Particle boards produced from cassava stalks: Evaluation of physical and mechanical properties

We investigated the potential use of cassava stalks for the production of bonded particle boards. Particle boards were produced from cassava stalks using urea-formaldehyde as a binder. Water absorption and thickness swelling tests were carried out to determine dimensional stability of the boards while modulus of rupture and modulus of elasticity tests were carried out to assess the mechanical strength of the boards. Particle boards produced using an adhesive–cassava stalk ratio of 3:1 gave the best results in terms of the lowest mean values of water absorption (20%) and thickness swelling (6.26%), as well as the highest values of modulus of rupture (4×10^6 N/m²) and modulus of elasticity (2366.74×10^6 N/m²). The particle boards produced met the ANSI/A208.1-1999 standard for general-purpose boards. The results of analyses of variance carried out revealed that the adhesive–cassava stalk ratio had a marked influence (p<0.05) on the physical properties (water absorption and thickness swelling) but not on the mechanical properties (modulus of rupture and modulus of elasticity).

Introduction

The start of the manufacture of modern particle boards can be traced back to the early 19th century.1 In Nigeria and throughout the world, the panel/board industry has experienced continuous growth in recent years, using wood mainly obtained from forest resources.2,3 The use of wood and wood-based panels/boards was estimated to be 2.866 million m² and 0.121 million m², respectively, in the early 1990s. These values are expected to rise to 4.704 million m² and 0.688 million m², respectively, within the next 20 years.4,5 The increased demand for wood and wood-based panel products in Nigeria has placed a significant pressure on current forest resources, which has consequently led to an increase in the price of wood.6,7 This demand has led to the need to find alternative raw materials for the production of boards and panels. One solution to this problem, as identified by researchers, is the use of agricultural residues such as the stalks of most cereal crops, rice husks, coconut fibres (coir), bagasse, maize cobs, peanut shells, cassava stalks, etc. These agricultural residues are typically left on the farm after the target crops have been harvested. Nigeria is the world’s largest producer of cassava, with an annual production capacity of 45 million tonnes.8 Agbro and Ogie9 reported that cassava has the highest output of residues generated in Nigeria and its estimated value is about 29 million metric tonnes per annum. In most underdeveloped and developing countries, these residues have very limited reuse capacity and they are typically inappropriately discarded or openly burnt.2,8-11

The improper disposal of these wastes has many negative environmental consequences. For instance, burning these wastes leads to increased levels of carbon dioxide in the atmosphere, which contributes to global warming. These wastes can also cause blockage of drains which consequently results in flooding. Accumulated wastes release offensive odours, thereby contributing to air pollution, and also serve as a breeding ground for mosquitoes and flies which spread several diseases. Waste products also add to space problems in landfills, as they remain in landfills until they are biodegraded.12 The use of these materials offers potential benefits both environmentally and socio-economically. They are cheap, abundantly available, resource oriented when handled appropriately and the environmental problems associated with inappropriate disposal are eliminated.13,14

Numerous studies on the use of these wastes have been carried out in many parts of the world, including Nigeria. Most of these studies were focused on determining the suitability of these wastes for the manufacture of composites.15 Some of the agro-wastes studied so far include rice husk16, rattan2, pine1, wood wastes15, wheat straw17, cotton straw18, sunflower stalks1, and date palm leaves19.

Particle board is a composite panel product traditionally produced from wood and wood wastes such as shavings, flakes, wafers, chips, sawdust, strands and wood wool.10,20 Particle board is commonly used in structural applications such as flooring, wall bracing, ceiling boards, furniture, partitioning and cladding.21,22,23 Synthetic resins are used to bond the agro-wastes together and other additives can be added to improve some of its properties. Resin-bonded panels are typically lighter, and thus have the potential to replace cement-bonded panels and concrete constructions like prefabricated walls and partitions.24 Several types of resins are commonly used, although urea-formaldehyde is the cheapest and easiest to use.

We investigated the potential use of cassava stalks for the production of bonded particle boards in this study. Our objective was to evaluate the physical and mechanical properties of cassava stalk bonded particle board. A manufacturing process such as this one has the potential to reduce the pressure on forest resources and at the same time provide solutions to the problems of agricultural waste disposal in Nigeria.

Materials and methods

Material collection and pretreatment

Cassava stalks were obtained from the Asaba cassava mill located in the Delta State of Nigeria. The urea-formaldehyde adhesive used as a binder was obtained from the Chemical Engineering Laboratory, University of Benin, Edo State, Nigeria. The cassava stalks were milled using a hammer mill and then sifted using standard sieves.
to obtain particles in the size range 0.85–2.0 mm. The milled cassava stalks were transferred into hot water at a constant temperature of 85 °C to extract inhibitory sugar compounds such as glucose, hemicelluloses and lignin. This extraction was done in order to ensure proper setting of the boards. The extracted materials were separately air dried to attain approximately 12% moisture content before use.

**Particle board formation and testing**

The milled cassava stalks were mixed thoroughly with the urea-formaldehyde adhesive based on the experimental design specified in Table 1 until a uniform lump-free matrix was obtained. After mixing, the material was put in a mat-forming box, with dimensions 0.35 m × 0.35 m × 0.006 m. A manual press machine was used to make a pre-pressing at 0.78 × 10⁶ N/m². The box was then put in a hydraulic press and the boards were made by using an 8-min press closing time at a pressure of 1.23 × 10⁶ N/m². The mat-forming box was covered with a polythene sheet prior to board formation to prevent the boards from sticking onto the box.

The nominal dimensions and density of the boards produced were 0.35 m × 0.35 m × 0.006 m and 1000 kg/m³, respectively. Three boards were produced for each treatment. About 20 mm of the edge of each board was trimmed off the samples using a buzz saw. The boards were subsequently put in a climatisation chamber at a temperature of 20±2 °C and a relative humidity of 65±2% for 21 days. They were thereafter subjected to physical tests – thickness swelling and water absorption tests – and mechanical tests – modulus of rupture and modulus of elasticity tests – in accordance with the procedures stipulated in ASTM D1037 and DIN 52362, respectively.²¹,²⁴

| Table 1: Experimental design for the manufacture of particle boards |
|-----------------------------|--------------------|-----------------|
| **Treatment (adhesive–cassava stalk ratio)** | **Adhesive** | **Material** |
| T1 (2:1) | Urea-formaldehyde | Cassava stalks |
| T2 (2.5:1) | | |
| T3 (3:1) | | |

<table>
<thead>
<tr>
<th><strong>Type</strong></th>
<th><strong>%</strong></th>
<th><strong>Type</strong></th>
<th><strong>%</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 (2:1)</td>
<td>66.7</td>
<td>33.3</td>
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<tr>
<td>T2 (2.5:1)</td>
<td>71.4</td>
<td>28.6</td>
<td></td>
</tr>
<tr>
<td>T3 (3:1)</td>
<td>75.0</td>
<td>25.0</td>
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</table>

**Statistical analysis**

The experimental design used in this work was a 3 x 1 factorial experiment in completely randomised design resulting in three treatments as shown in Table 1. The factors considered were material type (cassava stalks) and adhesive–cassava stalk ratio (by mass) (2:1, 2.5:1 and 3:1). The following properties were evaluated: water absorption after 24 h, thickness swelling after 24 h, modulus of elasticity and modulus of rupture. An analysis of variance (ANOVA) was performed and a 5% probability level was used to test the significance of treatment means.

**Results and discussion**

**Effect of material variables on physical properties of the boards**

The dimensional stability of the boards was assessed through water absorption and thickness swelling tests. Figure 1 shows the values of water absorption of particle boards produced from cassava stalks using different adhesive–cassava stalk ratios. The water absorption ranged from 20% to 43.12%. The highest water absorption was obtained for particle boards produced using an adhesive–cassava stalk ratio of 2:1, while the lowest water absorption was obtained for particle boards produced using an adhesive–cassava stalk ratio of 3:1. Small values of thickness swelling are indicative of dimensional stability; hence the boards produced using the 3:1 ratio would be expected to perform better than the others. It has been reported that the thickness swelling is affected by the presence of void spaces in the boards in the same way as water absorption, as these spaces enhance the absorption of water by the boards which leads to internal swelling.²² The results presented are also in agreement with those reported by Murakami et al.²³ and Mendes et al.²⁴ who observed that by increasing the adhesive content of the boards, the dimensional stability of the boards can be enhanced. The American National Standard Institute specifies a maximum thickness swelling of 8% for general-purpose particle boards (standard ANSI/A208.1-1999).

Figure 1: Percentage water absorption of particle board produced using different adhesive–cassava stalk ratios (2:1, 2.5:1 and 3:1).

**Table 2: Analysis of variance of the effect of material variables on water absorption**

<table>
<thead>
<tr>
<th><strong>Source</strong></th>
<th><strong>d.f.</strong></th>
<th><strong>Type III sum of squares</strong></th>
<th><strong>Mean square</strong></th>
<th><strong>F</strong></th>
<th><strong>p-value</strong></th>
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<tbody>
<tr>
<td>Adhesive–cassava stalk ratio</td>
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<td>364.38</td>
<td>182.19</td>
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</table>

*p < 0.05

There was a significant difference in water absorption after 24 h among the samples, as indicated by the ANOVA results presented in Table 2. The adhesive–cassava stalk ratio therefore significantly influenced the water absorption property of the particle boards.

Figure 2 shows the values of thickness swelling for particle boards produced from cassava stalks using different adhesive–cassava stalk ratios. The values of thickness swelling ranged from 6.26% to 24.54%. Copur et al.²⁶ and Mendes et al.²⁷ reported similar values for thickness swelling for boards produced from hazelnut husk and cassava bagasse, respectively. The highest value of thickness swelling was obtained for particle boards produced using an adhesive–cassava stalk ratio of 2:1 while the lowest thickness swelling was obtained for particle boards produced using an adhesive–cassava stalk ratio of 3:1. Small values of thickness swelling are indicative of dimensional stability; hence the boards produced using the 3:1 ratio would be expected to perform better than the others. It has been reported that the thickness swelling is affected by the presence of void spaces in the boards in the same way as water absorption, as these spaces enhance the absorption of water by the boards which leads to internal swelling.²² The results presented are also in agreement with those reported by Murakami et al.²³ and Adedji²⁴ who observed that by increasing the adhesive content of the boards, the dimensional stability of the boards can be enhanced. The American National Standard Institute specifies a maximum thickness swelling of 8% for general-purpose particle boards (standard ANSI/A208.1-1999).
The results obtained in this study, as presented in Figure 2, show that all the boards produced met the thickness swelling requirement specified by the American National Standard Institute (ANSI/A208.1-1999) for general-use boards.

![Figure 2: Thickness swelling of particle board produced using different adhesive–cassava stalk ratios (2:1, 2.5:1 and 3:1).](image)

Table 3: Analysis of variance of the effect of material variables on thickness swelling

<table>
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<tr>
<th>Source</th>
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<th>Mean square</th>
<th>F</th>
<th>p-value</th>
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<td>&lt;0.0001*</td>
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<td>Error</td>
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<tr>
<td>Total</td>
<td>14</td>
<td>1232.15</td>
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<td>3.15</td>
<td>0.085</td>
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</table>

* p < 0.05

The adhesive–cassava stalk ratio had a significant effect on the thickness swelling of the boards (Table 5; ANOVA, p < 0.05).

Effect of material variables on mechanical properties of the boards

The mean values of modulus of rupture of the different boards tested are presented in Figure 3. The highest value of modulus of rupture (4.0×10⁶ N/m²) was obtained for particle boards produced using an adhesive–cassava stalk ratio of 3:1 while the lowest modulus of rupture (2.56×10⁶ N/m²) was obtained for particle boards produced using an adhesive–cassava stalk ratio of 2:1. The relatively high values of modulus of rupture recorded could be as a result of the random distribution of the particles in the boards. This finding indicates that the boards are mechanically stable and can resist deformation under load. The adhesive–cassava stalk ratio did not significantly influence the modulus of rupture of the boards at the 5% probability level, as shown in Table 4. The American National Standard Institute standard ANSI/A208.1-1999 specifies a minimum modulus of rupture of 3×10⁶ N/m² for general-purpose particle boards. The results obtained in this study show that the boards produced using an adhesive–cassava stalk ratio of 2.5:1 and 3:1 met the requirements specified by the American National Standard Institute for general-use particle boards (ANSI/A208.1-1999). However, the boards produced using an adhesive–cassava stalk ratio of 2:1 did not meet the requirement.

![Figure 3: Modulus of rupture of particle board produced using different adhesive–cassava stalk ratios (2:1, 2.5:1 and 3:1).](image)

Table 4: Analysis of variance of the effect of material variables on modulus of rupture

<table>
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<tr>
<td>Total</td>
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</table>

ns, p > 0.05

Figure 4 shows the values of modulus of elasticity of the particle boards. The values ranged from 1075×10⁶ N/m² to 2367×10⁶ N/m². The highest modulus of elasticity was obtained for particle boards with an adhesive–cassava stalk ratio of 3:1 while the lowest modulus of elasticity was obtained for particle boards with an adhesive–cassava stalk ratio of 2:1. The results presented are also in agreement with those reported by Bamisaye. The minimum acceptable value of modulus of elasticity as specified by the American National Standard Institute standard ANSI/A208.1-1999 is 550×10⁶ N/m². The results obtained show that all the boards produced met this minimum requirement of the American National Standard Institute for general-use particle boards.

The adhesive–cassava stalk ratio did not significantly influence the modulus of elasticity of the boards (Table 5; ANOVA, p > 0.05).

![Figure 4: Modulus of elasticity of particle board produced using different adhesive–cassava stalk ratios (2:1, 2.5:1 and 3:1).](image)
Table 5: Analysis of variance of the effect of materials variables on modulus of elasticity

<table>
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</table>

ns. p>0.05

Conclusions

We investigated the potential use of cassava stalks for the production of particle boards using urea-formaldehyde as a binder. The following conclusions can be drawn:

- Particle boards can be produced from cassava stalks using urea-formaldehyde as a binder.
- Particle boards produced using an adhesive–cassava stalk ratio of 3:1 are more dimensionally stable as evident in their smaller values of water absorption and thickness swelling compared with the other samples.
- Particle boards produced using an adhesive–cassava stalk ratio of 3:1 have higher mechanical strengths as evident in the higher values of modulus of rupture and modulus of elasticity compared with the other samples.
- Particle boards that satisfy the ANSI/A208.1-1999 standard can be produced from cassava stalks using urea-formaldehyde as a binder.
- ANOVA results show that the adhesive–cassava stalk ratio significantly influenced the water absorption and thickness swelling but not the modulus of rupture and modulus of elasticity.

Authors’ contributions

F.A.A. and N.A.A. designed the study and K.C.B. performed the experiments. N.A.A. and K.C.B. managed the literature searches and N.A.A. wrote the first draft of the manuscript. F.A.A. provided analytical advice and corrected the manuscript. All authors read and approved the final manuscript.

References