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Decay Resistance of Particleboards Manufactured with Four Agro-Forest Residues Using Cassava Starch and Urea Formaldehyde as Adhesives

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Abstract

Many factors including depletion of the forest, environmental awareness, and generation of large quantities of agro-forest residues have increased the need to partially or wholly replace wood with agro-forest residue for particleboard production. This study assessed the decay resistance of particleboards produced from four agro-forest residues using cassava starch and urea formaldehyde as adhesives. *Musa paradisiaca pseudostem*, *Theobroma cacao* stem and pod, and sawdust of *Ceiba pentandra* were used for the study. Properties determined were: Weight loss, decay resistance rating and decay susceptibility index. These properties were evaluated after 12 weeks of exposure to *Coriolopsis polyzona* in accordance with ASTM D 2017-05. The results indicate that the weight loss for *Musa paradisiaca pseudostem* particleboard was least for both urea formaldehyde and cassava starch adhesives. Even though almost all the particleboards produced were classified as resistant or highly resistant to fungi attack, those produced with urea formaldehyde had better decay resistance properties than that of cassava starch. Furthermore, particleboards coated with synthetic polyvinyl lacquer had better resistance to fungi attack than the uncoated ones. At 5% level of significance, the agro-forest residue, adhesive and surface finish as well as their interactions had significant effects on decay resistance of the particleboards produced. It is recommended that further studies which aim at determining the effect of combination of the agro-forest residues and that of urea formaldehyde and cassava starch be conducted to determine their effects on decay properties of particleboards.

Keywords

Agro-Forest Residue, Cassava Starch, Decay Resistance, Particleboard, Urea Formaldehyde

1. Introduction

Particleboard is manufactured by hot compression of wood particles, blended with binding agent and forming the mixture into a sheet. The demand for particleboard products has increased substantially throughout the world, representing 57% of the total consumption of wood-based panels, a percentage that is continuously growing at a rate of 2% - 5% annually [1] [2]. Sawdust from timber processing industry has been the main source of raw material for this product. However, due to the depletion of the forest, this source could not be sustained [3].

Particleboards can be produced from any agro-forestry residues, as long as they have required physical, mechanical and biological resistance. The quality of the final product is directly related to the choice of the raw material [4]. Consequently, there have been a lot of studies on the suitability of the available lignocellulose materials in the production of particleboard. Some of these are oat hulls, corn stalk, elephant grass, canola straws, rice husk, sugarcane bagasse and corn cob [3] [5] [6] [7] [8]. There is the need to extend such studies to cover other lignocellulosic agricultural residues such as *Musa paradisiaca* pseudostem, *Theobroma cacao* stem (without the bark) and pod, and sawdust of *Ceiba pentandra*.

Musa paradisiaca pseudostem is a lignocellulosic agricultural residue which is readily available in large quantities on farmlands and has no special industrial application. Globally, the production of *Musa paradisiaca* grew at a compound annual rate of 3.7 percent, reaching a record of 117.9 million tonnes in 2015 from around 68.2 million tonnes in 2000 [9]. Ghana is the largest producer of *Musa paradisiaca* in West Africa and second in Africa [10] as cited in [11]. Studies indicate that at the end of the year 2016, about 7,184,842 tonnes of *M. paradisiaca* pseudostem residue were generated in Ghana [9]. This constitutes about 59% of the total agricultural crop residues generated. Therefore, a large amount of *Musa paradisiaca* pseudostem residue is generated annually in Ghana.

When *Theobroma cacao* plants are waned, the trees are felled for firewood because the stems are not large enough to produce lumber. In 2018, Ghana cut down 680,000 hectares of over-aged cocoa trees, representing 40 percent of the country's stock of cocoa trees [12]. These trees do not have any significant industrial application apart from being used as household fuel wood. However, particleboards can be made with lower grade plant materials than other wood composite panels such as oriented strand board and plywood. Thus, all plant materials can essentially be utilized for making particleboard. In addition, the cultivation and processing of *Theobroma cacao* generate a large amount of cocoa pods as residue which are either burnt on the farms causing environmental pollution or inefficiently used as fuel for cooking. The *Theobroma cacao* pod represents 70% to 75% of the whole cocoa fruit weight. Therefore, each ton of cocoa fruit will produce between 0.70 to 0.75 tonnes of cocoa pod [13]. Ghana and Cote d'lvoire produced 900,000 and 2,000,000 tonnes of cocoa respectively in 2018 [14]. Therefore, an estimated amount of 2,175,000 tonnes of waste cocoa pod was generated in 2018.

Lastly, wood residue in the form of sawdust which is generated in large quantities from processing round logs remain unutilized. About 10% - 13% of the total volume of the wood log is reduced to sawdust in milling operations [15]. One of the most frequently processed timber species in Ghana wood industries is *Ceiba pentandra*. *Ceiba pentandra* is a low-density species (409.22 kg/m^3) with acid-insoluble lignin and alpha-cellulose contents of 24.34% and 41.24% respectively [16]. The low particle density of *Ceiba pentandra* makes it most suitable for densified biomass products such as manufactured boards. This is because particles of *Ceiba pentandra* with low particle density would have higher tendency of undergoing plastic deformation at low compacting pressure leading to the formation of strong bonds.

This paper is part of a wider study conducted to characterize particleboard produced from selected agro-forest residues. Specifically, the paper reports the findings of decay resistance properties of particleboards produced from *Musa paradisiaca pseudostem*, *Theobroma cacao* stem and pod, and sawdust of *Ceiba pentandra* residues using cassava starch and urea formaldehyde.

2. Methodology

2.1. Particleboard Manufacture

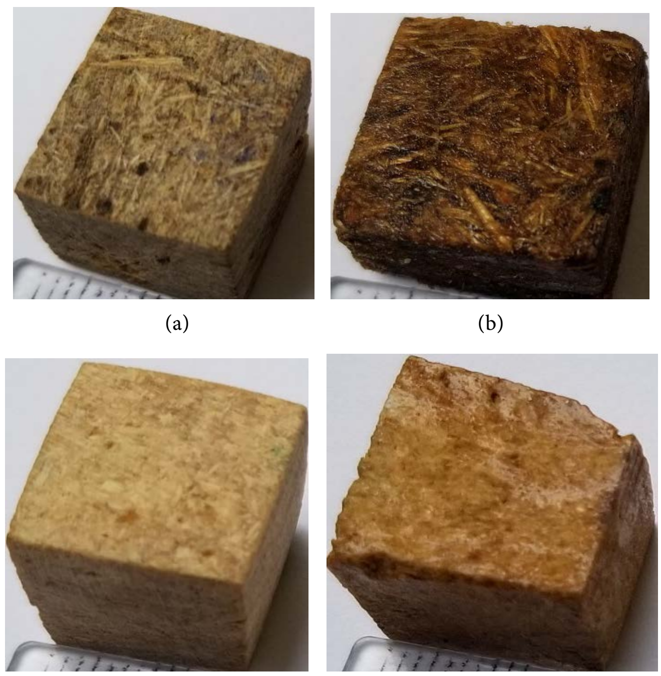
Musa paradisiaca pseudostem, *Theobroma cacao* stem (without the bark) and pod, and sawdust of *Ceiba pentandra* were used for the study. The *Musa paradisiaca* pseudostem was obtained from a commercial farm land after harvesting. The water was extracted, and the fibres oven-dried before milling. *Theobroma cacao* trees of twenty-five years were felled and converted into sawdust by sawing. Fresh *Theobroma cacao* pods were first sun-dried and then crushed into particles using a hammer mill. Sawdust of *Ceiba pentandra* was obtained from a timber processing company in Ghana. The four biomass materials were sun dried at an average relative humidity and temperature of 70% and 29˚C respectively for three weeks within the months of March and April. Thereafter, the materials were further dried to moisture content ranging from 3% to 6% using a solar dryer. The agro-forest raw materials were then classified and particle size (PS) 0.5 mm ≤ PS < 1.5 mm were blended with cassava starch (CS) and urea formaldehyde (UF) and formed mat with it. Ammonium chloride (NH_4Cl) was added as a curing catalyst based on the solid content of the adhesive.

The resinated particles were pre-pressed into 80 mm thick single layer of 300 mm × 300 mm aluminium sheet mould. Metal stops of dimension 20 mm × 20 mm were used in the press platens to allow the same particle thickness to be achieved for the entire test run. The mat was pressed with the following pressing conditions: Pressing temperature 170˚C; Pressing pressure 3.5 MPa; Pressing time 8 minutes; Pressing closing rate 3 - 4 mm/minute; Target thickness 20 mm; Target density 500 - 600 kg/m^3; Hardener 2%; Adhesive (UF and CS) and Compacting time 15 minutes. The produced particleboards were then trimmed and conditioned in a control room with a temperature of 20˚C ± 2˚C and a relative humidity of 62% ± 2% for 6 days before they were sawn into various sizes for further testing. Each type of particleboard was replicated five (5) times.

2.2. Preparation of Test Specimen

Two types of specimens of the particleboards produced were prepared for the study—the polished specimen and the unpolished specimen (**Figure 1**). The particleboards were planed to a thickness of 14 mm using a tungsten carbide tipped three-cutter block thicknesser planer with a cutting speed of 4000 rpm. Thereafter, sanding machine (Model number Bosch GSS20-40) with abrasive grit of 180 was used to smoothen the surface of the planed samples.

With the polished specimen, three layers of clear synthetic polyvinyl lacquer (SPL) were applied to the sanded surface using a hand brush at an environmental temperature of 32˚C and relative humidity of 78%. After each application, four hours were allowed for the drying of the previous one. In accordance with ASTM D 2017-05 standard [17], the samples were sawn into specimens of dimension 14



(a) (b) (c) (d)

Figure 1. Polished and unpolished particleboard specimens. (a) Unpolished *Musa paradisiaca pseudostem* specimen; (b) Polished *Musa paradisiaca pseudostem* specimen; (c) Unpolished *Ceiba pentandra* specimen; (d) Polished *Ceiba pentandra* specimen.

mm × 14 mm × 14 mm using a fine teeth dovetail saw. *Triplochiton scleroxylon* of dimension 15 mm × 50 mm × 300 mm was used as substrates.

2.3. Decay Resistance Test of Specimen

The decay resistance test of the specimens was conducted using simple accelerated laboratory (soil block) method in accordance with ASTM D 2017-05 [17]. French square bottles, three-quarter filled with moistened screened top soil were used as decay chamber. The soil had pH of 6.2 and moisture holding capacity of 39%. Seventy-two strips of *Triplochiton scleroxylon* were immersed in distilled water for 24 hours and placed on top of the soils in the glass jars. The glass jars were loosely closed with their plastic screw-lids and sterilized in an autoclave at a temperature of 121˚C with a pressure of 15 psi for 20 minutes. Actively growing mycelium discs of *Coriolopsis polyzona* of diameter 10 mm were placed on each of the *Triplochiton scleroxylon* wooden strips after cooling. The jars and their contents were placed in an incubator at a temperature of 25˚C and relative humidity of 70% for 4 weeks for complete colonization of the *Triplochiton scleroxylon* strips. Thereafter, an oven-dried sterilized specimen of the polished and unpolished particleboards were gently placed on the mycelial mat that had formed on the *Triplochiton scleroxylon* strips in the glass jars under sterile conditions.

The set-ups were then incubated again for 12 weeks at a temperature and relative humidity of 25˚C and 70% respectively in order to allow the *C. polyzona* to feed on the particleboard specimens. At the end of the period, the specimens were removed from the glass jar, cleaned by gently removing any adhering mycelium and oven dried for 24 hours at a temperature of 103˚C ± 2˚C until a constant weight was recorded. The percentage weight loss caused by the action of the decaying fungus was determined as shown in Equation (1):

$$\text{Percentage weight loss}\left(\%\right)=\frac{I_w-F_w}{I_w}\times 100 \quad (1)$$

where:

I_w = Initial oven-dry weight of specimen.

F_w = Final oven-dry weight of specimen.

2.4. Decay Resistance Rating of Test Specimen

The decay resistance rating of the test specimens was based on the weight loss classification adopted from the ASTM D2017-05 [17] as indicated in **Table 1**.

Table 1. Decay resistance classification for percentage weight loss.

Average weight loss (%)	Decay resistance class
0 - 10	Highly resistant (Class I)
11 - 24	Resistant (Class II)
25 - 44	Moderately resistant (Class III)
45 and above	Susceptible (Class IV)

2.5. Decay Susceptibility Index

Curlings and Murphy [18] proposed method for determination of decay susceptibility index (DSI) was used to determine the intensity of attack of the particleboard for the different finished surfaces, agro-forest residue type and the adhesives used. The actual mass losses of the manufactured particleboards caused by fungus *Coriolopsis polyzona* were compared with the mass losses of the appropriate reference timber (*Terminalia superba*). Based on this method the DSI for the samples were computed as shown in Equation (2):

$$\text{Decay susceptibility index}(\%) = \frac{\text{MLs}}{\text{MLc}} \times 100 \tag{2}$$

where:

MLs = Mass loss of the composite sample.

MLc = Mass loss of the appropriate reference timber (*Terminalia superba*).

2.6. Scanning Electron Micrograph Analysis of Specimen

Scanning electron micrographs of test specimen were obtained from Phenom ProX desktop SEM with EID. Sections of the test specimens were cut into dimension 10 mm × 10 mm × 5 mm; coated with a thin film of platinum to make them conductive; mounted on aluminum stub using carbon tape and then analyzed using acceleration of 15 kV with a magnification range of 1300× to 1500×.

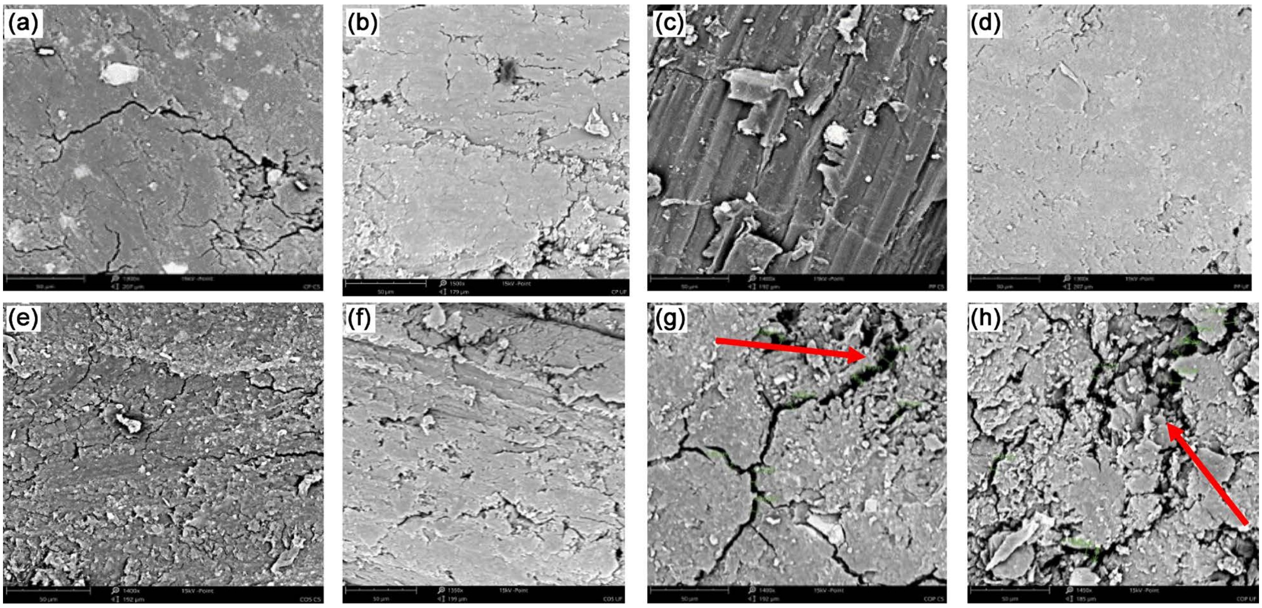
2.7. Statistical Analysis

The data obtained were analysed using descriptive and inferential statistics. Statistical software used for the analyses was version 20 of Statistical Package for Social Scientists (SPSS). The mean and standard deviation of the percentage weight loss were computed and the decay resistance class determined. Tukey's multiple comparison of means was used to establish significant difference between means of decay susceptibility index at 5% level of significance.

3. Results and Discussion

3.1. Surface Morphology

The surface morphology analysis of the manufactured particleboards was carried out using scanning electron microscope (SEM) and the images obtained are as shown in **Figures 2(a)-(h)**. The study of the surface morphology was significant in identifying the adhesive spread and the fibre arrangement in the manufactured particleboard which could influence the decay activity of the *C. polyzona*. The microstructure of *T. cacao* pod particleboards revealed major structure of micro cracks, pores and loose particles (**Figure 2(g)** and **Figure 2(h)** indicated with arrows). It was observed that the particles were detached from the adhesive. This could lead to water accumulation in such spaces thereby, creating a conducive environment for easy penetration of mycelium into the core of the specimen, thus increasing the rate of decay activity by the *C. polyzona*.



Legend: CP = *Ceiba pentandra*: MPP = *Musa paradisiaca* pseudostem: TCP = *Theobroma cacao* pod: TCS = *Theobroma cacao* stem: CS = Cassava starch: UF = Urea formaldehyde.

Figure 2. Scanning electron micrographs magnification range of 1300× to 1500× of the manufactured particleboards. (a) CP + 100% CS; (b) CP + 100% UF; (c) MPP + 100% CS; (d) MPP 100% UF; (e) TCS + 100% CS; (f) TCS + 100% UF; (g) TCP + 100% CS; (h) TCP + 100% UF.

The scanning micrographs of *C. pentandra*, *M. paradisiaca* pseudostem and *T. cacao* stem particleboards show clear and smooth agglomeration of adhesives on their surfaces (**Figures 2(a)-(f)**) at the magnification range of 1300× to 1500×. This therefore protects the surfaces against mycelium entry. This clear and smoothness of the surface of the particleboards is due to good interfacial bonding between the adhesives and the particles. Han *et al.* [19], Dalen, [20] and Idris *et al.* [21] indicated that such characteristic enhances the resistance of the particleboard to fungus invasion.

The SEM micrographs (**Figure 2**) indicate that the differences in the specimens were the vast display of particle-particle and particle-adhesive interactions which enhanced the bonding, thus, eliminating pores that could be exploited by *C. polyzona*. However, there existed micro cracks and pores (measured in average of 6.37 µm. at 1400×) on the surface of the *T. cacao* pod particleboards which could be caused by its high bulk density (323.96 km^3) and the presence of parenchyma tissues. *T. cacao* pod contains a higher proportion of parenchyma tissues which has greater affinity for water absorption. Ramle *et al.* [22] and Abdullah *et al.* [23] emphasized that parenchyma cells are more hygroscopic, naturally spongy and have high capacity for water absorption and storage than other cells. This provides conducive environment for active invasion by *C. polyzona*. The smooth surface of the particleboards manufactured from *M. paradisiaca* pseudostem, *T. cacao* stem and *C. pentandra* is an indication of good compatibility between the biomass particles and adhesives used. It was further observed that the particles were not detached from the adhesive. This might be due to good interfacial bonding between the adhesives and the particles as was observed by Han *et al.* [19] and Dalen [20]. Idris *et al.* [21] confirmed that this good bonding was achieved from compounding of particles and adhesives which inhibits access to *C. polyzona*, thus improving the decay resistance of the composite panel.

3.2. Decay Resistance

Figure 3 and Figure 4 indicate the weight loss of polished and unpolished particleboards produced from the four agro-forest residues using CS and UF as adhesives. With CS as an adhesive, the highest weight loss for the unpolished particleboards was obtained for *T. cacao* pod (46.18%), followed by *C. pentandra* (41.43%), *T. cacao* stem (22.08%) and *M. paradisiaca* pseudostem (15.54%) in that order. For the same adhesive, the polished particleboards showed a similar

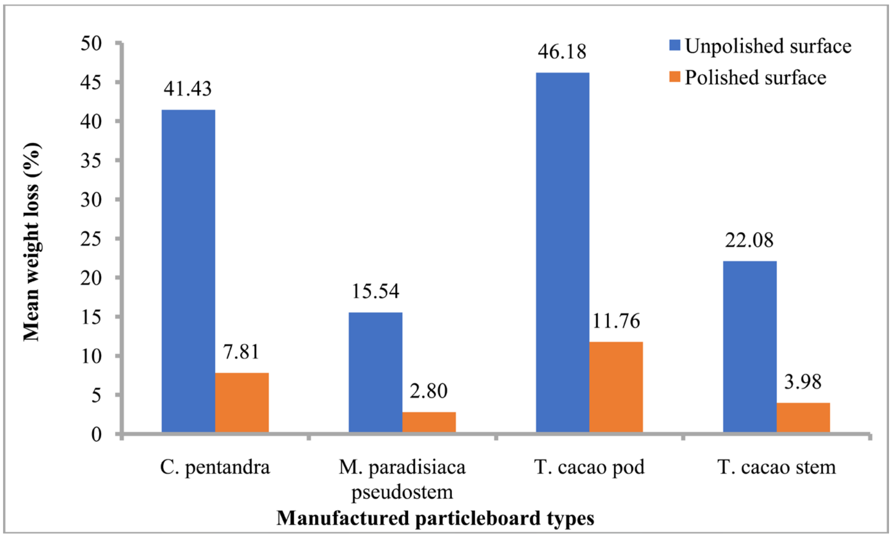


Figure 3. Weight loss of particleboards with cassava starch as adhesive.

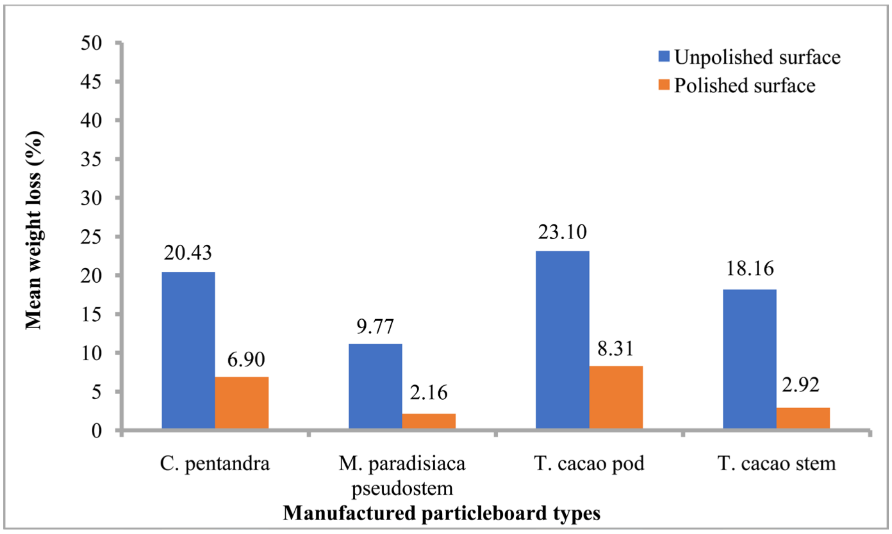


Figure 4. Weight loss of particleboards with urea formaldehyde as adhesive.

weight loss trend. The highest weight loss was obtained for *T. cacao* pod particleboard (11.77%) followed by *C. pentandra* (7.81%), *T. cacao* stem (3.98%) and *M. paradisiaca* pseudostem (2.80%) in that order. Similar trend of weight loss was obtained for particleboards produced using UF (**Figure 4**) with *T. cacao* pod recording the highest weight loss and *M. paradisiaca* pseudostem recording the least weight loss for both the polished and unpolished surfaces. The low weight loss of *M. paradisiaca* pseudostem could be attributed to its higher aspect ratio (153.03) as compared to the other agro-forest residues (*T. cacao* stem = 61.60; *C. pentandra* = 60.54) which resulted in better interlocking of the fibres to form stronger bonds. This therefore, resulted in less void space and more connected surface area (**Figure 2(c)** and **Figure 2(d)**) which inhibit fungi attack. Besides, *M. paradisiaca* pseudostem has high content of carbon, extractives and inorganic components which are difficult to digest by fungi [24].

The result further indicates that for the same raw material, particleboards produced using UF had weight loss far lower than their corresponding ones produced from CS. This could be attributed to the toxic preservative-chemicals found in UF meant to extend the service-life of particleboards manufactured with it [25] [26]. Therefore, using UF as an adhesive will lead to production of particleboards with better resistance to attack by *C. polyzona* than the use of CS.

Furthermore, for particleboards made from the same agro-forest residue the percentage weight loss of the polished specimens was lower than the unpolished ones. This could be due to the fact that the lacquer when applied seals the pores and produces a film of coating that protects the surface of the particleboard from *C. polyzona* colonization and penetration, thereby increasing its decay resistance. In addition, flavonoids, phenolic compounds and tannins in the lacquer act to improve the durability of the particleboards [27] [28] [29] [30] [31]. Similar results were indicated for the effect of varnish coating by Rafiquzzaman *et al.* [32], Sonmez *et al.* [33], Kaygin *et al.* [34] and Metha [35]. On the average, the weight loss of the particleboards produced was lower than the maximum value indicated by ASTM D 2017 (2005) [17] which is 50%. This suggests that all the particleboards produced have good resistance to *C. polyzona*.

Table 2 which indicates the ANOVA results shows that at 5% level of significance, the agro-forest residue, adhesive used and surface finish (*i.e.* polished or unpolished) as well as their interactions have significant effects on the weight loss of the particleboards produced (p-value < 0.05). The multiple coefficient of determination value (R^2) and root mean square error (RMSE) of the ANOVA model were 0.9150 and 4.2306 respectively. This suggests that about 91.50% of the variability in the weight loss of the manufactured particleboards could be explained by the agro-forest residue, the adhesives used, the surface finish and their interactions.

3.3. Decay Resistance Rating

The decay resistance rating of the polished and the unpolished manufactured particleboards are shown in Table 3. The analysis of weight loss caused by *Coriolopsis polyzona* indicates that the attack was intense on particleboard manufactured from *T. cacao* pod blended using CS as it is rated as being susceptible to *Coriolopsis polyzona* attack. All the particleboards produced from the other

Table 2. ANOVA of durability property of the manufactured particleboard.

Source	DF	ANOVA SS	Mean square	F-ratio	p-value
Agro-forest residue	3	3254.01	1084.67	60.60	0.000*
Adhesive	1	1337.44	1337.44	74.73	0.000*
Surface finish	1	8413.91	8413.91	470.10	0.000*
Agro-forest residue × Adhesive	3	531.51	177.17	9.90	0.000*
Agro-forest residue × Surface finish	3	806.23	268.74	15.02	0.000*
Adhesive × Surface finish	1	851.11	851.11	47.55	0.000*
Agro-forest residue × Adhesive × Surface finish	3	380.35	126.78	7.08	0.001*
Error	80	1431.86	17.90		
Total	96	39364.26			

*Statistically significant at 0.05 level of significance; DF = Degree of freedom.

Table 3. Durability ratings of manufactured particleboards.

Particleboard type	Weight losses (%)	Decay resistance class
Unpolished specimen		
C. pentandra + CS	41.43 (5.63)	Moderately resistant
C. pentandra + UF	20.43 (5.61)	Resistant
M. paradisiaca pseudostem + CS	15.54 (4.56)	Resistant
M. paradisiaca pseudostem + UF	9.77 (2.38)	Highly resistant
T. cacao pod + CS	46.18 (8.07)	Susceptible
T. cacao pod + UF	23.10 (0.63)	Resistant
T. cacao stem + CS	22.08 (4.96)	Resistant
T. cacao stem + UF	18.16 (4.87)	Resistant
Polished specimen		
C. pentandra + CS	7.81 (2.07)	Highly resistant
C. pentandra + UF	6.90 (2.69)	Highly resistant
M. paradisiaca pseudostem + CS	2.80 (1.17)	Highly resistant
M. paradisiaca pseudostem + UF	2.16 (0.83)	Highly resistant
T. cacao pod + CS	11.76 (4.99)	Resistant
T. cacao pod + UF	8.31 (1.51)	Highly resistant
T. cacao stem + CS	3.98 (1.62)	Highly resistant
T. cacao stem + UF	2.92 (0.55)	Highly resistant

agro-forest residues, polished and unpolished using both CS and UF as adhesives had decay resistance ratings ranging from moderately resistant to highly resistant. Most significantly, with the exception of particleboard produced from *T. cacao* pod using CS, all the particleboards for which the surfaces were polished were rated highly resistant.

3.4. Decay Susceptible Index

Decay susceptibility index (DSI) compensates for the differences stemming from panel thickness and makes it possible to establish a ranking of panels in terms of their resistance to wood decaying fungi (Fojutowski *et al.* [36]. The results of DSI of the particleboards produced are shown in **Table 4**. The DSI of *M. paradisiaca* pseudostem particleboard made with CS and UF were 53.91% and 40.58% respectively for the unpolished specimen and 8.77% and 8.22% respectively for the polished specimen. The worse situation was obtained for *T. cacao* pod particleboard using UF and CS for which the DSI was 152.64% and 100.20% respectively for the unpolished specimen, and 34.45% and 28.94% respectively for the polished specimen. This confirms the earlier result which indicates that particleboards manufactured from *M. paradisiaca* pseudostem show greater resistance to decay. Fojutowski *et al.* [36] and Curling and Murphy [18] indicated that manufactured particleboards with DSI value of 100% mean it has the same decay resistance as that of the wood used in the test for comparison. Also, particleboards with DSI values lower than 100% indicate more resistance to fungus attack than the wood used in the test for comparison, and finally, DSI values greater than 100% indicate particleboard with less resistance to fungus attack than the wood used in the test for comparison.

From the foregoing, it could be concluded that with the exception of unpolished particleboards produced from *C. pentandra* using CS, and the unpolished

Table 4. Decay susceptibility index of tested manufactured particleboards.

Particleboard type	Adhesive type (%)		Decay susceptibility index (%)	
	Cassava starch	Urea formaldehyde	Unpolished	Polished
C. pentandra	100	-	150.15^{f}	29.58^{f}
C. pentandra	-	100	69.68^{d}	26.26^{d}
M. paradisiacal pseudostem	100	-	53.91^{b}	8.77^{a}
M. paradisiacal pseudostem	-	100	40.58^{a}	8.22^{a}
T. cacao pod	100	-	152.64^{f}	34.45^{g}
T. cacao pod	-	100	100.20^{e}	28.94^{e}
T. cacao stem	100	-	72.46^{d}	13.67^{c}
T. cacao stem	-	100	62.47^{c}	10.17^{b}

Figures in columns with the same letters are not significantly different (Turkey's multiple test, $p > 0.05$).

ones produced from *T. cacao* pod using both CS and UF, all the other specimens used in the test were more resistant to the attack of *C. polyzona* than *Terminalia superba*.

4. Conclusion

The study investigated the decay resistance of particleboards produced from four agro-forest residues using cassava starch and urea formaldehyde as adhesives. It could be concluded that of all the four agro-forest residues used, *M. paradisiaca* pseudostem particleboard exhibited the best decay resistance characteristics against fungi attack for both urea formaldehyde and cassava starch adhesives. Additionally, particleboards produced using urea formaldehyde as an adhesive have better decay resistance properties than that of cassava starch. The above notwithstanding, almost all the particleboards produced were classified as being resistant or highly resistant to fungi attack. Therefore, cassava starch could be used as a substitute to urea formaldehyde in particleboard production. The study further concludes that particleboards coated with synthetic polyvinyl lacquer could have better resistant to fungi attack than the uncoated ones. This is due to the lacquer's ability to seal the pores and produce a coating film that protects the surface from fungi colonization and penetration in addition to flavonoids, phenolic compounds and tannins in the lacquer that improves durability. The implication is that if particleboards are coated with the appropriate finishes, they could prolong their service life. At 5% level of significance, the agro-forest residue, adhesive and surface finish as well as their interactions had significant effects on the decay resistance of the particleboards produced.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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