Development and characterization of bioboards from Abura sawdust using response surface methodology

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Abstract: Particleboards and fibreboards are commonly produced using synthetic binders which are harmful to humans and the environment. Replacing synthetic-based particleboards with renewable alternatives, such as binderless boards, are safer and promote circular economy. The best processing parameters need to be determined in order to produce high quality binderless boards from biomass materials. Limited studies exist on the use of abura wood for production of biodegradable boards. This study developed empirical models to predict physicomechanical characteristics of biodegradable boards produced from abura (*Mitragyna ciliata*) sawdust using a laboratory hot press. The independent variables were pressure (10-16 MPa), temperature (100°C -170°C) and pressing time (5-15 min). Regression models were suitable to predict the density (R^2 = 82.12%), Modulus of Rupture, MOR (R^2 = 82.59%), Modulus of Elasticity, MOE (R^2 = 68.55%), and Internal Bonding strength, IBS (R^2 = 71.16%) of the bioboards. From the results, pressure and temperature significantly determined the density and MOE of abura sawdust bioboards. The interaction between pressure and temperature was significant to MOE. The highest values of the density, MOR, MOE and IBS were 699.2 kg m^{-3}, 1.1 MPa, 100.4 MPa and 0.049 MPa, respectively. This study found that pressure of 16 MPa, pressing temperature of 170°C, and pressing time of 15 min resulted in the highest values of density, MOE, MOR and IBS. The findings from this study are useful in understanding and improving the manufacturing process of bioboards.

Keywords: Binderless biodegradable board; abura sawdust bioboard; modulus of elasticity; modulus of rupture; internal bonding strength; regression model

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1 Introduction

Particleboards and fibreboards have several uses which include their utilization in the construction of furniture, soundproofing and insulation. They are often made from particles and fibres from wood or other lignocellulosic materials which are bonded together by

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synthetic resins. The synthetic resins often contain formaldehyde which is produced from non-renewable sources (Vitrone et al., 2021). Formaldehyde is also carcinogenic making them harmful to humans (Khoshakhlagh et al., 2024). The replacement of the synthetic binders with bio-based alternatives seems viable and has been investigated by some researchers. However, there is a possibility of producing boards without the use of binders and this is also being exploited and studied to promote circular economy principles.

A procedure for production of board materials with improved strength and density from coconut husks without using synthetic binders was developed by Van Dam et al. (2004). The study investigated the influence of pressing conditions on the mechanical properties of the board and it was found that the maximum strength and stiffness were achieved at 180°C but the pressing force (300-750 kN) and pressing times (3-30 min) had less influence on the mechanical properties. The boards produced by Van Dam et al. (2004) had strength of 50 MPa, stiffness of 5 GPa, and density between 1.3-1.4 g cm^{-3}. Böger et al. (2018) produced binderless board from milled coconut husks with living fibre lengths between 5 and 20 mm using degassing step. It was noted that a moisture content between 10% and 25% was suitable for binderless board production with the boards having a density range between 900 and 1000 kg m^{-3}.

Zhang et al. (2016) produced biodegradable boards from rice straw and observed that rupture stress increased to a value of 18.50 MPa at elevated pressing temperature of 190°C. The density of boards was between 830 and 910 kg m^{-3}. Kurniati et al. (2015) evaluated the effect of temperature on the physicomechanical characteristics of binderless castor seed cake particleboards. The study noted that a big portion of the chemical components of castor seed cake were proteins, fibres and lignin which strongly contribute to self-bonding and provide adhesion in bioboards. It was observed that, with an increase in pressing temperature from 150°C to 190°C, modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IBS) tended to increase whilst water absorption (WA) and thickness swelling (TS) reduced. The best properties of the binderless particleboard were obtained at 170°C with MOR of 3.17 MPa, MOE of 244.45 MPa, IBS of 0.23 MPa, WA of 76.54%, and TS of 29.51%.

Ferrandez-Garcia et al. (2022) produced boards from olive tree pruning waste, about 5.95 mm thick, with densities of 887.8 kg m^{-3} and 936.3 kg m^{-3} using shredded and whole leaves, respectively. The boards, which were alternatives for thermal insulation, had satisfactory TS, WA and thermal conductivity. Hashim et al. (2012) investigated the physicomechanical characteristics of panels produced using different oil palm biomass without using adhesives. Panels produced using bark and leaves had insufficient strength and low dimensional stability while boards produced using the core had the highest MOR and IBS but the lowest TS and WA.

Xie et al. (2012) manufactured binderless fibreboards from defibrated poplar fibre. It was observed from the study that MOE, MOR, IBS and density improved, but TS decreased, as pressure, temperature and moisture content increased. Wu et al. (2015) developed bioboards from corn straws and investigated the influence of pressure on strength of boards. Density of bioboards ranged between 0.87 and 1.02 g cm^{-3} and it was established that the static toughness increases with an increase in pressure. Orisaleye et al. (2022a) studied the effect of pressure (10 and 16 MPa), time (5 and 15 min), temperature (100°C and 160°C) and particle size (less than 2.5 mm and greater than 2.5 mm) on the properties of bioboards made from corncob. The particle size was found to be the most influential variable for determining the density, MOR, MOE and IBS with the smaller particle sizes (less than 2.5 mm) resulting in better bioboard quality.

Mawardi et al. (2022) studied thermal and sound insulation characteristics of oil palm wood panels which had flexural strength ranging from 4.21 and 8.18 MPa. The study found that coarse particle size improved thermal and sound resistance but decreased density, water resistance and flexural strength. It was shown that the pressing time was not significant. Jerman et al. (2022) developed binderless boards from rape straw. The study established the steaming temperature for the optimum combinations of mechanical, moisture resistant and thermal properties of the boards. Domínguez-Robles et al. (2020) produced binderless boards from wheat straw residue. The physical and mechanical properties of the boards which were comparable to commercially available fibreboards. The study found that the mechanical performance of the wheat straw boards in wet conditions was better than the commercial fibreboards.

Boon et al. (2013) evaluated properties of experimental binderless particleboards produced from oil palm trunks reduced to particle size of 2 mm with a moisture content of 10%. The particleboards were produced using a mold press with temperatures between 160°C and 180°C, pressing times of 15 and 20 min and pressure of 5 and 10 MPa the mean density of the boards was between 0.62 and 0.65 g cm^{-3} and it was observed that increasing pressure, duration of hot pressing and pressure improved the properties of specimens. Xu et al. (2003) developed binderless particleboards from kenaf core using a steam injection press and produced boards with densities between 0.40 and 0.70 g cm^{-3}. At optimum conditions, the density, MOR, MOE and IBS were 12.6 MPa, 2.5 GPa and 0.49 MPa.

Abura is a tropical hardwood that is grown in Nigeria and is known to be a structural material used for timber bridge beams (Aguwa, 2013). Abura has low lignin content ranging between 19.0% and 21.5% compared to some other hardwoods available within the region (Ndukwe et al., 2012). Abura wood resources have been used for energy purposes such as the production of biomass briquettes (Orisaleye, 2019; Orisaleye et al., 2022b) and as fuel cookstoves (Akuma and Emma, 2017). Recently, a preliminary study on the utilization of abura for bioboards was carried out by Orisaleye et al. (2023). Jekayinfa et al. (2020) and Ojolo et al. (2012) noted that a large portion of forestry resources become residues.

Vitrone et al. (2021) stated that the choice of raw materials was influential on the characteristics of binderless boards in terms of mechanical, physical and thermal properties. In order to produce high quality binderless boards, the best processing parameters also need to be determined (Ahmad et al., 2019). Tajuddin et al. (2016) also opined that more study is required as regards the manufacturing process of binderless boards. Moreover, Abiodun et al. (2019) noted that there should be a continuous improvement of innovative materials from which eco-friendly benefits are derived. Hence, there is a need to eliminate harmful additives that are included during the manufacturing processes of particleboards and fibreboards.

In addition, there is a need to conduct investigations on various potential materials for manufacturing bioboards and optimizing their properties. Ojolo et al. (2012) report that a log in a sawmill generates about 10% of the timber as sawdust and 20% to 30% as wood chips. A huge quantity of sawdust is, therefore, produced from the logging process and they mostly constitute pollution sources due to inadequate disposal. Limited studies have been carried out on abura wood or by-products for materials development despite its availability, therefore, the possibility of utilizing it for manufacturing bioboards needs to be investigated. This study, therefore, aims to develop empirical models to predict the properties of biodegradable boards made from abura (*Mitrogyna ciliata*) sawdust without pretreatment using an experimental hot press.

2 Materials and methods

2.1 Material collection and characteristics

Abura sawdust used in this study was obtained from Oko Baba sawmill in Lagos State, Nigeria, which was the by-product of the logging process. The abura sawdust was air-dried in the laboratory at 28°C – 32°C for three months to attain a moisture content of 14.84% to fall within the permissible range of 5% – 20% specified by Nasir et al. (2019). The sawdust was sieved through a 9.5 mm sieve to remove unwanted and large materials and stored in jute bags for 5 days before the production of the bioboard. The sawdust had median particle size, D50, of 0.8 mm and geometric mean diameter of 1.18 mm with 90% of the particles less than 3.0 mm.

2.2 Hot press for bioboard production

The laboratory scale press used to press the sawdust particles into bioboards was designed to exert a maximum force of 150 kN and was fabricated in the engineering workshop of the University of Lagos, Nigeria. The pressing pressure is delivered using an instrumented hydraulic jack which delivered pressures up to 30 MPa. The press, presented in Figure 1, works on the principle of hot pressing to produce boards with dimensions of 200 × 100 mm. The pressing chamber has a length of 200 mm, width of 100 mm, and depth of 200 mm. A temperature controller regulated the temperature of the heating plates.

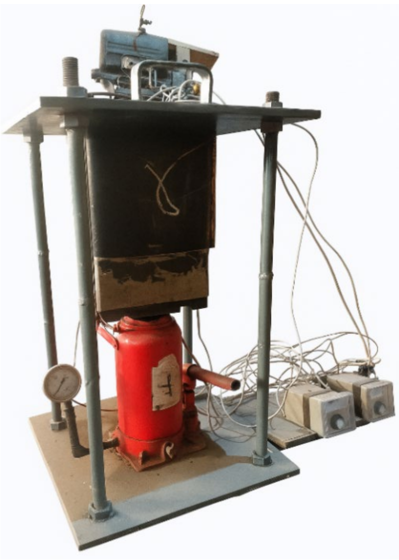


Figure 1 Hot press developed for bioboard production

2.3 Design of experiments

During this study, pressure, pressing temperature and pressing time were varied. To determine the appropriate range of parameters which would be suitable for pressing the abura sawdust into boards, preliminary experiments were carried out to determine the lower limits of the pressure, temperature and hold time. The lower limits were determined as the pressing parameters from which a board that retains its form and shape after ejecting from the press is formed. The upper limit of temperature was taken to be below the temperature at which the biomass begins to char (200°C) and the upper limit of the pressure was determined from the capacity of the hot press. The effects of the variables on the characteristics of abura sawdust binderless boards were determined using response surface methodology (RSM) which adopts a Box-Behnken design of experiments (DOE). The DOE was done using Design Expert (Version 13) and is presented in Table 1.

2.4 Production of Abura sawdust bioboards

Boards with surface dimensions of 200 × 100 mm were produced using the developed experimental hot mould press in Figure 1. Firstly, the temperature controller was adjusted to the required temperature between 100°C and 170°C and the heaters were powered on. After the required temperature was reached, sieved sawdust was fed into the pressing chamber and enclosed by the heated pressing plates. The lower pressing plate was then moved to compress the enclosed sawdust by operating the hydraulic jack until pressure between 10 and 16 MPa was reached which was read from the gauge attached to the hydraulic jack. The hot press was then allowed to stand for pressing time of 5 to 15 minutes. Thereafter, the board was ejected from the pressing chamber enclosure and allowed to cool.

2.5 Characterization of Abura sawdust bioboards

To determine the quality of the binderless bioboards produced using the hot press with the variables specified in Table 1, some characteristics were determined. The physical property considered was the density, which determined the degree of compaction of the bioboards. The mechanical properties include the IBS, MOR and MOE which were determined using the methods described in the ASTM D1037 standard. Average values of two specimens were used as representative values of the properties. Thirty boards, with a target density of 600 kg m^{-3} and nominal thickness of 7 mm, were produced with 2 bioboards produced for each run in the experimental design. Whole boards were used to determine the density whilst prepared specimens from the boards were used to determine the mechanical properties of the boards.

Table 1 Box-Behnken DOE for the production of abura sawdust bioboards

Run order	Pressure (MPa)	Temperature (°C)	Time (min)
1	13	100	5
2	10	170	10
3	13	135	10
4	10	100	10
5	13	170	15
6	13	170	5
7	16	135	5
8	13	100	15
9	13	135	10
10	13	135	10
11	16	170	10
12	10	135	15
13	16	100	10
14	16	135	15
15	10	135	5

2.5.1 Density

The length, breadth and depth of the biodegradable boards were measured with a vernier calliper. The mass of each board was measured using a digital weighing scale. The density of each of the abura sawdust bioboard was then estimated as the mass per unit volume of the board using Equation 1. The average density of 2 bioboards with dimensions 200 × 100 × thickness (mm), produced using the same set of variables in an experimental run, was utilized as representative density for the bioboards.

$$Density\ ({}^{kg}/_{m^3}) = \frac{mass}{length \times breadth \times thickness} \qquad (1)$$

2.5.2 Determination of mechanical properties

The MOE, MOR and IBS of the bioboards were obtained from static flexural tests using Instron Machine (Series 3369) following ASTM D1037. For the experiment, the specimens for the MOE and MOR were cut to a width of 50 mm and the support span was 65 mm, while for the IBS the specimens were cut to width of 50 mm and effective length of 60 mm.

The MOE determines the capability of the bioboard to resist bending. The MOE was estimated from the gradient of the linear section of the force-deflection curve obtained during a flexural test. As stated in ASTM D1037, the MOE was estimated using:

$$MOE(MPa) = \frac{L^3}{4bd^3}\frac{\Delta P}{\Delta y} \qquad (2)$$

Where,

$\Delta P/\Delta y$ is the gradient of the linear section of the force-deflection curve (N mm^{-1});

L is the length of the supported span(mm);

b is the breadth of bioboard (mm) and d is the depth of bioboard (mm).

The MOR is the ultimate bending stress of the board. The MOR is used as a measure of comparison of the suitability of different materials for an application. From the ASTM D1037, the MOR is estimated using:

$$MOR\ (MPa) = \frac{3P_{max}L}{2bd^2} \qquad (3)$$

Where, P_{max} is the maximum bending force (N).

Tension test of the boards determines their cohesiveness in the direction perpendicular to the plane of the board. Tensile strength determines the capability of the board to resist failure under tension applied in a direction perpendicular to the plane of the bioboard. The IBS was determined from:

$$IBS\ (MPa) = \frac{P_{max}}{bL} \qquad (4)$$

2.6 Statistical analysis

Analysis of Variance (ANOVA) was utilized to identify variables, and their interactions, which were significant to the quality parameters of the bioboards. Backward elimination was performed on a full quadratic model to exclude insignificant variables to enhance the quality of the empirical models developed. The predictive capability of the models was checked by comparison with experimental observations.

3 Results and discussion

The average responses of specimens from each board produced per run obtained from utilizing the Box-Behnken DOE (Table 1) are shown in Table 2 for density, MOR, MOE and IBS. The ANOVA parameters for density, MOR, MOE and IBS of abura sawdust bioboards is presented in Table 3.

Table 2 Experimental results for abura sawdust bioboards

Run Order	Density (kg m^{-3})	MOE (MPa)	MOR (MPa)	IBS (MPa)
1	569.0	20.33	1.10	0.011
2	539.4	36.78	0.73	0.029
3	563.7	0.01	0.39	0.000
4	591.8	34.21	0.67	0.024
5	550.7	39.68	0.70	0.028
6	541.2	59.13	0.70	0.038
7	658.6	12.20	0.60	0.009
8	637.7	0.01	0.48	0.000
9	617.1	3.26	0.63	0.004
10	609.5	18.99	0.48	0.028
11	625.8	100.40	0.27	0.049
12	561.1	21.37	0.40	0.014
13	699.2	73.44	0.40	0.043
14	655.4	84.16	0.75	0.041
15	594.2	37.21	0.77	0.028

3.1 Density of abura sawdust bioboards

The density which is affected by several parameters could vary during pressing (Mitchual et al., 2020). From Table 2, the average density of the manufactured biodegradable boards from abura sawdust range between 539.40 and 699.20 kg m^{-3}. ANOVA parameters for density of abura sawdust bioboards is presented in Table 3, and it can be seen that pressure and pressing temperature are statistically significant ($p < 0.05$) to density of abura sawdust bioboards. Pressure is important to push the particles together to enhance improved compaction and consequently increase the density whilst the temperature is required for internal bonding of the binderless boards. Pressing time is not significant to the density and have been eliminated to improve the analysis. The lack of significance of the pressing time might have resulted from insufficient time to allow bonding of particles, or due to the low level of internal bonding of sawdust used for the production of the bioboard. The interaction terms are not significant to the density of abura sawdust bioboards which signifies that the effect of one variable on the density is not determined by any other variable. From the analysis of main effects using fitted means, the highest density was obtained at the highest pressing pressure of 16 MPa and at the lowest temperature of 100°C. The pressure, however, has a greater effect on the density than the temperature. Based on the terms presented in the ANOVA for the density of the boards, Equation 5 adequately represents the relationship between the terms and the density of abura sawdust boards. The coefficients of regression, R^2 and adjusted R^2, of the model are 82.12% and 77.25%, respectively.

$$Density = 1101.80 - (76.48 \times P) - (0.86 \times T) + (3.51 \times P^2) \quad (5)$$

Where, P is the pressure and T is the pressing temperature.

Predicted responses are compared with the experimentally obtained responses in Figure 2. The predicted responses obtained from the model and the observed values from experimental runs are close. Figure 3 shows surface plots for the density of abura sawdust bioboards. The plots show that high pressures are required for high density bioboards. It is deduced from the plots that the pressure has more effect on the density than the pressing temperature, as was observed from the main effects. The highest density was obtained at 100°C which was the lowest temperature used in the study. This is probably due to the lower effect the temperature has on the density of the boards as densities are in close range for different settings of pressure.

The density of the abura sawdust bioboards obtained from this study fell within the range of 400 to 900 kg m^{-3} specified by JIS A 5908 (2003) and is also comparable to densities obtained from other studies. For instance, Saad et al. (2020) obtained densities ranging between 0.72 and 0.78 kg m^{-3} for boards produced from trees pine bark and oil palm empty fruit bunches. Unlike findings on the abura sawdust bioboards, Ferrandez-Garcia et al. (2022) found that pressing time and temperature were significant in determining the density of olive tree bioboards which ranged between 887.8 and 936.3 kg m^{-3}. Whilst for abura sawdust pressing time was not significant to density, Orisaleye et al. (2022a) found that pressure, pressing time and temperature were all significant determinants of the density of corncob bioboards which had values between 565.5 and 827.3 kg m^{-3}. Boon et al. (2013) had mean density of oil palm trunk binderless particle board ranging between 0.62 and 0.65 g cm^{-3}.

3.2 Modulus of elasticity of abura sawdust bioboards

The average MOE of binderless abura sawdust bioboards reached 100.4 MPa as seen in Table 2. During the flexural test, it was observed that some of the samples could not withstand applied stress and failed with application of low load levels. This is evidenced by the nearly flattened nature of the stress strain curve visualized from the analysis while other samples had bell-shaped curves where the maximum flexural stress was obvious. The significant terms ($p <$ 0.05) to the MOE are pressure, the interaction between the pressure and pressing time, together with square terms of pressure and temperature. At a lower confidence level of 90%, the pressing temperature is significant ($p <$ 0.1) to the MOE mainly because it activates the internal bonding components of the sawdust. The ANOVA shows that the pressing time is not significant ($p >$ 0.1) in determining the MOE of the abura bioboards.

Table 3 ANOVA parameters for density, MOE, MOR and IBS of abura sawdust bioboards

Term	Parameter	Density	MOE	MOR	IBS
Model	Df	3	6	6	6
	F-value	16.84	6.32	2.91	3.29
	p-value	0.0002	0.0102	0.0825	0.0616
	R^2	0.8212	0.8259	0.6855	0.7116
	Adjusted R^2	0.7725	0.6953	0.4497	0.4953
Pressure	Df	1	1	1	1
	F-value	29.63	8.48	1.59	2.14
	p-value	0.0002	0.0195	0.2431	0.1815
Temperature	Df	1	1	1	1
	F-value	13.80	5.00	0.3282	4.22
	p-value	0.0034	0.0558	0.5825	0.0739
Time	Df	-	1	1	1
	F-value	-	0.1146	3.71	0.0087
	p-value	-	0.7427	0.0904	0.9279
Pressure × Temperature	Df	-	-	-	-
	F-value	-	-	-	-
	p-value	-	-	-	-
Pressure × Time	Df	-	1	1	1
	F-value	-	6.61	2.84	4.10
	p-value	-	0.0331	0.1304	0.0774
Temperature × Time	Df	-	-	1	-
	F-value	-	-	4.04	-
	p-value	-	-	0.0794	-
(Pressure)^2	Df	1	1	-	1
	F-value	7.09	12.53	-	6.35
	p-value	0.0221	0.0076	-	0.0358
(Temperature)^2	Df	-	1	-	1
	F-value	-	6.40	-	3.55
	p-value	-	0.0352	-	0.0964
(Time)^2	Df	-	-	1	-
	F-value	-	-	4.94	-
	p-value	-	-	0.0569	-
Lack of Fit	Df	9	6	6	6
	F-value	0.5455	3.44	1.83	0.4163
	p-value	0.7851	0.2423	0.3953	0.8287

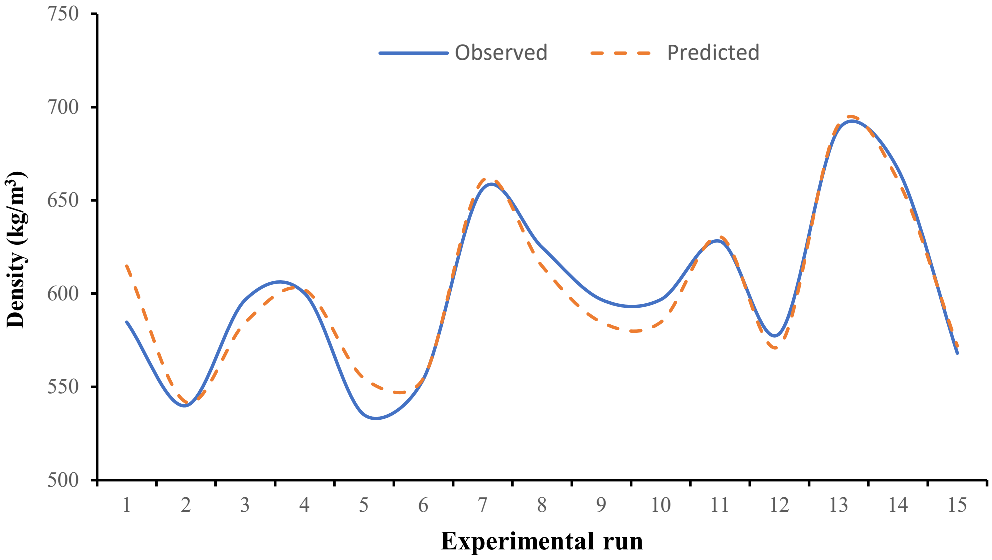


Figure 2 Comparison of experimental and predicted density of abura bioboards

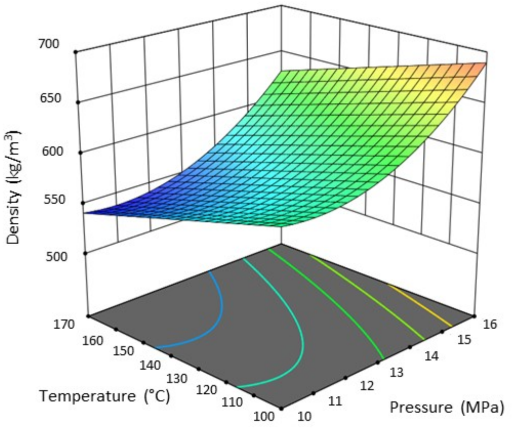


Figure 3 Surface plot for density of abura sawdust bioboards to observe the effect of pressure and temperature

The study of the main effects using fitted means show that the highest mean of MOE was obtained at the highest pressure, temperature and time. It was realized that the pressure had the highest main effect on the MOE of the abura sawdust bioboards whilst the time had the least effect. From the terms in the ANOVA for MOE of abura sawdust bioboards, the model is significant and is stated in Equation 6. The model which contains the terms in the ANOVA in Table 3 has an R^2 of 82.59%, and an adjusted R^2 of 69.53%.

$$\boldsymbol{MOE = 987.99 - (99.40 \times P) - (4.56 \times T) - (18.61 \times t) + (3.49 \times P^2) + (0.02 \times T^2) + (1.46 \times P \times t)} \quad (6)$$

Where, P is the pressure;

t is the pressing time;

T is the pressing temperature.

Figure 4 compares the results of experimental runs with predicted values obtained from the empirical model. The model is seen to be a good predictor of the MOE. The surface plots for the MOE are presented in Figure 5. The highest values of MOE were obtained with the settings of 16 MPa, 170°C and 15 min. In addition to this, the pressing time did not have as much effect on the MOE as the pressure and temperature. At lower pressure and temperature, the pressing time did not have an effect on the MOE of the abura sawdust bioboards.

Mitchual et al. (2020) noted that, according to ANSI A202.1 (1999), the minimum value for the MOE of particleboards was 1550 MPa when used for furniture production and general application. The binderless boards from abura sawdust produced had MOE of 100.4 MPa and do not meet up with this standard. The limited quantity of lignin as noted by Ndukwe et al. (2012), being a major internal binding component in abura could be the reason for the lack of significance of the pressing time. It is opined that more internal binding components can be made available for better binding of the particles by pretreatment methods such as steam treatment to allow a more efficient utilization of the internal binding components. However, noting that the lignin quantity is low, there may be the need to utilize biodegradable binders from other sources. Another method considered suitable is the production of boards from composite materials where one of the materials would be rich in lignin.

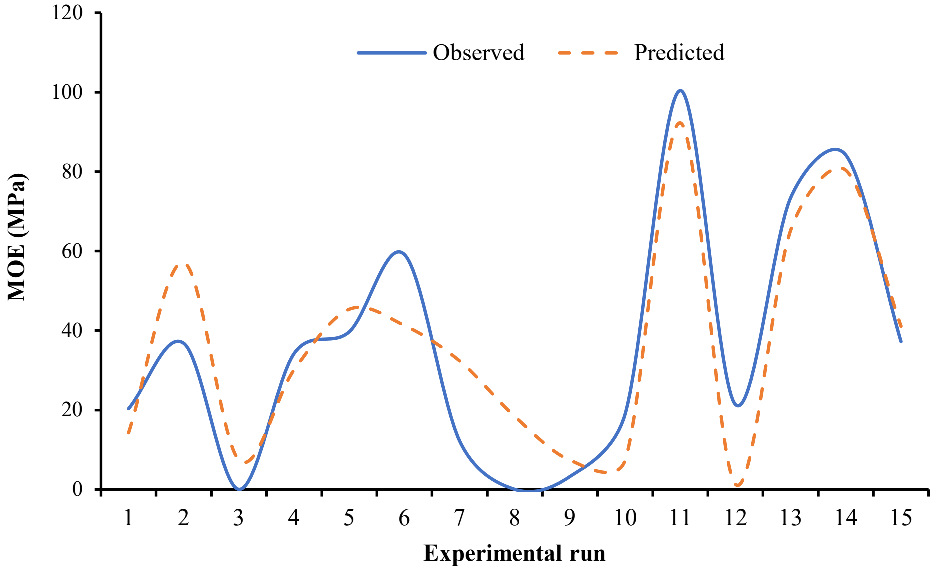
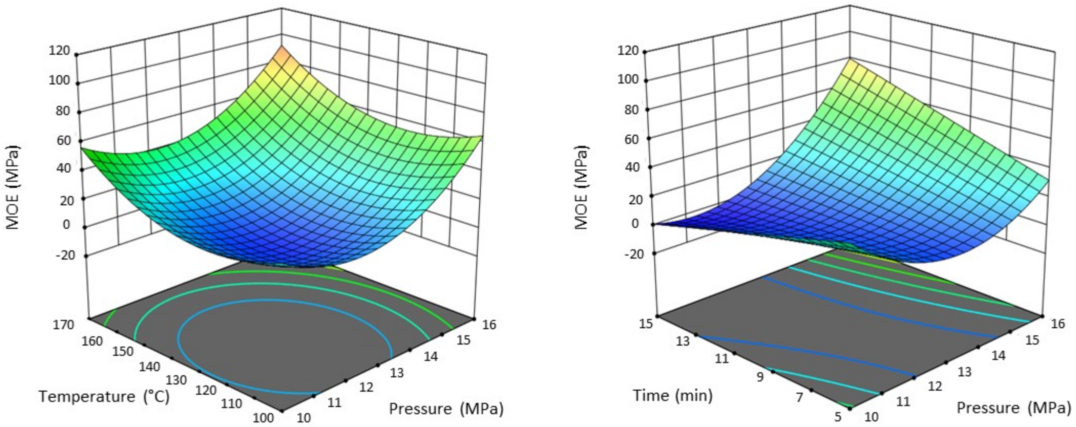
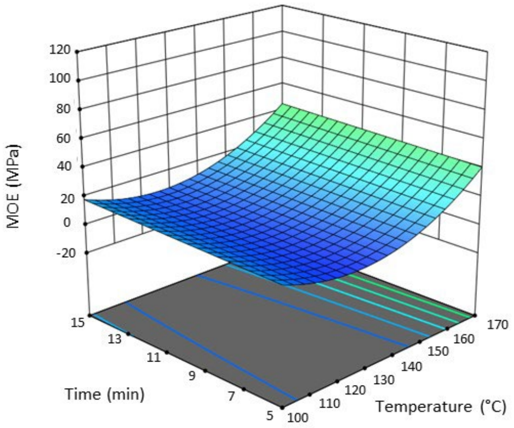


Figure 4 Comparison of observed and predicted MOE of abura bioboards



(a) pressure and pressing temperature

(b) pressure and pressing time



(c) pressing temperature and pressing time

Figure 5 Surface plots for MOE of abura sawdust bioboards to investigate effects

The highest MOE of abura sawdust bioboards produced was lower than 683 MPa obtained for pine bark and oil palm empty fruit branches (Saad et al., 2020) but higher than 34.10 MPa obtained for corncob bioboard (Orisaleye et al., 2022a). For straw-based binderless boards, Wang et al. (2018) observed that temperature significantly influenced MOE. In line with observations from this study, Ferrandez-Garcia et al. (2022) established that temperature was significant to MOE of Olive leaves bioboards but the pressing time was not. However, Orisaleye et al. (2022a) did not find pressure, pressing time or pressing temperature to be significantly influential on the MOE of corncob bioboards. At higher temperature, a higher MOE was obtained by Ferrandez-Garcia et al. (2022) for olive tree bioboards and, similar to findings in this study, it was shown that the pressing temperature was significant to the MOE but pressing time was not significant.

3.3 Modulus of rupture of abura sawdust bioboards

The average MOR for abura sawdust bioboards was between 0.27 and 1.10 MPa. As explained for the MOE, some samples had a nearly flat stress-strain curve which signified that they failed upon the application of low load levels. The parameters from the ANOVA for the MOR are presented in Table 3. From the ANOVA, none of the terms is statistically significant at a confidence level of 95%. It is seen that pressure and pressing temperature did not significantly influence the MOR of the abura bioboards ($p > 0.1$). This is most likely due to the nature of the material and the insufficient bonding of the material as a result of low lignin levels. The study of the main effects reveal that the pressing time had the highest effect on the MOR with the mean of MOR occurring at the pressure of 10 MPa, temperature of 100°C and pressing time of 5 min.

The model developed from the terms in the ANOVA is presented in Equation 7 and has R^2 and adjusted R^2 of 68.55% and 44.97%, respectively.

$$MOR = 4.171 - (0.1096 \times P) - (0.00975 \times T) - (0.395 \times t) + (0.00710 \times t^2) + (0.00867 \times P \times t) + (0.000886 \times T \times t) \quad (7)$$

Where,

P is the pressure;

T is the pressing temperature and t is the pressing time.

The comparison of the predicted MOR using Equation 7and the experimentally observed values is presented in Figure 6. The model is seen to fit well with the experimentally observed values. The surface plots show the effect of the combination of the variables on the MOR in Figure 7. It is observed from the plots that the pressing time had the greatest effect on the MOR.

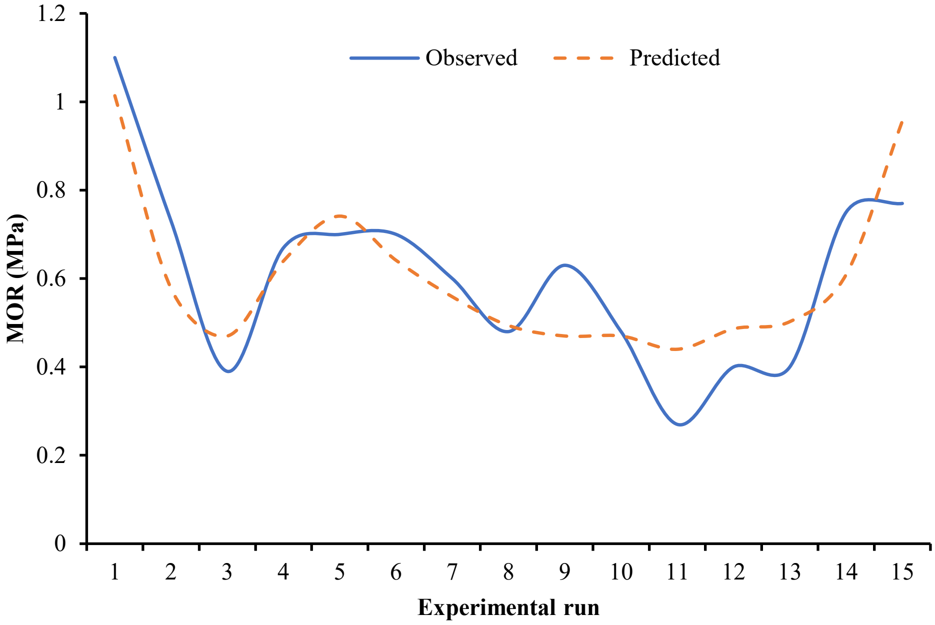
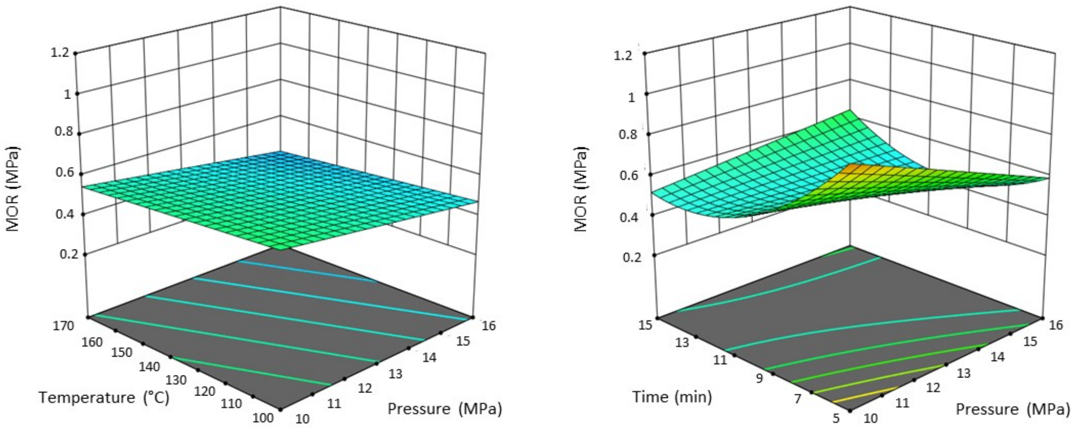
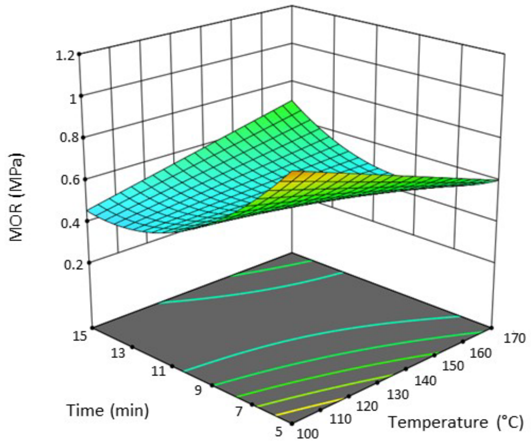


Figure 6 Comparison of observed and predicted MOR of abura bioboards



(a) pressure and pressing temperature (b) pressure and pressing time



(c) pressing temperature and pressing time

Figure 7 Surface plots for MOR of abura sawdust bioboards to investigate effects

The MOR obtained for the abura sawdust bioboards was lower than 10 MPa which, for interior fitments, is the minimum value based on ANSI A208.1 (2010). As earlier discussed for the MOE, the low level of available lignin is a major cause of the low MOR obtained for the abura bioboards. This suggests the need for further treatment of the biomass resource or the utilization of external biodegradable binders to be able to utilize the abura resource for the production of bioboards. The MOR obtained was also lower than 5.02 MPa and 5.67 MPa obtained by Ferrandez-Garcia et al. (2022) for whole leaf olive boards and shredded leaves olive boards, respectively. Similar to findings in this study, Ferrandez-Garcia et al. (2022) showed that pressing time was significant to the MOR but the pressing temperature was not significant.

3.4 Internal bonding strength of abura sawdust bioboards

The average IBS of abura sawdust bioboards reached 0.049 MPa (Table 1). The highest IBS was obtained at the same conditions that produced the highest MOE. The parameters obtained from the ANOVA for the IBS using backward elimination is shown in Table 3. From the table, none of the linear or interaction terms are significant to the IBS, however, the square term of pressure is significant ($p < 0.05$). This implies that none of the variables depend on other variables to determine influence on the MOR. From the study of the main effects using fitted means, the highest IBS occurred at the highest pressure (16 MPa) and temperature (170°C) but at the lowest pressing time (5 min). The pressure and temperature had nearly similar main effects on the IBS, but the main effect of the pressing time was almost negligible.

$$IBS = 0.496 - (0.0486 \times P) - (0.00221 \times T) - (0.01004 \times t) + (0.001650 \times P^2) + (0.000009 \times T^2) + (0.000767 \times P \times t) \quad (8)$$

Where,

P is the pressure;

T is the pressing temperature;

t is the pressing time.

The regression model to predict the IBS from the terms in the ANOVA is stated in Equation 8. The model has R^2 and adjusted R^2 values of 71.16% and 49.53%, respectively.

Figure 8 shows that the model could be used in predicting the IBS of the sawdust bioboards to a good extent. Figure 9 shows the surface plots of the IBS showing how combinations of manufacturing parameters affect the board property. From the plots, it is observed that the combination of the settings of 16 MPa, 170°C and 15 min results in the highest values of IBS.

The values of IBS obtained for the abura sawdust bioboards are lesser than the recommended least IBS of 0.4 MPa by EN 312 and 0.5 MPa specified by ANSI A208.1 (2010) for application in load-bearing construction applications. This further emphasizes the need for more internal binding component of the abura sawdust to be made available through further treatment or the utilization of external biodegradable binders. Orisaleye et al. (2022a) obtained maximum IBS obtained for corncob bioboards was 0.047 MPa which was in the close to the maximum IBS of abura sawdust bioboards. Similarly, Ferrandez-Garcia et al. (2022) obtained 0.051 MPa for values of IBS for shredded olive tree boards which was close to the IBS for abura sawdust, and 0.012 MPa for whole leaves olive boards which was lower than abura sawdust boards. Mitchual et al. (2020) obtained IBS of 0.97 MPa for plantain pseudostem boards and 0.63 MPa for boards from cocoa pods. Vitrone et al. (2021) observed that increasing the pressing time, along with the pressing temperature, causes an increase in IBS. From the investigation by Orisaleye et al. (2022a), pressure, temperature, and pressing time did not significantly influence the IBS of corncob bioboards.

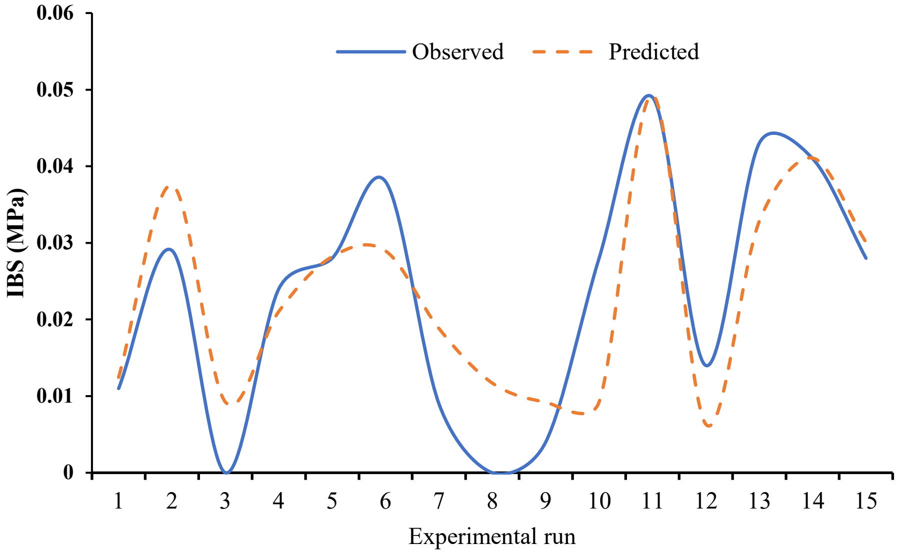
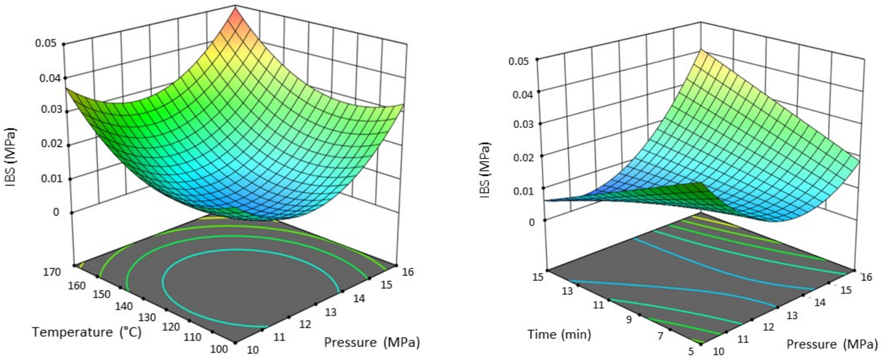
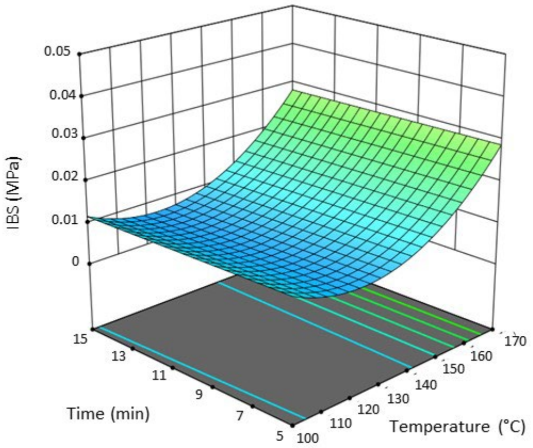


Figure 8 Comparison of observed and predicted IBS of abura bioboards



(a) pressure and pressing temperature

(b) pressure and pressing time



(c) pressing temperature and pressing time

Figure 9 Surface plots for IBS of sawdust bioboards to investigate effects

3.5 Economic and sustainability considerations

According to Olorunnisola (2023), the building industry alone consumes about 80% of Nigeria's total annual timber production. It is predicted that the rate will continue to grow with the rise in the population and cause a deterioration on the available timber resources. With sufficient processing and adequate binding considerations, sawdust from the wood industry, of which abura sawdust constitutes a part, has a good potential for application in bioboards which can be used in the building industry. As noted by Ojolo et al. (2012), sawdust from the wood is normally about 10% of the logging residues. Ojolo et al. (2012) found that sawdust had an annual generation of 185,000 tonnes of which just 80,000 tonnes are utilized for various purposes. The rest of the generated residue is treated unsustainably by dumping in refuse sites or burnt in open air. The production of bioboards from this residue will not only preserve the environment by preventing pollution but also be of economic value. The various means of applying the bioboards as sustainable building materials include partitioning boards, insulation boards, ceiling boards and interior design. Utilizing these sustainable building materials aligns with the circular economy principles and will contribute to lower emissions and limit the use of materials that are harmful to the environment and human health. Whilst the equipment has a good potential to be scaled up, the holistic view on the scalability of the production process will depend on the consistent availability of the biomass material and the economic feasibility of the large-scale hot-pressing process. To properly situate the binderless boards within the broader scope of green building materials, future research should focus on the technoeconomic analysis and life cycle assessment of the bioboards from various biomass resources.

4 Conclusions

In this study, binderless biodegradable boards have been successfully produced from sawdust produced from logging process of abura wood. The effect of the production parameters on the quality of biodegradable boards produced from abura (*Mitragyna ciliata*) sawdust were investigated. The density of the biodegradable boards ranged from 539.40 to 699.20 kg $m^{-3}$and was within the range specified for particleboards by JIS A 5908 (2003) standard. The MOE, MOR and IBS fell below the required standard and limits the applicability of the boards. Empirical analysis carried out using RSM suitably identified the significant terms for each board property. Pressure and temperature are important variables to determine the density, MOE and IBS of abura sawdust bioboards. Boards with characteristics obtained from the parameters from the current study are useful as insulation boards. Further investigations into the modification of the characteristics of the raw material through various techniques of pre-treatment before board production could improve the properties of the sawdust bioboards. For refinement of the model, further experiments will be required to consider other variables that affect the properties of bioboards such particle size, moisture content and addition of biodegradable binders.

Declarations

Ethics approval and consent to participate: Not applicable.

Acknowledgements

Not applicable.

References

Abiodun, Y. O., O. M. Sadiq, S. O. Adeosun, and G. L. Oyekan. 2019. Mineralogical Properties of Kaolin and Metakaolin from Selected Areas in Nigeria and Its Application to Concrete Production. *West Indian Journal of Engineering*, 42(1): 57-64.

Ahmad, Z., M. Tajuddin, M. A. Maleque, and Z. Halim. 2019. Effects of particle sizes on the properties of binderless boards made from rattan furniture waste. *Journal of Engineering Science*, 15: 49-61.

Aguwa, J. I. 2013. Structural reliability of the Nigerian grown abura timber bridge beam subjected to bending and deflection forces. *Nigerian Journal of Technology*, 32(2): 241-252.

Akuma, O., and A. Emma. 2017. Fabrication and testing of institutional stove using abura wood as fuel. *IOSR Journal of Biotechnology and Biochemistry*, 3(2):105-110.

Böger, T., S. Bianchi, C. Salzer, and F. Pichelin. 2018. Binderless boards made of milled coconut husk: an analysis of the technical feasibility and process restraints. *International Wood Products Journal*, 9(1): 3-8.

Boon, J. G., R. Hashim, O. Sulaiman, S. Hiziroglu, T. Sugimoto, and M. Sato. 2013. Influence of processing parameters on some properties of oil palm trunk binderless particleboard. *European Journal of Wood and Wood Products*, 71(5):583–589.

Domínguez-Robles, J., Q. Tarrés, M. Alcalà, N. E. El Mansouri, A. Rodríguez, P. Mutjé, and M. Delgado-Aguilar. 2020. Development of high-performance binderless fiberboards from wheat straw residue. *Construction and Building Materials*, 232: 117247.

Ferrandez-Garcia, A., M. T. Ferrandez-Garcia, T. G. Ortuño, F. Mata-Cabrera, and M. Ferrandez-Villena. 2022. Analysis of the manufacturing variables of binderless panels made of leaves of olive tree (*Olea europaea* L.) pruning waste. *Agronomy*, 12(1): 93.

Hashim, R., W. N. A. W. Nadhari, O. Sulaiman, M. Sato, S. Hiziroglu, F. Kawamura, T. Sugimoto, T. G. Seng, and R. Tanaka. 2012. Properties of binderless particleboard panels manufactured from oil palm biomass. *BioResources*, 7(1): 1352-1365.

Jekayinfa, S. O., J. I. Orisaleye, and R. Pecenka. 2020. An assessment of potential resources for biomass energy in Nigeria. *Resources*, 9(8): 92.

Jerman, M., M. Böhm, J. Dušek, and R. Černy. 2022. Effect of steaming temperature on microstructure and mechanical, hygric, and thermal properties of binderless rape straw fiberboards. *Building and Environment*, 223: 109474.

Khoshakhlagh, A. H., M. Mohammadzadeh, P. Sicard, and U. Bamel. 2024. Human exposure to formaldehyde and health risk assessment: a 46-year systematic literature review. *Environmental Geochemistry and Health*, 46(6): 206.

Kurniati, M., F. Fahma, I. A. Kartika, T. C. Sunarti, K. Syamsu, D. Hermawan, Y. Sait, and M. Sato. 2015. Binderless particleboard from castor seed cake: effect of pressing temperature on physical and mechanical properties. *Asian Journal of Agricultural Research*, 9(4):180-188.

Mawardi, I., S. Aprilia, M. Faisal, Ikramullah, and S. Rizal. 2022. An investigation of thermal conductivity and sound absorption from binderless panels made of oil palm wood as bio-insulation materials. *Results in Engineering*, 13: 100319.

Mitchual, S. J., P. Mensah, K. Frimpong-Mensah, and E. Appiah-Kubi. 2020. Characterization of particleboard produced from residues of plantain pseudostem, cacao pod and stem and ceiba. *Materials Sciences and Applications*, 11(12): 817.

Nasir, M., D. P. Khali, M. Jawaid, P. M. Tahir, R. Siakeng, M. Asim, and T. A. Khan. 2019. Recent development in binderless fiber-board fabrication from agricultural residues: A review. *Construction and Building Materials*, 211: 502-516.

Ndukwe, N. A., W. O. Okiei, and B. I. Alo. 2012. Correlates of the yield of chemical pulp, lignin and the extractive materials of tropical hardwoods. *African Journal of Agricultural Research*, 7(40): 5518-5524.

Ojolo, S. J., J. I. Orisaleye, S. O. Ismail, and S. M. Abolarin. 2012. Technical potential of biomass energy in Nigeria. *Ife Journal of Technology*, 21(2): 60-65.

Olorunnisola, A. O. 2023. The past, present and future outlook of the wood industry in Nigeria. In *Wood Industry-Past, Present and Future Outlook*, eds G. Du, and X. Zhou, ch. 4, 105794. London, UK: IntechOpen.

Orisaleye, J. I. 2019. Parametric analysis and design optimization of screw extruder biomass briquetting machines. Ph.D. diss., University of Lagos, Akoka, Nigeria.

Orisaleye, J. I., Y. O. Abiodun, A. A. Ogundare, O. A. Adefuye, S. J. Ojolo, and S. O. Jekayinfa. 2022a. Effects of manufacturing parameters on the properties of binderless boards produced from corncobs. *Transactions of the Indian National Academy of Engineering*, 7(4):1311-1325.

Orisaleye, J. I., S. O. Jekayinfa, O. M. Braimoh, and V. O. Edhere. 2022b. Empirical models for physical properties of abura (*Mitragyna ciliata*) sawdust briquettes using response surface methodology. *Cleaner Engineeing and Technology*, 7: 100447.

Orisaleye, J. I., A. A. Ogundare, Y. O. Abiodun, M. O. Oyekeye, O. A. Adefuye, S. J. Ojolo, and O. E. Owoeye. 2023. An Investigation of the effects of manufacturing parameters on properties of binderless boards produced from abura (*Mitragyna ciliata*) sawdust. *International Journal of Integrated Engineering*, 15(4): 89-99.

Saad, A., A. Kasim, and S. Gunawarman. 2020. Characteristics of particleboard made from trees pine bark and oil palm empty fruit bunches. *International Journal of Scientific and Technology Research*, 9(9): 320-327.

Tajuddin, M., Z. Ahmad, and H. Ismail. 2016. A review of natural fibers and processing operations for the production of binderless boards. *BioResources*, 11(2):5600-5617.

Van Dam, J. E., M. J. van den Oever, and E. R. Keijsers. 2004. Production process for high density high performance binderless boards from whole coconut husk. *Industrial Crops and Products*, 20(1): 97-101.

Vitrone, F., D. Ramos, F. Ferrando, and J. Salvadó. 2021. Binderless fiberboards for sustainable construction, materials, production methods and applications. *Journal of Building Engineering*, 44:102625.

Wang, L., S. Ge, D. Li, W. Yang, and W. Peng. 2018. Characteristics of nontoxic bamboo bioboard by melamine and cellulose adhesive. *Wood Research*, 63(2): 287-294.

Wu, T., X. Wang, and K. Kito. 2015. Effects of pressures on the mechanical properties of corn straw bio-board. *Engineering in Agriculture, Environment and Food*, 8(3): 123-129.

Xie, L., J. Liu, and A. Du. 2012. Effect of hot-pressing factors on binderless fiberboard properties. In *Proc. of 2012 International Conference on Biobase Material Science and Engineering*, 8-11. Changsha, China, 21-23 October.

Xu, J., G. Han, E. D. Wong, and S. Kawai. 2003. Development of binderless particleboard from kenaf core using steam-injection pressing. *Journal of Wood Science*, 49(4): 327–332.

Zhang, J., X. Wang, and K. Kito. 2016. Effect of heating temperature on strength of rice straw bio-board. *Journal of Environmental Conservation Engineering*, 45(7): 377-384.