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RESEARCH ARTICLE

Production of composite boards from *Bambusa blumeana* Schult.f. and *Dendrocalamus asper* (Schult.) Backer

Lowell G. Aribal[1*] . Jason A. Parlucha[2] . Jayson N. Gelaga[3] Raynilda J. Aribal[4] . Policarpo E. Sedenio[5]

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Abstract: The study aims to produce composite boards from two bamboo species i.e., *Bambusa blumeana* and *Dendrocalamus asper*. The composites were termed as "strip-board" and "shavings-board" to indicate that such was processed from shavings and strips, respectively. The strip-board was produced from 1.2 meter poles. The poles were turned into slats and were deskinned, denoded, and further processed into thin long strips. The shavings-board were made from the internodes converted into slats, deskinned, and processed into thin materials. During defibering, the vascular bundles were cooked in three varying NaOH-water concentrations (i.e., 1%, 3%, and 5%) for 3 hours. The cooked bundles were thoroughly washed and dried to 14% MC, applied with polyvinyl acetate, and pressed at 1000 psi. The produced boards were cured, dried, and samples were subsequently tested for tensile, compression, and bending strength following the ASTM D-143-22 standards. The data were analyzed using the 2×2×3 (i.e., species, board type, NaOH concentration) factorial experiment in CRD. Results showed that the pressing pressure used was insufficient to produce void-free boards. No interaction was noted between the three factors, but the main effect indicated that *B. blumeana* has significantly higher tensile and compression strength compared to *D. asper*. The strip-boards also obtained the same compared to shavings-boards. Despite the strength properties exhibited by *B. blumeana*, boards from *D. asper* were economical because of the lower price per pole and production cost. We conclude that the high pressing pressure was the most crucial factor in producing void-free, tightly compacted dense boards.

Keywords: composite boards, bamboo, *Bambusa*, *Dendrocalamus*

**Corresponding Authors*

[1] Department of Forest Biological Science, College of Forestry and Environmental Science, Central Mindanao University, Bukidnon, 8714, Philippines

[2] Department of Wood Science and Technology, College of Forestry and Environmental Science, Central Mindanao University, Bukidnon, 8714, Philippines

[3] College of Forestry and Environmental Science, Central Mindanao University, Bukidnon, 8714, Philippines

[4] College of Forestry and Environmental Science, Central Mindanao University, Bukidnon, 8714, Philippines

[5] Department of Wood Science and Technology, College of Forestry and Environmental Science, Central Mindanao University, Bukidnon, 8714, Philippines
✉ aribalowell@gmail.com

Introduction

The increasing scarcity of wood in the Philippines requires the need to search for an alternative renewable material and necessitates the exploration of other unconventional sources particularly the non-timber forest products (NTFP) to meet the demands of wood. In essence, the most practical solution to wood sufficiency and consequently address the wood shortage and lower the cost of wood products is to increase the production of logs from plantation forests as well as small-scale forest tree farms. Unfortunately, the current collective national total timber production from these sources ranges only at ≥ 0.008 cubic meters per capita, which obviously could not suffice the gap. Unless the establishment of industrial plantations and community tree farms is accelerated and given proper incentives from the government, wood supply from natural forests would fail to meet the needs of the country and it would be inadequate to merely protect the forests if the demand for wood cannot be satisfied (PCAARRD, 2008). Therefore, alternative raw materials from various lignocellulosic sources should be explored and developed because without such, construction materials derived from wood or timber are expected to continually increase and will be relatively more costly in the future.

Among the NTFP, bamboo exhibits the potential to provide a promising solution to the declining wood supply. If properly processed, bamboo can compete with solid wood in terms of strength, figure, and finishing properties, making bamboo the best substitute for wood or even its replacement. The relatively abundant supply and a shorter rotation period of bamboo is a major advantage over timber. And unlike trees, repeated harvesting and stand regeneration are possible. Further, bamboo has fibers that are stiff and strong, making it a very suitable substitute for wood for the production of composite materials that are needed in construction where medium to high strength are the requirements. According to Mohanty *et al.,* (2015), it has now been realized that bamboo produces biomass faster and has superior physical and mechanical properties compared to wood from many fast-growing wood species. With modern techniques and adapted technologies, bamboo can be processed into a wide range of products that successfully compete with wood and other materials (Chaowana, 2013).

Promising it can be, however, the cost-effective processing technology appropriate for the local bamboo species in the Philippines is still desirable. Also, there is a need to address the challenge of increasing the utilization percentage of the bamboo culms along with the development of novel and economically promising products while the present technology adapted to produce glue-laminated bamboo products should be improved to make them more affordable. Villanueva *et al*., (2010) stressed that there are still limited technologies, inadequate promotion, and slow commercialization of the developed technologies for the manufacture of engineered bamboo products, engineered bamboo-based furniture, and handicrafts hence, there is a need to develop new technologies and applications for engineered bamboo processing. Without these technologies, the Philippines could not capitalize on the opportunities posed by the rising world demand for bamboo products which was valued at US$10 billion and is expected to grow to US$ 15-20 billion per year according to the department of trade and industry (DTI).

Composite boards made of bamboo are technologies developed to maximize the fibrous strands of bamboo material. Whether in scrimber, zephyr strands, shavings, and strips, the technology basically disintegrates the natural form of bamboo and apply force to compress the material and mold into target dimension (Nugroho & Ando, 2000; Chen *et al*., 2021). In contrast to laminated bamboo where strips are cut in rectangular shape and laminated to form boards, bamboo composite boards made from extract fiber utilizes approximately 80% of the pole as compared to the 30% from laminated bamboo (van der Lugt, 2008). The critical process is how to effectively defibrillate bamboo poles in order to extract the fibers. This leads to the production of strips and shavings. Mechanical process is commonly applied which includes steam explosion, retting, crushing, grinding and rolling of the bamboo in a mill to extract the fiber (Muhammad *et al*., 2018). Chemical method is also applied to facilitate the extraction process by softening the lignin content within the molecular complex of fiber (Manalo *et al*., 2015). The fibers are then soaked to resin or adhesive and compressed at high pressure and heat to mold the fibers into lumber size boards. This production technology is well developed in China but studies are limited only to few species available in the country (Sharma *et al*., 2015). To conclude on the best or ideal species for the production of the composite boards, factors such as processing, production cost, availability of raw materials, quality of boards in terms of compaction and density, and strength properties were important considerations. Thus, this present study intends to produce composite boards from the two erect bamboo species namely *Bambusa blumeana* Schult.f. (Kawayan tinik) and *Dendrocalamus asper* (Schult.f.) Backer (Giant Bamboo). With its high abundance in plantation and natural forest in the

Philippines added with excellent physical and mechanical properties, these species have huge potential for the production of bamboo composite boards. These raw materials shall be maximized by increasing the culm utilization rate to 70% against the 30% traditional glue-laminated bamboo composites. This is the first attempt to produce composite boards from the two mentioned species in the Philippines. These composites were termed shavings-board and strip-board because the culms were processed from shavings and strips, respectively.

Materials and Methods

Collection of culms

Culms from two erect species of bamboo were collected from various stands. Only the matured culms aged 3 –5 years were harvested/collected using a chainsaw for a maximum of 50 culms per species. Collected culms were transported and processed immediately after collection. No prior drying and/or treatments were administered because culms were disintegrated immediately and processed as detailed below which suppresses the decay and staining-fungi attacks.

Manufacturing of Bamboo Composite Boards

For the shavings-boards, the green culms of *B. blumeana* and *D. asper* were cut into 2.44 meter using a pole cutter. Then, the culms were split into slats, denoded, and deskinned. Shavings were produced from the slats up to 0.6-meter length. The shavings were then cooked in NaOH-water solution in a vat (1.2 m x 1.2 m x 3 m) using the three concentrations by volume of water, i.e., 1%, 3%, and 5%. For 1%, the amount of NaOH flakes was 0.05 m^3, and water of 4.47 m^3. For the 3%, the NaOH flakes were 0.14 m^3, and water of 4.39 m^3. At 5%, the NaOH flakes were at 0.23 m^3 and water of 4.30 m^3. The shavings were restrained for complete immersion in the solution or at least 0.10 m above the level of the shavings. The shavings were cooked for 3 hours to remove the starch content and soften the lignin. The cooked shavings were washed thoroughly with tap water. The shavings were undergone roller pressing to defibrillate and to remove the water completely. The shaving was then sundried for three (3) weeks until the 14% MC was achieved. Ten-kilogram commercial glue (polyvinyl acetate) was manually and uniformly applied to the shavings using a roller brush and the mixture was evenly spread manually to the 0.30 m x 0.60 m x 2.44 m molder and was pressed at a constant pressure of 1000 psi for a minimum of 12 hours. Supposedly there should be at least three (3) pressing pressures such as 500, 800, and 1000 psi that will be conducted as part of the experimentation however initial test revealed that compaction of bamboo strands was not achieved for both 500 and 800 psi hence the 1000 psi was used. To achieve a uniform pressing, a metal plate was used to retain the pressure in each mold. The board created from pressing was cured in a rack for a minimum of 30 days to provide adequate time for the board to stabilize at equilibrium moisture content (EMC). After curing when the moisture was at 12 to 14%, the board was cut into the desired dimensions and was further dried in a kiln dryer for 12 hours followed by sanding and finishing operations. A total of 12 boards of *B. blumeana* (6) and *D. asper* (6) were prepared. The same set of processes in the production of shavings-board was employed except that the green culms were split and turned into long strips of about ≤3 mm thick.

Testing of Bamboo Composite Boards

Testing of strength properties such as tensile, bending, and compression was conducted using the Universal Testing Machine (UTM) in accordance with ASTM D-143-22 (i.e., testing of small clear specimens) . There were three (3) samples per board that was tested for each test with a total of 24 samples for all the treatment combinations.

Statistical Analysis

The data on bending, tensile, and compression strength of bamboo composites was analyzed using a 2x2x3 factorial experiment in CRD.

Result and Discussions

Factors Considered in Developing Composite Boards

Based on the result, all three factors (i.e., species, cooking solution concentration, and pressing pressure applied) influenced the production of both shavings-board and strip-board. In terms of species, *B. blumeana* exhibits toughness because boiling the vascular bundles at higher concentrations of NaOH (i.e., 5% by weight) was not able to substantially soften the material for both shavings and strips. This eventually affects the compaction during pressing because it limits the surface contact between the bundles creating void spaces or starved joints. According to Chen *et al*., (2020), the softening process is considered very helpful for easier subsequent processing with defibering as one of the necessary preconditions. Suffice to conclude that the softening of bamboo vascular bundles and eventually defibering could be species-specific. For instance, Chen *et al*., (2020) also found out that a better softening effect was obtained for Moso bamboo (*Phyllostachys edulis*) if the bundles were boiled at 3% by weight NaOH or Na_2CO_3. However, it should also be noted that there was no mention of the duration of the cooking time/ period. As observed, the softening of the bundles of *B. blumeana* was completely achieved when the cooking duration was extended up to 6 hours. For *D. asper*, the softening of vascular bundles was way easier. Based on the result, the higher the NaOH concentration in the cooking solution, the easier the vascular bundles to disintegrate hence more compact and dense boards with fewer void spaces or starve joints. The observed difference between these two species could be due to their specific gravity. According to Espiloy (1996), *B. blumeana* has a specific gravity that ranges from 0.644 to 0.694 at the butt (basal portion) to the top part of the pole hence considered the hardest and heaviest among the erect species in the Philippines. On the contrary, *D. asper* has relative densities that are almost 10% lower than of *B. blumeana* (Razal *et al*., 2012).

Finally, the most crucial factor in the production of both the shavings-board and strip-boards is the high pressing pressure to achieve compact, void-free, and dense boards that would resemble wood. In this case, the 1000 psi pressure used in this study was not sufficient to produce dense and compact boards thus exhibiting many void spaces or starve joints in the tangential, radial, and longitudinal planes of the board (Figs. 1a, b, c), contrary to the claims of Chung and Wang (2017) that a 100 kg/cm^{-2} (=1,422.33 psi) hot

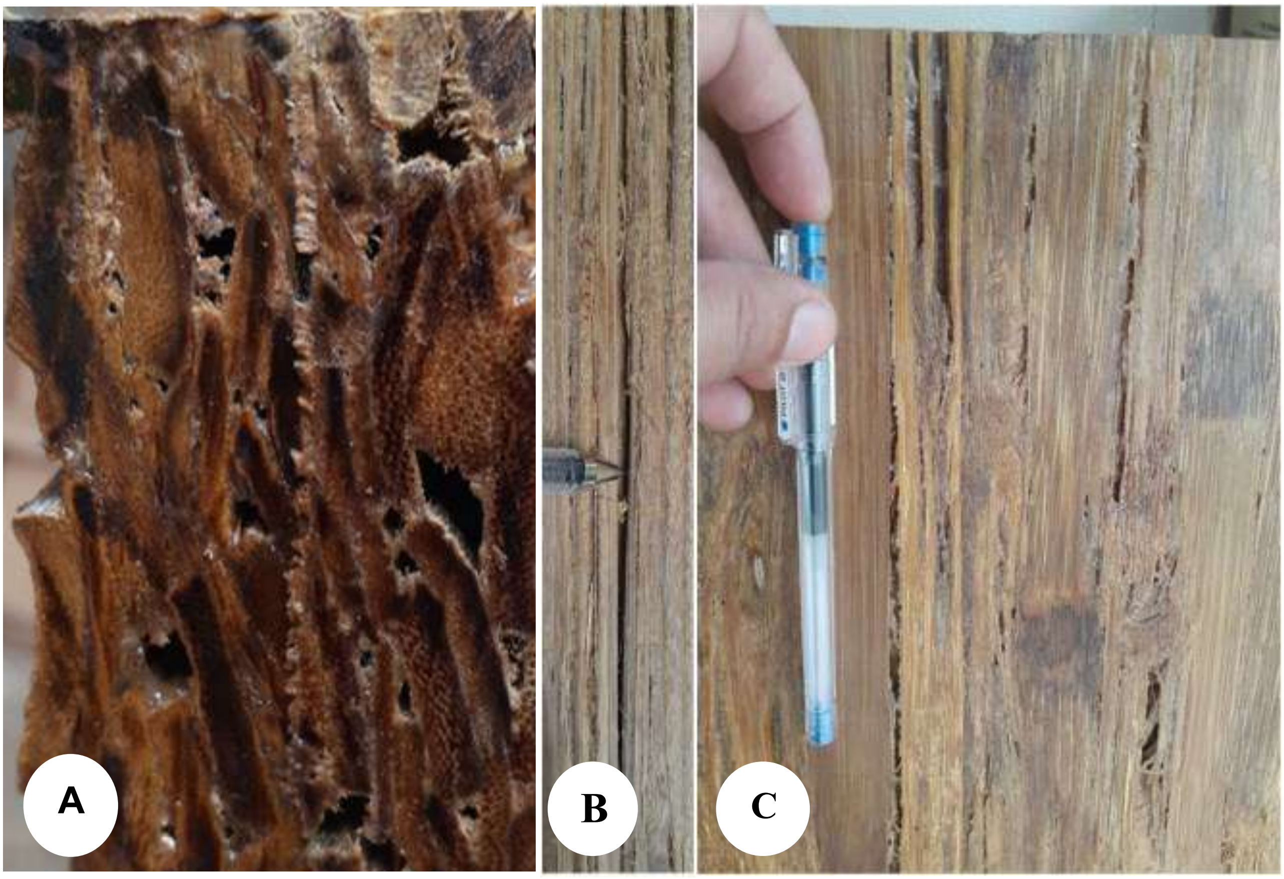

Fig 1. Void spaces or starve joints in the tangential (a); radial (b); and longitudinal planes (c) of the composite boards developed from *Bambusa blumeana* (*B. blumeana*).

pressing method could produce dense bamboo scrimber. The result of this study strongly agrees with that of Chen et al. (2020) who stressed that in the production of bamboo scrimber and similarly-related products, very high pressure of about 60–100 MPa or 8,702.26–14,503.8 psi was recommended because such pressure could produce very dense boards that could even exceed 1.2 g/cm3 (Yao, 2018).

Strength Properties of Composite Boards

Following ASTM D143-22, samples were prepared and undergo tensile strength parallel to the grain test. Combined tension and shear with splintering in the edges were the commonly observed failure modes in all composite boards. This type of failure occurs when there are voids between fiber contacts which serve as stress concentration when force is applied to the material. In the study of Wang *et al*. (2021) on bamboo scrimber, when tension force is applied, microscopic failures are concentrated on matrix fracture, interfacial debonding, and fiber fracture. The weak matrix in the composite served as the first stress concentration during tensile loading resulting in initial cracks. This is followed by the development of shear stress generating failures in the interfaces and later transferred to fibers resulting in fractures and consequently tension failure (Wang *et al*., 2021). At the macroscopic level, this was observed as the splintering of the composite board structure since the material is not that elastic to respond by straining when force is applied. Fibers are critical in restraining microscopic crack formation in the matrix but considering the composite internal structure of the material, the fiber-matrix interface is still prone to failures (Habibi & Lu, 2014; Liu *et al*., 2016; Wang *et al*., 2021).

The stress-strain curve showed a hard and strong behavior with low ductility performance, a typical property of wood/fiber based composite materials. Shown in Table 1 are the results of the tensile test (f_t) per factor combination. The average f_t was 41.6 MPa with a maximum value of 55.1 MPa and minimum value of 32.7 MPa. This mean value is higher than the 20 MPa f_t in glue-laminated bamboo as reported (Xiao *et al*., 2008). Analysis of variance revealed a highly significant difference in the three factors evaluated: species, boards (i.e., shavings and strips), and NaOH-water concentration (Table 2). Interaction between factors failed to influence the f_t of the composite.

Table 1. Mechanical properties of bamboo composite (at 13.9% average MC during testing)

Species	Board type	NaOH Conc.	Tensile Strength (f_T) (MPa)	Compression (f_c) (MPa)	Bending (f_b) (MPa)
D. asper	Shavings	1%	35.2	22.2	16.1
D. asper	Shavings	3%	35.6	26.8	16.2
D. asper	Shavings	5%	33.3	22.5	15.5
D. asper	Strips	1%	49.9	30.6	14.8
D. asper	Strips	3%	47.6	28.3	15.2
D. asper	Strips	5%	32.7	24.8	16.0
B. blumeana	Shavings	1%	40.0	36.6	16.0
B. blumeana	Shavings	3%	41.2	26.4	16.8
B. blumeana	Shavings	5%	38.6	30.0	15.7
B. blumeana	Strips	1%	41.0	40.2	15.6
B. blumeana	Strips	3%	48.6	29.8	15.5
B. blumeana	Strips	5%	55.1	36.5	16.2

Table 2. Two-way analysis of variance on the tensile strength parallel to grain of the composite boards

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1405.490[a]	10	140.549	4.117	.006
Intercept	35050.220	1	35050.220	1.027E3	.001
Species (S)	379.869	1	379.869	11.127	.004
Board type (B)	584.040	1	584.040	17.107	.001
Conc. of Cooking Solution (S)	99.418	2	49.709	1.456	.262
S * B	45.764	1	45.764	1.340	.264
S * C	128.962	2	64.481	1.889	.183
B * C	44.431	2	22.216	.651	.535
S * B * C	135.484	1	135.484	3.968	.064
Error	546.242	16	34.140		
Total	48381.793	27			
Corrected Total	1951.732	26			

Table 3. Mean values of tensile strength per species, boards, and NaOH concentration factor

Factor S	Mean f_t (MPa)	95% Confidence Interval	
		Lower Bound	Upper Bound
D. asper	37.6	27.968	49.856
B. blumeana	45*	31.488	60.576
Factor B			
Shavings	37.7	31.488	48.352
Strips	46.2*	27.968	60.576
Factor C			
1% NaOH Concentration	37.7	33.632	41.504
3% NaOH Concentration	42.9	31.808	52.768
5% NaOH Concentration	41.2	27.968	60.576

Presented in Table 3 are the mean values of f_t computed per each factor. Between the two species, results revealed that the composite boards develop from *B. blumeana* obtained a significantly higher f_t of 45 MPa than *D. asper* with only 37.6 MPa despite the numerous starved joints observed. This implies that *B. blumeana* boards could withstand pulling and has higher breaking strength than the boards produced from *D. asper*. However, our results contradict the study of Bauza *et al*. (2003) on the laminated panels developed from the *B. blumeana* and *D. asper* glued with both urea-formaldehyde (UF) and polyvinyl acetate (PVA) which exhibit no significant difference in terms of f_t. Although this present study slightly differs from that of Bauza *et al*. (2003) particularly on the softening and defibering of vascular bundles however, it is strongly recognize that the observed significant difference in the f_t could be due to the higher specific gravity of *B. blumeana* (0.813) over *D. asper* (0.751) contrary to that of Bauza *et al*., (2003) which reported that *D. asper* has a higher average specific gravity of 0.76 than *B. blumeana* with 0.69 only.

Moreover, between the shavings-board and strip-boards, the latter could resist more tension than the former with f_t of 46.2 MPa compared to 37.7 MPa in shavings -board. It also appears that concentration of solution during defibering also influences the board properties. Increasing the concentration of cooking solution improves the tensile properties as boards with shavings/ strips processed in 3% and 5% NaOH concentration yielded a significantly higher f_t of 42.9 MPa and 41.2 MPa, respectively compared to 37.7 MPa of boards processed in 1% NaOH concentration of cooking solution.

Compression Strength (f_c) parallel to grain

Compression Strength (f_c) parallel to the grain of composite boards was conducted following ASTM D143. Samples were prepared with a sample size of 25 x 25 x 100 mm based on the secondary method specimens of the standards. The f_c of bamboo composites showed an average of 29.6 MPa and ranges from 22.2 MPa to 40.2 MPa ultimate f_c (Table 1). This is relatively higher compared to the reported values of 25 MPa in glue-laminated bamboo (Xiao *et al*., 2008) but lower compared to the 70.5 MPa hot pressed scrimber bamboo as reported by Huang *et al.* (2019). Failure forms observed in both *B. blumeana* and *D. asper* are presented in fig. 2. Delamination failure occurs when stress during compression is concentrated

Fig 2. Failure forms of bamboo composite boards after compression test: A. Delamination/splitting failure; B. Splitting with buckling failure and C. Buckling failure

Table 4. Two-way analysis of variance on the compression strength parallel to grain of composite boards

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	916.001[a]	11	83.273	13.144	.001
Intercept	27097.228	1	27097.228	4.277E3	.001
Species (S)	437.407	1	437.407	69.041	.001
Board type (B)	153.106	1	153.106	24.167	.001
Conc. of Cooking Solution (C)	135.468	2	67.734	10.691	.001
S * B	1.101	1	1.101	.174	.681
S * C	198.256	2	99.128	15.647	.060
B * C	20.007	2	10.004	1.579	.231
S * B * C	20.903	2	10.451	1.650	.217
Error	126.709	20	6.335		
Total	28530.800	32			
Corrected Total	1042.709	31			

Table 5. Analysis of Variance on the Compression Strength for Species, Boards, and NaOH Concentrations

Factor S	Mean	95% Confidence Interval	
		Lower Bound	Upper Bound
D. asper	25.9	24.6	27.2
B. blumeana	33.4[a]	32	34.8
Factor B			
Shavings	27.4	26.1	28.7
Strips	31.9[a]	30.5	33.2
Factor C			
1% NaOH Concentration	32.6[a]	30.9	34.3
3% NaOH Concentration	27.8	26.2	29.4
5% NaOH Concentration	28.5	26.9	30.1

in contact points between fibers. During compression, the capacity of the boards to absorb the force applied is largely dependent on the stiffness of the fiber-matrix interface which acts as an "elastic foundation" restricting transverse deformation (Xu *et al*., 2017). When there are weak points in the fiber-matrix interface such as voids due to underdeveloped glue-fiber contact, the compression parallel to grain direction expands the voids resulting in the formation of defects and further splitting (Chen *et al*., 2020). The shearing action that occurs in the interface also results in the formation of failures such as buckling of fibers in the upper/lower section and splitting as shown in Fig 2.

Statistical analysis revealed that there was no interaction between factors that affected the f_c of composite boards (Table 4). Assessing the main effect showed that f_c between the two species was significantly different (Table 5). Conforming to the results in f_t, *B. blumeana* showed a higher f_c with 33.4 MPa compared to the 25.9 MPa in *D. asper*. The variations in the anatomical, physical, and mechanical properties of raw bamboo species are significant which could influence when bamboo is processed into composite materials (Huang *et al*. 2019). A similar observation was found by Xie *et al*. (2016) when bamboo is processed into bamboo-fiber bundle composite which emphasized that species should be taken into consideration when fibers are processed into a composite material. The *B. blumeana* has a higher average frequency (10-20 mm^{-1}) of vascular bundle compared to the *D. asper* (8-16mm^{-1}) but fiber length, fiber diameter, and fiber wall thickness were comparatively lower (Siam *et al*., 2019). Thus, a more detailed assessment of their inherent anatomical properties is necessary.

The difference between shavings-board and strip-board was also significant. Consistent with the tensile strength, the strip-board attained a higher f_c of 31.9 MPa compared to the 27.4 MPa f_c in the shavings-board. The concentration of cooking solution during defibering also influenced the f_c of bamboo composite boards. Tukey HSD analysis revealed that boards treated with 1% NaOH concentration of cooking solution obtained 32.6 MPa f_c which was significantly higher compared to 3% and 5% NaOH concentration treated boards having 27.8 MPa and 28.5 MPa, respectively (Table 5).

Fig 3. Bending failure modes observed in composite boards. (A) excessive compression failure in the upper-side, (B) Cross grain tension, and (C) Splintering tensions

Table 6. Two-way analysis of variance on the bending strength of composite boards

Source	Type I Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9.089[a]	10	.909	.948	.509
Intercept	8369.840	1	8369.840	8.734E3	.001
Species (S)	.199	1	.199	.208	.653
Board type (B)	2.611	1	2.611	2.725	.111
Conc.of Cooking Solution (C)	1.408	2	.704	.735	.490
S * B	.013	1	.013	.013	.909
S * C	.721	2	.361	.376	.690
B * C	4.992	2	2.496	2.605	.094
S * B * C	.013	1	.013	.013	.909
Error	23.957	25	.958		
Total	9012.601	36			
Corrected Total					

Table 7. Mean values of bending strength per species, boards, and NaOH concentration factor

Factor S	Mean	95% Confidence Interval	
		Lower Bound	Upper Bound
D. asper	15.6	15.1	16.1
B. blumeana	16	15.5	16.5
Factor B			
Shavings	16	15.6	16.5
Strips	15.5	15	16
Factor C			
1% NaOH Concentration	15.6	14.9	16.2
3% NaOH Concentration	15.9	15.3	16.5
5% NaOH Concentration	15.8	15.3	16.4

Bending strength (f_B) perpendicular to grain

A bending strength test (f_B) of composite boards was also performed to evaluate the flexural performance of slats under load conditions perpendicular to the grain. Samples were prepared with a secondary method size of 25x25x410 mm. The mean f_B obtained was 15.8 MPa with a minimum range of 14.8 MPa and a maximum range of 16.8 MPa. The f_B is a critical test for composite boards especially when the material is applied to structural members such as beams. Furniture applications such as tabletop also rely on the bending strength properties. Common failure modes observed in the composite boards are shown in Fig 3. Excessive compression in the upper-side results in failure (Fig. 3A) which later shows delamination in the lower side upon reaching the modulus of rupture. Cross-grain failure was also observed (Fig. 3B) exhibited by the formation of diagonal cracks from the lower side to the upper side of the boards. Splintering (Fig. 3C) is readily observed in all samples as tension force in the lower side induces splintering of fibers. Delamination occurs after splintering as cracks expand inducing a shearing force in the interface between fibers strips/ shavings.

Analysis of variance revealed no significant difference between the f_B properties of composite boards (Table 6). There was no significant interaction found between factors and the main effect did not show significant results. This implies that species, board type, and concentration of cooking solution did not affect f_B properties. Arithmetically, *B. blumeana* has a higher mean f_B than *D. asper* (Table 7). Although not significant, the mean f_B between board types was not consistent with other properties. Although not significant, shavings showed higher mean bending strength compared to strips. This may be attributed to the flatter surface contact and relatively non-defibered structure of shavings oriented at random directions which withstands multiple stresses when bending force was applied. A more detailed investigation towards understanding the structure of matrix interface in shavings and strips is also suggested.

In general, *D. asper* may outweigh *B. blumeana* in terms of ease of processing, cost of production, availability of raw materials, and compaction. Since *D. asper* is relatively "softer" than *B. blumeana*, processing the raw materials is straightforward hence much lower energy consumption from pole cutting to pressing. Moreover, *D. asper* is widely available in the province of Bukidnon while *B. blumeana* has limited supply due to improper harvesting and lack of silvicultural treatments on stand regeneration. However, in terms of strength properties, *B. blumeana* is much better compared to *D. asper* as revealed in the test conducted. Talabgaew and Laemlaksakul (2007) recommend the use of *D. asper* over *B. blumeana* in the production of glue-laminated composite boards because of high MOR and MOE.

Conclusions

The most important factor affecting the production of the composite boards is the pressing pressure. The highest pressure applied in this study (i.e., 1000 psi) was not enough to produce void-free boards across all planes. Moreover, although there was a significant result on the variation of concentration of NaOH in cooking solution in the tensile strength, the influence of such factor is not the apparent. Defibering may be accomplished even at a 1% solution of NaOH. The variation in the board type (strip vs. shaving) has a huge impact on the compressive and tensile performance of the composite boards. In general, the production of composite boards from defibered *B. blumeana* and *D. asper* was feasible, however, between the two, the latter could be the ideal species given the abundance and ease of processing although its strength properties are slightly lower compared to the former, particularly in tensile and compressive strength. Moreover, *B. blumeana* is more costly on a per pole basis compared to *D. asper*. The difficulty in harvesting due to the presence of thorns requires additional cost hence higher the price and since *B. blumeana* has higher specific gravity, the processing is more arduous. We conclude that the production of composite boards using the two species and board type is feasible but requires the high pressure necessary to produce void-free, well-compacted, and dense boards with higher material strength.

References

Bauza, E., Natividad, R.A., and Palisoc, J.G. 2003. Development of Laminated Panels from Bamboo Slats. *FPRDI Journal 29 (1&2):* 52–61.

Chaowana, P. 2013. Bamboo: An Alternative Raw Material for Wood and Wood-Based Composites. *Journal of Materials Science Research. 2(2):* 90–102.

Chen, J., Guagliano, M., Shi, M., Jiang, X., & Zhou, H. 2021. A comprehensive overview of bamboo scrimber and its new development in China. *European Journal of Wood and Wood Products*, 79(2), 363-379.

Chew, LT, Rahim, S, and Jamaludin, K. 1992. *Bambusa vulgaris* for urea and cement-bonded particleboard manufacture. Journal Tropical Forest Science, 4(3), 249–256.

Chung, M., and Wang, S. 2017.Mechanical properties of oriented bamboo scrimber boards made of *Phyllostachys pubescens* (moso bamboo) from Taiwan and China as a function of density. Holzforschung 72(2), 151-158.

Espiloy, Z.B. 1996. Properties and Utilization of Philippine Bamboos. FPRDI Research Chair Paper presentation, 04 Jul 1996.

Habibi, M.K., and Lu, Y. 2014. Crack propagation in bamboo's hierarchical cellular structure. Scientific reports, 4(1), 1–7.

Huang, Y., Ji, Y., and Yu, W. 2019. Development of bamboo scrimber: A literature review. *J. Wood Sci. 65(1):* 1–10.

Liu, H., Wang, X., Zhang, X., Sun, Z., and Jiang, Z. 2016. In situ detection of the fracture behaviour of moso bamboo (*Phyllostachys pubescens*) by scanning electron microscopy. *Holzforschung. 70(12):*1183–1190.

Manalo AC, Wani E, Zukarnain NA, Karunasena W, Lau KT. 2015. Effects of alkali treatment and elevated temperature on the mechanical properties of bamboo fiber-polyester composites. *Compos Part B Eng* 80:73–83

Mohanty, B.N., Sujatha, D., and Uday, D.N. 2015. Bamboo Composite material: Game-changer for developing economies. *10th World Bamboo Congress.*

Muhammad, A., Rahman, M., Hamdan, S., & Sanaullah, K. 2018. Recent developments in bamboo fiber-based composites: a review. *Polymer bulletin*, 76, 2655-2682.

Nugroho, N., & Ando, N. 2000. Development of structural composite products made from bamboo I: fundamental properties of bamboo zephyr board. *Journal of wood science*, 46, 68-74.

Razal, R.A., Dolom, P.C., Palacpac, A.B., Villanueva, M.M.B., Camacho, S.C., Alipoon, M.B., Bantayan, R.B., and Malab, S.C. 2012. Mainstreaming Engineered -Bamboo Products for Construction and Furniture. *Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development and Forestry Development Center, University of the Philippines Los Baños*. Pp 157.

Siam, N.A, Uyup, M.K.A., Husain, H., and Awalludin, M.F. 2019. Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species. *BioRes. 14(2):* 3925–3943.

Talabgaew, S., and Laemlaksakul, V. 2007. Experimental Studies on the Mechanical Property of Laminated Bamboo in Thailand. *World Academy of Science, Engineering, and Technology*, 34.

Sharma, B., Gatoo, A., Bock, M., Mulligan, H., & Ramage, M. 2015. Engineered bamboo: state of the art. *Proceedings of the Institution of Civil Engineers-Construction Materials*, 168(2), 57-67.

van der Lugt P. 2008. Design Interventions for Stimulating Bamboo Commercialization: Dutch Design meets Bamboo as a Replicable Model. VSSD, Delft, the Netherlands.

Wang, M.T., Cai, X.F., Lu, Y.B., Noori, A., Chen, F.M., Chen, L.B., and Liu, J.Q. 2021. Tensile mechanical properties and failure mechanism of bamboo scrimber under different strain rates. *Construction and Building Materials, 299*: 124-258.

Xiao, Y., Shan, B., Chen, G., Zhou, Q., and She, L.Y. 2008. Development of a new type Glulam—GluBam. *In: Xe, Y., et al. (eds.)* Modern Bamboo Structures. CRC, Changsha.

Xie, J., Qi, J., Hu, T., Cornelis, F., Hse, C.Y., and Shupe, T.F. 2016. Effect of fabricated density and bamboo species on physical–mechanical properties of bamboo fiber bundle reinforced composites. *J. Materials Sci. 51(16),* 7480–7490.

Xu, M., Cui, Z., Chen, Z., and Xiang, J. 2017. Experimental study on compressive and tensile properties of a bamboo scrimber at elevated temperatures. *Construction and Building Materials,* 151: 732–741.

Yao, Y. 2018. Current status of bamboo scrimber industry in China. *International Wood Industry,* 48:58–62.