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Investigation of Factors Affecting the Production and Properties of Maize Cob-Particleboards

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Abstract The aim of this research was investigating the factors that affect the properties and production of particleboards from maize cobs. The particleboards were produced at three different levels of resin content (125, 188, and 250 g) while using particles in the size ranges of 1.13 to <3.35 mm and 3.35–8 mm. Compaction ratio, pressing pressure, and mass of maize cob particles were production variables which were considered during the experiment. The maize cob particleboards were pressed under a pressure of 13 MPa and were left to cure for 17 h while holding at a pressure of 10 MPa. Properties of maize cob particleboards such as density, modulus of rupture (MOR), modulus of elasticity (MOE), water absorption, thickness swelling and linear expansion were investigated. The densities of maize cob particleboards ranged from 386 ± 49.96 to 723 ± 34.65 kg/m^3, which were comparable to the particleboard densities of 590 and 800 kg/m^3 of wood product industry. Maize cob particleboards produced using particles of size 3.35–8 mm presented a higher density as compared to other maize cob particleboards. The modulus of elasticity for maize cob particleboards was in the range 5.89 ± 6.00 to 61.82 ± 10.09 MPa, while the modulus of rupture ranged from 0.32 ± 0.14 to 1.50 ± 0.16 MPa, thus maize cob particleboards could be used as ceiling boards and wall claddings. Particleboards produced from particles of size in the range 1.13–8 mm presented better mechanical properties (MOE and MOR) as compared to other particleboards. The maize particleboards showed poor properties to moisture and thus applicable to interior applications. From ANOVA analysis, particle size and resin content significantly affected ($p \leq 0.01$) the properties of maize cob particleboards.

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Abbreviations

ANOVA	Analysis of Variance
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CVEC	Chippewa Valley Ethanol Company
LE	Linear Expansion
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MUARIK	Makerere University Agricultural Research Institute Kabanyolo
NEMA	National Environment Management Authority
TS	Thickness Swelling
URA	Uganda Revenue Authority
WA	Water Absorption
WPI	Wood Product Industry

Introduction

Recent interest in environmentally-friendly materials has lead to the creation of new composite materials such as particleboards [20]. Considering the shortage and pressure to decrease the dependence on wood, there is an interest in other renewable materials such as agricultural wastes. Different researchers have reported on the usage of agricultural materials to produce particleboards. [20] took a study on the production of particleboard from fibers of coffee husk and hulls using standard thermosetting resins, [17] studied the properties of wheat straw particleboards

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bonded with different types on resin, [2] studied the durability characteristics of cement bonded particleboards manufactured from maize stalk residue, and [21] studied the thermal insulation and physical properties of particleboards produced from pineapple leaves. Maize cobs have a potential to be used in particleboard production [11]. [18] studied the thermal insulation performance of particleboards produced from maize cobs, while [8] studied the sound insulation, and fire resistance properties of corn cob particleboards. Depending on the application, there many factors which affect the properties of particleboards. [26] studied the effect of starch resin contents on properties of corn cob particleboards, [2] studied the effect of additive concentration on properties of cement board particleboards produced from maize stalks, [5] studied the effect of particle to binder ratio on properties of cement bonded particleboards from rice-husk, and [14] studied the effect of particle shape on the linear expansion of particleboards made from wood. However, our study focuses on the effect of particle size and resin content on the properties of particleboards produced from maize cobs.

Uganda has a potential of producing up to 7.5 million metric tons of maize (grains) annually by utilizing the current area under maize [16]. [19] stated the proportions of maize plant parts as 45.9 % grain, 27.5 % stalk, 11.4 % leaf, 8.2 % cob and 7.0 % husk on dry matter basis. Hence, the country has the potential of generating one million metric tons of maize cobs per year. After drying and grain shelling, maize cobs are available for different usages on the farmers' yard such as energetic use by combustion and fertilizer [13]. The contents within maize cobs are 32.3–45.6 % cellulose, 39.8 % hemicelluloses and 6.7–13.9 % lignin [7]. [10] showed that almost 90 % of maize cobs might be sustainably removed from the field without adversely affecting soil quality or erosion control by estimating the total replacement cost of nutrients removed by cob harvest as $8.29/ac which is low compared to $135.53 and $127.12 for grain and stover, respectively. [6] adds that maize cobs add limited nutrient value to the soil due to their negligible impact on soil carbon. The high ash content, low combustibility and lower ash softening point are reasons as to why maize cobs are less favorable for fuel [13]. Thus, the low nutrient content and low combustibility of maize cobs adds to its potential sustainable use as a raw material for maize cob particleboard production as the amount of nutrients removed with the cobs at harvest, which would later need to be replaced to maintain soil nutrient levels is minimal [12].

Uganda spends over US $2.5 million per year on importation of soft boards, with particleboards and oriented strand boards taking the biggest percentage [23]. Generally the importation costs have increased in the recent years. Amidst this expenditure, the trend of maize cob production is increasing per year [24]. Hence, utilization of over one million metric tons of maize cobs to produce particleboards would not only allow saving of US $2.5 million but will also increase on farmers' income through selling of maize cobs, reduce on importation of particleboards and encourage higher production of maize within the country. This study aims at the exploring the possibility of producing particleboards from maize cobs, investigating the effect of particle size and resin content on density, moisture and mechanical properties on maize cob particleboard.

Methods and Materials

Maize cobs were collected from Makerere University Agricultural Research Institute Kabanyolo (MUARIK). The maize cobs were crushed using a machine designed developed by [22], and had moisture content of 7.8 % after crushing. Particles of size 1.13–<3.35 mm (Type 1), 3.35–8 mm (Type 2), and 1.13–8 mm (Type 3) were chosen for production of particleboards from maize cobs. Type 3 particles were obtained by thorough mixing of Type 2 and Type 1 particles in equal quantities. The layered particleboard (Type 4) was made using all particle size ranges. Type 2 particles formed the interior of the board while Type 1 particles were layered on the outside surfaces of the board. Maize cob particles of size <1.13 mm were not used for production of particleboards because they are difficult to mix and take a lot of resin which exerts an economic constraint to production of particleboards boards.

Experimental Design

A factorial experiment in a complete randomized design (Table 1) was used to generate 12 experimental treatments. Each treatment was replicated three times prior to testing. Anova analysis was carried out to investigate the effect of each factor on the properties of maize cob-particleboards.

Parameter Selection Criteria

Following the experimental trials which were carried out, holding pressure (10 MPa), holding time (17 h) and drying time (3 days) were selected to be the constant parameters for each type of maize cob particleboard during the experiment. Resin quantity (125, 188, and 250 g) and Maize cob particles of sizes 1.13–8.00 mm were selected for particleboard production. Maize cob particles of size <1.13 mm were used as releasing materials. Synthetic Fevicol resin which has properties of being water and heat resistant was used in the experiment.

Table 1 Experimental treatment combinations

Resin levels (g)	Factorial treatment combination			
	Type 1 (1.13 to <3.35 mm) 600 g T_1	Type 2 (3.35–8.00 mm) 400 g T_2	Type 3 (1.13–8.00 mm) 400 g T_3	Type 4 (layered particleboard) 400 g T_4
125 (L1)	L_1T_1	L_1T_2	L_1T_3	L_1T_4
188 (L2)	L_2T_1	L_2T_2	L_2T_3	L_2T_4
250 (L3)	L_3T_1	L_3T_2	L_3T_3	L_3T_4

$T_{n=\ 1,\ 2,\ 3\ \text{and}\ 4}$ = particle sizes

Particle Blending

Maize cob particles were blended with the resin following the experimental design in Table 1, where 600 g of Type 1, 400 g of Type 2 and 400 g of Type 3 were each mixed with Fevicol resin at levels of 125, 188 and 250 g. For Type 4, 200 g of particles of Type 2 were blended separately from 200 g of Type 1 while maintaining the same mixing ratios. Type 1 particles were then halved (100 g) to form the outer layers of the board. However, during blending 10 g of resin was estimated to have remained on the walls of blending bags. Therefore, an additional 10 g of resin was added to balance this loss. Particles and resin were mixed by first weighing the quantity of particles into the mixing bag, adding a quantity of the resin followed by repeated compressions on the bag to mix its contents and finally adding the remaining quantity of the resin with continued compressions to obtain a relatively homogeneous mixture. Thereafter, the particle-resin mixture was poured from the bag into the molds and spread uniformly prior to pressing.

Maize Cob-Particleboard Production

After blending, the mixtures of maize cob particles with resin were put in the molds (die) of 200 mm × 200 mm × 20 mm, pre-pressed and finally cold pressed under a pressure of 13 ± 0.2 MPa using a hydraulic press machine. The boards were left to set under a pressure of 10 MPa for 17 h so as to prevent the effect of swelling/springing back. Maize cob particleboards were then air dried for 3 days before trimming to the required size. After trimming, maize cob particleboards were tested for strength and moisture absorption abilities.

Determination of Density

Density of maize cob particleboards was determined as per [4] procedures. The test pieces were 50 mm × 50 mm × 6 mm. The moisture content of the specimens was in the range of 13–16 % at the time of measurement.

Determination of Mechanical Properties of Maize Cob Particleboard

Mechanical tests were carried out in the Department of Forestry, Biodiversity and Tourism, Makerere University using the Tinius Olsen, H50KT Universal testing machine. Specimens were of dimensions 110 mm × 60 mm and had moisture content in the range of 13–16 %.The increase in moisture during testing was attributed to moisture gain from the resin. The distance between supports was 100 mm and loading was done at 2.5 mm/min.

Determination of Water Absorption, Thickness Swelling Test and Linear Expansion

The procedures for determination of water absorption, and thickness swelling outlined in the ASTM-1037 were followed. Test specimens of 50 mm × 50 mm were conditioned in the oven prior to soaking. Conditioning of specimens involved drying of the specimens in the oven at 100 °C for 24 h. The specimens were then soaked in water for 24 h. At the end of immersion period, the specimens were removed from water and then hanged for 10 min to allow surface water to drip off.

Results and Discussion

Effect of Particle Size on Density of Maize Cob Particleboards

Considering maize cob particleboards of Type 1 (1.13 to <3.35 mm) and Type 2 (3.35–8.00 mm), an increase in particle size of maize cob leads to rise in the density of maize cob particleboards. This is attributed to the difference in mass of individual maize cob particles irrespective of the difference in compression ratio. Figure 1, further shows that the maximum density (567 ± 35 kg/m^3) of maize cob particleboard Type 1 was approximating to the least density value of maize cob particleboard Type 2 (593 ± 50 kg/m^3). Maize cob particleboard of Type 3 had a higher density (600 ± 50 to 693 ± 35 kg/m^3) than the density (533 ± 50 to 633 ± 35 kg/m^3) of maize cob particleboard of Type 4. Hence, the arrangement of maize cob particles has an impact on the density of maize cob particleboards. By making coarse particles to form the core of maize cob particleboards, there are many chances of voids being left unfilled. However, mixing coarse particles and finer particles leads to a high bond contact between the particles as finer particles fill up the gaps between the coarse particles. Thus, the density of maize cob particleboards can be improved by producing maize cob particleboards containing a combination of all different particle size ranges. This is shown by the behavior of maize cob particleboards of Type 3 and Type 4 as their density is relatively higher than that of maize cob particleboard Type 1.

Effect of Resin Content on Density of Maize Cob Particleboards

From Fig. 1, an increase in binder quantity led to a rise in density of maize cob particleboards. Irrespective of the size of the maize cob particles, a change in resin content determines the average number of voids within the maize cob particleboard. A small quantity of binder is shared by particles and thus, no excess binder is left out. However, if the quantity of binder is increased, some of the binder is shared among the particles and the excess fills up the voids which might have remained. The presence of this excess binder could be the reason for the variation in density of maize cob particleboards. However, the density values of all maize cob particleboards were in the range of 590–800 kg/m^3, stated by [25] and [3] for low density particleboards. A one-way analysis of variance (ANOVA) showed that particle size and resin content significantly ($p \leq 0.01$) affected the density of maize cob particleboards.

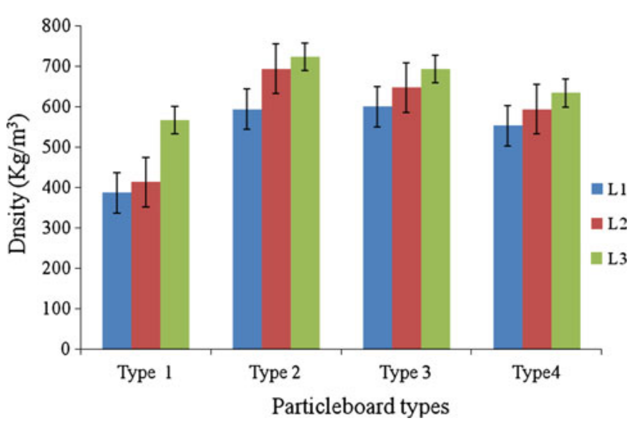

Fig. 1 A graph of density of maize cob particleboards at different levels of binder content

Effect of Particle Size and Resin Content on Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of Maize Cob Particleboards

Maize cob particleboard of Type 3 had the highest value of MOE (61.82 ± 10.09 MPa) and MOR (1.50 ± 0.02 MPa) among all particleboard types. The difference in MOE and MOR of maize cob particleboards was contributed to improved bond quality resulting from increased surface contact between the binder, fine particles and coarse particles. Maize cob particleboards of Type 1 had the least value MOE among all the particleboards. This might be due to smaller size of the particles. Smaller particles held less force thus, they were more reliable to higher extensions when a force was applied to them compared to bigger particles.

Figures 2, 3 show that an increase in the resin content and particle size led to an increase in MOE and MOR of maize cob particleboards. MOE and MOR are influenced by the particle geometry, percentage of adhesives and density [15, 20]. Coarse particles resist stresses which were applied to them thus there are somehow inelastic while smaller particles had good elastic properties, hence are much affected by any stress applied to them. The difference in extension and rigidity when a force is applied to maize cob particleboards

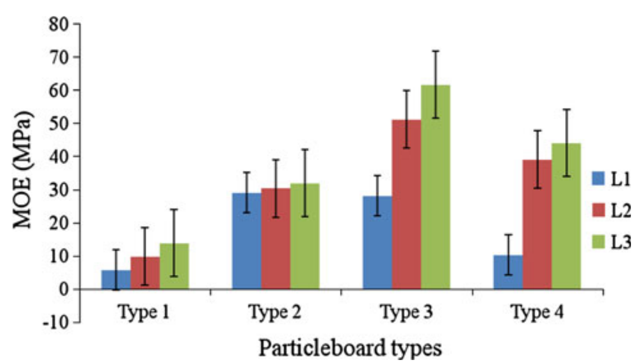

Fig. 2 A graph of MOE of maize cob particleboards at different levels of binder content

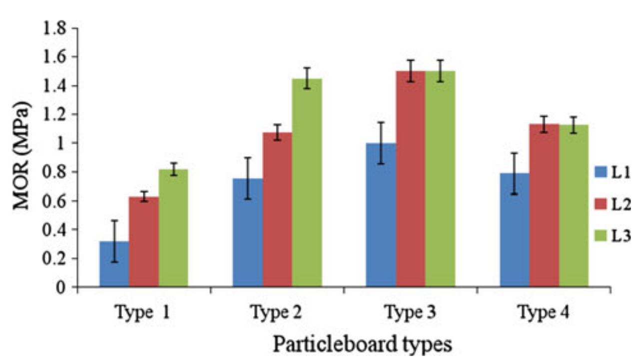

Fig. 3 A graph of MOR of maize cob particleboards at different levels of binder content

were points which caused a difference in the mechanical properties (MOE and MOR) of maize cob particleboards. Considering the effect of binder in the particleboards, high levels of binder increases the bond contact between individual particles [2]. This is contributed to improved surface contact which is created when a large film of binder is surrounding every maize cob particle. The arrangement of particles has an impact on the mechanical properties of maize cob particleboards as distinct layers hold stresses differently. Hence, maize cob particleboard of Type 4 had lower values of MOE (10.46 ± 6.00 to 44.23 ± 10.09 MPa) and MOR (0.79 ± 0.14 to 1.13 ± 0.16 MPa) as compared to particleboard Type 3 of MOE (28.27 ± 6.00 to 61.82 ± 10.09 MPa) and MOR (0.99 ± 0.14 to 1.50 ± 0.16 MPa). From the ANOVA, particle size had the big influence ($p \leq 0.01$) on MOE and MOR of maize cob particleboards while resin content was significant at $p \leq 0.05$. Maize cob particleboards produced using Fevicol resin presented low values for MOE (61.82 ± 10.09 MPa) and MOR (1.50 ± 0.02 MPa) as compared to the cement board particleboards reported by [2, 5]. The mechanical properties of maize cob particleboards were below those recommended by [3]. This could have been due to the difference in resin type and production method.

Effect of Resin Content and Particle Size on Linear Expansion (LE), Thickness Swelling (TS) and Water Absorption (WA) of Maize Cob Particleboards

Figures 4, 5, 6, show that an increase in resin content results into a decrease in TS, LE, and WA respectively. High resin content results into high bond quality between maize cob particles and thus, increase resistance to water penetration into the maize cob particleboards. Maize cob particleboards exhibited high values of WA as they were more than 100 % and thus could not satisfy the ANSI standards. The WA values obtained in the experiment were

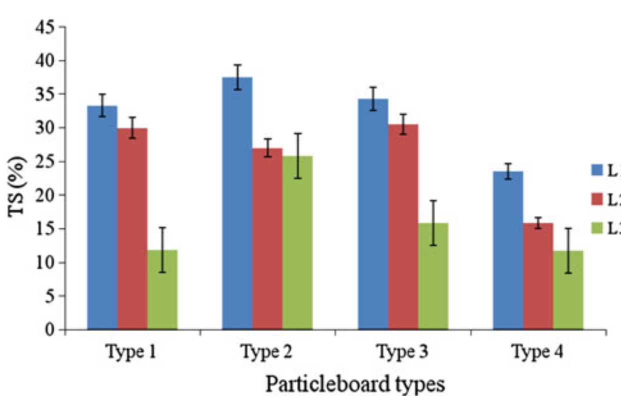

Fig. 4 A graph of TS of maize cob particleboards at different levels of binder content

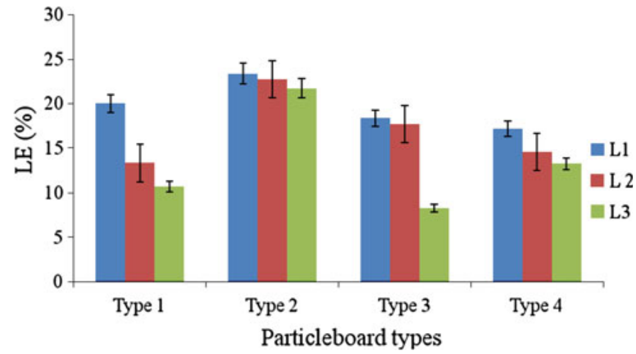

Fig. 5 A graph of LE of maize cob particleboards at different levels of binder content

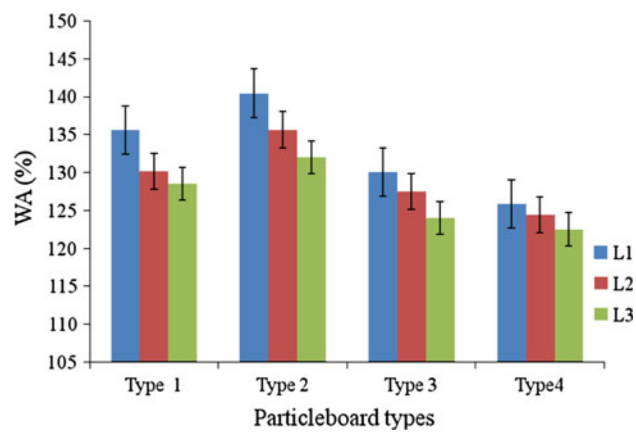

Fig. 6 A graph of WA of maize cob particleboards at different levels of binder content

in the range of 109.60–152.18 %, which was reported by [9] for corn stubble. This is due to organic, formy structure, and hygroscopic nature of maize cob particles. Maize cob particleboards of Type 4 exhibited low values of TS, LE, and WA. This could be due to absence of voids which could allow penetration of water into the board [1]. Coarse particles possess a lot of voids hence; allow free water penetration into the board making maize cob particleboard of Type 2 having the highest value of TS (37.5 ± 3.02 %), LE (23.33 ± 1.35 %), and WA (140.5 ± 3.68 %). Arrangement of particles also exhibited some impact on the value of TS, LE, and WA. Type 4 particleboards had small values of TS (23.5 ± 3.32 %), LE (17.33 ± 1.35 %), and WA (125.92 ± 3.68 %) as compared to other maize cob particleboards. Face layering of particleboards with fine particles provides a seal for coarse particles thus impeding water penetration into the maize cob particleboards. TS and LE satisfied the ANSI standards for low density particleboards although WA was higher compared to ANSI standards. Therefore, maize cob particleboards can be used for interior applications where moisture levels are minimal.

Conclusion

The properties exhibited by the maize cob particleboards showed that the boards could well be used in low moisture conditions and applications where low stresses are expected. The Properties of maize cob particleboards were affected by particle size, binder ratio and particle size arrangement. Particles sizes in the range of 3.35–8 mm presented good properties compared to particles in the range 1.13 to < 3.35 mm). However, a combination of both particle size ranges improved the properties of the maize cob particleboards. Maize cob particleboards are more prone to effects of moisture thus need to be laminated in case they are to have a long life span. The results show that high quality particleboards could be produced at highest levels of the production variables. However, further studies need to be carried out on the following; (1) investigate the effect of pressing pressure, compression ratio, drying time, holding time, and thickness on the properties of maize cob particleboards, (2) carry out a feasibility study on economic status and properties of maize cob particleboards, (3) study the properties of maize cob particleboards when mixed with other agricultural wastes such as rice husks, coffee hulls and husks. And, (4) investigate if different maize varieties affect the physical qualities of the maize cob particleboards.

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