

Review on Bamboo Utilization as Biocomposites, Pulp and Bioenergy

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Abstract. One of potential non wood bioresources utilized in industrial application is bamboos. Bamboos are include in gramineae family which have high biomass productivity, easy and rapid production, wide availability and high holocellulose content. Indonesia has a huge potential of bamboos, more than 162 bamboo species are found however only some of them are planted that have a high economic value. Bamboos have some advantages such as can be harvested at 3 years, straight culm, high strength, easy to be processed, and relatively cheap. Research Center for Biomaterials has developed utilization of bamboo culm for ply bamboo product as alternative of plywood since 1995, using gombong bamboo, tali bamboo, sembilang bamboo, andong bamboo with PF resin as adhesive. Other biocomposite products from bamboos include particle board, cement board and polymer-bamboo fiber composites. In term of processing technique and final product quality, bamboo composites from ply bamboo are the most prospectable material to be utilized in industrial application. Yellow bamboo and betung bamboo have also been developed as pulp and paper. Biopulping using soda and kraft pulping after biological pretreatment using white rot fungi to remove lignin was used as pulping method in this conversion. Biokraft pulping with *Trametes versicolor* for 45 days with inoculum loading of 10% resulted better pulp quality compared to the other fungi. Betung bamboo had good morphological characteristics and chemical component content to be converted into bioenergy such as bioethanol. Several pretreatment methods have been developed in order to result high sugar yield. Microwave assisted acid hydrolysis was preferred in producing higher yield from the pretreated bamboo compared to enzymatic hydrolysis. By using this method, the bamboo pretreated by biological-microwave pretreatment results higher improvement to increase sugar yield.

1. Introduction

Among various non-wood lignocellulosic bioresources, bamboo has attracted many researchers attention. Bamboos has high biomass productivity, easy and readily to grow in many various land types, wide availability and high holocellulose content. Indonesia has a huge potential of bamboos, more than 162 bamboo species were found [1]. However only some are planted that have a high economic value. Bamboos have some advantages such as can be harvested at 3 years, straight culms, high strength, easy to be processed, and relatively cheap. Bamboos can be found good growing in Asia including Indonesia, in which Bamboo plantations in Indonesia, India and China include as first, second and third rank [2].

Bamboos can be utilized into many purposes such as reinforced fiber, composites, pulp and paper, lactic acid, methane, construction, textile, food, bioenergy [3]. Bamboos for traditional utilization such as construction and composites, all bamboo culms can be utilized without discarding certain bamboo parts. In advanced utilization of bamboos such



bamboo for bioenergy, pulp and paper, and wood plastic composites, chemical component (cellulose, hemicellulose and lignin) of biomass must be removed by pretreatment process. In this case, lignin can become major inhibitor in the conversion process. Even though, all bamboo species can be converted into derived materials, there are variation in their basic properties. Evaluation on its basic properties can be done before further utilization. In advance utilization, the effectivity of pretreatment was affected by bamboo's properties and also the chosen pretreatment method. Many development processes have been reported in bamboo utilization for composites, pulp and bioenergy, and Research Center for Biomaterials LIPI also contributed in this area by conducting some research improvement continuously. This development give possibility in utilization of derived materials from bamboos to be applied in industrial scale. It is in line with growing researcher interest in the world to utilize bamboo optimally. This paper was intended to review some research results on bamboos that have been carried out in RC Biomaterials LIPI especially for biocomposites, pulp and sugar production as material for bioethanol. By this study, it might become an effective media for technology transferring or open mutual research collaboration with other institutions.

2. Utilization of Bamboo for Production of Biocomposites, Pulp and Bioenergy

2.1 Bamboo as Raw Material for Composite Products

Bamboo culms have been processed to produce plies, particles or bamboo pulp then used in composite products. Those treatments were intended to obtain the optimal utilization of bamboos.

2.1.1 Ply Bamboo Board

Utilization of bamboo culms for ply bamboo product can be used as an alternative of plywood [4]. Research on ply bamboo made from Talibamboo and Gombong bamboo using phenol formaldehyde (PF) resin has been conducted [5-6]. In 2016, Subyakto et al [7] investigated characteristics of ply bamboo board from Sembilang bamboo and Andong bamboo using PF resin as adhesive.

Sudijono et al. [5] has produced ply bamboo board using Tali bamboo (*Gigantochloa apus*) and PF resin at glue spread variation of 400, 450 and 500 g/m². Bamboos were cut to 600 mm (face/back) and 400 mm (core) and soaked in water for 30 days to remove starch content. Then, they were split into 2-3 parts and crushed using bamboo crusher machine to produce zephyr bamboo. Outer and inner parts of zephyr bamboo were sanded to remove bamboo bark about 2-3 mm, resulted in thickness of 4 mm (for face and back) and 7 mm (for core). Zephyr bamboos were dried in dry kiln to reach moisture content of about 7-8 %. Dry zephyr bamboos were mixed with PF resin at the amount of 400, 450 and 500 g/m² and hand formed to make 3 layer mat with the core layer oriented perpendicularly. The mat was cold press for 10 min at 10 kg/cm² then hot press at 160°C for 15 min at 10 kg/cm² to produce 15 x 400 x 600 mm board. After conditioning for 2 weeks, the boards were tested for bending, shear strength and thickness swelling in accordance with Japanese Agricultural Standard (JAS) No 516-1992: Structural plywood.

Tali bamboo zephyr (ply) board with the amount of PF resin of 450 g/m² gave the best properties [5]. The mechanical properties of bamboo zephyr (ply) board were as follow: MOE = 127.000 kg/cm² or 12.45 GPa, MOR = 791 kg/cm² or 77.57 MPa. In addition, delamination testing showed that at dry test, shear strength was 23.84 kg/cm², while at steam treatment test, the shear strength was 15.86 kg/cm² and at cycle boiling test, shear strength was 12.66 kg/cm². The thickness swelling of bamboo zephyr (ply)

board was 12.3% demonstrated that Tali bamboo zephyr (ply) board was good enough for outdoor application.

Gopar and Subyakto [6] produced zephyr board made from Gombong bamboo bonded with urea formaldehyde (UF) or PF. Gombong bamboo has relatively big diameter, tall and thick wall. Bamboos were split, crushed and planned into ply bamboo with 7 mm thickness. Those bamboos were planned to remove inner barks, while the outer barks were remained. The resin content was applied to about 17% based on oven dry weight of the ply bamboos. Mat of ply bamboo and resin was hot pressed at temperature of 160°C for PF and 140°C for UF. Pressing time was 20 minutes with three steps of pressing schedule; 5 min at pressure of 30 kgf/cm², 5 min at pressure of 10 kgf/cm² and then 10 min at pressure of 7.5 kgf/cm². The target of board density was 0.75 g/cm³. The boards were tested in accordance with the Japanese Agricultural Standard (JAS) No 516, 1992: Structural Plywood.

Gopar and Subyakto [6] reported that the thickness swelling of the ply bamboo boards which inner and outer barks were removed, and bonded with UF or PF were 6.55% and 11.818% respectively. While the water absorption values were 39.48% and 34.61%. The shear strength, MOR and screw withdrawal of ply bamboo board bonded with PF were higher than that of ply bamboo bonded with UF. The shear strength, MOR and screw withdrawal of ply bamboo bonded with PF were 13.24 kgf/cm², 686.82 kgf/cm² and 799.47 kgf, respectively. While the shear strength, MOR and screw withdrawal of ply bamboo bonded with UF were 11.18 kgf/cm², 436.13 kgf/cm² and 184.00 kgf, respectively. The shear strength and MOR of ply bamboo board were higher than minimal values in JAS standard, which were 10 kgf/cm² for shear strength and 240 kgf/cm² for MOR. It proved that ply bamboo board from Gombong bamboo bonded with UF or PF had fulfilled the requirement for structural application.

Considering the results of Sudijono et al [5] and Gopar-Subyakto [6], we can conclude that the physical and mechanical properties of plybamboo boards were affected by bamboo species and the type of resin used in plybamboo board production.

2.1.2 Bamboo Particle Board

Kusumaningrum et al. [8] employed Betung bamboo (*Dendrocalamus asper*) to produce bamboo particle board. Bamboo culm was cut, splitted and crushed, then processed in hammer mill to produce bamboo particles. Screening was conducted to obtain bamboo particles which were passed a 10-mesh screen and remained on 10-mesh screen. Bamboo particles were air-dried until the moisture content reached about 8%. Two types of adhesives were used i.e UF (produced by PT Palmolite Adhesive Industry, West Java, Indonesia) and isocyanate (produced by PT Polychemia Asia Pacific Permai, Jakarta, Indonesia). Board dimension was 25 x 25 x 1 cm with target density of 0.6 g/cm³. The adhesive content used was 10% based on particle dry weight. Bamboo particles were sprayed with UF or isocyanate in drum mixer using spray gun. Then they were put in forming box, hand pressed and hot pressed for 10 minutes at pressure at 20 kgf/cm² and at degree at 140°C for UF and 150°C for isocyanate. The particle boards were conditioned at room temperature for 14 days prior to physical and mechanical testing in accordance with JIS A 5908-2003.

Kusumaningrum [8] also reported that the moisture content of bamboo particle board bonded with UF or isocyanate was 8% and it fulfilled the requirement of JIS. The physical properties of bamboo particle board indicated that thickness swelling after 24 hours water soaking was 25.96% for bamboo particle board bonded with UF and 19.58% for bamboo particle board bonded with isocyanate. The MOE value of bamboo particle board bonded with UF or isocyanate was 1119.17 N/mm² and 2173.79 N/mm², respectively. The MOR values of bamboo particle board bonded with UF or isocyanate

were 12.24 N/mm² and 13.44 N/mm², respectively. The internal bond values of bamboo particle board bonded with urea formaldehyde or isocyanate were 0.57 N/mm² and 0.65 N/mm². The screw withdrawal values of bamboo particleboard bonded with urea formaldehyde or isocyanate were 437.99 N and 364.08 N.

Besides using formaldehyde based adhesive, bamboo particles had been used to produce particleboard using natural adhesive, such as citric acid [9]. Three bamboo species particles, i.e. Petung (*D. asper*) bamboo, Wulung bamboo (*G. atrovioleacea*), and Apus bamboo (*G. apus*) were used in Widyorini et al [9] study. Bamboo particles were screened passing through a ten mesh (fine materials). All of the particles were then air-dried to a moisture content of around 12 %. Citric acid (anhydrous) was used without further purification. Citric acid was dissolved in water to a solution concentration of 59–60 wt.%. The solution was used as adhesive and sprayed onto each bamboo species particle at 0%, 15% and 30 wt.% resin content based on the weight of the dried particles. The sprayed particles were then oven dried over night at 80°C to reduce moisture content. The moisture content of the mat was 4–6 %. The particles were hand-formed into a mat by using forming box, followed by hot pressing into particleboard. The boards were pressed at 180°C for 10 min at a pressure of 3 MPa.

Apus bamboo particles bonded with 30% citric acid produced particleboard with the best thickness swelling value (2%) and water absorption (12%), compared to Petung bamboo and Wulung bamboo(Widyorini et al [9]). The physical properties of bamboo particleboards is presented in Table 1. It indicates that Apus bamboo produced particleboard which is more durable when exposed outdoor, compared to Petung and Wulung bamboo.

Table 1. Physical properties of bamboo particleboard with variation of citric acid content

Raw Material	Water Absorption (%)			Thickness Swelling (%)		
	0 wt%	15 wt%	30 wt%	0 wt%	15 wt%	30 wt%
Petung	98	35	15	35	9	4
Wulung	70	17	13	28	7	3
Apus	85	16	12	45	7	2

Sources: Widyorini et al. [9]

Widyorini et al. [9] reported that modulus of rupture of Apus bamboo particle board was the the highest compared to Petung bamboo or Wulung bamboo particle boards, when bonded with 30 wt% citric acid, which reached 15 MPa. On the other hand, modulus of elasticity of Petung bamboo particle board was the highest, when bonded with 30 wt% citric acid, which was 4.1 GPa. Furthermore, Petung bamboo with 30 wt% citric acid was also produced particle board with highest internal bond (0.53 MPa). Although Widyorini declared that different holocellulose content of three bamboo species had almost no effect on mechanical properties of the particle boards, we assume that mechanical properties of particleboard areaaffected by hemicellulose content of bamboos. The hemicellulose content in Petung bamboo and Apus bamboo was 29.58% and 30.27%, respectively. While hemicellulose content in Wulung bamboo was only 24.08%. On the other hand, cellulose and lignin content of those three bamboo species were almost not different [9].

2.1.3. Bamboo Cement Board

Bamboo particles has been also used as cement board. Bakri [10] manufactured cement board from three different species which were Parring bamboo (*Gigantochloa atter*), Betung bamboo (*Dendrocalamus asper*), and Tallang bamboo (*Schizostachyium brachycladum*). The ratio of bamboo particles, Portland cement and water was 1 : 2.5 : 1.25. Density of the cement board was targeted at 1 g/cm³ and thickness was 1 cm. Finer bamboo particles which passed a 10-mesh screen and remained on 20-mesh screen were used for face and back layers. In other hand, coarser bamboo particles which passed a 10-mesh screen and remained on 20-mesh screen were used for core layer in cement board. Particle size ratio of face : core : back was 15% : 70 % : 15 %. Bamboo particles were immersed in water for 48 hours to remove the extractives and dried in room temperature until moisture content of 30%. Bamboo particles, Portland cement and water were stirred until homogenous mixture obtained. Mixture poured into iron plate of 25 cm x 25 cm x 1 cm was covered by plastic sheet and pressed for 24 hours to form cement board. It was converted to solid cement board after setting time completed. Injection of CO₂ in liquid phase into the cement board carried out for curing for 30 minutes. Sample of cement board was put into injection tube and CO₂ was flowed into the injection tube. Liquid phase of CO₂ can reached by setting the tube temperature at 15° C and tube pressure at 50 kg/cm² for 30 minutes. Cement board was removed from the tube and put into desiccator for 15 minutes. Cement board was weighed and put into oven for the next curing at 80° C for 10 hours. Samples of cement board were tested for physical and mechanical properties according to Japanese Industrial Standard (JIS) A JIS A 5417:1992. These properties of bamboo cement board were summarized in Table 2.

Table 2. Physical and mechanical properties of cement board

Raw Material	Physical Properties		Mechanical Properties		
	TS (%)	WA (%)	MOE (kg/cm ²)	MOR (kg/cm ²)	IB (kg/cm ²)
Schizostachyium brachycladum	0.87	49.20	5030	79.59	0.74
Gigantochloa atter	0.65	45.11	2339	49.75	0.41
Dendrocalamus asper	1.35	57.60	1339	40.12	0.18

Sources: Bakri [10]

2.1.4 Composite of polypropylene or polylactic acid and bamboo micro fibers (BMF)

Besides using resin as adhesive to produce bamboo composite, polymer has also been used as matrix in polymer and bamboo composite. In polymer composites, bamboo should be processed mechanically into powder or chemically to obtain pulp or cellulose fibers before blended with polymer. Some polymers such as polypropylene and polylactic acid have been employed as matrix in Betung bamboo (*Dendrocalamus asper*) pulp.

Production of bamboo micro fibers

Fibers of bamboo were processed into pulp as follow. Fresh Betung bamboos were cut into 1 m length, debarked and split into two parts. Bamboo parts were processed with bamboo crusher for 10 times, and then cut into about 5 cm length. Fibers of bamboo at amount of 250 g (oven dried/DW) were cooked in NaOH 2.5% (1 part of fiber soaked in 10 part of solution) for 2 hours. Pulp were separated from the cooking liquid and washed until free alkaline. Pulps then were processed using beater Hollander for 90 minutes. The pulp grinding was continued using stone grinder for 5 times. The pulp was stored in a freezer before use. The morphological characteristics by Scanning Electron Microscope (SEM) was observed to the pulp before and after stone grinder treatment.

Production of PP/bamboo micro fibers

Ratios of bamboo fibers / PP (polypropylene) were 30/70, 40/60, and 50/50. Composites of fiber/PP were prepared by mixing of dry pulp with polymer. Dry pulp was prepared by filtering and drying wet pulp in an oven at temperature of 60°C for 24 hours. Dry pulp was tear into small pieces about 1 cm by 1 cm and mixed with PP in a Laboplastomill at temperature of 175°C, 60 rpm for 20 minutes. Maleic anhydride modified PP (MAPP) at the amount of 5% was added when fiber/PP was mixed. Compound then was hot pressed at temperature of 180°C, pressure of 1 MPa for 30 seconds. Immediately compound was taken and cold pressed at pressure of 1 MPa for 5 minutes. And finished sample was taken.

Production of PLA/bamboo micro fibers

Ratios of bamboo fibers/PLA (poly lactic acid) were 30/70, 40/60, and 50/50. Composite of fiber/PLA was prepared by soaking PLA in dichloromethane, and then wet pulp were added and mixed until homogenous. Triacetin as plasticizer at the amount of 7% was added when mixing fiber/PLA. This compound was oven dried at temperature of 60°C for 6 hours. Dry compound was processed in a Laboplastomill at temperature of 170°C, 60 rpm for 20 minutes. Further process was similar to that of fiber/PP composite (hot pressing and cold pressing).

Size of bamboo fibers/PP or bamboo fiber/PLA composites was 150 mm by 50 mm by 3 mm, with target density of 1.0 g/cm³ for fiber/PP composite and 1.3 g/cm³ for fiber/PLA composite. Composites were conditioned at room temperature for 3 days and tested for mechanical properties using Universal Testing Machine (UTM). The span was 100 mm and crosshead speed of test was 50 mm/min.

Mechanical properties of bamboo fibers/PP or bamboo fibers/PLA

The research of bamboo fibers and polypropylene composite has been conducted by Subyakto et al [11]. SEM observation was done for bamboo fibers prior and after stone grinding process. The average diameter size of fibers is less than 10 µm, and classified as micro fiber. The mechanical properties of bamboo fiber/PP composite and bamboo fiber/PLA composite were presented in Table 3. Micro fibers of bamboo as reinforcement of PP or PLA composites yielded in higher mechanical properties compared to those of pure PP or PLA.

Table 3. Mechanical properties of bamboo fiber /PP or PLA composites

Ratio Bamboo fibers / PP or PLA	Bamboo fiber / PP composite		Bamboo fiber / PLA composite	
	MOR (MPa)	MOE (GPa)	MOR (MPa)	MOE (GPa)
PP	27.52	1.18	-	-
PLA	-	-	70.36	3.17
30/70	52.36	2.80	100.83	6.15
40/60	47.52	2.78	105.23	7.06
50/50	47.71	3.25	73.31	6.11

Souces: Subyakto et al. [11]

Subyakto et al. [11] reported that bamboo fiber/PP composites with ratio of 30/70 and 5% MAPP showed the highest MOR (52.36 MPa). While the highest MOE values (3.25 GPa) was resulted from bamboo fibers/PP composite with ratio of 50/50 and 5% MAPP. This result is slightly different from the result that reported by Okubo et al. [12]

who found that the optimum ratio of bamboo fiber/PP was 50/50 with 5% MAPP. While bamboo fiber/PP composites with ratio of 40/60, Okubo [12] obtained tensile strength of 30.3 MPa and Young's modulus of 3.66 GPa.

Composites of bamboo fibers/PLA have higher mechanical properties compared to those of fibers/PP. This might be caused by the difference in density. Composites of fibers/PLA have higher density (1.3 g/cm^3) compared to those of fibers/PP (1.0 g/cm^3). Composites of bamboo fiber/PLA have higher flexural strength compared to those of bamboo fiber/PP composites. MOR ranged 73.31 – 105.23 MPa and MOE was at range of 6.11 – 7.05 GPa. Lee et al. [13] found that bamboo fiber/PLA composites with ratio of 30/70 and added 5% MAPP have tensile strength of 35 MPa and Young's modulus of 2.72 GPa. They observed that increase of fiber ratio decreased tensile strength but Young's modulus was since in versa.

2.2 Bamboo for Pulp Production

2.2.1 Determination of the most suitable bamboo species

As reported by Fatriasari and Hermiati [14], 2 year old of six commercial bamboo species from Gunung Sindur Bogor, Indonesia were observed the morphological, physical-chemical properties for determining their potency as pulp and paper raw material. They were Andong bamboo (*Gigantochloa verticillata* (Wild) Munro), Tali/apus bamboo (*Gigantochloa apus* (Bl.ex Schult.f.) Kurz), Hitam bamboo (*Gigantochloa nigrocillata* Kurz.), Ampel bamboo (*Bambusa vulgaris*), Betung bamboo (*Dendrocalamus asper* (Schult.f.) Backer ex Heyne) and Kuning bamboo (*Bambusa vulgaris* Schard var. *vitata*). To determine the fiber dimension including fiber length, fiber diameter, lumen diameter, and cell wall thickness, the bamboo chips were mercerized using schultze method. The fiber derived values (runkell ratio, felting power, muhlsteph ratio, coefficient of rigidity, flexibility ratio) were also calculated from its fiber dimension. Physical properties including specific gravity and colour of bamboo were observed. Chemical properties of bamboo including ethanol-benzene solubility (ASTM D 1107-56, Reapproved 1995), hot and cold water solubility (ASTM D-1110-84, Reapproved 1995), 1 % NaOH solubility (ASTM D1190-84, Reapproved 1995), lignin content (klason method), holocellulose (wise method), ash content (TAPPI T 211 cm-86) and silica content (TAPPI T 245 om-94) were also measured. Rank system in all parameter (the highest and lowest value of 6 and 1, respectively) was used to determine the highest total value identified as the most potential bamboo species for raw material pulp and paper.

Based on this analysis, six bamboo species can be categorized as long fiber (up to 2 mm) including in quality class I based on criteria of LPHH requirement for pulp and paper with high holocellulose content and medium lignin content [14]. Long fibers can serve to create a good interfiber bonding, facilitate the pulp washing easily. They also affected on the smoothness of pulp sheet [15]. A good fiber bonding in bamboo especially Andong, betung and Hitam bamboo due to their long fibers between 4-5 mm played to strengthen the paper sheet from tear strength. Therefore, the sheets cannot be penetrated by light easily. Fiber diameter, consisted of cell wall and lumen cell, was the other important characteristics in paper properties, in which the widest lumen cell and the thinnest cell wall belongs to Kuning bamboo. This characteristic facilitates to provide wide surface for interfiber bonding thus the tensile strength and folding power of paper sheet can be obtained [16].

The fiber dimension derivatives as resulted from interaction of the fiber dimension give more complete prediction on pulp and paper sheet properties. These characteristics showed that Hitam bamboo was superior in runkell ratio, felting power and flexibility

ratio, while Ampel bamboo has the best felting power. Besides that observation on the chemical and physical properties of bamboos that summarized in rank system indicated that Betung and Hitam bamboo were predicted producing a good pulp quality considering their lignin content (25-30 %). The lowest lignin, the highest pulp quality. Lignin having rigid properties can become inhibitor during interfiber bonding to create high paper sheet properties. It also causes brown or dark color in the paper sheet surface. Furthermore, all bamboo species have good holocellulose content with the highest content was in Ampel bamboo. Based on the physical properties, Betung bamboo has the lowest density indicating the most suitable for pulp and paper raw material. Summary of all bamboo properties by rank system also showed that Kuning bamboo and Betung bamboo had been selected as the first and second best candidate for pulp and paper raw material. Therefore, these bamboos then were subjected in pulping process [14].

2.2.2 Biopulping of Kuning and Betung bamboo

We have choosed two pulping process to produce pulp including semichemical (soda open hot soda) and chemical pulping (kraft and soda). Prior to pulping process, barkless bamboo chips were pretreated by biological pretreatment using white rot fungi such as *Trametes versicolor* (TV), *Pleurotus ostreatus* (PO), *Phanerochaete chrysosporium* (PC) and *Schizophyllum commune* [17], [18], [19], [20], [21]. Application of fungi culture into bamboos was used two methods, i.e single and mixed culture and then incubated for 30 and 45 days. After incubation finished, the treated bamboos were evaluated the anatomical structure changes after single culture fungi pretreatment [22] and mixed culture fungi pretreatment [23].

Except for Muhlstep ratio, an improvement of morphology and fiber derived value characteristics was found after mixed culture pretreatment of white rot fungi. The treated bamboos were predicted resulting a good quality pulp (grade I) based on FAO and LPHH requirements. The best fiber dimension and derived value were resulted after co culture of PC dan TV for 45 days. Delignification of pretreated bamboo was initiated by the fungi hyphae colonization on the surface area of bamboo, afterwards the mycelium penetrated into inner bamboo part [23].

Treatment using single culture of white rot fungi on Betung bamboo showed similar finding with mixed culture of white rot fungi. Based on macroscopic image observation, no significant difference degradation pattern of pretreated bamboo was observed. Considering these properties and its fiber derived value, bamboo pretreated TV for 30 days was identified able to produce the best pulp properties including in grade I [22].

In soda pulping, pretreated chips were cooked for 3 hours at 170 °C by 20% of NaOH to dry weight of bamboos and liquor to wood ratio of 10:1. After soda pulping, cooked bamboo chips and black liquor were then separated, washed by trap water until alkaline free, and defiberized using disk refiner 3 times [20], [21] before further analysis. The pretreated chips were also kraft pulped for 3 hour of maximum temperature (170 °C) using 20 and 15% of active alkali and sulfidity to oven dried bamboo with the liquor to wood ratio of 5: 1. To optimize penetration of cooking solution residue, the pulp was soaked for 24 h. Characterization of pulp included total yield (TAPPI T210 cm-93), Kappa number (TAPPI 236 cm – 85), freeness (TAPPI 227 cm-85), selectivity delignification (rasio of carbohydrate and residual lignin in pulp) and brightness level (SNI 14-4733-1998) [20], [21]. The other pulping method of bamboo was open-hot soda in which these chips were cooked for 2 h at 100 °C using NaOH of 20 % to oven dried chips with liquor to wood ratio of 10:1. The cooked chips were then also washed until alkali free and fibrillated by hollander beater for 90 min and stone refiner for 1 times.

Fibrillated pulp was measured the pulp yield, Kappa number and degree of freeness in triplicate.

Biological pretreatment using single culture of PO and TV fungi followed by open-hot soda also affected in improvement of pulp characteristics (increase of pulp yield and reduction of Kappa number and degree of freeness). Prolonging incubation time had correlation in reducing of kappa number. And based on observation of pulp properties, pretreatment of TV on Betung bamboo for 30 days had chosen as the best pretreatment condition [18]. However, compared with chemical pulping, this open-hot soda pulping has less improvement in pulp qualities. *S. commune* pretreatment on Betung and Kuning bamboo prior to open-hot soda pulping was also conducted. Insignificant effect on pulp properties (Kappa number, delignification selectivity and pulp yield) was observed after treatment. In this pulping process, pulp yield of Betung bamboo was lower than that of Kuning bamboo.

Kraft pulping of pretreated bamboo using single culture of TV and PO fungi gave more influence than that of soda pulping. Based on the biokraft pulp properties, TV for 45 days showed the best pretreatment condition indicated by the highest pulp yield and delignification selectivity and the lowest degree of freeness and Kappa number. With the same observation, this pretreatment condition was also demonstrated the best pulp qualities of soda pulping. Therefore, incubation using TV for 45 days was proposed as the best pretreatment condition prior to chemical pulp [20]. As mention before, according the anomical structure analysis, bamboo pretreated TV for 30 days can be predicted as the best pulp properties [22], however the pulping method played important contribution on pulp properties. Thus, the different best pretreatment condition was obtained.

Fatriasari et al. [19] reported that decrease of pulp yield occurred after treatment of bamboo with mixing between two or three fungi culture especially on PO and PC and PC for 45 days. It was caused competition of space and consumption of limited nutrients. These treatment combinations might not degrade selectively on lignin following degradation of some holocellulose mainly on aldehyde end grup. From three categories of fungi interaction types that identified by Body [24], POPC and POPCTV incubated for 45 days can be included in antagonist interaction. However, compared to control, biological pretreatment of bamboo proved succesfully to improve the pulp yield. After mixed culture fungi pretreatment, as much as 77-91% of Kappa number of pulp decreased, the highest and the lowest decrease was found in TVPC and TVPCPO for 30 days. It is indicated that these treatments were effective to remove lignin. Evaluation of biological pretreatment effectivity can be accessed by delignification selectivity in which mixed culture treatments. They were able to increase delignification selectivity and the highest value was POPC for 45 days. Prior to kraft pulping, lignin degradation occurred. Thus the pulping become more effective. In general, prolonging incubation time tended to decrease Kappa number and increase delignification selectivity and pulp yield. Regarding the pulp properties, the best mixed fungi culture treatment was co culture of TV and PC for 30 days. It did not in line with evaluation on anatomical characteristics and fiber derived value that reported in Fatriasari et al. [23]. The pulping method might give effect on the final properties of pulp.

During biological pretreatment, addition of corn steep liquor (CSL) in the inoculum of PC was also observed. A better pulp yield was obtained by increasing CSL amount. The longer incubation time tended to increase pulp yield, while the Kappa number was since versa. The treatment caused degradation in cell walls according to SEM analysis. The kraft pulping of bamboo treated by 10% CSL incubated for 30 days showed the best pulp properties [21]. Based on evaluation on pulp properties, kraft pulping was preferred as pulping method compared to the other methods.

2.2.3 Bamboo for production of sugar for bioenergy

Betung bamboo was reported suitable for pulp raw material. Therefore, in bamboo conversion for sugar production, this bamboo species was used. Biological pretreatment with TV on Betung bamboo using single or combination with microwave pretreatment has been reported before [25]. These treatments facilitated to decrease of lignin content and delignification selectivity. This result was inline with biological pretreatment before chemical pulping [20]. Incubation for 30 days showed the higher delignification selectivity compared to incubation for 15 and 45 days. Pretreatment caused more opened biomass structure, soften substrate, fiber fibrillation and more exposed cellulose. Some lignin losses in pretreated bamboo mainly were caused by decrease in lignin aromatic rings. The structure changes in pretreated bamboo facilitated in increasing the enzyme accessibility in breaking down the cellulose into glucose.

The pretreated bamboo was then hydrolyzed using enzymatic and sulfuric acid hydrolysis. The highest reducing sugar yield per biomass (17.06 %) was found after microwave assisted acid hydrolysis of pretreated bamboo. This yield was higher than that of enzymatic hydrolysis (2.53%). Until 12.5 min irradiation time, the longer irradiation time, the higher reducing sugar yield. Inoculum loading of 5% resulted higher reducing sugar yield compared to 10%. Biological pretreatment with 5% inoculum loading irradiated for 12.5 min using 1% sulfuric acid showed the highest reducing sugar yield. In this condition, about 22.75% holocellulose can be converted into reducing sugar.

Besides biological pretreatment, bamboo was also pretreated by microwave pretreatment in water medium. And irradiation time for 5, 10, 12.5 min with power level of 330 watt (W) and irradiation for 5 min with power level of 770 W was selected for combining with bamboo pretreated by biological pretreatment. The combination treatment increased reducing sugar yield as much as 8.4 fold compared to the highest reducing sugar resulted from enzymatic hydrolysis, and it improved 13.7 fold to control. The highest reducing sugar yield about 16.65% was achieved after hydrolysis for 12.5 min of bamboo pretreated 5% inoculum loading followed by microwave pretreatment for 5 min (330 W). About 27.21% holocellulose of bamboo was converted into reducing sugar [26].

The other biological pretreatment method on bamboo that was also developed is two-stage fungal pretreatment method by using white rot fungi pretreatment for 30 days followed by brown rot pretreatment for 30 days or since in versa [27]. The single pretreatment was used to compare the microwave assisted acid pretreatment. In this method, white rot fungi, PC was to degrade lignin, while brown rot (*Fomitopsis polustris*) pretreatment was for depolymerization of cellulose. This pretreatment combination resulted high delignification selectivity. The highest reducing sugar yield was obtained in pretreatment of brown rot (12.19%). The lowest reducing sugar yield (7.66%) was resulted after microwave assisted acid hydrolysis of bamboo pretreated *F.polustris*-PC. Compared to control, two-stage fungal pretreatment can increase the sugar yield. Lignin content was not only one factor affecting in sugar yield.

3. Conclusion

The physical and mechanical properties of ply bamboo boards are affected by bamboo species and the type of resin. Three layers of bamboo zephyr board using PF resin is potential as a substitute of ply wood for pallet in concrete block production. In bamboo particle board production, Betung bamboo bonded with isocyanate produced particle board with higher modulus of rupture, modulus of elasticity and internal bond compare to Betung bamboo bonded with UF. Furthermore, particle board produced with Apus bamboo and citric acid as environmental friendly adhesive, showed higher modulus of rupture than of Petung bamboo or Wulung bamboo. On the other hand, modulus of

elasticity and internal bond of Petung Bamboo and citric acid particleboard is the highest. The mechanical properties of Tallang bamboo cement board were higher than that of Atter bamboo and Betung bamboo cement boards. Composites of bamboo fibers/PLA have higher mechanical properties compared to those of bamboo fibers/PP composites. The optimum ratio of bamboo fiber/PLA composites is 40/60. Kuning bamboo and betung bamboo are proposed to be used as pulp and paper raw material considering the fiber properties and physical and chemical properties, fiber derived value as well. Biopulping of Kuning bamboo and Betung bamboo was conducted successfully to produce bamboo pulp. Biological pretreatment of bamboo using white rot fungi (TV, PO and PC) in single and mixed culture prior to pulping process facilitates in lignin removal. Biopulping pretreatment improved the pulp qualities mainly increase the pulp yield and delignification selectivity, also reduce the kappa number. In conversion of bamboo for sugar production, biological, biological and microwave method, two-stage fungal pretreatment, have been developed. By biological pretreatment, 17.06% reducing sugar yield can be resulted after microwave assisted hydrolysis for 12.5 min.

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References

- [1] Dransfield S, Widjaja E A 1995 *Plant Resources of South-East Asia No. 7 Bamboos* (Backhuys Publisher Leiden) p.189
- [2] Lobovikov M, Paudel S, Piazza M, Ren H, Wu J 2007 World bamboo resources. a thematic study prepared in the framework of the global forest resources assessment 2005 Non Wood Forest Products 18 Food and Agricultural Organization of the United Nations Rome p. 73
- [3] Fatriasari W 2014 Reducing sugar production through pretreatment process engineering of betung bamboo (*Dendrocalamus asper* (Schult. f)) Doctoral Thesis Graduate School Bogor Agricultural University Indonesia
- [4] Subiyanto B, Subyakto 1995 Development of processing technology of semi fiber bamboo board I. shortening the press cycle *Proceedings of The IVth International Bamboo Congress 3* Bali June 1995 pp. 155-164
- [5] Sudijono, Subyakto, Subiyanto B 2002 Effects of resin content of phenol formaldehyde on internal bond strength of zephyr bamboo board made from tali (*Gigantochloa apus* Kurs) *Proceedings of National Seminar of MAPEKI IV* 6-9 Agustus 2001 Samarinda pp. IV.220-IV.224 (in Indonesian)
- [6] Gopar M, Subyakto 2002 Physical and mechanical properties of zephyr board made from gombong bamboo *Proceedings of The Fourth International Wood Science Symposium* Serpong Indonesia 2-3 September 2002 pp. 257-261
- [7] Subyakto, Romansyah E, Zakaria A, Bachtiar G, Nasution N, Prihantono. 2016. Physical and mechanical properties of ply-bamboo made from sembilang (*Dendrocalamus giganteous*) and Andong (*Gigantochloa pseudoarundinacea*) bamboos. *Proceeding of The 7th International Symposium of Indonesian Wood Research Society* 5-6 November 2010 Bandung West Java Indonesia
- [8] Kusumaningrum WB, Syamani FA, Subyakto 2010 Papan komposit sisal (*Agave sisalana* Perr.) dan bambu betung (*Dendrocalamus asper* (Schultes f) Backer ex. Heyne). *Proceeding of Seminar Nasional MAPEKI XII*, 23-25 Juli 2009 Bandung West Java Indonesia.

- [9] Widyorini R, Umemura K, Isnan R, Putra D R, Awaludin A, Prayitno T A 2016. Manufacture and properties of citric acid-bonded particleboard made from bamboo materials *Eur. J. Wood Prod.***74** 57–65
- [10] Bakri 2015 Application of carbon dioxide injection technology in bamboo cement board production *Proceeding of The fifth International Symposium of Indonesian Wood Research Society* 7-9 November 2013 Balikpapan East Kalimantan Indonesia
- [11] Subyakto, Hermiati E, Yanto DHY, Masruchin M, Fitria, Prasetyo KW, Ismadi 2010 Biocomposites of polypropylene or polylactic acid reinforced with sisal or bamboo micro fibers *Proceedings of The First International Symposium of Indonesian Wood Research Society*
- [12] Okubo K, Fujii T, Yamamoto Y 2004 Development of bamboo-based composites and their mechanical properties *Composites Part A***35**377-383
- [13] Lee SH, Ohkita T, Kitagawa K 2004 Eco-composite from poly(lactic acid) and bamboo fiber. *Holzforschung* **58** 529-536
- [14] Fatriasari W, Hermiati E 2008 Analisis morfologi serat dan sifat fisis-kimia pada enam jenis bambu sebagai bahan baku pulp dan kertas *Jurnal Ilmu dan Teknologi Hasil Hutan***1**(2) 67-72
- [15] Haygreen J G, Bowyer J L 1996 *Hasil Hutan dan Ilmu Kayu: Suatu Pengantar Terjemahan* (Gajah Mada University Press Yogyakarta)
- [16] Casey J P 1980 *Pulping Chemistry and Chemical Technology Volume I Pulping and Paper Making* (Interscience Publisher Inc. New York)
- [17] Fitria, Ermawar R A, Fatriasari W, Fajriutami T, Yanto DHY, Falah F, Hermiati E 2013 Biopulping of bamboo using white-rot fungi *Schizophyllum commune* *Proceedings The 2nd International Symposium for Sustainable Humanosphere Bandung* 29th August, 2012 pp.8-13
- [18] Fatriasari W, Ermawar R A, Falah F, Yanto D H Y, Hermiati E 2009 Pulping soda panas terbuka bambu betung dengan praperlakuan fungi pelapuk putih (*Pleurotus ostreatus* dan *Trametes versicolor*) *J Ilmu dan Teknologi Hasil Hutan* **2**(2) 45-50
- [19] Fatriasari W, Anita S H, Falah F, Adi D T N, Hermiati E 2010 Biopulping of betung bamboo using mixed culture of white rot fungi (*Trametes versicolor*, *Pleurotus ostreatus* dan *Phanerochaete chrysosporium*) *Berita selulosa* **45**(2) 44-56
- [20] Fatriasari W, Ermawar RA, Falah F, Yanto DHY, Adi DTN, Anita S H, Hermiati E 2011 Kraft and soda pulping of white rot pretreated betung bamboo *Jurnal Ilmu dan Teknologi Kayu Tropis* **9**(1) 42-55
- [21] Falah F, Fatriasari W, Ermawar A R, Adi D T N, Hermiati E 2011 Effect of corn steep liquor on bamboo biochemical pulping using *Phanerochaete chrysosporium*. *Jurnal Ilmu dan Teknologi Kayu Tropis* **9**(2) 111-125
- [22] Fatriasari W, Damayanti R, Anita S H 2012a The pretreatment effect of single culture white rot fungi on the anatomical structure of betung bamboo *Jurnal Ilmu dan Teknologi Kayu Tropis* **10**(1) 66-75
- [23] Fatriasari W, Damayanti R, Anita S H 2013 Fiber qualities of pretreated betung bamboo (*Dendrocalamus asper*) by mixed culture of white-rot fungi with respect to its use for pulp and paper *Journal of Forestry Research* **10** (2) 95-106
- [24] Boddy L 2000 Interspecific combative interactions between wood-decaying *FEMS Microbiology Ecology* **31** 185-194
- [25] Fatriasari W, Syafii W, Wistara N J, Syamsu K, Prasetya B 2014a Digestibility of betung bamboo fiber following fungal pretreatment *Makara Journal Technology* **18**(2):51-58

- [26] FatriasariW,Syafii W, WistaraN J, Syamsu K, Prasetya B 2014b Performance of microwave pretreatment on enzymatic and microwave hydrolysis of betung bamboo (*Dendrocalamus asper*) *Teknologi Indonesia* **37**(3) 162-167
- [27] Fatriasari W, A S Heris 2012b Evaluation of two-stage fungal pretreatment for the microwave hydrolysis of betung bamboo *The 2nd Korea – Indonesia Workshop & International Symposium on Bioenergy from Biomass* P 83-86