Aims: The effect of process variable on shattering index and compressive strength characteristics of the water hyacinth briquettes were evaluated.

Study Design: The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design.

Place and Duration of Study: The samples were collected from Port- Harcourt, Niger Delta and are located between latitudes 4º 2" and 6º 2" North of the equator and longitudes 5º1" and 7º 2" East of the Greenwich meridian, between Jan 2009 and March 2010. The laboratory work was conducted in the Mechanical Engineering Department, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

Methodology: The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design. This study involved three particle sizes of dried and ground water hyacinth (D₁, D₂, D₃) at levels 0.5, 1.6 and 4mm, pressure (P₁, P₂, P₃, P₄) at level 3.0, 5.0, 7.0 and 9.0MPa with plantain peels were used as binder (B₁, B₂, B₃, B₄, B₅) in the ratio of 10, 20, 30 40 and 50% by weight of residue. They were arranged in Randomize Complete Block Design with three replications per experiment.

Results: The shattering index and compressive strength of the briquettes produced from...
this densification variables competed favourably with charcoal. The mean shattering index ranged between 0.62±0.02 \( (B_1) \) to 0.96±0.01 \( (B_5) \) and variation of the values were significant \( (P<.001) \). The compressive strength of the briquettes ranged between 0.84±0.05 Nmm\(^{-2}\) \( (B_1) \) and 2.66±0.05Nmm\(^{-2}\) \( (B_5) \) at different binder proportions. It could be inferred that the amount of binder used have significant influence on the durability rating of the briquettes \( (P<.05) \).

**Conclusion:** The observation showed that briquettes produced from water hyacinth are durable, reliable and able to stand mechanical handling and as well transportation.

**Keywords:** Densification; biomass; physical; plantain peels; binder.

### 1. INTRODUCTION

Water hyacinth spreads rapidly clogging drainage, ditches, shading out other aquatic vegetation and interfering with shipping and recreation. In view of this, water hyacinth has attracted the attention of scientists to use it as a potential biomass for production of biomass for the production of biofuel because of its high growth yield and availability in large amount throughout the year and all over the world \[1,2\].

The major limitations in utilizing biomass as an energy source include low bulk densities and irregular size, making transportation, handling and storage cost enormous. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific values, reduces transportation, collection, and storage costs and makes it available for a variety of applications \[3\]. Due to the advantages of densification, several biomass materials have been experimentally studied to convert to densified fuels, for example, saw dust, rice husk, peanut shell, coconut fibre, palm fruit fibre \[4\], rice straw \[5\], water hyacinth \[6\], pine cone, olive refuse, paper mill waste, cotton refuse, \[7\] palm shell \[8\] wheat straw \[9\], and waste paper \[10\].

Today, biomass is seen as the most promising energy source to mitigate greenhouse gas emission. Large scale introduction of biomass energy could contribute to sustainable development on several fronts namely, environmental, social, and economical \[1\]. Reece \[11\] studied the effect of quality of alfalfa hay on briquette durability. That study attributed the hay quality to the differences in the amount of stems, roots and leaves. Lower durability briquette (49.5%) was obtained for hay containing 58% stems, 19% leaves, and 23% fines that passed through 2-4mm screen (mostly broken leaves). Higher wafer durability (above 90%) was obtained for hay containing 44% stems, 41% leaves, and 15% fines that passed through 2-4mm screen (mostly broken leaves). Similarly, Adapa et al. \[12\] studied the percentages of leaves with stems and their effect on pellet durability. The leaf contents in the range of 25-100% produced higher durability (75-85%) than that for 0% leaves (i.e 100% stems), where the pellet durability was 43- 73% \[13\]. The effect of binder type and their proportion on the durability of briquettes produced from neem residue was studied Sotannde et al. \[14\]. It was reported that briquettes produced from gum Arabic and cassava starch and of the same blending ratio had different durability rating and the values were significantly different. The objectives of this study are to investigate: the optimum binder proportion, compaction pressure and particle size that will produce briquettes with the highest handling characteristics.
2. MATERIALS AND METHODS

The study area was Port- Harcourt, Niger Delta and is located between latitudes 4°2" and 6°2" North of the equator and longitudes 5°1" and 7°2" East of the Greenwich meridian. Field work for this study involved collection of samples from Rivers State [15]. The samples (water hyacinth) were harvested manually from fish pond. Water hyacinth samples were cleaned to devoid of foreign matters (stone, dust and plant materials) prior drying. The sample was sundried and milled using hammer mill. A Ro-Tap sieve shaker was used to determine the particle size [2]. The water hyacinth grind was mixed with binder produced from plantain peel until a homogenous mixture was formed. The percentages of binder used in the mixture were 10, 20, 30, 40 and 50%. The mixture of water hyacinth (W) and binder (B) blends (W:B) in each charge were in ratios of 50:50, 60:40, 70:30, 80:20 and 90:10. Three different particle sizes of water hyacinth of 0.5mm, 1.6mm and 4.0mm were utilized for the experiments.

Prior to briquetting experiments, the moisture content of mixed samples was determined using ASABE Standard [16]. Compaction tests on the blend samples were carried out using hydraulic press machine with maximum capacity of 20tonnes. A steel cylindrical die of dimension 14.3cm height and 4.7cm diameter was used for this study. The die was freely filled with pre-determined weight of (charge) of each sample mixture. A known pressure was applied at a time on the material in the die and was allowed to stay for 45 seconds (dwell time) using stop watch before released and the briquette formed was then be extruded. Compaction pressure ranged from 3.0 – 9.0MPa.

Briquettes shattering index (durability index) was measured according to ASTM D440-86(2002) of drop shatter developed for coal [13,17]. The test was conducted after two weeks of briquettes samples formation. A test sample of five briquettes of known weight \((W_1)\) was placed in a plastic polythene bag. The bag was dropped from a height of 2m onto concrete floor three times. After the dropping, the briquettes and fractions was placed on top of a 35cm square mesh screen and sieved. The experiment was replicated three times. The durability rating for each type of briquette was expressed as the ratio of weight of material retained on the screen \((W_2)\) to weight of briquettes before the dropping. The handling durability of the briquettes was computed as:

\[
\text{Shattering index} = \frac{\text{Weight of briquettes retained on the screen after dropping}}{\text{Weight of briquettes before dropping}}
\]

The axial compressive strength \((\text{Nmm}^2)\) of the briquette was measured using Universal Testing Machine. The briquette was position directly under the plunger to be pressed. The machine operated until failure occurred on the briquette. Then, record the maximum force that corresponds to failure. This machine consists of a sensor to measure the breaking force \((F)\) of the briquette up to 50KN. The maximum load to cause failure was read on the computer attached to the equipment. Then calculate the compressive strength as follows:

\[
\text{Compressive strength} = \frac{\text{Maximum force applied (N)}}{\text{Mean area of the face of the sample (mm}^2\text{)}}
\]

Bulk density was determined according to ASABE [16]. Compressive and relaxed density were measured according to Olorunnisola [18] and Bamigboye and Bolufawi [19].
The different process variables used were compaction pressure, binder proportion and particle size as shown in Table 1.

### Table 1. Process variable

| Process variable   | Different levels                                      |
|--------------------|-------------------------------------------------------|
| Compaction pressure| \( P_1 \) (3MPa), \( P_2 \) (5MPa), \( P_3 \) (7MPa) and \( P_4 \) (9MPa). |
| Binder proportion  | \( B_1 \) (10%), \( B_2 \) (20%), \( B_3 \) (30%), \( B_4 \) (40%) and \( B_5 \) (50%). |
| Particle size      | \( D_1 \) (0.5mm), \( D_2 \) (1.6mm) and \( D_3 \) (4.0mm). |

The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design. This study involved three particle sizes of dried and ground water hyacinth \( (D_1, D_2, D_3) \) at levels 0.5, 1.6 and 4mm, compaction pressure \( (P_1, P_2, P_3, P_4) \) at level 3.0, 5.0, 7.0 and 9.0MPa with plantain peels were used as binder \( (B_1, B_2, B_3, B_4, B_5) \) in the ratio of 10, 20, 30 40 and 50% by weight of water hyacinth residue. They were arranged in Randomize Complete Block Design with three replications per experiment. A total of 180 experiments were conducted. The analysis of variance, Duncan Multiply Range Tests and descriptive statistics were used.

### 3. RESULTS AND DISCUSSION

The obtained values for initial density of uncompressed mixture of water hyacinth at different binder level varied from 133.14±7.40 \( (B_1) \) to 174.28±8.76kg/m\(^3\) \( (B_5) \) (Fig. 1). The initial bulk density increased with increased in binder proportion. The recorded values of compressive density were higher than the initial bulk density (133.14±7.40kg/m\(^3\)) of the uncompressed mixture of water hyacinth and binder. The relaxed density increased with increased binder proportion. Increased in relaxed density with increased binder proportion was equally observed by Chin and Siddiqui [4] for production of some briquettes from sawdust, rice husk, peanut shell, coconut fibre and palm fibre.

Shattering index and compressive strength is a measure of the ability of a briquette to withstand mechanical handling. The durability of briquettes is a very important parameter to be considered for transportation processes and feeding combustion equipment.

The effect of binder proportion on the durability of the briquettes was tested as shown in Fig. 2. The mean shattering index ranged between 0.62±0.02 \( (B_1) \) to 0.96 ±0.01 \( (B_5) \) and variation of the values were significant \( (P<.001) \). It could be inferred that the amount of binder used have significant influence on the durability rating of the briquettes \( (P<.05) \). The mean values of shattering index for binders \( B_1 \) (0.62±0.02) and \( B_2 \) (0.78±0.02) were low and showed significant difference \( (P<.05) \) thus they might not be suitable for briquettes production. Meanwhile, the mean values of shattering index of \( B_4 \) (0.95±0.01) and \( B_5 \) (0.96±0.01) exhibited no significant difference but most suitable for briquettes production [13]. The implication of this observation is that \( B_4 \) is the optimum binder level requirement to produce durable, reliable and stable briquettes that stands mechanical handling and transportation, economical feasible and environmentally friendliness. However, binder \( B_5 \) is equally suitable for the briquettes production but not economical.

Singh and Singh [20] studied the effect of some binders on the durability of briquettes. That study reported that adding 10–25% (by weight) of molasses or sodium silicate, or a mixture of 50% molasses and 50% sodium silicate with rice straw produced briquettes with 40–80%
durability at a particle size 0.15mm and forming pressure of 29.4MPa. In addition, that study concluded that the higher the amount of binder added, the higher the briquette durability rating.

The strength and durability values of briquettes produced using binder B_4 matched with the quality requirement for transportation. Altun et al. [21], Borowski and Kuczmaszewski [22] and Borowski [23] reported the effect of binder on the durability of briquettes. Those studies reported that utilization of fine-grained binding agents in the production of briquettes had positive relationship with durability of the briquettes. Increasing the amount of binder to B_4 (40%) had positive correlation on the durability of the briquettes. Furthermore, increase in the binder beyond B_4, could not have significant improvement on the durability of the briquettes for particle size 0.5mm. However, increasing in binder ratio within the studied levels had positive effect on the durability rating of the briquettes.

Similar, trend was reported by Ajayi and Lawal [24] on increased in durability with increasing in the quantity of binder. Sotannde et al. [14] discovered that increasing in binder proportion and types of binder have significant effect on the durability rating of the briquettes. It was also reported that durability rating of 98.74% obtained in gum Arabic bonded briquettes was higher than 83.26% obtained in starch bonded briquettes and the values were statistically significant at 5% probability level.

The shattering index of the briquettes varied from 0.71±0.02 (P_1) to 0.95±0.02 (P_4) as shown in Fig. 3. The obtained values indicated that increase pressure might increase durability of the briquettes. The effect of pressure on the durability is enormous. Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area. Singh and Kashyap [25] found that increasing pressure from 7.8 to 31.2MPa increased the durability of rice husk briquettes from 80 to 95% where the briquettes were made from rice husk with an average particle size of 4.05mm and added with 25% molasses.
The interaction between particle size and shattering index are shown in Fig. 4. The durability varied between 0.67±0.02 (D$_3$) and 0.95±0.01 (D$_1$) and variation of the values was significant (P<.001). Considering, the briquettes made from particle size D$_1$ recorded the highest durability rating while the briquettes particle size 4mm obtained the least durability rating. The relationship between the durability and particle size was an inverse relationship. The corresponding values reported by Wamukonya and Jenkins, [9] for sawdust and wheat straw briquettes were similar to the present study values for particle size 4mm D$_3$. Densification variables such as binder types, binder ratio, compressive pressure and density have significant effect on the durability rating of the briquettes [8, 18]. Hence, it can be summarized that optimum shattering index requirement for pressure, binder and particle size for production of stable, reliable and durable briquettes is briquette B$_4$P$_4$D$_1$.

The compressive strength of the briquettes ranged significantly between 0.84±0.05 Nmm$^{-2}$ (B$_1$) and 2.66±0.05Nmm$^{-2}$ (B$_5$) at different binder proportions (P<.05) (Fig. 2). The compressive strength (compressibility) of briquettes increased with increased binder proportions. Based on this plantain peels could be regarded as good binder for the briquetting of water hyacinth. For briquette quality control, the physical parameters such as density and compressive strength were found to be the best indicators of additive quality.

The compressive strength of the briquettes varied significantly from 0.92±0.05 Nmm$^{-2}$ (P$_1$) to 2.28±0.07Nmm$^{-2}$ (P$_4$) at different compaction pressure levels (Fig. 3). ANOVA indicated significant difference among the mean compressive strength of briquette (P<.05). Compressive strength is one of the most important characteristics that determined the
suitability of a briquette when subjected into mechanical handling [13]. It is also the major quality index for fuel briquettes. The obtained values of compressive strength at the different compaction pressure were in agreement with those of Chin and Siddiqui, [4] on the effect of compaction pressure on the compressive strength of some biomass namely sawdust, rice husk, peanut shell, coconut and palm fibre. Clark and Marsh [27] used pulp black liquor (a byproduct from the pulp production industry) to increase the strength of bio-coal briquettes (20–30% corn stalk and 70–80% coal), which had an initial breaking strength of 0.5MPa. Adding 5–20% of pulp black liquor increased the breaking strength of briquettes from 5 to 17MPa.

![Graph](image_url)

**Fig. 3. Effect compaction pressure on shattering index and compressive strength of briquette**

*Means of different letters are significantly important (P<.05)*

The effect of particle size on the compressive strength showed indirect correlation. It implied that the finer the particle sizes of briquettes the higher the compressive strength. The values ranged significantly from 0.95±0.03Nmm$^{-2}$ ($D_3$) to 2.01±0.04Nmm$^{-2}$ ($D_1$) (Fig.4). It is clearly showed that briquettes produced with 0.5mm particle size are durable and are less likely to disintegrate and crumble in the process of transportation than the briquettes produced by particle sizes of 1.6 and 4.0mm. Compressive strength tests offer a quick measure of the quality of briquettes. The obtained results confirmed the findings of other studies on fuel briquettes produced under different conditions such as compaction pressure, binder ratio and particle sizes to have different handling characteristics. Besides, these characteristics were also found to be strongly affected by raw material properties [13].
4. CONCLUSION

This work was conducted to investigate the effect of process variable on the durability of the briquettes produced from water hyacinth and plantain peels at different levels of binder, particle size and compaction pressure. The quality of the briquettes improved with binder proportion and as well as compaction pressure. The binder proportion, compaction pressure and particle size had significant effect on the durability of the briquettes ($P<.05$).

The optimum binder level, compaction pressure and particle size required to produce the briquettes with highest durability strength is tagged $D_B P_B S_B$ and 96%. The result compared favourably with fuelwood. Thus, densification process had improved the handling characteristics of briquettes. The briquettes fuel produced are environmental friendly, reduce health hazard associated with the use of fuelwood and reduce desertification and its environmental implication. Therefore, combination of water hyacinth and plantain peels are very suitable for briquette production for domestic and industrial uses.

COMPETING INTERESTS

Authors declare that there is no competing interest concerning this work.

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