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EFFECT OF MIXING COCOA POD PARTICLES WITH PLANTAIN PSEUDOSTEM ON PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD

Prosper MENSAH
CSIR-Forestry Research Institute of Ghana, Wood Industry and Utilisation Division
Address: P. O. Box UP 63, KNUST, Kumasi-Ghana
E-mail: pmensah@csir-forig.org.gh

Stephen Jobson MITCHUAL*
Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Department of Construction and Wood Technology Education
Address: P. O. Box 1277, Kumasi, Ghana
E-mail: stephenjobsonmitchual@gmail.com

Kwasi FRIMPONG-MENSAH
Kwame Nkrumah University of Science and Technology, Department of Wood Science and Technology
Address: Private Mail Bag, University Post Office, KNUST, Kumasi-Ghana
E-mail: frimpongmensahk@yahoo.com

Emmanuel APPIAH-KUBI
Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Department of Construction and Wood Technology Education
Address: P. O. Box 1277, Kumasi, Ghana
E-mail: appiahkemma@gmail.com

Mark Bright DONKOH
Tamale Technical University, Department of Wood Technology
Address: P. O. Box ER 3 Tamale, Northern Region, Ghana
E-mail: kmspecialtech@gmial.com

Abstract:

The study assessed the effect which plantain pseudostem particles in combination with cocoa pod had on the physical and mechanical properties of particleboards. This is against the backdrop that previous studies have indicated that particleboards produced from only plantain pseudostem particles had very good physical and mechanical properties whilst those produced from only cocoa pod had poor physical and mechanical properties. The two biomass materials were blended at the following ratios: 100:0; 90:10; 70:30; 50:50; 30:70; 10:90 and 0:100 (plantain pseudostem: cocoa pod). Cassava starch and urea formaldehyde were used as adhesives. Physical and mechanical properties of particleboards tested using ASTM standard procedures were: density, thickness swelling, water absorption, modulus of elasticity, modulus of rupture, hardness and internal bond strength. The results indicate that with the exception of density, all the physical and mechanical properties of the particleboards improved significantly with increased percentages of plantain pseudostem in the biomass mix. This is due to low bulk density, relatively high lignin content and higher aspect ratio of the plantain pseudostem particles. Generally, the particleboards produced met or exceeded the EN and JIS standard requirements. At 5% level of significance, the raw material mix and the adhesive type had significant effect on the physical and mechanical properties of the particleboards produced. In view of the results obtained the manufactured particleboards could be utilized for general purpose work including furniture for interior environments.

Key words: *cocoa pod; mechanical properties; particleboard; physical properties; plantain pseudostem.*

INTRODUCTION

Wood is the primary raw material of many production fields. One of them is the production of wood-based composites, an industrial field that recently has gained increased popularity in structural applications as well as in furniture production (Kowaluk *et al.* 2020). In the light of the increasing diversity of raw materials for the production of lignocellulosic panels, alternative materials such as fast-growing species were used to produce particleboard panels as a value-added application alternative to their traditional usage (Klímek *et al*. 2018). Additionally, there is a strong trend towards utilization of under-utilized non-timber species and agricultural waste as raw material to manufacture composite panels. These approaches could result in

* Corresponding author

reducing deforestation rates in many countries and also convert such resources into value-added panel products (Bekhta and Hiziroglu 2010). Ghana is an agricultural country and has an estimated workforce of over 60% in the agricultural sector (Amesimeku 2012). This culminates into the cultivation of various crops such as millet, rice, maize, sugar cane and cocoa by farmers. This leads to the generation of large volumes of agricultural crop residues such as maize cobs, rice husk, millet stalks, bagasse, and cocoa tree and shells (Mitchual 2013).

Plantain pseudostem and cocoa pod are agricultural residues generated abundantly in Ghana from the cultivation of plantain and cocoa. Studies indicate that in the year 2016, an estimated 7,184,842 tonnes of plantain pseudostem was generated in Ghana (FAO 2019). For cocoa, Ghana is second to Cote d'Ivoire in global production, producing about 20% of the crop. Cocoa pods, stem, leaves, husk and branches are residues generated from cocoa production in Ghana. The cocoa pods are normally left in the farms to decay. The methane emitted by the cocoa compost into the atmosphere is 25 times that of carbon dioxide. This significantly contributes to the degradation of the ozone layer (GMI US EPA 2016).

Recent studies on the potential use of agricultural residues for particleboard production show that the following could be used as a substitute to wood in particleboard production: date palm branches, wheat straw, coconut coir, cotton stalk, bamboo chips, kenaf core and stalks, mimosa bark, cotton carpel, sunflower stalk, oil palm empty fruit bunch, elephant grass, pepper stalks, oil palm, hazelnut husk, rice straw, wheat straw, watermelon peels, peanut hull, oil palm trunk, corn cob and stalk, and sugar cane bagasse (Norgren and Notley 2010; Ratnasingam *et al.* 2008; Li *et al.* 2010; Idris *et al.* 2011; Guler and Büyüksarı 2011; Abdullah *et al.* 2012; Silva *et al.* 2014; Andoh 2017). However, the major problem associated with industrial utilization of agricultural residues in the particleboard industry is the high cost of collecting, transporting and storing of the raw materials. It has been suggested that these challenges could be overcome by building local small-scale mills close to the areas where such residues are generated (Guler 2015).

Further studies by Mensah *et al.* (2020) and Mitchual *et al.* (2020) indicate that particleboards with good physical, mechanical and decay resistance properties could be produced from plantain pseudostem and cocoa stem and that they are suitable for producing cabinet, cladding and other interior fittings. The study by Mitchual *et al.* (2020) further reveals that particleboards produced from plantain pseudostem were significantly better than those produced from cocoa pod and in most cases they were two times better than that of cocoa pod. Some of the reasons assigned for the better performance of plantain pseudostem as raw material for particleboard production were its high aspect ratio and low bulk density. In view of the foregoing this study sought to assess the effect blending cocoa pod with plantain pseudostem will have on physical and mechanical properties of particleboards. It also sought to examine how such mixture would perform when combined with urea formaldehyde or cassava starch. Specifically, this study aimed at evaluating the mechanical and physical properties of particleboards produced from blend of plantain pseudostem and cocoa pod.

OBJECTIVE

This study aimed at determining the effect plantain pseudostem and cocoa pod particles combination had on the physical and mechanical properties of particleboards using cassava starch and urea formaldehyde as adhesives.

MATERIALS AND METHODS

Preparation of particles of plantain pseudostem and cocoa pod

Plantain pseudostem, cocoa pod, urea formaldehyde and cassava starch were used for the study. The plantain pseudostem was obtained from a farm land after harvesting. The moisture in the stem was extracted, and the fibers oven-dried before milling them into particles as shown in Fig. 1.

a. *b.* *c.*

Fig. 1.
Stages of processing plantain pseudostem into particles: a - fresh plantain pseudostem; b - water extraction from plantain Pseudostem; c - plantain pseudostem particles. Source (Mitchual et al. 2020)

a. b. c.

Fig. 2.
Stages of processing cocoa pod into particles: a - fresh cocoa pod; b - dried cocoa pod; c - cocoa pod particles. Source (Mitchual et al. 2020).

Fig. 2. shows the stages of conversion of cocoa pod residues into particles. The fresh cocoa pods were first sun-dried and then crushed into particles using a hammer mill. The particle sizes of the residue used for the study ranged from 0.5mm to 1.5mm.

Urea formaldehyde

Urea formaldehyde (UF) resin with a ratio of 1:1, of 65% solid content, specific gravity of 1.266g/cm³ at 30°C, viscosity of 2.3MPs at 30°C, pH of 7.5 and a gel time of 65 seconds at 100°C was used as one of the adhesives for making the particleboard.

Preparation of cassava starch

Fresh cassava tubers were obtained, washed, peeled and milled to obtain cassava dough. The dough was diluted with clean water to form a solution. Thereafter, the solution was strained with 1mm wire mesh and allowed to stand for 24 hours to allow the starch to settle. The water was decanted to obtain the cassava starch. The starch was air-dried for ten days and then ground to obtain the powdered starch.

Particleboard manufacture

The plantain pseudostem and cocoa pod with bulk densities of 96.63kg/m^3 and 323.96kg/m^3 respectively were each dried to a moisture content of 4%. The materials were blended at mixing percentages of: 100:0; 90:10; 70:30; 50:50; 30:70; 10:90 and 0:100 (plantain pseudostem: cocoa pod) and then thoroughly mixed with the adhesives. Ammonium chloride was added as a curing catalyst. The mixture was pre-pressed into an 80mm single layer in 350mmx350mm aluminium sheet mould. A 20mm thick metal stopper was used to ensure that the boards produced had the same thickness. The mat was then pressed using a multiple column industrial press, BECKER and VAN HüLLEN 10224 under the following conditions: Pressing temperature 170^{o}C; pressing pressure 3.5MPa; pressing time 8 minutes; pressing closing rate 3 - 4mm/minutes, target thickness 20mm; hardener 2% and compacting time 15 minutes. The particleboards produced were conditioned in a climate-controlled room having a temperature of 20±2^{o}C and a relative humidity of 62±2% for 6 days before they were sawn into various sizes for further studies.

Moisture content

The moisture content (MC) on oven-dry basis of the raw agro-forest materials and the particleboards was determined in accordance with the ASTM D 1037 - 06a (1999). In each case five samples were placed in a laboratory oven at a temperature of 103±2^{o}C until the difference in mass between two successive weighings separated by an interval of two hours was 0.01g or less. The moisture content of the specimen was then computed as shown in Equation 1.

$$MC\ (\%)\ db = \frac{M_i - M_f}{M_f} \times 100 \qquad (1)$$

where:

M_i = Initial mass of the specimen (g);
M_f = Final oven-dry mass of the specimen (g).

Density

The density (D) of the particleboards was determined in accordance with ASTM D-1037 - 06a (1999). Specimen of dimensions 20mmx20mmx30mm were prepared from the particleboards produced. The mass was determined using an electronic balance. The dimensions of the specimen namely length, width and thickness were determined using a digital veneer calliper. Density of each specimen was then computed using Equation 2.

$$D\left(\frac{kg}{m^3}\right) = \frac{Mass}{L\,x\,W\,x\,T} \quad (2)$$

where:

L = Length of specimen (mm);
W = Width of specimen (mm);
T = Thickness of specimen (mm).

Thickness swelling

The thickness swelling (TS) property of the particleboards was determined in accordance with ASTM D1037 - 06a (1999). A test specimen with dimension 20mmx76mmx152mm was soaked in pure water at room temperature (27^{o}C) for 2 hours and 24 hours. The initial and the final thickness of the specimen after the period of submersion were determined with a digital veneer calliper. The thickness swelling for the 2-hour and 24-hour submersions was then computed using Equation 3.

$$TS\,(\%) = \frac{T_f - T_o}{T_o} \times 100 \quad (3)$$

where:

T_o = Initial thickness of test sample before soaking (mm);
T_f = Final thickness of test sample after soaking (mm).

Water absorption

The water absorption (WA) property of the particleboards was determined in accordance with ASTM D1037 - 06a (1999). A sample of dimension 20mmx76mmx152mm was weighed and submerged horizontally under 25mm depth of pure water at room temperature (27^{o}C) for 2 hours and 24 hours. For each of them, the excess water on the surface of the sample was removed with hand paper towel and was immediately weighed. The 2-hour and 24-hour water absorption properties were then computed using Equation 4.

$$WA\,(\%) = \frac{W_f - W_o}{W_o} \times 100 \quad (4)$$

where:

W_o= Initial weight of test sample before soaking (g);
W_f = Final weight of test sample after soaking (g).

Modulus of elasticity and modulus of rupture

The modulus of elasticity and modulus of rupture of the particleboards were determined in accordance with ASTM D 1037-06a (1999). Specimen of size 20mmx50mmx250mm were prepared from the particleboards produced. A Universal Testing Machine (model Inspekt 50-1, Am Gründchen 1, 01683 Nossen, Germany) operated with a load cell capacity of 50kN was used for the test. The loading rate applied was 4mm/min.

Hardness

The hardness of the particleboards was determined in accordance with the American Society for Testing and Materials standard methods ASTM D 1037-06a (1999). The particleboards were laminated to obtain the given thickness and subsequently cut into dimension 25mmx75mmx150mm, as specified by the standard. Janka ball test was used for determining the hardness of the particleboards using “Instron” universal testing machine (Instron Model 4482, Norwood, MA, USA) with the hardness test fixture. The steel ball with diameter 11.28mm was driven into the specimen and the load necessary to force it into the test piece, to a depth of 5.6mm, by the steel ball was recorded automatically by the "Instron" machine as the failure load.

Internal Bond

The internal bond (IB) test was conducted in accordance with ASTM D 7519-11 (2011) and ASTM D 1037-06a (1999). Twenty-four strips of particleboards (152mmx305mm) with three replicates produced from each of the agro-forest residues using the two adhesives were subjected to the following exposure cycle: 16 hours of oven drying at a temperature of 70^{o}C, followed by a 3-hour soaking in water at a temperature of 20^{o}C. This was immediately followed by a 2-hour oven drying at a temperature of 70^{o}C, and immediately followed by a 3-hour soaking in water at 20^{o}C. After the third exposure cycle, the boards were dried for 16 hours in an oven at a temperature of 70^{o}C. Finally, four specimen blocks of dimension 50mmx50mm were cut from each of the strips. Tension perpendicular to surface (Internal Bond) test was conducted according to the test method of ASTM D 1037-06a (1999). The internal bond of each specimen was calculated using Equation 5.

$$IB\ (\frac{N}{mm^2}) = \frac{Pmax}{ab} \quad (5)$$

where:

$Pmax$ = Maximum load (N);
a = Width of the specimen (mm);
b = Length of the specimen (mm).

RESULTS AND DISCUSSION

Density

Fig. 3. indicates the relationship between percentages of plantain pseudostem in a blend of plantain pseudostem and cocoa pod particles, and the density of particleboards produced using cassava starch (CS) and urea formaldehydes (UF) as adhesives. The result shows that the density of the particleboards decreased with increasing percentage of plantain pseudostem in the mixture for both CS and UF. The density of the particleboard with CS as an adhesive ranged from 542.58kg/m^3 (100% plantain pseudostem) to 598.06kg/m^3 (0% plantain pseudostem) and that of UF ranged from 493.04kg/m^3 (100% plantain pseudostem) to 557.30kg/m^3 (0% plantain pseudostem). This result means that particleboards produced from a blend of plantain pseudostem and cocoa pod with higher proportion of plantain pseudostem in the mixture would have lower density. This trend is due to the low bulk density of the plantain pseudostem material (96.63kg/m^3) as compared to that of the cocoa pod particles (323.96kg/m^3). The density of particleboard produced is comparable to that obtained from maize cob which ranged from 386kg/m^3 to 723kg/m^3 (Sekaluvu *et al.* 2014). Also, this result compares favorably with that obtained from other agricultural residues like rice stalk, wheat stalk and rice husk.

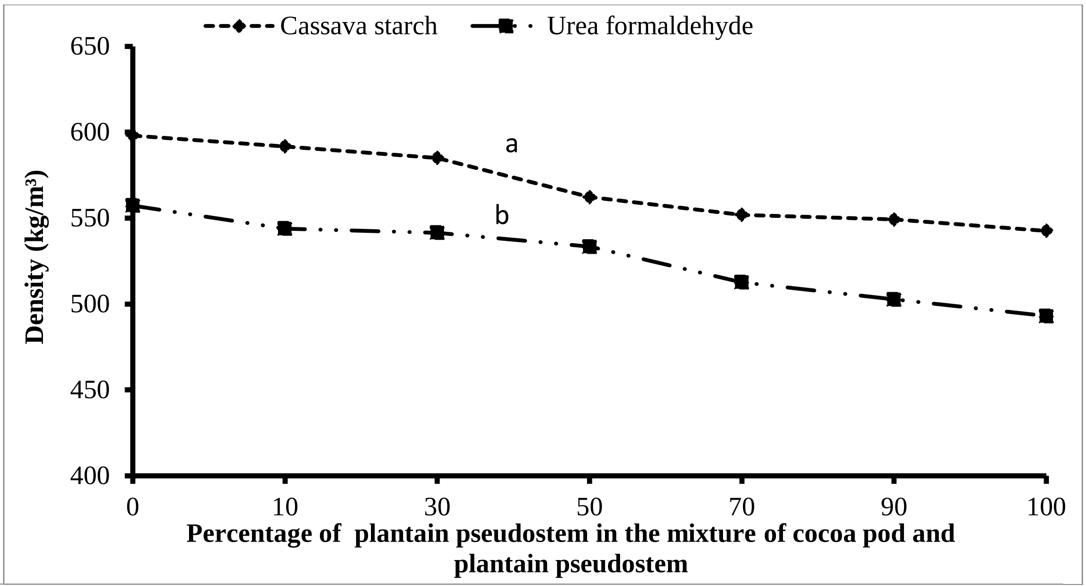

Fig. 3.
Relationship between density of particleboard and percentage of plantain pseudostem in the biomass mix.

An independent-sample t-test conducted to compare the density of the manufactured particleboards blended with CS and UF showed that at 5% level of significance, there was significant difference in the densities of the particleboards produced using CS and that of UF (p-value < 0.05). This has been indicated with different letters 'a' and 'b' on Fig. 3. This therefore suggests that the adhesive used had significant influence on the density of the particleboard produced.

Thickness swelling

Fig. 4. indicates the relationship between percentages of plantain pseudostem particles in a mixture of plantain pseudostem and cocoa pod particles, and 2-hour and 24-hour thickness swelling (TS) of particleboards having CS and UF as adhesives. The results show that increase in the percentage of plantain pseudostem particles in the mix reduced the TS of the manufactured particleboards for both CS and UF, and

for both 2-hour and 24-hour immersion periods. Thickness swelling values of all the mixed percentages for the 2-hour immersion, were lower (better) than the maximum requirement of EN 312-4 (2005) standard which is 8% for use in non-load bearing application in humid conditions. However, with the 24-hour immersion TS for mixtures with plantain pseudostem particles below 50% (UF) and 90% (CS) exceeded the maximum limit for the EN 312-4 (2005) standard requirement as indicated in Fig. 4.

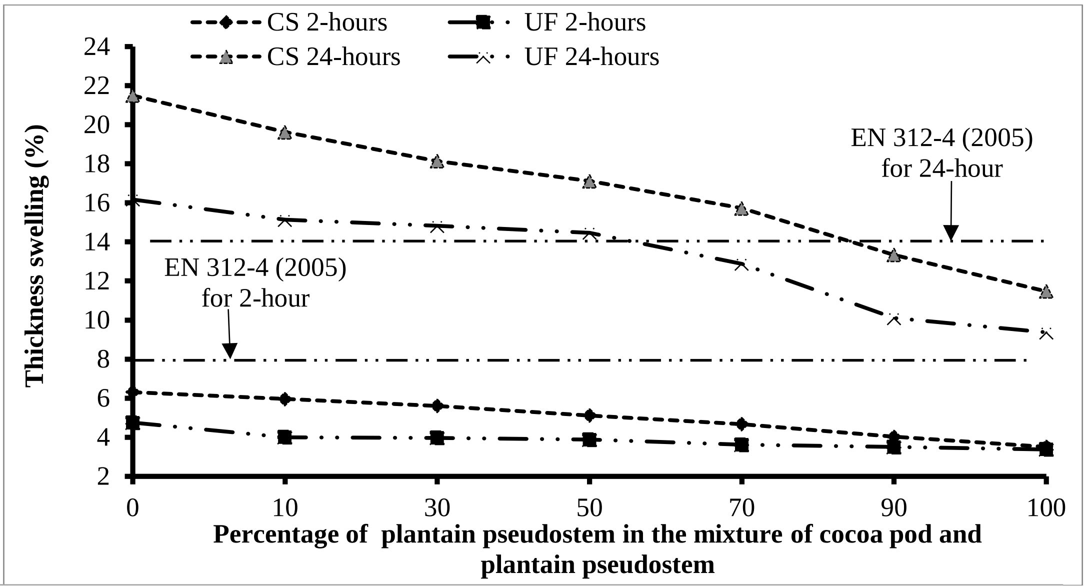

Fig. 4.
Relationship between thickness swelling of particleboard and percentage of plantain pseudostem in the biomass mix.

From this study it could be concluded that addition of plantain pseudostem to cocoa pod could improve the TS properties of particleboards. Thickness swelling of particleboards depends on compatibility of the particles and adhesive, chemical composition of furnish and the anatomical properties of the biomass materials. In this study the geometrical characteristics of the plantain pseudostem particles might have contributed to the binding of the porous sites in the mat by improving the flowability of the adhesive thereby resulting in the formation of good bonding between the biomass material and the adhesive. Additionally, the low bulk density of the plantain pseudostem material (96.63kg/m^3) as compared to that of the cocoa pod particles (323.96kg/m^3) might have led to higher compactness when the proportion of plantain pseudostem in the mixture was increased thereby improving the TS property of the particleboards produced. Furthermore, high lignin content of plantain pseudostem (11.24%) compared to cocoa pod (6.24%) might have contributed to the increased bonding of the particleboard leading to improved TS with increased plantain pseudostem in the mixture.

Table 1
ANOVA analysis of thickness swelling properties of the manufactured particleboard

Source	DF	ANOVA SS	Mean square	F-ratio	p-value
Biomass material	6	425.197	70.866	52.858	0.000*
Adhesive	1	189.644	189.644	141.452	0.000*
Duration	1	3915.003	3915.003	2920.133	0.000*
Biomass material x Adhesive	6	21.011	3.502	2.612	0.021*
Biomass material x Duration	6	161.976	26.996	20.136	0.000*
Adhesive x Duration	1	42.546	42.546	31.734	0.000*
Biomass material x Adhesive x Duration	6	4.062	0.677	0.505	0.803†
Error	112	150.158	1.341		
Total	140	12834.714			

*Statistically significant at 0.05 level of significance; †Not statistically significant at 0.05 level of significance. DF = Degree of freedom.

The effect of the biomass mix, adhesive and the duration of immersion (i.e. 2-hour and 24-hour) on the TS property of the manufactured particleboards is as indicated in Table 1. The ANOVA analysis shows that at 5% level of significance, the biomass mix, adhesive and duration of immersion had significant effects on the thickness swelling of the particleboard produced (p-value < 0.01). The multiple coefficient of determination value (R^2) and root mean square error (RMSE) of the ANOVA model were 0.9690 and 1.1580 respectively. This suggests that about 96.90% of the variability in the TS of the manufactured particleboards could be explained by the biomass raw materials, the adhesive used, and the duration of immersion.

Water absorption

Water absorption (WA) is a physical property that related to particleboard's response to soaking conditions. The result (Fig. 5.) shows that increased proportion of plantain pseudostem in the mixture improved the WA property of the particleboard (lower WA value). For both the 2-hour and 24-hour soaking, particleboards produced with UF had better WA properties than that of CS. Improved WA as a result of increased proportion of plantain pseudostem in the mixture could be due to its low bulk density, high aspect ratio, relatively high contents of lignin and low extractive content which led to improved compaction and bonding of the particleboards produced. High extractive content of the cocoa pod (18.78%) compared to that of plantain pseudostem (13.66%) may influence adhesive curing by making weaker the adhesive-particle bond, hence resulting in low strength of the produced panels (Guimarães *et al.* 2014).

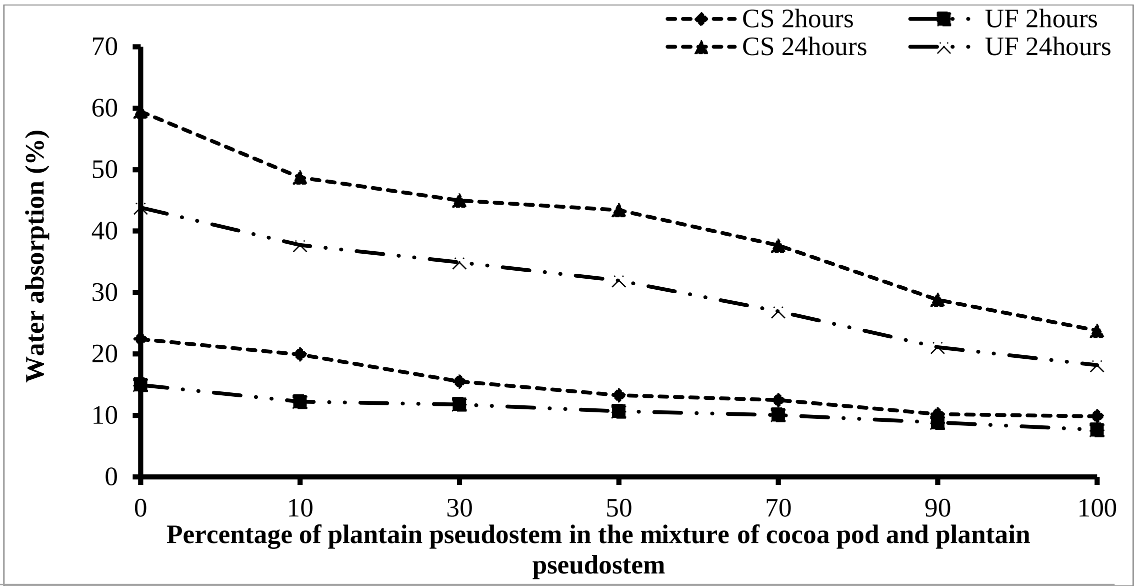

Fig. 5.
Relationship between water absorption of particleboard and percentage of plantain pseudostem in the biomass mix.

Furthermore, lignin is a hydrophobic substance. Therefore, increasing the plantain pseudostem in the mix with higher lignin content improved the WA property of the particleboards produced (Guimarães *et al.* 2014). On the contrary, cocoa pod is full of parenchyma tissues which consist of more hydroxyl groups that enable more hydrogen bonding to be formed. Therefore, the parenchyma tissues behave like a sponge which facilitates water absorption (Abdul Khalil *et al.* 2010; Abdullah *et al.* 2012; Kord *et al.* 2016). Generally, the WA values obtained in this study are similar or lower than those obtained in other studies using either solid wood or biomass materials (Hegazy and Aref 2011; Nazerian *et al.* 2011; Guler 2015; Ejiogu *et al.* 2018).

Table 2

ANOVA of water absorption properties of the manufactured particleboard

Source	DF	ANOVA SS	Mean square	F-ratio	p-value
Biomass material	6	5786.854	964.176	341.675	0.000*
Adhesive	1	1866.464	1866.464	661.213	0.000*
Duration	1	18162.038	18162.038	6434.078	0.000*
Biomass material x Adhesive	6	193.468	32.245	11.423	0.000*

Biomass material x Duration	6	1641.993	273.665	96.949	0.000*
Adhesive x Duration	1	319.818	319.818	113.299	0.000*
Biomass material x Adhesive x Duration	6	57.145	9.524	3.374	0.004*
Error	112	316.152	2.823		
Total	140	111864.244			

*Statistically significant at 0.001 level of significance; DF = Degree of freedom.

Analysis of variance (ANOVA) of the effect of biomass mix, adhesive and duration of immersion (i.e. 2-hour and 24-hour) on the WA property (Table 2) indicates that at 5% level of significance, the biomass mix, adhesive and duration of immersion (i.e. 2-hour and 24-hour) and their interactions had significant effects (p-value < 0.01) on the WA property of the particleboards produced. The multiple coefficient of determination value (R^2) and root mean square error (RMSE) of the ANOVA model were 0.9890 and 1.6802 respectively. This suggests that about 98.90% of the variability in the WA property of the particleboards could be explained by the biomass mix, adhesive, and the duration of immersion of the samples.

Modulus of elasticity

Modulus of elasticity (MOE) is an indication of the relative stiffness of a material. The relationship between percentages of plantain pseudostem in a blend of plantain pseudostem and cocoa pod particles, and the MOE of manufactured particleboard is as indicated in Fig. 6. The result shows that the MOE increased significantly as the proportion of plantain pseudostem in the mixture increased. This suggests that MOE of particleboard made from cocoa pod could be enhanced if plantain pseudostem is added to it. Plantain pseudostem is a fibrous biomass material having fiber length and aspect ratio of 2.79mm and 135.03 respectively. Therefore, the improved MOE resulting from increased percentages of plantain pseudostem in the mixture resulted from improved bond formation due to mechanical interlock of the fibers of the plantain pseudostem (Tabil *et al.* 2011).

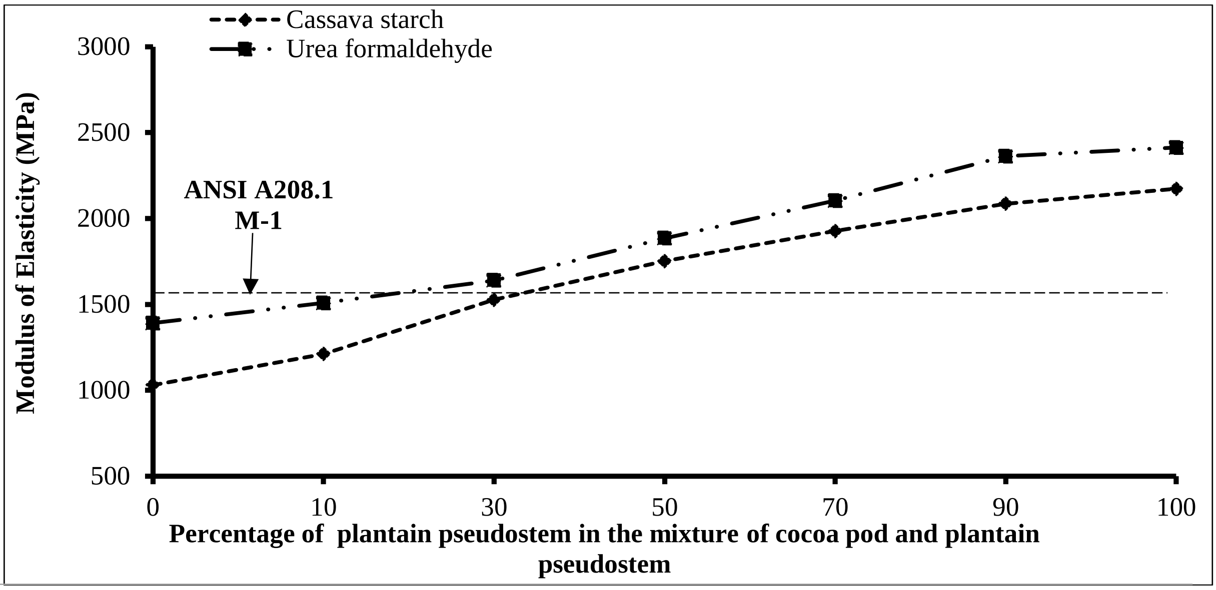

Fig. 6.
Relationship between modulus of elasticity of particleboard and percentage of plantain pseudostem in the biomass mix.

Furthermore, the low bulk density of the plantain pseudostem particles could have resulted in better compactness between the particles leading to a better adhesion during hot pressing. Similar observations were made by Fu *et al.* (2008), Roussière *et al.* (2012), Kord *et al.* (2016) and Tay *et al.* (2016). The study further indicates that for both CS and UF particleboards, having about 35% or more of plantain pseudostem particles in the mixture could produce particleboards with higher MOE than the minimum values required by the ANSI A208.1, M-1 (1999) standard, which is 1550 MPa for general uses and furniture production. Generally, the UF particleboards exhibited higher MOE than that of CS therefore they are likely to be stiffer.

Modulus of rupture

Fig. 7. illustrates the relationship between the modulus of rupture (MOR) of particleboards and percentages of plantain pseudostem particles in a mixture of plantain pseudostem and cocoa pod. Generally, increase in the percentage of plantain pseudostem in the mixture resulted in an increase in the MOR of the particleboards produced. This suggests that addition of plantain pseudostem to cocoa pod particles could significantly enhance the MOR of particleboards produced.

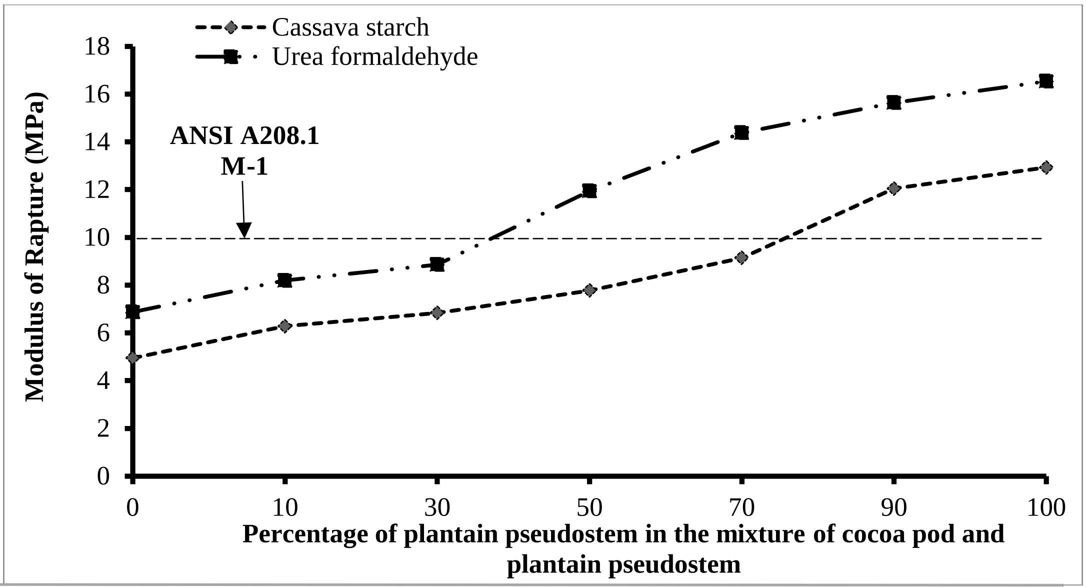

Fig. 7.

Relationship between modulus of rupture of particleboard and percentage of plantain pseudostem in the biomass mix.

Modulus of rupture of the manufactured particleboards strongly depends on the strength of the bonding between the polymer matrix, surface topology, and lignocellulosic property of the biomass particles (Singha and Thakur 2009). The MOR obtained when cocoa pod alone was used was not adequate compared with the ANSI A208.1 M-1 standard which recommends 10MPa as the minimum requirements for MOR of particleboards for general uses and interior fitments (including furniture). However, when the percentage of plantain pseudostem was increased beyond 36% and 75% respectively for UF and CS adhesives the particleboards produced had adequate MOR.

Hardness

Fig. 8. shows the relationship between percentages of plantain pseudostem in the blend of plantain pseudostem and cocoa pod particles, and the hardness of particleboards produced. The highest value of 8.78kN was obtained for 100% plantain pseudostem particleboards using UF as an adhesive and the least value of 2.49kN was obtained for particleboards produced from 100% cocoa pod particles using CS as adhesive. Generally, the hardness of the particleboards increased with increasing percentage of plantain pseudostem in the biomass mix. This result suggests that adding plantain pseudostem particles to cocoa pod particles could enhance the hardness of manufactured particleboards.

All the manufactured particleboards met the requirements of ANSI A208.1-1999 standard for general purpose usage which is 2.8kN, except the mixture having 10% and 0% of plantain pseudostem with CS as adhesive (Fig. 8.). Therefore, plantain pseudostem and cocoa pod combination could be employed to produce particleboards with adequate hardness for general purpose use using CS and UF as adhesive in the particleboard industry. On the average, for the same raw material the particleboards produced using UF was better than those produced using CS.

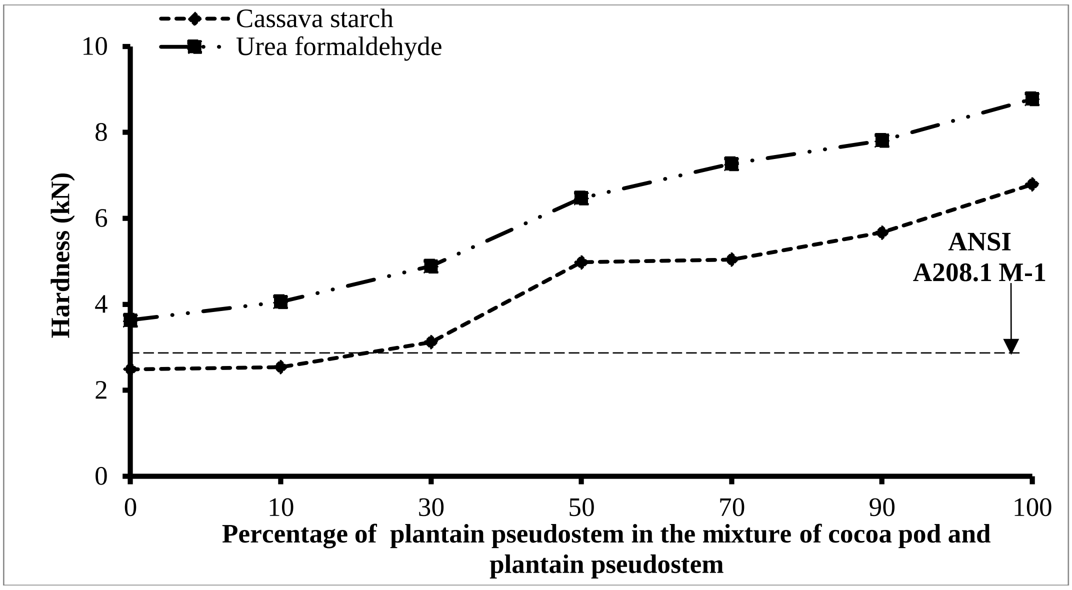

Fig. 8.
Relationship between hardness of particleboard and percentage of plantain pseudostem in the biomass mix.

Internal bond

Fig. 9. shows the relationship between the internal bond strength of particleboards produced and percentages of plantain pseudostem particles in the mixture. The internal bond strength increased with increasing percentage of plantain pseudostem in the mixture for both CS and UF adhesives. The highest internal bond strength value of 1.14N/mm^2 was obtained for 100% plantain pseudostem particles with UF as adhesive whilst the lowest internal bond strength of 0.58N/mm^2 was obtained for 100% cocoa pod particles with CS as an adhesive. Generally, the addition of plantain pseudostem to cocoa pod particles enhanced the internal bond of particleboards produced.

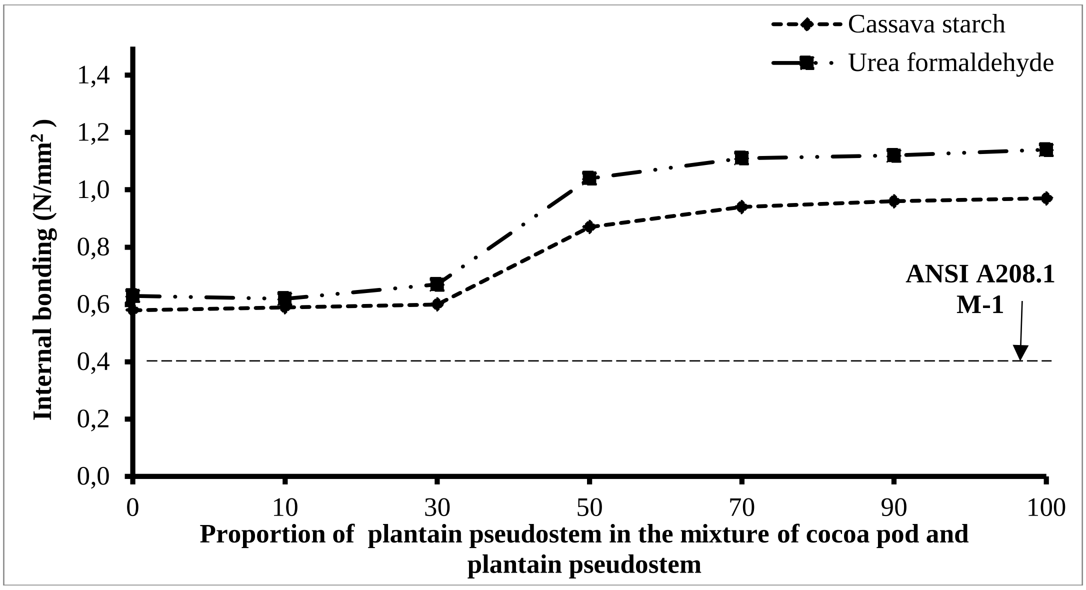

Fig. 9.
Relationship between internal bond strength of particleboard and percentage of plantain pseudostem in the biomass mix.

Increase in internal bond strength as a result of increase in the proportion of plantain pseudostem particles in the mixture was partly as a result of the high aspect ratio of the particles of the plantain pseudostem (135.03) as compared to the cocoa pods which has no fibers (Mitchual *et al.* 2020). Higher aspect ratio of the plantain pseudostem particles led to mechanical interlocking of relatively longer particles therefore, resulting in the formation of stronger bond and increased internal bond strength. Furthermore, high percentage of lignin in plantain pseudostem (11.24%) compared to cocoa pod (6.24%) might have contributed to better adhesion among particles in the panel thereby resulting in improved internal bonding of the particleboards produced. Joseleau *et al.* (2004) and Khedari *et al.* (2004) indicated that lignin is a natural adhesive that can contribute to improved adhesion between particles in the panel which could lead to improved bonding and dimensional stability. The manufactured particleboards met the requirement for M-1 and PBU grades of the ANSI A208.1 (2009) (0.4MPa) and JIS A 5908 (1994) (0.3MPa) standards for interior fitments and furniture (Fig. 9.).

Table 3

ANOVA of effect of the biomass mix and adhesive on internal bond strength of manufactured particleboard

Source	DF	ANOVA SS	Mean Square	F-Ratio	p-value
Biomass Material	6	2.894	0.482	90.269	0.000*
Adhesive	1	0.247	0.247	46. 203	0.000*
Biomass material x Adhesives	6	0.053	0.009	1.643	0.153†
Error	40	0.226	0.006		
Total	50	39.553			

*Statistically significant at 0.05 level of significance; †Not statistically significant.
Legend: DF = Degree of freedom

Analysis of variance (Table 3) shows that at 5% level of significance, the biomass mixes and type of adhesive used had significant effect on the internal bond strength of the particleboards produced. The multiple coefficient of determination and root mean square error for the ANOVA model were 0.9120 and 0.0775 respectively. Thus, the experimental factors could explain about 91.20% of the variability in the internal bond strength of the particleboards produced.

CONCLUSION

This study investigated the effect of percentages of plantain pseudostem particles in a mixture of cocoa pod and plantain pseudostem on the physical and mechanical properties of particleboards produced. The focus of the study was to determine if plantain pseudostem could be used to improve the physical and mechanical properties of particleboards produced from cocoa pod. From the result of the study, it could be concluded that the addition of plantain pseudostem to cocoa pod particles could significantly improve the physical and mechanical properties of particleboards produced from cocoa pod. This will therefore lead to improved load bearing capacity of the boards. Additionally, most of the mechanical and physical properties of the manufactured particleboards meet the minimum requirement of ANSI, JIS and EN standard for general grade particleboards. In the case of modulus of rupture, the result obtained when cocoa pod alone was used was not adequate compared with the ANSI A208.1 M-1 standard requirement which recommends 10 MPa as the minimum requirements. However, when the percentage of plantain pseudostem was increased beyond 36% and 75% respectively for urea formaldehyde and cassava starch adhesives, the particleboards produced had adequate modulus of rupture. The result of the study gives an assurance that cocoa pod could be added to the list of agro-forest residues that could be used for particleboard production. This study also confirms that generally particleboards produced using urea formaldehyde as an adhesive has better physical and mechanical properties than that of cassava starch. It is recommended that future studies look at the effect of a blend of cassava starch and urea formaldehyde as adhesive on the properties of particleboards.

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