conventional incineration process of sawdust may produce environmentally hazardous pollutants such as polychlorinated dibenzo-dioxins and dibenzo-furans (Frombo *et al*. 2009; Terazawa 2003). In addition, sawdust being essentially a lignocellulosic material, it is not easily rotten but rather recalcitrant in the environment, and rarely produces odor during its long-term biodegradation process (Terazawa *et al*. 1999; Zavala *et al*. 2005).

In the field of composting science, sawdust has been referred to not only as a bulking reagent but as substrate for enhanced composting processes (Horisawa *et al*. 1999; Zavala *et al*. 2004). The benefits of using sawdust as a substrate are its physical properties like low apparent specific gravity, high porosity, high water retention, moderate water drainage, high bacteria tolerance, and biodegradability at an acceptable rate (Kitsui and Terazawa 1999). Physical properties of sawdust can also be modified by combined proportion on their particle size (Agnew and Leonard 2003; Dikinya *et al*. 2006; Houghton *et al*. 2002). Regarding the utilization of sawdust as substrate, it is important to pay attention not only to the chemical component but also to the wood density characteristics. The wood density is an important property for wood utilization and conversion (Hillis 1979; Zobel and van Buijtenan 1989). Wood density also has been recognized as an important variable for improving physical (Agnew and Leonard 2003; Johnson *et al*. 2003; Redding, *et al*. 2005) and chemical estimates (Gelbrich *et al*. 2008; Johnson *et al*. 2003; Ona *et al*. 1998). However, information about wood density in the tropical forest of East Kalimantan, Indonesia was often intended for technological and commercial uses rather than as substrate. On the other hand, no studies about commercial tropical wood density variation effects on physical properties and its functions as substrate have been reported.

This study was carried out to determine the physical properties including particle size distribution, particle density, porosity and water retention of sawdust based on wood density variation. If there are any correlations between wood density and the physical properties of sawdust, its might be inferred from data on the variation of wood densities. With this in mind, variations in physical properties of sawdust were examined according to different wood density, taking sixteen different wood species in the different wood density users into consideration. These species were selected because they are representative species available on a commercial basis, and also have potential abundance in the production forest in East Kalimantan (MFor 2007). We analyzed whether wood density variation reflects the physical properties of sawdust. This study, therefore, provides basic information on its adaptability as substrate for a breakthrough in the utilization of tropical wood sawdust.

Materials and Methods

Sample Preparation

The wood density of sixteen tree species (Table 1) was determined directly during sample preparation with a dimension 5cm x 5cm x 5cm of green mass. Wood density (g/cm^3) was expressed as green mass/green volume (Johnson *et al.* 2003). Further, sawdust of each wood species was prepared with a milling machine (type CE TUV, made in Germany) with thickness of band saw size of 2 mm. In addition, the physical properties (particle size distribution, particle density, porosity, and water retention) were analyzed in the Laboratory of Forest Chemistry and Forest Resource Biology of Graduate School of Agriculture, Hokkaido University, Japan.

Table 1. Wood density variations of 16 tropical wood species.

Tropical wood species	Wood density (g/cm^3)	SD (+/-)
Macaranga triloba	0.35	0.01
Euodia alba	0.47	0.05
Artocarpus altilis	0.49	0.01
Gliricidia sp.	0.49	0.01
Shorea leprosula	0.51	0.04
Cocoa sp.	0.54	0.02
Pterocarpus indicus	0.59	0.02
Terminalia cattapa	0.63	0.01
Dryobalanops lanceolata	0.71	0.02
Artocarpus integer	0.76	0.01
Peronema canescens	0.78	0.02
Acacia mangium	0.79	0.01
Hevea brasiliensis	0.80	0.02
Dipterocarpus cornutus	0.83	0.04
Shorea laevis	0.96	0.03
Eusideroxylon zwageri	1.20	0.02

Notes: n = 3 replicates.

Particle Size Distribution

Sawdust for particle size distribution was determined directly from the milling machine. Particle size distribution of sawdust (12~17% moisture content) was classified into 3 fraction sizes: oversized, coarse and fine using a sieve machine. The classification oversized (OS) is used for particle size < 24 mesh (<710 μm), coarse particle size (CPS) for particle size 24~60 mesh (350μm~710 μm) and fine particle size (FPS) for 60~80 mesh (177 μm~250 μm). In relation with the objective of this study, OS particles were excluded, due to being the lowest in proportion but showed high variation in size.

Particle Density

Particle density was determined by Araki and Terazawa (2004), and Rühlmann *et al*. (2006) methods. It was determined by adding the sawdust (=100 cm^3) to a volumetric cylinder (Vo), and subtracting the weight (g) of the volumetric cylinder (Wa) from the total weight (g) of the cylinder plus the sawdust (Wb). Particle density was expressed as the following formula:

$$\text{Particle density } (g/cm^3) = (Wb-Wa)/Vo$$

Porosity

The percentage of porosity was determined by Horisawa *et al.* (1999) method. Sawdust (apparent volume: 100 cm^3) was placed in a volumetric cylinder. Tap water was poured gently into it until the surface of water reached a marked line at the 100 cm^3 level. A meshed top as a stopper was equipped at the 100 cm^3 level so that the sawdust, mostly floating on water, would not go beyond it. Porosity was expressed as the following formula:

$$\text{Porosity } (\%) = (Va/Vo) \times 100$$

where Va, and Vo are the volume of poured water (cm^3), and the volume of sawdust (=100 cm^3) respectively.

Water Retention

The percentage of water retention was determined by Horisawa *et al*. (1999) method. A glass column (inner diameter: 50 mm) equipped with a faucet at its bottom part was packed with 100 cm^3 of sawdust, and the faucet was closed. A hundred milli-liters of water was poured in gently. Ten minutes later, the faucet was opened to drain the water gravimetrically until no more drainage of water was observed. Water retention was expressed as follows:

$$\text{Water retention } (\%) = \{(Vb+Vc-Vd)/Vo\} \times 100$$

where Vb stands for the volume of poured water (=100 cm^3); Vc is the volume of water in 100 cm^3 of sawdust; Vd is the volume of drained water (cm^3); and Vo is the volume of sawdust (=100 cm^3).

Statistical Analysis

Paired *t*-test was conducted to analyze the differences between wood density variations on their physical properties (particle size distribution, particle density, porosity and water retention). In addition a correlation analysis was used to determine the influence of variation in the wood densities within CPS and FPS on physical properties. The correlation and paired *t*-test analysis were conducted by using Statgraphics™ software version XV for Windows™ (Statistical graphics Corp 2007).

Results and Discussion

The physical properties of sawdust including particle size distribution, particle density, porosity and water retention of tropical wood species were examined taking sixteen different wood densities as raw materials. The mean and standard deviation values of the wood density for each species are presented in Table 1.

Particle Size Distribution

Particle size distribution of sawdust was measured directly after the milling process. The mean ± standard deviation (SD) of particle size distribution, combined for all different wood species was highest in FPS that was 70.6 ± 3.3% (range: 63.0~75.0%) followed by CPS (mean ± SD = 22.8 ± 3.1%, range 17.0-28.0%), and OS (mean ± SD = 6.7 ± 4.3%, range: 2.0~15%). A comparison of particle size distribution between different wood densities resulted in a similar pattern, i.e the percentage of FPS was largest followed by CPS then OS, Figure 1. There are some variations in the percentage of particle size distribution between different wood densities, and paired *t*-test analysis showed significant differences in the particle size

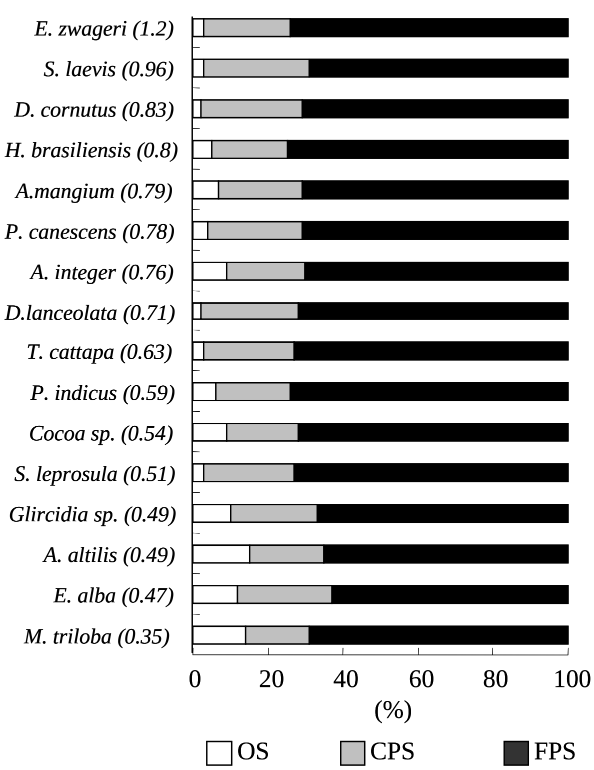

Figure 1. Proportions of particle size distribution in the different particle size classes based on wood density variations.

distribution between OS and CPS (*t*-test = -9.522, *P*-value < 0.001); OS and FPS (*t*-test = -36.091, *P*-value < 0.001), and between CPS and FPS (*t*-test = -40.383, *P*-value < 0.001). Although the result of this study showed significant differences in particle size distribution between particle size classes however the correlation coefficient between wood density and particle size distribution for each particle size categories in OS (R^2 = 43.32, correlation coefficient (*Cc*) = -0.66, n = 16) CPS (R^2 = 19.40, *Cc* = 0.44, n = 16) and FPS (R^2 = 20.92, *Cc* = 0.45, n = 16), indicating a relatively weak relationship between wood density and particle size distribution (Figure 1).

This patterns probably due to the fact that particle size distribution influenced by type or size of knife rather than wood densities. A similar pattern was reported by Paulrud *et al*. (2002) and Bergström *et al*. (2008); particle size distribution has been associated with the size of sawdust and the types of mill that are used for producing sawdust. Moreover, Himmel *et al*. (1985) and Houghton (2002) reported that the size of knife used will affect particle size distribution, and that increasing the size of knife has also been associated with larger particle size. Thus it is reasonable if the samples in this study, which were processed by a similar knife size, produced a more homogenous percentage of particle size distribution across different wood densities.

Particle Density

It is generally accepted that particle size of the raw material influences the density (Bergström *et al*. 2008; Hwang *et al*. 2002). This study demonstrated the strength effect of wood density and particle size classes on the particle density. A comparison of particle density between CPS and FPS showed a similar pattern for each wood species, which was that the particle density of CPS (mean ± SD = 0.18 ± 0.06) was smaller than that FPS (0.21 ± 0.10) although statistical analysis showed not significant differences (t-test = -1.682, *P*-value = 0.113). *M. triloba* with the lowest wood density (0.35 g/cm^3) has the smallest particle density (CPS = 0.08 g/cm^3; FPS = 0.09 g/cm^3), and *E. zwageri* with the highest wood density (1.20 g/cm^3) has the highest particle density (CPS = 0.31 g/cm^3; FPS = 0.35 g/cm^3) (Figure 2a.). A correlative analysis found that increasing wood density was significantly positively correlated with particle density in CPS (R^2 = 84.4%, *Cc* = 0.92, *F* = 75.87, $P < 0.001$, n=16) and also in FPS (R^2 = 52.2%, *Cc* = 0.72, *F* = 15.30, $P <$ 0.002, *n* = 16) (Table 2).

The pattern of wood density differences corresponded well with the patterns of particle density. High wood density tended to make higher particle density of sawdust. This pattern could be explained by hypothesizing that high wood density will influence the average weight of sawdust. In addition, a relatively larger particle size of CPS tended to have a relatively lower particle density than that of FPS. A previous study by

Coudray *et al*. (2009) supported this result during measurement of fine aerosol fraction from wood, where the particle densities decreased according to the increase in particle size.

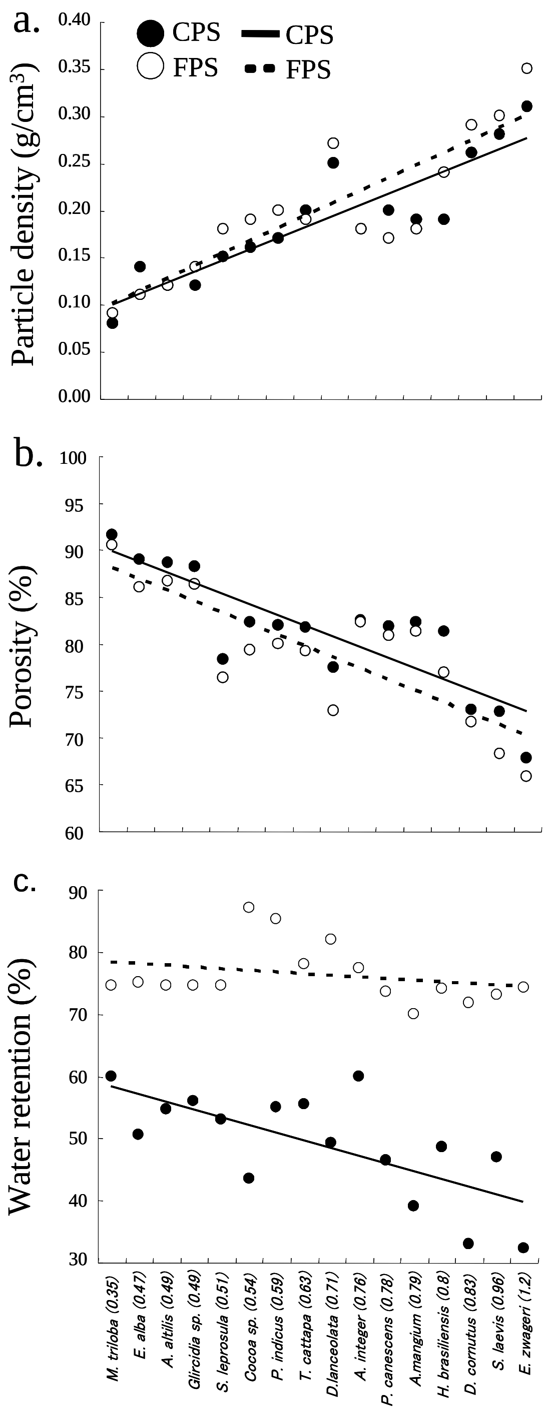

Figure 2a-c. Proportions of CPS and FPS among wood density variations in relation with; a. Particle density, b. Porosity, and c. Water retention.

Porosity

Porosity of sawdust can be defined as a measure of void volume of sawdust grains, composed principally of inter-spaces among and intra-spaces within the particles (Agnew and Leonard 2003; Bouma *et al*. 2003a), or percentage of air and water filled voids (Baker *et al*. 1998). Comparison of CPS and FPS on porosity within and between wood species can be considered separately. Within each wood density, the porosity of CPS was significantly higher (*t*-test = 6.873; *P*-value < 0.001) than that of FPS for each wood species (Figure 2b). It was suggested that particle distribution of FPS is more compact than that of CPS, and that compaction effects on FPS are more directly related to a decrease in porosity.

A comparison between wood species in particle density showed that *M. triloba* with the lowest wood and particle density was highest in porosity (CPS = 91.6%; FPS =90.5%). In contrast, *E. zwageri* which had the highest wood density has been lowest in porosity (CPS = 67.8%; FPS = 65.8%). An increase in wood density was negatively related to porosity in CPS and FPS. It was demonstrated that the porosity of sawdust is influenced by wood and particle density. The porosity of sawdust decreased with an increase in wood density (CPS: R^2 = 74.35%, Cc = -0.86, F = 40.58, P < 0.001; FPS: R^2 = 69.38, Cc = 0.83, F = 31.72, P < 0.001; Table 2). Since particle density is influenced by wood density, an increase of wood density in the tropical wood species has either been associated with the increase of particle density or a decreased volume of pores. Thus, sawdust from high wood density trees tends to have low porosity.

Water Retention

In compost science, water retention is defined as the ability of compost to hold water for a period that is longer than infiltration or the ability of compost to hold and retain water (Agnew and Leonard 2003; Bouma *et al*. 2003b). Comparisons of water retention percentages between CPS and FPS generally showed a similar pattern within each wood density. The water retention of CPS was significantly smaller (*t*-test = -9.429; P <0.001) than FPS (Figure 2c).

The linear relationship between water retention and wood density for CPS and for FPS had similar patterns. There is not a significant relationship between water retention and wood density in CPS (R^2 = 32.85%, *Cc* = -0.57; F = 6.85, P < 0.020), and also in FPS (R^2 = 7.747%, Cc = -0.28; F = 1.18, P < 0.297).

Table 2. The linear regression analysis of CPS and FPS between wood density and physical properties of tropical wood sawdust.

Physical properties of sawdust	The equation for y = a + b*x	Cc	R^2	*F*-Ratio	P-Value
Particle size distribution OS	y = 15.68 - 13.20*WD	-0.66	43.31	10.70	0.006
Particle size distribution CPS	y = 18.46 + 6.29*WD	0.44	19.40	3.37	0.088
Particle size distribution FPS	y = 65.86 + 6.90*WD	0.45	20.09	3.52	0.082
Particle density CPS	y = 0.006 + 0.27*WD	0.92	84.42	75.87	< 0.001
Particle density FPS	y = -0.019 + 0.34*WD	0.72	52.21	15.30	0.002
Porosity CPS	y = 98.70 - 25.61*WD	-0.86	74.35	40.58	< 0.001
Porosity FPS	y = 97.05 - 26.49*WD	-0.83	69.38	31.72	< 0.001
Water retention CPS	y = 68.46 - 33.17*WD	-0.57	32.85	6.85	0.020
Water retention FPS	y = 80.33 - 6.07*WD	-0.28	-0.28	1.18	0.297

Notes: n = 16 species, OS = Over size, CPS = Coarse particle size, FPS = Fine particle size, Cc = coefficient correlation, WD = wood density.

Wood density differences showed not significant influence on water retention values, than particle size differences did. It was suggested that the smaller particle size in FPS than that of CPS led to increased high values of water retention in FPS, this may be due to a decrease in particle size and/or increased particle adhesion of sawdust. Figure 2c showed the strength of influence of the different particle size classes on water retention. A previous study had similar results of many different kinds of particle size in soil and compost science, and it has been reported that particle size has strong influence on water retention (Agnew and Leonard, 2003; Hwang *et al*. 2002; Dikinya *et al*. 2006). Smaller particle size tended to keep higher water content than larger particle size (Dikinya *et al*. 2006).

Conclusions

A comparison between CPS and FPS within each wood density found that particle size distribution of CPS was higher than that of FPS. Wood density corresponded well with the physical properties (particle density, porosity and water retention) of sawdust. Wood density positively correlated with particle density while it negatively correlated with the porosity. Comparisons between species demonstrated that *E. zwageri*, with the highest wood density tended to be the highest particle density, lowest in porosity and highest in water retention compared to *M. triloba* with the lowest wood density. The positive correspondence in wood density, particle density, and particle size classes indicates that wood density variations within a particle size class may reflect particle density variation and consequently physical property variations. Thus, this study would provide basic information on physical properties of tropical wood sawdust for better use as substrate for mushroom cultivation.

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