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Evaluating the Physical and Mechanical Properties of Particleboards Fabricated from Vernonia Arborea Buch. -Ham and Eleocharis sp. Fibers with PVAc Adhesive

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ABSTRACT

This study aimed to evaluate the physical and mechanical properties of particleboards fabricated from *Vernonia arborea* Buch.-Ham and *Eleocharis* sp. fibers with PVAc adhesive based on the SNI 03-2105-2006. A two-factor factorial in completely randomized design was used with adhesive contents of 10% and 20% as the first, and ratios of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 30/70, 50/50 and 70/30 as the second factor. The materials were *V. arborea* Buch.-Ham wood shaving (mesh size of 4), *Eleocharis* sp. (chop length of 1-2cm), and PVAc adhesive. The parameters were moisture content, density, water absorption, and thickness swelling for physical properties, and modulus of elasticity, modulus of rupture, internal bond strength, and screw holding strength for mechanical properties. However, both properties do not meet the SNI 03-2105-2006 (except for thickness swelling), allegedly caused by imprecise concentration and uneven distribution of PVAc. Additionally, 3h boiling of *Eleocharis* sp. is not able to remove its wax layer, causing less optimal adhesion between materials. Particleboard with 20% PVAc shows the best result. Principally, the adhesive concentration has significant effects, while the combination between *V. arborea* Buch.-Ham and *Eleocharis* sp. has insignificant effects on the physical and mechanical properties of particleboards. The evaluated composition is recommended for interior uses (partition walls, wall panels, information boards, and lightweight ceilings), with the addition of coating to improve durability and decorative value. As an additional material, *Eleocharis* sp. has a high sustainability value due to its availability in nature.

1. INTRODUCTION

Particleboard is a wood panel produced from a mixture of wood particles or other lignocellulosic materials, organic or synthetic adhesives, and other materials through a compression process [1]. It is defect-free and adjustable in size and density, but low in dimensional stability and higher hygroscopic [2]. Studies on the fabrication of particleboards using assorted woods and additional materials have been done to improve their qualities. Among them are the use of barks, reeds, bamboo, rice stalks, and cocoa pod husk [3-7] that can increase the strength of particleboards and meet the SNI [8] and JIS [9].

The present study used *V. arborea* Buch.-Ham, which is classified in Strength Class III, with *Eleocharis* sp. as the additional material. *V. arborea* Buch.-Ham contains more than 68% holocellulose, 40% α-cellulose, 24% lignin, and 0.6% ash [10]. Its specific gravity ranges between 0.40 and 0.60 [11]. Nevertheless, a preliminary study showed it generated low strength particleboard [12]. *Eleocharis* sp. is a lignocellulosic rich material with moderate lignin content and relatively high cellulose content [13]. Its abundant and sustainability in the wild, particularly in peat swamp land, posed its prospective in the fabrication of particleboard [1]. In Tumbang Nusa Village, Pulang Pisau Sub-district, Central Kalimantan, for instance, there was approximately 900ha of *Eleocharis* sp. [14] used as a mainstay for the local community apart from farming and fishing. It is popular and has been used by the community for generations as a material for craftings such as woven mats, hats, and baskets [15]. Previously, *Eleocharis dulcis* was used in the fabrication of particleboard that met the criteria of SNI 03 2105 2006 [16].

The adhesive used in making particle board is Polyvinyl acetate (PVAc). This adhesive is a thermoplastic synthetic adhesive which is widely used in the furniture processing industry. PVAc is a thermoplastic polymer which is widely known as a raw material in the adhesive industry [17]. In which it easily melts when heated and solidifies again when cooling without any changes in chemical properties [18]. As an emulsion polymer product, it is often used for wood and paper glue [19]. It is easy handling and anti-microbial, and has unlimited storage period, similar gap-filling to animal-based adhesives, and low compression pressure. This non-staining adhesive is also suitable for wooded products and their derivatives [20]. It is also environmentally friendly as it does not emit emissions that are harmful to health like formaldehyde-based adhesives. Nevertheless, due to its sensitivity to moisture, it is limited only for interior decoration since its adhesive strength decreases rapidly at temperatures of over 70℃ [21].

This study attempted to evaluate the physical and mechanical properties of particleboards fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp. fibers with PVAc adhesive. In fact, it is the first study using *Eleocharis* sp. in the fabrication of particleboard while previous similar study using different species, namely *Eleocharis dulcis*. The physical and mechanical properties of the produced particleboard were tested, including moisture content, density, water absorption, thickness swelling, modulus of elasticity, modulus of rupture, internal bond strength, and screw holding strength.

2. RESEARCH METHODS

2.1 Place and time

This study was carried out for approximately three months at Forest Products Technology Workshop, Department of Forestry, Faculty of Agriculture, University of Palangka Raya. Research activities included preparation, fabrication of particleboard, specimen cutting and testing, data processing, and data presentation.

2.2 Materials and equipment

The material of *V. arborea* Buch.-Ham was obtained from branch-free tree of 14m in height and 37cm in diameter in the Hampangen Educational Forest (coordinates 1º5'44"S 113º45'34"E). The wood was planned and sieved into 4 mesh size chips. Meanwhile, dried *Eleocharis* sp. was obtained from Tumbang Nusa Village, Pulang Pisau Sub-district, Central Kalimantan. It was chopped into 1-2cm. Fox PVAc with 40% solid resin was used as the adhesive. The equipment included 4 mesh sieves, hot press machine, handsaws, analytical scale, calipers, screw micrometer, oven, desiccator, and UTM.

2.3 Procedure

The fabrication and testing of particleboard referred to SNI 03-2105-2006 [8]. The parameters for physical properties were moisture content, density, thickness swelling, and water absorption, while for mechanical properties were modulus of elasticity, modulus of rupture, internal bond strength, and screw holding strength. The formulas were presented in Table 1.

2.4 Data analysis

A two-factor factorial in CRD was employed. The first factor was adhesive concentrations of 10% (A1) and 20% (A2). The second factor was three compositions of *V. arborea* Buch.-Ham and *Eleocharis* sp.: 30/70 (B1), 50/50 (B2), and 70/30 (B3). Each treatment was replicated three times. Totally, 18 treatments were completed and 90 specimens were prepared for testing five parameters. Subsequently, the data was analyzed using analysis of variance with a 95% confidence interval.

3. RESULTS AND DISCUSSION

Particleboards fabricated from different ratios of *V. arborea* Buch.-Ham and *Eleocharis* sp. and two concentrations of PVAc were fabricated without any delamination. Each treatment also produced distinctive particleboard. The characteristics of particleboard with 30% *Eleocharis* sp. were similar to those in general. Nevertheless, the higher the composition of *Eleocharis* sp., the more decorative the produced particleboard with a woven mat pattern. The surfaces of particleboards with 10% and 20% PVAc (A1 and A2, respectively) and different ratios of *V. arborea* Buch.-Ham to *Eleocharis* sp., namely 30/70 (B1), 50/50 (B2), and 70/30 (B3) were presented in Figure 1.

Table 1. Parameters and formulas for physical and mechanical properties of particleboards

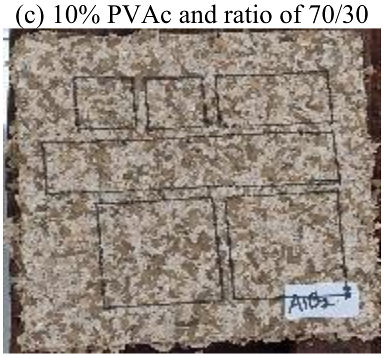
Parameter	Equation	Description
Density	$D\ (g.cm^{-3}) = W/V$	W=weight (g) V=volume (cm^3)
Moisture content	$MC(\%) = [(Wi - Wd)/Wd] \times 100\%$	Wi=initial weight (g) Wd=absolute dry weight (g)
Water absorption	$WA\ (\%) = \left[\left(W2 - \frac{W1}{W1}\right)\right] \times 100\%$	WA=water absorption (%) W_1=specimen weight before immersion (g) W_2=Specimen weight after immersion (g)
Thickness swelling	$TS\ (\%) = [(T2 - T1)] \times 100\%$	TS=thickness swelling (%) T_1=specimen thickness before immersion (mm) T_2=specimen thickness after immersion (mm)
Modulus of Elasticity	$MoE\ (kgf.cm^{-2}) = l^3 \Delta P / 4wt^3 \Delta D$	l=span (cm) w=width (cm) t=thickness (cm) ΔP=load difference from the curve (kgf) ΔD=deflection of load difference (cm)
Modulus of Rupture	$MoR\ (kgf.cm^{-2}) = 3Pl/2\ wt^2$	P=applied load (kgf) l=span (cm) w=width (cm) t=thickness (cm)
Internal bond strength	$IB\ (kgf.cm^{-2}) = P/l\text{xw}$	P=maximum load (kgf) l=length (cm) w=width (cm)
Screw holding strength	$SH\ (kgf.cm^{-2}) = P/l\text{xw}$	P=maximum load (kgf) l=length (cm) w=width (cm)


(a) 10% PVAc and ratio of 30/70


(b) 10% PVAc and ratio of 50/50


(c) 10% PVAc and ratio of 70/30


(d) 20% PVAc and ratio of 30/70


(e) 20% PVAc and ratio of 50/50

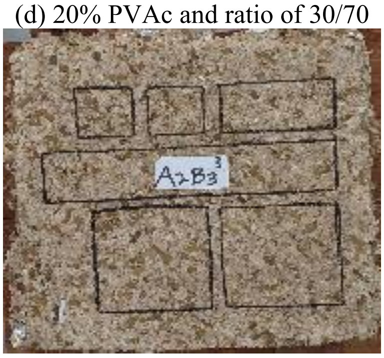
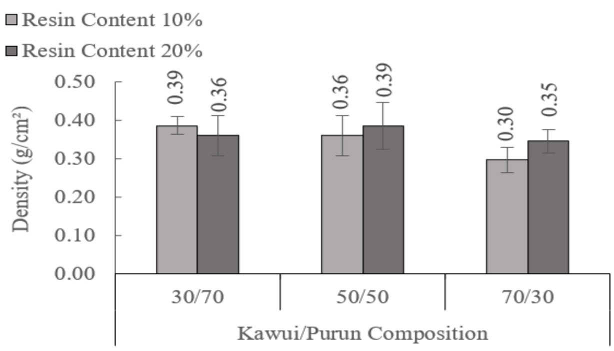
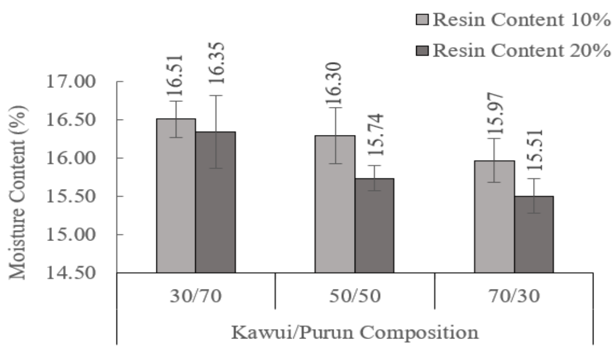

(f) 20% PVAc and ratio of 70/30

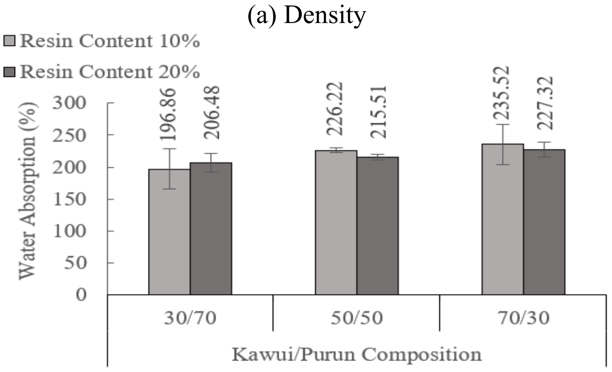
Figure 1. Particleboard fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp.



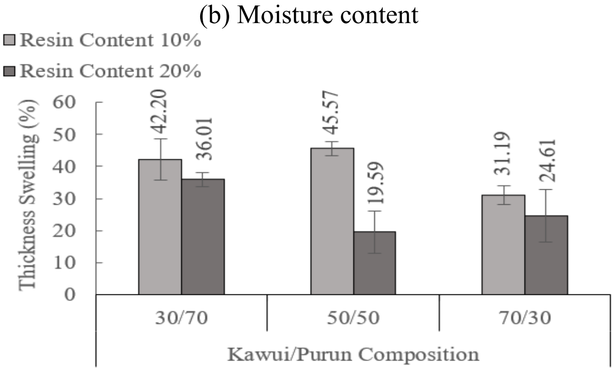
(a) Density



(b) Moisture content



(c) Water absorption



(d) Thickness swelling

Figure 2. The physical properties of particleboards

Table 2. The results of physical property analysis of particleboards

Explanatory Variable	Source of Variance	*df*	*SS*	*MSS*	*F-Value*	*P-Value*	
						5%	*1%*
Density	A	1	2.28	2.28	5.99*	4.75	9.33
	B	2	2.29	1.15	3.01	3.88	6.93
	AB	2	0.04	0.02	0.05	3.88	6.93
Moisture content	A	1	4,644.06	4,644.06	6.00*	4.75	9.33
	B	2	4,644.80	2,322.40	3.00	3.88	6.93
	AB	2	4.67	2.33	0.00	3.88	6.93
Thickness swelling	A	1	20,589.31	20,589.31	5.83*	4.75	9.33
	B	2	20,218.59	10,109.30	2.86	3.88	6.93
	AB	2	3,413.83	1,706.91	0.48	3.88	6.93
Water absorption	A	1	855,366.16	855,366.16	5.99*	4.75	9.33
	B	2	858,052.36	429,026.18	3.01	3.88	6.93
	AB	2	6,650.23	3,325.11	0.02	3.88	6.93

Notes: 1. A=PVAc concentration. 2. B=ratio of V. *Arborea* Buch.-Ham to *Eleocharis* sp. 3. AB=Interaction factor. 4. *=Statistically significant at a 5% level

3.1 Physical properties of particleboards

The physical properties of particleboard fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp. with two PVAc concentrations are presented in Figure 2. The results of the analysis are presented in Table 2.

3.1.1 Density

Density is the ratio between the mass and volume of particleboard. It indicates the compactness level of particles in particleboard. The higher the density value, the more compact the particles that make up the particleboard [22]. Density affects the physical and mechanical properties of particleboard in which the higher the density of a particleboard, the better the physical and mechanical properties of a particleboard. In the present study, the lowest density (0.30 g.cm^{-3}) was obtained by particleboard fabricated from 70/30*V. arborea* Buch.-Ham and *Eleocharis* sp. and 10% PVAc. Meanwhile, the highest (0.39 g.cm^{-3}) was obtained by the compositions of *V. arborea* Buch.-Ham and *Eleocharis* sp. of 30/70 and 50/50 with 10% PVAc. These values are below the Indonesian National Standard (SNI) 03-2105- 20060 [8], namely 0.40 to 0.90 g.cm^{-3}. Particleboard with a density less than 0.40 g.cm^{-3} is categorized into low group [23]. The values are also similar to the result of a preliminary test using 11% PVAc without the addition of *Eleocharis* sp. [12], namely 0.37 gr.cm^{-3}. However, they are much lower than the density of particleboards fabricated from wood, bamboo and rice husk, which ranges from 0.63 to 0.69 gr.cm^{-3} [6]. Principally, the density of particleboard is affected by the density of the material, adhesive concentration, and additional materials [24].

3.1.2 Moisture content

Moisture content is the amount of moisture, both water and water vapor, in the particleboard. It is greatly influenced by the presence of free hydroxyl groups in the material. Essentially, it significantly determines the quality of a material. Figure 2 shows the highest moisture content was obtained by particleboard with a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 30/70 and 10% PVAc, while the lowest was obtained by that with a ratio of 70/30 and 20% PVAc. These values were affected by the moisture content of both materials. The initial moisture content of *V. arborea* Buch.-Ham was 10%, while *Eleocharis* sp. was unknown. Before fabricating the particleboard, *Eleocharis* sp. was boiled for 3h to remove the wax on the leaf surface. However, the drying process was allegedly less optimal and consequently, the moisture content was still high. Moreover, both *V. arborea* Buch.-Ham and *Eleocharis* sp. are hygroscopic due to their lignin and cellulose content.

In addition to the materials, the type of adhesive also contributes to the moisture content of particleboard. PVAc is made up of a water-based emulsion and it takes more time to evaporate [18]. The results of the analysis of variance (Table 2) indicate that PVAc concentration significantly affects the moisture content of particleboard at a 5% level. Meanwhile, the ratio of *V. arborea* Buch.-Ham and *Eleocharis* sp. and the interaction between ratio and PVAc concentration have no effect on moisture content. The lower the moisture content, the higher the quality of the particleboard. The present study verifies that the moisture content of particleboards with 20% PVAc are lower than those with 10% PVAc. However, moisture content values between 15.51% to 16.35% in particleboard fabricated from *V. arborea* Buch.-Ham and 20% PVAc do not meet the Indonesian National Standard (SNI) 03-2105-2006 [8], which stipulates the moisture content for particleboard is less than or equal to 14%. Previous preliminary study on particleboard fabricated from *V. arborea* Buch.-Ham and 11% PVAc without *Eleocharis* sp. obtained similar value of moisture content, namely 15.70% [12]. However, it is higher than the moisture content of particleboards fabricated from sawdust, reeds, and cocodust using 12% adhesive [5], namely 10-12%. While the moisture content of particleboards fabricated from wood, bamboo, and rice husks was 8.29% to 8.75% [6]. The moisture content of particleboard can be minimized by reducing the moisture content of material before hot pressing, followed by precise cooling and conditioning time. Increasing adhesive content and pressing temperature are also among the solutions. It has been shown by previous study using PVAc with pressing temperature of 110°C [5], which results particleboard with lower moisture content than the present study (temperature of 60°C). Pressing temperature and time are inversely proportional to the moisture content of particleboard: the higher the pressing temperature and time, the lower the moisture content of particleboard fabricated from *Paraserienthes falcataria* (L.) Nielson [25].

3.1.3 Water absorption

The lowest water absorption was obtained by particleboard fabricated from a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 30/70 with 10% PVAc, while the highest was obtained by a ratio of 70/30 with similar PVAc concentration. Analysis of variance shows that adhesive concentration significantly affects water absorption, while ratio of materials and the interaction between the adhesive concentration and ratio have insignificant effect on water absorption. The lower the value of water absorption, the better the quality of the particleboard. The lowest value of 196.86% is lower than the result of preliminary test of particleboards fabricated from *V. arborea* Buch.-Ham without *Eleocharis* sp. using 11% PVAc, namely 201.31% [12]. While water absorption is not included in the Indonesian National Standard (SNI) 03-2105-2006 [8], it significantly affects the quality of particleboard and is a consideration for selecting particleboard [4]. Water absorption correlates with thickness swelling. In general, the higher the water absorption, the higher the thickness swelling of a particleboard and vice versa [26]. Water absorption occurs through the formation of hydrogen bonding in the cell walls, causing the swelling of cell walls that is reflected by a change in the dimensions of the composites [27]. Particleboards with low water absorption can be used for outdoors or exteriors, while those with high value are suitable for indoors or interiors. Factors contribute to water absorption value include differences in particle size between *V. arborea* Buch.-Ham and *Eleocharis* sp., and uneven blend between material and adhesive, leading to the formation of cavities where water can enter during immersion process.

3.1.4 Thickness swelling

Testing thickness swelling was carried out after 24h immersion of specimens. It aimed at observing any changes in the dimension of particleboard that reflect the stability of particleboard against humidity. The test results indicated that the lowest value was obtained by particleboard fabricated from a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 50/50 with 20% PVAc, while the highest was obtained by the same ratio with 10% PVAc. The lower the thickness swelling value, the better the quality of the particleboard. The results of the analysis of variance indicate that adhesive concentration has a significant effect on thickness swelling. Meanwhile, the ratio of materials and the interaction between the ratio and adhesive concentration have insignificant effect on thickness swelling. In this study, the lowest value (19.59%) as the best treatment does not meet the SNI 03-2105-2006 [8] that requires a maximum thickness swelling of 12%. The lowest value in this study is also higher than the result of preliminary test of particleboards fabricated from *V. arborea* Buch.-Ham without *Eleocharis* sp. using 11% PVAc, namely 12.98% [12]. It is allegedly caused by the chemical properties of *Eleocharis* sp. that has higher cellulose and lignin content (46% and 26.6%, respectively) [13] than *V. arborea* Buch.-Ham (40% and 24%, respectively) [10]. Consequently, the fabricated particleboard in this study is more hygroscopic.

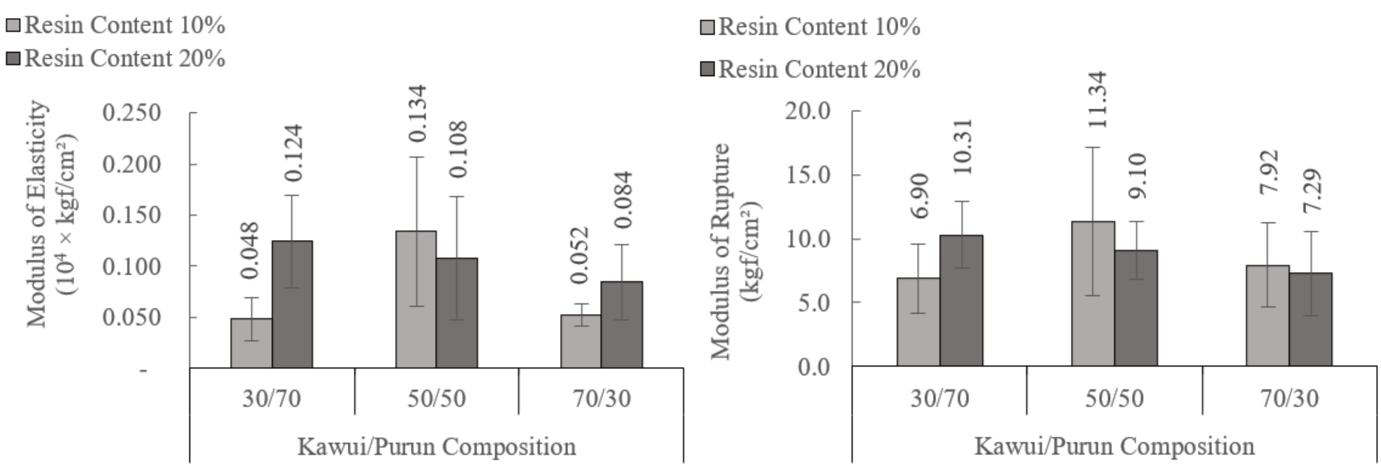
3.2 Mechanical properties of particleboard

The results of the mechanical property analysis of particleboards fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp. using two concentrations of adhesive are presented in Figure 3. The results of the analysis of variance are presented in Table 3.

Table 3. The results of mechanical property analysis of particleboards

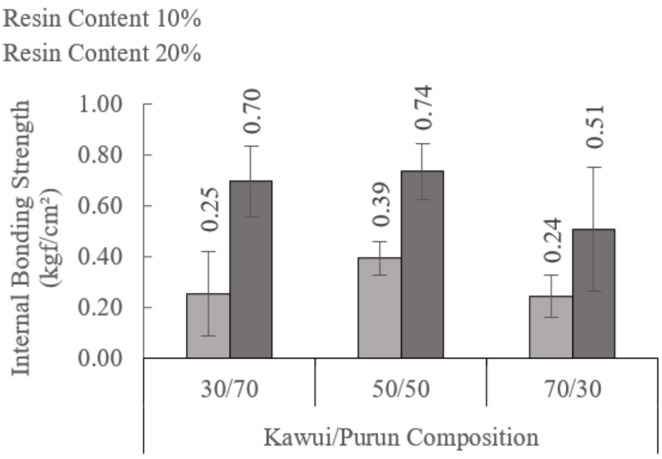
Variable	Source of Variance	*df*	*SS*	*MSS*	*F-Value*	*P-Value*	
						5%	*1%*
MoE	A	1	6.67	6.67	7.13*	4.75	9.33
	B	2	6.77	3.38	3.62	3.88	6.93
	AB	2	2.00	1.00	1.07	3.88	6.93
MoR	A	1	1,397.41	1,397.41	6.12*	4.75	9.33
	B	2	1,418.17	709.08	3.11	3.88	6.93
	AB	2	118.54	59.27	0.26	3.88	6.93
IB	A	1	4.56	4.56	6.00*	4.75	9.33
	B	2	4.11	2.06	2.71	3.88	6.93
	AB	2	1.39	0.70	0.92	3.88	6.93
SH	A	1	12,744.32	12,744.32	5.96*	4.75	9.33
	B	2	12,939.98	6,469.99	3.03	3.88	6.93
	AB	2	599.27	299.64	0.14	3.88	6.93

Notes: 1. A=PVAc concentration. 2. B=ratio of V. *Arborea* Buch.-Ham to *Eleocharis* sp. 3. AB=Interaction factor. 4. *=Statistically significant at a 5% level

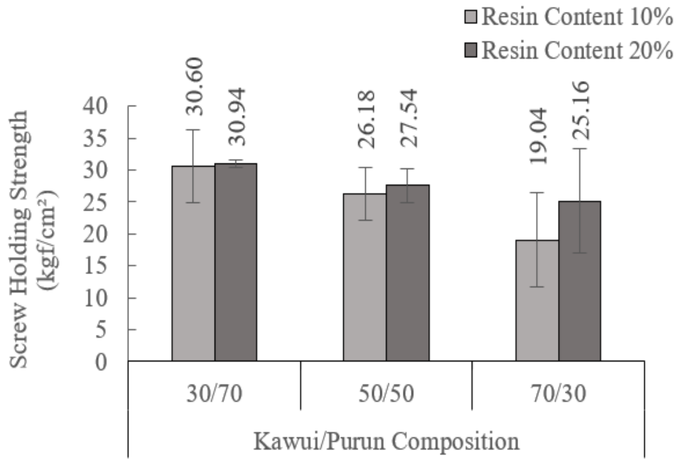


(a) Modulus of elasticity (MoE)

(b) Modulus of rupture



(c) Internal bond strength (IB)



(d) Screw holding strength (SH)

Figure 3. The mechanical properties of particleboards

3.2.1 Modulus of elasticity (MoE)

The mean MoE value is presented in Figure 3. The lowest value (0.048×10^4 kgf.cm^{-2}) was obtained by particleboard fabricated from a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 70/30 using 10% PVAc. Meanwhile, the highest value (0.134×10^4 kgf.cm^{-2}) was obtained by that with a ratio of 50/50 using 20% PVAc, which is still lower than the MoE values of acacia-based particleboard using 20% PVAc [11] and composites fabricated from *Eleocharis dulcis* with urea-formaldehyde adhesive [16] of 2.47×10^4 and 10.750×10^4 kgf.cm^{-2}, respectively. However, these values have not met the Indonesian National Standard (SNI) 03-2105-2006 [8], which requires a value at least 2.04×10^4 kgf.cm^{-2}. Modulus of Elasticity is an indicator that determines the ability of particleboard to return to its original shape after being subjected to a load. The higher the MoE value, the higher the elasticity of particleboard. The results of the analysis of variance (Table 3) indicate that adhesive concentration has a significant effect on the MoE of particleboard. Increasing the amount of adhesive will enhance the bond between particles [3]. In the present study, particleboard using 10% PVAc has a lower MoE than that with 20% PVAc. It is possibly caused by the treatment of 3h boiling of *Eleocharis* sp. prior the fabrication of particleboard. Under certain conditions, the presence of hot water-soluble extractives in the material positively contributes to the elasticity of particleboard. Hot water extraction considerably reduces the elasticity of particleboard glued with polysaccharide adhesive due to possible fiber damage and sugar loss during the extraction process [28, 29].

3.2.2 Modulus of rupture (MoR)

Modulus of rupture indicates the ability of particleboard to withstand maximum load before rupture. It is an important parameter for assessing the properties of particleboard for structural purposes. The static bending strength of particleboard is influenced by the adhesiveness level of the surface of particleboard [30]. Surface with a high adhesiveness level has high densification and also high static bending strength. The mean MoR value presented in Figure 3 showed the highest and lowest MoR were obtained by particleboards fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp. at 50/50 and 30/70 ratio, respectively, using 10% PVAc. According to the Indonesian National Standard (SNI) 3-2105-2006 [8], a MoR of 82kgf.cm^{-2} is required. Therefore, the value obtained by particleboard in this study (6.9-11.37kgf.cm^{-2}) was not comparable to the standard. The analysis of variance (Table 3) shows that adhesive concentration has a significant influence on MoR of particleboard. The ratio of the materials has insignificant effect on the MoR of particleboard. Particleboard with 10% PVAc adhesive concentration with a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 50/50 had the highest MoR value.

3.2.3 Internal bond strength (IB)

Internal bond strength is the tensile strength perpendicular to the surface of particleboard or panel. It is a reliable parameter to determine the quality of particleboard. It measures the interparticle bonding after the process of adding adhesive, forming, and hot pressing [2]. The mean IB value presented in Figure 3 shows that the highest value (0.74kgf.cm^{-2}) was obtained by particleboard fabricated from a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 50/50 and 20% PVAc. Meanwhile, the lowest value (0.24kgf.cm^{-2}) was found in particleboard with a ratio of 70/30 and 10% PVAc. The IB value does not meet the Indonesian National Standard (SNI) 03-2105-2006 [8], which requires a minimum value of 1.5kgf.cm^{-2}. Compared to the IB values reported by a preliminary test on particleboards fabricated from *V. arborea* Buch.-Ham using 11% and 15% adhesive, namely 0.03 and 0.41kgf.cm^{-2}, respectively [12], the present study obtained higher values. Enhancing adhesive concentration and adding *Eleocharis* sp. on the fabricated particleboard successfully increased the IB of the particleboard. The analysis of variance in Table 3 shows that the adhesive concentration significantly affects the IB of the particleboard, while the ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. insignificantly affects it.

3.2.4 Screw holding strength (SH)

Screw holding strength is a substantial element in assessing wood panel as material for manufacturing furniture. The effect of enhancing adhesive concentration and adding other material on the screw holding strength of the particleboards is illustrated in Figure 3. The highest value (30.94kgf/cm^2) was found on the particleboard with a ratio of *V. arborea* Buch.-Ham to *Eleocharis* sp. of 30/70 and 20% PVAc. This value meets the Indonesian National Standard (SNI) 03-2105-2006 [8], namely a minimum of 31kgf/cm^2. The analysis of variance in Table 3 verifies that the adhesive concentration has a significant effect on the screw holding strength of the particleboard. Meanwhile, the ratio of the materials and the interaction between the ratio and adhesive concentration have insignificant effect on the screw holding strength of the fabricated particleboards. Additionally, the value reported in this study was higher than that from preliminary test on the particleboard fabricated from *V. arborea* Buch.-Ham without the addition of *Eleocharis* sp. using 11% and 15% adhesive, namely 11.22 and 14.28kgf.cm^2, respectively [12].

In general, the findings indicated that the physical properties of the evaluated particleboards did not meet the referenced standards (SNI 03-2105-2006), except for the thickness swelling. The physical properties of particleboard are highly affected by the characteristics of adhesive and raw materials. In this study, the use of water-based material with a 40% solid content possibly increased the moisture content and absorption capacity of particle. Meanwhile, the low density was allegedly caused by the use of low specific gravity wood. In addition, this study also found that the mechanical properties of the evaluated particleboards did not meet the SNI 03-2105-2006. It was possibly caused by the low density of particleboard, namely less than 0.4, thus affecting all of its mechanical properties.

This study also found that higher concentration of adhesive and additional material improved the quality of particleboard. It was likely caused by the mechanism of increasing adhesive concentration thus the adhesive-covered surface of the materials (*V. arborea* Buch.-Ham+*Eleocharis* sp.) was broader and the adhesion between the materials was stronger. Since *V. arborea* Buch.-Ham has a low specific gravity, namely 0.4-0.60, it is necessary to add other materials with high lignocellulose content such as *Eleocharis* sp. to enhance the strength of the particleboard.

Another obstacle regarding the properties of particleboard was caused by improper process of removing the wax layer on the surface of *Eleocharis* sp. The treatment of 3h boiling of *Eleocharis* sp. was not able to optimally remove its wax layer. Consequently, the remaining wax prevented the adhesive from entering the material being bonded, causing less optimal adhesion between materials.

4. CONCLUSIONS

The physical and mechanical properties of the particleboards fabricated from different ratios of *V. arborea* Buch.-Ham to *Eleocharis* sp. and adhesive concentrations have been evaluated. The physical properties of the fabricated particleboards do not meet the Indonesian National Standard (SNI) 03-2105-2006, except for the parameter of thickness swelling. Meanwhile the mechanical properties do not meet the standard of all parameters. The results are possibly caused by a low concentration and uneven distribution of the adhesive. It is also predicted that the 3h boiling of *Eleocharis* sp. is not able to optimally remove its wax layer and prevent optimal bonding between the materials. Therefore, it is suggested for further research to lengthen the boiling time for more than 3h. Based on the analysis of physical and mechanical properties and the appearance of particleboards fabricated from *V. arborea* Buch.-Ham and *Eleocharis* sp., the products are suitable for interior use, i.e., partition walls, wall panels, information boards, and lightweight ceilings with notes without loading or with a very light load. The use of *Eleocharis* sp. as an additional material has a high sustainability value due to its abundance in the nature.

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NOMENCLATURE

PVAc	polyvinyl acetate
UTM	universal testing machine
SNI	Indonesian National Standard
D	Density (g/cm^3)
W	Weight (g)
V	Volume (cm^3)
MC	Moisture content (%)
Wi	initial weight (g)
Wd	absolute dry weight (g)
WA	water absorption (%)
W_1	specimen weight before immersion (mm)
W_2	Specimen weight after immersion (mm)
TS	thickness swelling (%)
T_1	specimen thickness before immersion (mm)
T_2	specimen thickness after immersion (mm)
MoE	Modulus of Elasticity (kgf.cm^{-2})
l	l=length(cm)
w	w=width (cm)
t	t=thickness (cm)
ΔP	ΔP=load difference from the curve (kgf)
ΔD	ΔD=deflection of load difference (cm)
MoR	Modulus of Rupture (kgf.cm^{-2})
IB	Internal bond strength (kgf/cm²)
P	maximum load (kgf)
SHS	Screw holding strength(kgf/cm²)
CRD	completely randomized design
JIS	Japanese Industrial Standards