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Suitability and availability analysis of tropical forest wood species for ethanol production: a case study in East Kalimantan

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Abstract. *Amirta R, Mukhdlor A, Mujiasih D, Septia E, Supriadi, Susanto D. 2016. Suitability and availability analysis of tropical forest wood species for ethanol production: a case study in East Kalimantan. Biodiversitas 17: 544-552.* Fifteen species of woody biomass from tropical forest of East Kalimantan, Indonesia and identified as *Acacia mangium*, *Aleurites moluccana*, *Alstonia scholaris*, *Anthocephalus cadamba*, *Artocarpus altilis*, *Artocarpus elasticus*, *Cananga odorata*, *Gmelina arborea*, *Lagerstroemia speciosa*, *Leucaena leucocephala*, *Macaranga gigantea*, *Macaranga tanarius*, *Paraserianthes falcataria*, *Shorea leprosula* and *Swietenia macrophylla* were characterized and studied to find out and discover their potential utilization as suitable feedstocks for biofuel (ethanol) production. Characterization was done by evaluation of lignin, holocellulose and cellulose contents of woody biomass including the yield of reducing sugar (saccharification) after pretreated with alkaline (NaOH) at moderate temperature. Among 15 species of tropical forest wood biomass evaluated, our findings showed that *M. gigantea* was gave the highest yield of saccharified sugar (42.22%, weight of original wood dry basis) and also yield of theoretical ethanol (± 273 L/ton). We also found growth of *M. gigantea* was very fast to produce approximately 26,119 kg ha^{-1} dry biomass within 3 years. In general, the tropical wood biomass such as *M. gigantea, A. moluccana, G. arborea, A. cadamba*, and *P. falcataria* are suitable and potentially to be used as feedstocks for ethanol production due to their fast growing ability, availability and attractive chemical composition to produce high saccharified sugar and yield of ethanol.

Keywords: Ethanol, suitability, tropical forest, wood biomass, East Kalimantan

INTRODUCTION

Nowadays, energy crisis is one of the most serious threats towards the sustainability of human kinds and civilization. Although industrial revolution has changed the world to its sophisticated edge, excessive dependent on fossil fuels as the main source of energy has leads to the diminishing of this non-renewable supply. Furthermore, demand for petroleum-derived fuels is not slowing down but instead increases substantially over the past few decades (Goh et al. 2011). Regarding to this issue, as one of the countries which have abundant reserves of forest biomass and agricultural residues, Indonesia government has declared to start production of fuels and energy from renewable sources. The government realizes that the biofuels and bioenergy industries will increase the amount of domestic supply of fuels and electricity with decrease in subsidy for promotion of the biofuels (DGEEU, Indonesia Ministry of Energy and Mineral Resources 2005; Watanabe et al. 2008). Thus far, natural and industrial forest plantation in Indonesia has been managed and designed to produce construction wood materials, boards and papers, and potency of wood biomass as a source for biofuel production has received much less attention. However, tropical rain forest includes a wide variety of wood species which has no values for the current industry but may have a great deal of potential for production of biofuels and chemicals. From the view point of biodiversity and potential of the bioresources for sustainable society, WWF Indonesia pointed out importance of the tropical forests in Indonesia, particularly in Kayan Mentarang Forest, Malinau East Kalimantan, which includes around 15,000 species of plants (Pio and D'Cruz 2005). The biodiversity value of forest is the highest compared to other places on the earth. Forest in Kalimantan is characterized also by richness in endemic species. There are at least 6,000 endemic species of plants, including 155 dipterocarp trees species. The lack of information on the basic properties, function and suitability as the feedstock for the fuels and energy production including conversion process, are believed as the main reason and barrier factor for utilization of those wood species (Amirta et al. 2016a,b). Therefore, herein this preliminary study the fifteen species of wood biomass that commonly growth in primary forest, secondary, and also plantation forest in East Kalimantan, Indonesia were characterized with the special emphasize to point out and discover their potential utilization as suitable feedstocks for biofuel (ethanol) production. The growth ability of wood species was also discussed to get more information about their availability as potential feedstock for ethanol production in the near future.

MATERIALS AND METHODS

Study area

The field observation and plant material including wood biomass was collected from Universitas Mulawarman Education Forest located at Samarinda Botanical Garden (Kebun Raya UNMUL Samarinda-KRUS), Samarinda, East Kalimantan, Indonesia (0°25'10"LS – 0°25'10"LS and, 117°14'00"BT-117°14'14"BT-300 ha) (Figure1).

Wood material

Wood samples (biomass) from 15 species of tropical wood biomass with diameter about 10-20 cm were collected from Universitas Mulawarman Education Forest located at Samarinda Botanical Garden, Samarinda, Indonesia. Their leaves and wood samples were identified as *Acacia mangium* Willd., *Aleurites moluccana* (L.) Willd., *Alstonia scholaris* (L.) R.Br., *Anthocephalus cadamba* (Roxb.) Miq., *Artocarpus altilis* (Parkinson) Fosberg, *Artocarpus elasticus* Reinw. ex Blume, *Cananga odorata* (Lam.) Hook. f. & T. Thomson, *Gmelina arborea* Roxb., *Lagerstroemia speciosa* (L.) Pers., *Leucaena leucocephala* (Lam.) de Wit, *Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg., *Macaranga tanarius* (L.) Mull.Arg., *Paraserianthes falcataria* (L.) Nielsen, *Shorea leprosula* Miq., and *Swietenia macrophylla* King (Figure 2) in the Laboratory of Forest Dendrology, Faculty of Forestry, Universitas Mulawarman, Samarinda, Indonesia. The wood samples were debarked, cutted, chipped and air dried up to approximately 12% moisture content (MC), and used throughout this study.

Alkaline pretreatment of woody biomass

Alkaline pretreatment of wood biomass was carried out for 60 min at 160ºC using a liquid-to-solid ratio 8:1 (w/w) and NaOH concentration between 3.5% and 5.0% based on dry weight of the woody biomass. The reactions were carried out using a rotary digester equipped with a controller for pressure, rotary speed and temperature. After the reaction, the pulp fraction was separated by filtration and washed extensively with tap water until neutral pH.

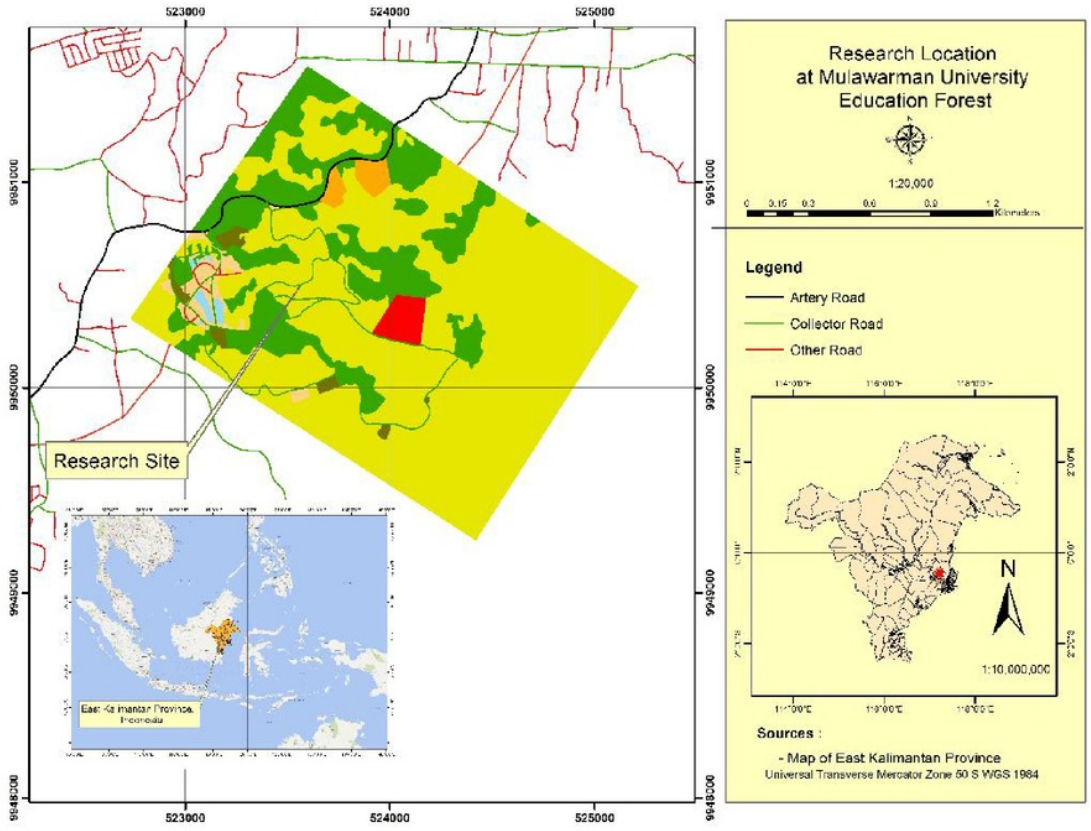

Figure 1. Sampling location at Samarinda Botanical Garden-Education Forest of Universitas Mulawarman, East Kalimantan, Indonesia

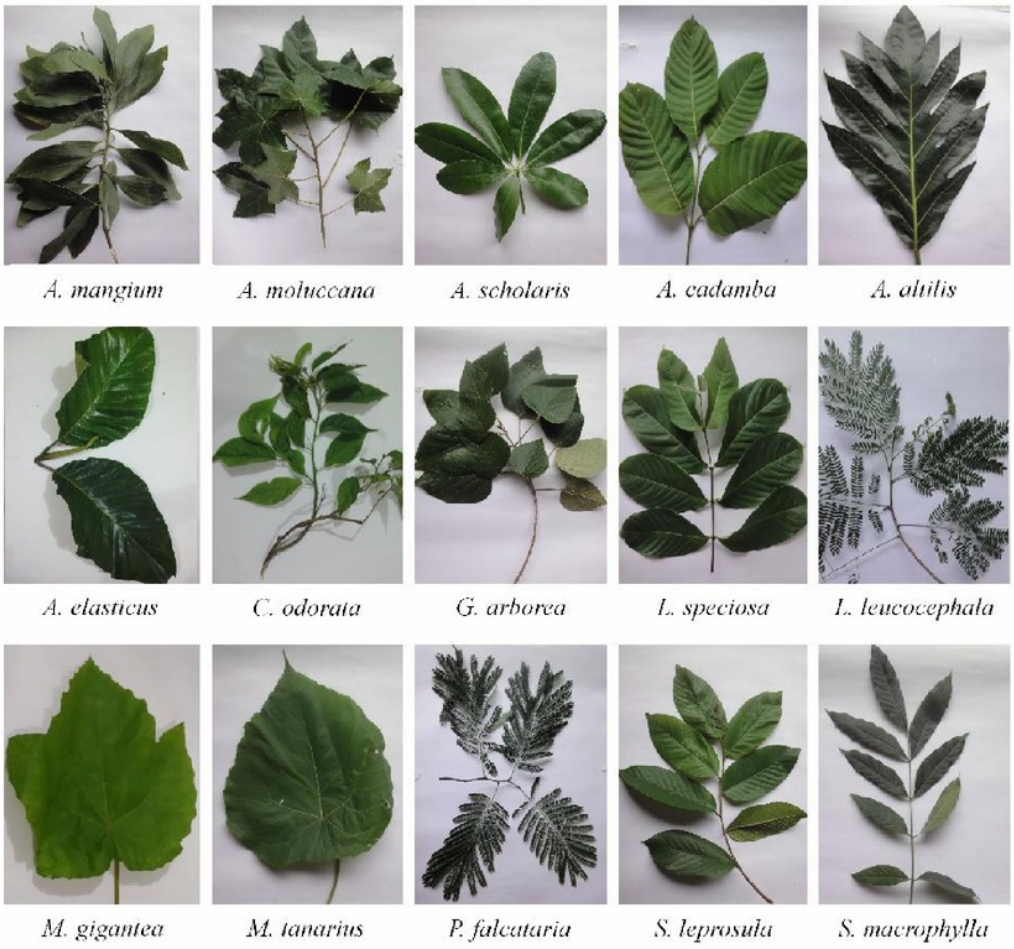

Figure 2. Leaves shape of fifteen species of tropical wood biomass studied

Wood component analysis

The Klason lignin content was determined by the TAPPI standard method (TAPPI 1998a). The holocellulose and α-cellulose contents were determined according to Wise's chlorite method (Wise et al. 1946) and the TAPPI standard method (TAPPI 1988b), respectively. The reducing sugar content was determined by the Somogyi–Nelson method (Somogyi 1952).

Enzyme activity

Filter paper unit activities were assayed in reaction mixture containing 50 mg (w/v) Whatman filter paper number 1, 50 mM tartrate buffer, pH 4.5 and the enzyme. After incubation at 50ºC for 30 min., the reducing sugars produced were determined by Somogyi-Nelson method (Somogyi 1952). One unit (U) of each enzyme activity is defined as the amount of enzyme, which produce 1 mol reducing sugar as glucose in the reaction mixture per minute under above specific condition.

Saccharification of wood biomass

The wet pulp fraction was hydrolyzed with a commercial cellulose preparation, meisellase from *Trichoderma viride* (Meiji Seika Co., Ltd., 224 filter paper units (FPU)/g, β-glucosidase activity 264 IU/g). The cellulase enzyme loading was an 8-FPU/g substrate. Enzymatic hydrolysis was performed at a substrate concentration of 2% in 0.05 M sodium citrate buffer (pH 4.5) containing 0.02% sodium azide at 45ºC on a rotary shaker (NTS-4000C, Rikakikai, Japan) at 140 rpm for 48 h (Itoh et al. 2003). The saccharification ratio per pulp was calculated according to the NREL LAP-009 procedure (Brown and Torget 1996). The sugar yield per wood is based on the weight percentage of the reducing sugars to the original wood. The overall yield of sugars per wood is calculated by multiplying the saccharification ratio per pulp and the pulp yield. All enzymatic hydrolysis experiments were performed in triplicate.

Estimation of ethanol production from woody biomass

Potential ethanol production from Macaranga wood was estimated based on the amount of hexose sugar (HXTEL) in the lignocellulosic material obtained by enzymatic saccharification of the insoluble pulp fraction. Due to the high content of glucose in the pulp fraction, HXTEL was approximated by the amount of reducing sugars obtained from the pulp fraction (equation 1). The ethanol yields (ETOHBIO) based on the weight of original biomass was calculated from equation (2)

$$HEXTEL = HEX \times a \quad (mg/kg) \quad \text{eq.1}$$

$$ETOHBIO = HXTEL \times Ye.h/b \quad (mL/kg) \quad \text{eq.2}$$

Where, HEX is the hexose (D-glucose) yield upon saccharification from hexosan (w/w, of original wood basis), a is the weight of substrate (1000 mg, 1kg), Ye.h is the theoretical ethanol yield from hexose (D-glucose) (0.511), and b is the ethanol density (0.789 kg/L) (modified from Premjet et al. 2013).

Estimation of dry wood biomass production

The potency of above ground tree dry biomass was estimated using allometric equations that previously reported by Hiratsuka et al. (2006). The equation was specifically developed to estimate the above ground tree dry biomass of Macaranga, particularly M. gigantea and M. hypoleuca. The equation is (equation 3):

$$M = 5.64 \times 10^{-2} (D)^{2.47}; \quad r^2 = 0.96 \quad \text{eq.3}$$

Where, M is the total aboveground dry mass of an individual tree (kg) and D is the trunk diameter at 1.3 m aboveground of the tree (cm).

RESULTS AND DISCUSSION

Lignocellulosic components of wood biomass

In this work we evaluated lignin, holocellulose, and also cellulose contents of wood biomass to point out their correlations to saccharification and estimated yield of ethanol. Among 15 species of wood biomass tested, we found that the highest lignin content was 31.97% from *A. elasticus* and followed by 31.07% (*S. leprosula*), 30.40% (*M. tanarius*), 29.32% (*L. leucocephala*), 29.22% (*L. speciosa*), and 28.15% (*S. mahagoni*) (Table 1). On the other hand, the lowest lignin content was obtained from *A. moluccana* (22.23%). Our finding also demonstrated that the highest cellulose content was 51.41% from *P. falcataria*, and followed by 49.88% from *A. scholaris,* 49.05% (*A. elasticus*), 47.54% (*L. leucocephala*), 46.95% (*S. leprosula*), 46.81% (*S. mahagoni*), 46.73% (*A. altilis*), and 46.67% (*M. gigantea*). These values were higher than several weed and wood biomass that previously reported (Premjet et al. 2013; Tye et al. 2016). We also found that *A. cadamba* was gave the highest hemicellulose content (31.86%) and followed by *A. moluccana* (30.60%), *S. mahagoni* (28.87%) and *G. arborea* (28.13%). The present results were also showed that the amounts of cellulose, and lignin were variable for the biomass species examined. In line with our findings, the previous papers reported that the diversity of biomass composition was dependent on the plant species, soil nutrients, climate and competition (McKendry 2001; Premjet et al. 2013).

Effects of alkaline pretreatment on lignocellulosic components of wood biomass

Effects of alkaline pretreatment on the change of wood components were also analyzed. We found the alkaline pretreatment was effectively defibrillated and delignified the woody biomass that marked by the residual pulp fractions and decreased of Klason lignin content (Table 2,3). In general discussion, we found two different types of the residual pulp fraction, hard fiber and soft fiber. The formation of residual pulp fraction was really dependent on the concentration of alkaline and also biomass species used (Table 2, Figure 3). The highest decrease of lignin content was obtained when 5.0% NaOH applied at 160ºC to gave the lowest residual lignin content at 1.81~6.19%, respectively (Table 3). Decrease of lignin during alkaline pretreatment correspond to the cleavage of hydrolysable linkages such as α-and β-aryl ethers in lignin and glycosidic bonds in carbohydrates constitute the primary reactions that lead to the dissolution of lignin and carbohydrate with lower alkali stability (Lai 1991; Wang et al. 2008). The removal of lignin is beneficial for enzymatic saccharification due to increased accessibility of hydrolases to cellulose and hemicelluloses and decrease in non-productive binding between lignin and the enzymes (Zhao et al. 2007; Taherzadeh and Karimi 2008; Kumar et al. 2009; Gupta and Lee 2010; Alvarez et al. 2013; Rahikainen et al. 2013; Bali et al. 2014; Amirta et al. 2016a; Jönsson and Martin 2016).

Figure 3. Pulp properties: A. Hard fiber (left); B. Soft fiber

Table 1. Lignocellulosic compositions of 15 species of tropical wood biomass (sound wood or original wood components)

Wood biomass (species and local name)		Lignin (%)	Holocellulose (%)	Cellulose (%)
Acacia mangium Willd.	Akasia	27.80 ± 0.38	64.37 ± 0.18	38.94 ± 0.41
Aleurites moluccana (L.) Willd.	Kemiri	22.23 ± 0.14	76.08 ± 0.06	45.48 ± 0.19
Alstonia scholaris (L.) R.Br.	Pulai	25.05 ± 0.17	70.05 ± 0.04	49.88 ± 0.05
Anthocephalus cadamba (Roxb.) Miq.	Jabon	24.92 ± 0.12	69.22 ± 0.06	37.36 ± 0.61
Artocarpus altilis (Parkinson) Fosberg	Sukun	26.87 ± 0.47	69.39 ± 0.33	46.73 ± 0.98
Artocarpus elasticus Reinw. ex Blume	Terap	31.97 ± 0.05	68.80 ± 0.06	49.05 ± 0.88
Cananga odorata (Lam.) Hook. f. & T. Thomson	Kenanga	24.40 ± 0.14	64.14 ± 0.25	43.05 ± 0.61
Gmelina arborea Roxb.	Gmelina	25.73 ± 0.14	71.30 ± 0.20	43.17 ± 0.50
Lagerstroemia speciosa (L.) Pers.	Bungur	29.22 ± 0.17	70.36 ± 0.03	43.22 ± 1.11
Leucaena leucocephala (Lam.) de Wit	Lamtoro	29.32 ± 0.78	68.90 ± 0.11	47.54 ± 0.68
Macaranga gigantea (Rchb.f. & Zoll.) Müll.Arg.	Mahang	24.14 ± 0.27	71.14 ± 0.42	46.67± 0.55
Macaranga tanarius (L.) Mull.Arg.	Mara	30.40 ± 0.28	69.32 ± 0.28	45.49 ± 0.12
Paraserianthes falcataria (L.) Nielsen	Sengon	23.82 ± 0.45	69.64 ± 0.03	51.41 ± 0.86
Shorea leprosula Miq.	Meranti	31.07 ± 0.19	68.89 ± 0.04	46.95 ± 0.73
Swietenia macrophylla King	Mahoni	28.15 ± 0.21	75.68 ± 0.20	46.81 ± 1.34

Table 2. Pulp yield and pulp properties of wood biomass pretreated with 3.5% and 5.0% NaOH at 160°C for 60 min

Wood biomass		3.5% NaOH		5.0% NaOH	
Species	Local name	Pulp (%)	Pulp Properties	Pulp (%)	Pulp Properties
A. mangium	Akasia	58.86	hard fiber	48.64	soft fiber
A. moluccana	Kemiri	57.60	soft fiber	52.76	soft fiber
A. scholaris	Pulai	56.81	soft fiber	54.34	soft fiber
A. cadamba	Jabon	50.38	soft fiber	46.58	soft fiber
A. altilis	Sukun	66.12	soft fiber	53.24	soft fiber
A. elasticus	Terap	66.23	hard fiber	53.94	soft fiber
C. odorata	Kenanga	56.15	soft fiber	34.29	soft fiber
G. arborea	Gmelina	65.71	soft fiber	53.53	soft fiber
L. speciosa	Bungur	57.49	hard fiber	44.78	soft fiber
L. leucocephala	Lamtoro	70.01	hard fiber	59.11	soft fiber
M. gigantea	Mahang	75.90	hard fiber	58.86	soft fiber
M. tanarius	Mara	69.61	soft fiber	63.00	soft fiber
P. falcataria	Sengon	61.61	soft fiber	49.02	soft fiber
S. leprosula	Meranti	57.99	hard fiber	44.87	soft fiber
S. macrophylla	Mahoni	59.00	hard fiber	49.82	soft fiber

Table 3. Residual lignin, holocellulose and cellulose of wood biomass pretreated with 3.5% and 5.0% NaOH at 160°C for 60 min

Wood biomass		Lignin (%)		Holocellulose (%)		Cellulose (%)	
Species	Local name	3.5% NaOH	5.0% NaOH	3.5% NaOH	5.0% NaOH	3.5% NaOH	5.0% NaOH
A. mangium	Akasia	6.39 ± 0.07	4.96 ± 0.02	47.03 ± 0.03	42.44 ± 0.06	35.73 ± 0.45	35.30 ± 0.02
A. moluccana	Kemiri	5.85 ± 0.07	2.51 ± 0.04	51.09 ± 0.44	50.20 ± 0.28	42. 95 ± 0.60	38.79 ± 0.98
A. scholaris	Pulai	6.51 ± 0.02	6.15 ± 0.01	43.77 ± 0.07	43.70 ± 0.23	38.95 ± 0.29	40.98 ± 0.66
A. cadamba	Jabon	4.34 ± 0.01	2.88 ± 0.06	45.62 ± 0.26	42.42 ± 0.30	35.29 ± 0.16	30.37 ± 0.05
A. altilis	Sukun	7.16 ± 0.08	4.97 ± 0.07	53.27 ± 0.22	47.61 ± 0.30	45.55 ± 0.23	41.86 ± 0.64
A. elasticus	Terap	10.82 ± 0.03	5.79 ± 0.01	50.86 ± 0.18	43.90 ± 0.36	43.71 ± 0.34	40.20 ± 0.11
C. odorata	Kenanga	5.29 ± 0.01	1.81 ± 0.01	47.40 ± 0.28	32.37 ± 0.06	39.61 ± 0.12	28.44 ± 0.85
G. arborea	Gmelina	6.97 ± 0.07	3.60 ± 0.02	52.40 ± 0.07	49.57 ± 0.26	41.20 ± 0.24	38.66 ± 0.25
L. speciosa	Bungur	5.78 ± 0.04	4.58 ± 0.01	46.03 ± 0.36	39.30 ± 0.06	38.65 ± 0.63	32.34 ± 0.06
L. leucocephala	Lamtoro	6.35 ± 0.08	5.97 ± 0.05	62.51 ± 0.54	52.59 ± 0.41	43.39 ± 0.13	41.94 ± 1.12
M. gigantea	Mahang	6.12 ± 0.09	6.17 ± 0.27	55.75 ± 0.52	53.52 ± 0.33	45.56 ± 0.22	44.43 ± 0.48
M. tanarius	Mara	7.74 ± 0.06	6.19 ± 0.03	56.52 ± 0.28	55.03 ± 0.01	49.65 ± 0.20	36.48 ± 0.39
P. falcataria	Sengon	5.98 ± 0.03	2.14 ± 0.09	53.39 ± 0.22	44.37 ± 0.32	47.71 ± 0.21	34.61 ± 0.28
S. leprosula	Meranti	6.68 ± 0.02	4.63 ± 0.03	46.55 ± 0.52	39.70 ± 0.23	43.55 ± 0.03	28.64 ± 0.13
S. macrophylla	Mahoni	8.98 ± 0.01	4.27 ± 0.04	48.11 ± 0.03	45.26 ± 0.60	41.48 ± 0.15	33.48 ± 0.34

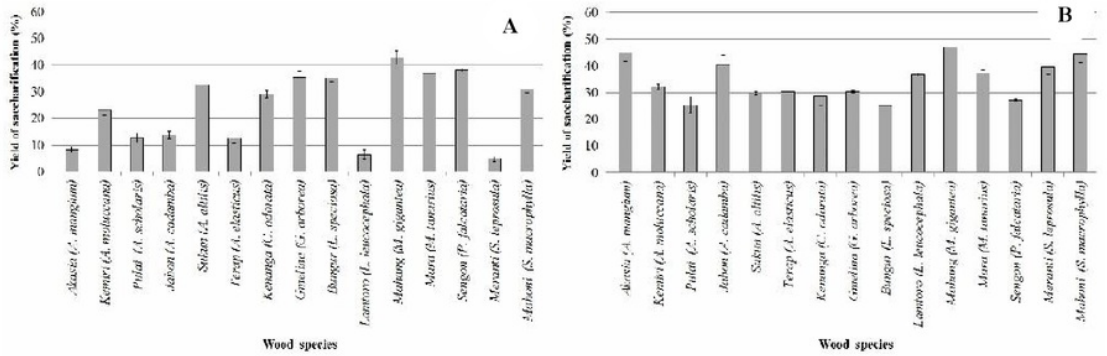

Figure 4. Yield of saccharification of tropical wood biomass pretreated with alkaline (original wood basis): A. 3.5% NaOH and B. 5.0% NaOH

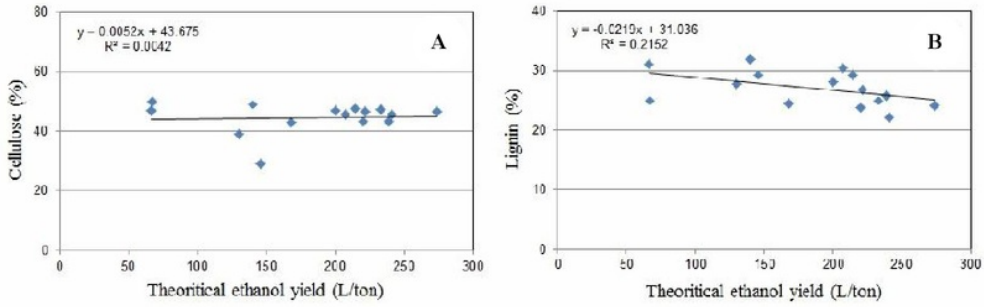

Figure 5. Correlation between: A. Cellulose and theoretical yield of ethanol, B. Lignin and theoretical yield of ethanol pretreated with 5.0% NaOH

Table 4. Saccharification yield of wood biomass pretreated with 3.5% and 5.0% NaOH at 160°C for 60 min

Wood biomass		Pulp saccharification (w/w, pulp basis)	
Species	**Local name**	**3.5% NaOH**	**5.0% NaOH**
A. mangium	Akasia	13.58 ± 1.84	45.87 ± 6.01
A. moluccana	Kemiri	42.95 ± 1.98	78.29 ± 1.07
A. scholaris	Pulai	10.39 ± 3.07	21.13 ± 3.10
A. cadamba	Jabon	68.30 ± 7.05	85.67 ± 3.59
A. altilis	Sukun	27.36 ± 4.07	71.42 ± 0.51
A. elasticus	Terap	10.49 ± 2.20	44.46 ± 0.09
C. odorata	Kenanga	59.07 ± 1.46	84.05 ± 3.68
G. arborea	Gmelina	40.78 ± 2.50	76.58 ± 0.33
L. speciosa	Bungur	35.00 ± 1.36	55.92 ± 0.23
L. leucocephala	Lamtoro	26.62 ± 3.04	62.15 ± 0.17
M. gigantea	Mahang	26.84 ± 2.58	79.70 ± 5.48
M. tanarius	Mara	23.48 ± 4.63	56.48 ± 0.91
P. falcataria	Sengon	47.33 ± 0.59	77.11 ± 0.37
S. leprosula	Meranti	10.16 ± 1.67	25.21 ± 2.62
S. macrophylla	Mahoni	42.66 ± 1.34	68.90 ± 3.05

Enzymatic saccharification of wood biomass

In order to evaluate the effective alkaline pretreatment on sugar production, enzymatic saccharification of wood biomass was studied. The effects of alkaline pretreatment on enzymatic saccharification was analyzed at two different concentrations of NaOH, 3.5% and 5.0% at 160°C for 60 min using a commercial cellulase from *T. viride*, Meicelase (Fig. 4). General trend for promotion of sugar yield by higher concentration of NaOH with the decreased amount of remaining lignin was found (Fig. 4 and Table 4), in accordance with the previous report (Taherzadeh and Karimi 2008; Wang 2008; Zhao et al. 2007; Mirahmadi et al. 2010; Chiaramonti et al. 2012; Sing and Trivedi 2013; Amirta et al. 2016a), who described that the hydrolisability of treated hardwood increased with decrease in lignin content. The alkaline pretreatment was effectively facilitated enzyme to digested tropical rain forest wood biomass to produce reducing sugar. The results also demonstrated that increase in the NaOH concentration from 3.5% to 5.0% increased the sugar yield by 8.24% (*A. mangium*), 10.63% (*A. moluccana*), 5.02% (*A. scholaris*), 4.96% (*A. cadamba*), 17.94% (*A. altilis*), 15.93% (*A. elasticus*), 12.78% (*G. arborea*), 4.43% (*L. speciosa*), 16.29% (*L. leucocephala*), 23.89% (*M. gigantea*), 17.31% (*M. tanarius*), 7.78% (*P. falcataria*), and 4.88% (*S. leprosula*). On the contrary, sugar yield of *C. odorata* with 3.5% NaOH was higher (29.85%) than the pretreatment

with 5.0% NaOH to gave the sugar yield only 25.94%. Among the fifteen species of tropical wood biomass tested, our finding showed that five species of wood biomass such as *M. gigantea*, *A. moluccana*, *G. arborea*, *A. cadamba*, and *A. altilis* were gave more than 35% of sugar yield based on the original weight of wood used. The highest sugar yield, 42.22% (weight of original wood basis) was obtained for *M. gigantea* at the alkaline concentration 5.0% NaOH and followed by *A. moluccana* (37.18%), *G. arborea* (36.89%), *A. cadamba* (35.91%) and *A. altilis* (34.22%).

Theoretical ethanol production from wood biomass

In this study, we found that the lowest theoretical yield of ethanol was from *S. leprosula* (66 L/ton) and *A. scholaris* (67 L/ton). On the other hand, the highest theoretical ethanol yield was from *M. gigantea* (273 L/ton) and followed by *A. moluccana* (241 L/ton), *G. arborea* (239 L/ton), *A. cadamba* (233 L/ton), *A. altilis* (222 L/ton) and *P. falcataria* (220 L/ton). The higher theoretical yield of ethanol was obtained from the biomass with the lower lignin content (22.23%~25.73%) and the high cellulose content (43.17%~47.36%), respectively. There have been correlations between lignin, cellulose and yield of ethanol (Fig. 5). Similar with results that we mentioned earlier, general trend for higher theoretical yield of ethanol by higher cellulose content and lower Klason lignin were also found. This finding was in line with the previous results reported (McKendry 2001; Premjet et al. 2013; Amirta et al. 2016a). *M. gigantea, A. moluccana, G. arborea, A. cadamba,* and *P. falcataria* are attractive for their high conversion efficiency and susceptibility to the pretreatment.

Availability of wood biomass

Sustainable feedstock availability is one of the important factors that should be considered on the idea to utilize wood biomass for ethanol production in the near future. In term of that in this study, availability of *A. moluccana, G. arborea, A. cadamba, P. falcataria,* and *M. gigantea,* that are attractive for their high conversion efficiency and susceptibility to the pretreatment and produced high saccharified sugar and ethanol yield were also discussed. In general practices we knew *G. arborea, A. cadamba,* and *P. falcataria,* were planted for the mass production of wood for the construction purposes and also pulp and fiber production in the scheme of industrial forest plantation and also community forest development programs in Indonesia, including in East Kalimantan. In addition, *A. moluccana*, was traditionally planted for the production of candle nut since thousands years ago. The waste of wood biomass that annually obtained from the thinning and harvesting activities of the industrial forest industry and unproductive and mature cutting stem waste of *A. moluccana* for replanting purposes are potential feedstock that can be used for ethanol production. The wood biomass feedstock could also obtain by putting the additional sharing portion (quota) of forest plantation and wood production for ethanol as well as regulated for CPO (crude palm oil) production. Nowadays, CPO production was not only utilized for the domestic cooking oil production and exported to foreign countries. The new regulation released by the Indonesia Government and also the East Kalimantan Province was clearly stated that 20% of total CPO production should be provided and shared for domestic feedstocks for biodiesel production purposes. In term of this, more than 500,000 cubic meters of wood biomass will be available annually (Table 5) and number of feedstock potentially increased due to development target of the East Kalimantan Government to have more than two millions hectares of plantation forest in 2016 (East Kalimantan Planning Agency-BAPPEDA 2015). The source of plantation forest developed was not only belongs of the private companies but also owned by communities (community forest).

Fast growing ability and productivity of *M. gigantea*

Different then *G. arborea, A. cadamba, P. falcataria* and *A. moluccana,* the pioneer wood species *M. gigantea* was not commercially planted yet. The tropical fast growing species *M. gigantea* was reported growth dominantly on the secondary forest of Kalimantan (Borneo Island). *M. gigantea* was commonly used for natural indicator on succession process of secondary forest in this area (Slik et al. 2003, 2005). Our result also demonstrated growth of pioneer species was very fast to rise of plant diameter approximately 3-6 cm annually (Fig. 6 and Table 6). Based on the data of plant growth collected from the trial planting plot of *M. gigantea* located at Universitas Mulawarman Education Forest, we estimated the production of dry weight wood biomass were 1,297 kg ha^{-1} (1st year), 17,154 kg ha^{-1} (2nd years) and 26,119 kg ha^{-1} (3rd years), respectively (Table 6). The high yield production of dry wood biomass was very promising for sustainable ethanol feedstock in the near future.

Table 5. Biomass production from Industrial Forest Plantation in East Kalimantan FY 2014

Wood species	Wood production (m^3)	Harvesting waste		20% Sharing production quota (m^3)
		%*	m^3	
A. mangium	1,971,292.22	4.39	86,539.73	394,258.44
E. pelita	200,193.69	2.64	5,285.11	40,038.74
G. arborea	95,281.77	3.50	3,334.86	19,056.35
P. falcataria	26,167.77	3.50	915.87	5,233.55
	2,292,935.45		**96,075.58**	**458,587.09**

Note: *Waste biomass from harvesting activity of industrial forest plantation in East Kalimantan (Syahrinudin 2014)

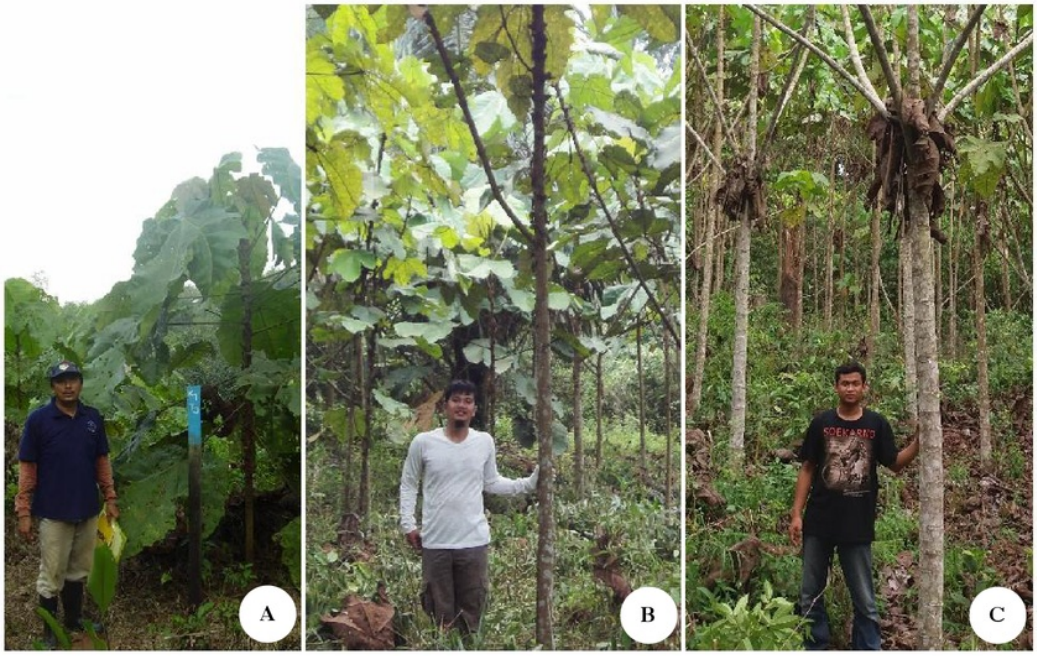

Figure 6. Description of fast growing ability of *M. gigantea*. A. 1st year, B. 2nd year, C. 3rd year

Table 6. Growth of diameter, high and biomass production of *M. gigantea* for 3 years of plantation

Growth indicators	1st year	2nd years	3rd years
Plant density (g/cm^3)	-	0.30 ± 0.05	0.33 ± 0.07
Plant diameter (cm)	3.41 ± 0.53	9.70 ± 0.25	11.50 ± 2.10
Plant high (m)	1.76 ± 0.34	7.51 ± 1.60	9.00 ± 1.70
Plant Biomass (kg ha^{-1} dry wood)	1,297	17,154	26,119

The present study gives a new role in the *M. gigantea,* and other secondary forest wood species as a resource for ethanol production (bio refinery). Design of the sustainable cycle including forest plantation of the *Macaranga* and other wood species, and their conversion into fuels and chemicals will activate the local economy in the tropics with concomitant contribution to the global environment. This is an essential point because of those woody materials were not be considered as potential biomass feedstock for the biofuel production as far, except for *P. falcataria, G. arborea* and *A. cadamba* which are planted in forest plantation for years in Indonesia especially in East Kalimantan. Nowadays, *A. moluccana* and *A. altilis* and *A. elasticus* are daily used by rural people in East Kalimantan for tree fruit (candle nut, bread fruit and keledang fruit). *M. gigantea* and *M. tanarius* have been used as firewood species by local people in East and North Kalimantan Provinces, instead of the higher density wood species such as *Vitex pinnata, Nephelium lappaceum, Blumeodendron kurzii* and *Dipterocarpus* sp. (Yuliansyah et al. 2012). Furthermore, the dried root and fresh leaves of *Macaranga* was also used to cover wounds to prevent inflammation, as an emetic agent, antipyretic, antioxidant and antitussive in Thailand and Malaysia (Chulaborn et al. 2002; Lim et al. 2009). The bioactive compound of *M. tanarius* was also reported effective to be used as an antidiabetic (Puteri and Kawabata 2010). Instead of firewood and medicine, since many years ago *Macaranga* was traditionally used by Dayak people in East Kalimantan as the natural plant indicator to determine the end of the recovery period of forest land after ground fire or shifting cultivation activities.

The tropical wood biomass particularly *M. gigantea, A. moluccana*, *G. arborea*, *A. cadamba* and *P. falcataria*, are attractive for their fast growth ability, availability, chemical composition and also conversion process. These wood species are promising and potentially to be used and developed widely as suitable feedstocks for ethanol production, chemical and also other bio refinery purposes in the near future. Further investigation required to explore and find more attractive conversion system for the tropical wood biomass plant species that abundance in the rain forest area of East Kalimantan, Indonesia.

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