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Some physical and mechanical properties of water lettuce (*Pistia stratiotes*) briquettes

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Abstract
The study evaluated the physical and mechanical properties of briquettes made from water lettuce (*Pistia stratiotes*) at different binder ratios of banana peels, yam peels and cassava peels at compaction pressure of 10 MPa. The water lettuce was collected from Amassoma River, cleaned and sun-dried. Binder levels of 10, 20, 30, 40 and 50% by weight of each feedstock were used. A steel cylindrical die of dimension 17.0 mm height and 6.0 mm diameter was used to produce briquettes using hydraulic press with dwell time of 45 seconds. The ASAE standard methods were used to determine the physical properties of briquettes. The obtained data was statistically analysed using Analysis of Variance (ANOVA) and simple statistical tools such as means and standard errors. The obtained values for initial bulk density of milled uncompressed mixture of water lettuce, yam peels, cassava peels and banana peels at different binder ratios were 142.39 kg/m^3, 221.26 kg/m^3, 208.30 kg/m^3 and 243.54 kg/m^3. Compressive density of briquettes at different binder proportions showed significant difference at $P<0.05$. The relaxed density increased with increased binder proportion. The water resistance capacity, compressive strength, densification ratio and durability of the briquettes improved with increased binder proportion and compaction pressure. It could be concluded that the production of briquettes from pent wood sawdust and plantain peels is feasible and are environmentally friendliness as compared to firewood, mangrove wood and charcoal.

1. Introduction

Agricultural plants and aquatic wastes are produced in large quantities annually and vastly under-utilized [1]. More than 60% of Nigeria living in the rural areas depends on fuelwood for domestic cooking [2]. Nigeria consumes over 50 million metric tons of fuelwood annually. The decreasing availability of fuel wood, coupled with the ever-rising prices of kerosene and cooking gas in Nigeria, draw attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country [1, 3]. The demand for fuel wood is expected to have risen to about 213.4 x103 metric tons, while the supply would have decreased to about 28.4 x103 metric tons by the year 2030 [3, 4] The need for renewable and sustainable alternative energy sources are growing due to the rapid depletion of fuel wood, the non-renewable fossil energy resources and the negative impacts fossil fuel shortage, ever-rising prices of kerosene and cooking gas, global warming including other environmental problems are of critical issues [4, 5, 6]. The miscellaneous advantages such as abundance, availability, low cost, carbon dioxide neutral feature and rapid growth of water lettuce make them an ideal candidate for biofuel, particularly in the developing countries [4, 5].

Water lettuce is an aquatic weed that grows at an extremely rapid pace. The harvest frequency for aquatic plants tends to be in the order of days, whereas the frequency for trees and crops are the order of years and months. It devastates lakes, canals, rivers and pond in the Niger Delta. This prolific aquatic weed smoothers water bodies, chokes other aquatic lives, prevent navigation, favour mosquitoes breeding and fosters water borne diseases, environmental nuisance and threat to ecodiversity. The plant is also a breeding ground for many insects and mollusks which are vectors of diseases like bilharzias, river blindness and malaria [7].

The greater percentage of biomass in its natural form is difficult to be utilized as fuel because it is bulk, wet and dispersed [8, 9, 10]. The major limitations in utilizing biomass as an energy source include low bulk densities and irregular size, making transportation, handling and storage cost enormous. Densification of biomass wastes to the briquettes form is an attractive option for upgrading the biomass properties. 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 [11]. 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 [12], rice straw [13],water hyacinth [14], pine cone, olive refuse, paper mill waste, cotton refuse [15], palm shell [16], wheat straw [17, 18] and wastes paper [6].

Densification increases the biomass bulk density 40-200 Kgm^{-3} to a final bulk density of 600-800 Kgm^{-3}[19]. These limitations can be overcome by compacting and converting the residues into a high density form. Compression bailing can reduce biomass volume to one-fifth of its loose bulk volume. The briquetting of biomass can be done by direct compact, piston press and screw press technology without mixing it with some kind of binder, or using roll or char briquetting [19, 20]. Factors affecting the strength of briquettes include the chemical and physical characteristics of the biomass and as well as the variables of the densification processes such as forming pressure, moisture content, temperature, feed constituent, die dimension, feed particle size. The present study provides valuable information on some engineering properties of the briquettes produced from water lettuce and binder types (cassava, banana and yam peels) at different binder ratios and low compaction pressure.

2. Materials and Methods

The water lettuce samples were harvested manually from Amassoma River. Water lettuce samples were cleaned of foreign matters (that is, stones, dust and other plant materials) prior drying. The samples were sundried and milled using hammer mill. A Ro-Tap sieve shaker was used to determine the particle size [21]. The water lettuce grind was mixed with binders produced from banana peels, yam peels and cassava peels until a homogenous mixture was formed. The concentrations of binder used in the mixture were 10, 20, 30, 40 and 50% by weight of residue while compaction pressure and particle size were 10.0 MPa and 0.5 mm for yam peels, 0.31 mm for cassava peels and 0.32 mm for banana peels. Banana, yam and cassava peels were sun dried, ground into powder (particle size 0.075 mm) using hammer mill and sieved with Tyler sieve. It was hydrated with a pre-determined quantity of hot water to form colloidal solution of the binder and later boiled. The colloidal solution was constantly stirred until smooth paste was formed. This facilitated the proper agglomeration of the particle. Consistency of the binder was maintained at a fixed level with its concentration in the sample mixture varied at 10, 20, 30, 40 and 50% level of the residue.

Prior to briquetting, the moisture content of the mixed samples was determined using ASABE standard method [22]. Compaction tests on the blend samples were carried out using hydraulic press machine with maximum capacity of 20 tons. A steel cylindrical die of dimension 17.0 mm height and 6.0 mm diameter was used to produce briquettes using hydraulic press which was freely filled with pre-determined weight of each sample mixture (charge). 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 briquettes formed were then extruded. The prepared briquettes were kept for two weeks in the laboratory conditions of temperature 28±3 ^{0}C and relative humidity of 80±3% hence the briquettes could be stabilized. The briquettes were subjected to hygroscopic tests for assessing the water resistance capacity. The relaxed briquettes were immersed in a circular glass container filled with distilled water at temperature of 28±3 ^{0}C for the period of three hours. Measurements were taken for the length and diameter changes of the briquettes [23]. Each of the experiment was replicated three times.

Briquettes shattering index (durability index) was measured according to ASTM D440-86 [24] of drop shatter developed for coal. The test was conducted after two weeks of briquettes samples formation. A test sample of five briquettes of known weight was placed in a plastic polythene bag. The bag was dropped from a height of 2 m onto concrete floor three times. After the dropping, the briquettes and fractions were placed on top of a 0.35 cm 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 to weight of briquettes before the dropping. The handling durability of the briquettes was computed as:

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

Bulk density was determined according to ASABE [22]. Tap, compressed and relaxed densities were measured according to Olorunnisola [6] and Bamgboye and Bolufawi [25].

The experimental design for this study was 1 x 3 x 4 Randomized Complete Block Design. They were arranged in Randomized Complete Block Design with three replications per experiment. A total of 36 experiments were conducted. Data was subjected to statistical analyses for analysis of variance (ANOVA) and descriptive statistics.

3. Results and Discussion

The bulk density of milled water lettuce, yam peels, cassava peels and banana peels were 142.39 kg/m^3, 221.26 kg/m^3, 208 kg/m^3 and 243.54 kg/m^3 (Table 1). This value was higher than the minimum value of 40 kg/m^3 reported by Kaliyan and Morey [19]. The mean values of bulk density of raw white and yellow maize corncob (unground) were 50.32 and 51.44 kg/m^3 [26]. The variation in the bulk density might be adduced to particle shape and size, orientation of the particles, specific density of the individual particles and particle size distribution. Köser et al. [8] recorded bulk density of 100 kg/m^3 for water hyacinth of particle size ranging from 0.5-2.5 mm and moisture content 11.8% wet basis. The bulk densities of loose and standard baled straw were 40 kg/m^3 and 110 kg/m^3, as compared with bulk density of unprocessed wood residue, which is approximately 250 kg/m^3 [27]. Loose bulk densities of switch grass and wheat straw varied from 49.44 kg/m^3 and 24.16 kg/m^3 to 266.52 kg/m^3 and 111.13 kg/m^3 at 8-60% moisture content for 6, 12, 25 and 50 mm particle sizes [28]. The tap density of milled water lettuce, yam peels, cassava peels and banana peels were 154.29 kg/m^3, 287.85 kg/m^3, 215.07 kg/m^3 and 301.28 kg/m^3. The corresponding tap densities of water hyacinth and plantain peels varied from 133.14±7.40 to 174.28±8.76 kg/m^3 [29].

The initial bulk density increased with increased binder concentration (Fig.1). The initial bulk density was significantly affected by binder ratio at $P<0.05$.The corresponding initial bulk densities of water hyacinth with binder were higher (177.08 kg/m^3, 155.64 kg/m^3 and 124.99 kg/m^3) than those of unmilled (34.69 kg/m^3) and milled (155.56 kg/m^3, 106.69 kg/m^3 and 82.55 kg/m^3) 100% water hyacinth [29]. This could be explained that, the finer the particle size is, the lesser the pore spaces and more mass of the material per given volume, which is good for briquetting. The compressed density of the briquettes at different binder proportions showed increased in binder (10–50%) with increased compressive density, 844.19 (B_1) to 985.96 kg/m^3 (B_5) for banana peels, 964.73 (B_1) to 1076.53 kg/m^3 (B_5) for yam peels, while 821.32 (B_1) to 1157.0kg/m^3 (B5) for cassava peels (Fig. 2). The increase observed in compressed density with increased binder inclusion could be attributed to relative increase in the initial bulk density of the water lettuce with binder ratio. Similar trend was reported on effect of binder types and ratio on compressed density [4, 12, 27, 31, 32].

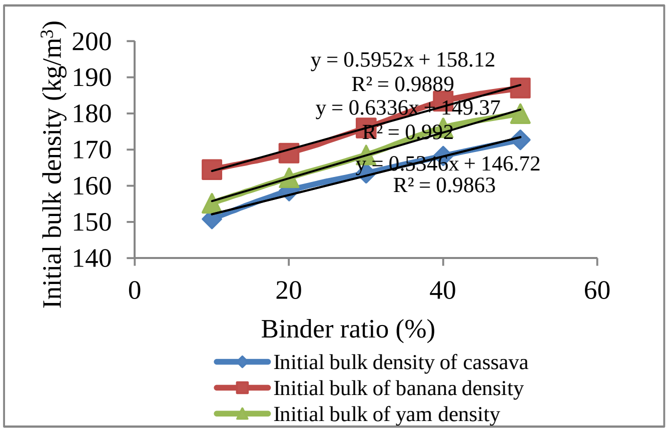

Fig. 1. *Effect of binder ratio on water lettuce briquettes*

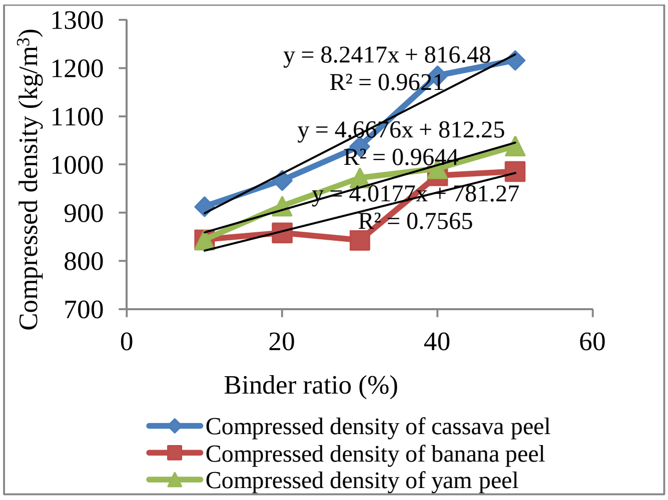

Fig. 2. *Effect of binder ratio on compressed density of briquettes*

The results showed that the relaxed density and binder levels varied from 402.67 g/cm^3 (B_I) to 589.93 g/cm^3 (B_5) for yam peels; 322.74±7.63 kg/m^3 (B_1) to 478.09±9.21 kg/m^3 (B_5) for banana peels, and 454.52 kg/cm^3 (B_1) to 636.01±7.09 kg/m^3 (B_5) for cassava peels (Fig.3). The relaxed density increased with increased binder proportion. However, the relaxed density of briquettes produced from cassava peels was higher that of briquettes from yam peels and banana peels. The relaxed density can be seen to be lower than the compressed density. This reduction in relaxed density was an indication of considerable elastic recovery and stress relaxation processes that occurred after the briquette was removed from the die to attain its final and stable state. The produced briquettes have the required strength to withstand handling and storage, with transportation. Similar trend was reported on effect of binder types and ratio on relaxed density [4, 12, 32, 33]. At this level of binder, the produced briquettes have the required strength to withstand handling, transportation and storage. The corresponding report revealed that the binder types and blending ratio had no significant influence (P>0.05) on compressed density [31]. The used binder (cassava, yam and banana peels) competed favourably with more than 50 organic and inorganic binders that have been reported for densification. A similar trend was reported on the relationship between relaxed density and binder ratio [27].

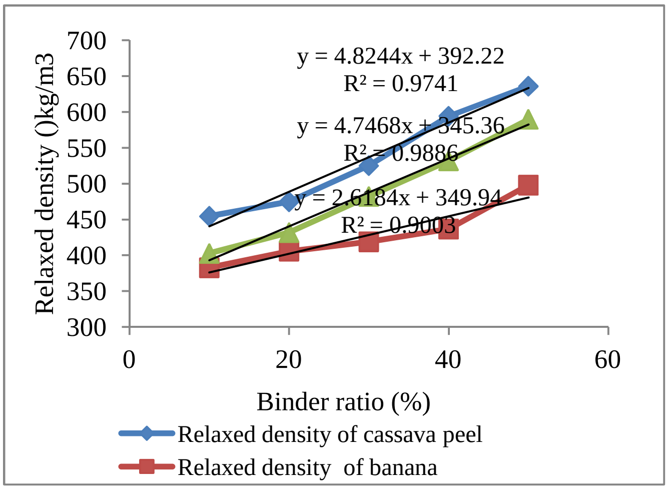

Fig. 3. *Effect of binder ratio on relaxed density of briquettes*

The effect of this binder ratio and types on the compaction ratio ranged from 6.05 (B_1) to 7.04 (B_5) for cassava peels, 5.13 (B_1) to 5.27 (B5) for banana peels and 5.44(B_1) to 5.77 (B_5) for yam peels for all the binders proportions (Fig. 4). The observed high values signified more volume displacement which is good for packaging, storage, and transportation. It was an indication of good quality briquettes. The results contained in the research could be compared with others notable biomass residues. The corresponding reports on the effect of binder ratio and binder types on compaction ratio ranged from 3.194 to 9.730 for briquettes from guinea corn and cassava starch and 2.23 to 6.50 for briquettes produced from corncob from white maize [27, 28]. While compaction ratios of 3.5 and 4.2 were obtained during briquetting of groundnut and melon shells [34].The compaction ratio of 3.80 was obtained during briquetting of rice husk [35].

The effect of these binder ratio and types on the relaxation ratio ranged from 1.76 (B_5) to 2.09 (B_1) for yam peels, 1.91 (B_5) to 2.01 (B_1) for cassava peels and 2.02 (B_5) to 2.21(B_1) for banana peels for all the binders proportions (Fig. 5). The observed low values were indication that the briquettes possess good packaging, storage and transportation qualities. The difference in the relaxation ratio of briquettes at the different binder proportions was significant (P<0.001). The obtained range of relaxation ratio in this study was within the reported range of 1.8 to 2.5 and 1.65 to 1.8 [6, 35]. Relaxation ratio values 1.11 and 1.32 for briquettes produced from charcoal and Arabic gum respectively but briquettes made from charcoal and cassava starch had relaxation ratio values of 1.17 and 1.34 [32]. The obtained values of relaxation ratio signified that briquettes of low relaxation ratio exhibited low elastic property and more stable while briquettes of high relaxation ratio exhibited high tendency of elastic property and less stable. Similar observation was made for briquettes produced from hay material and relaxation ratio of 1.68 to 1.8 was recorded [35]. The lower values ratio indicated a more stable briquette, while higher value indicated high tendency towards relaxation i.e. less stable briquette.

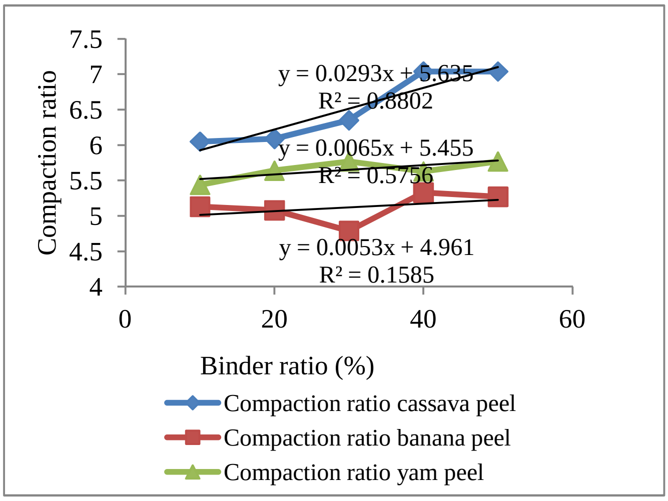

Fig. 4. *Effect of binder ratio on compaction ratio of briquettes*

The water absorption capacity of briquettes using different binder levels and types was investigated. The relative change in length of briquettes ranged between 3.30±0.12% (B_5) and 10.00±1.01% (B_1) for yam peels, 6.40±0.03% (B_5) and 15.20±0.51% (B_1) for banana peels and 6.00±0.05% (B_5) and 11.70±0.51% (B_1) for cassava peels (Table 2). The hygroscopic property of briquettes at different binder proportions showed an increase in water resistance capacity with increased quantity of binder utilized. Similar observation was made for the effect of binder inclusion on the relative change in the height of briquettes for sawdust with palm oil sludge as binder [4]. This is an indication that water lettuce had high affinity for water compared to the binders. The implication of this observation is that in high relative humidity areas such as Niger Delta of Nigeria, briquettes made up of 50% binder (B_5) might be more suitable and appropriate for production of briquettes. The post-immersion linear expansion of the briquettes ranged between 0 and 10% after 72 hours immersion in water for production of briquettes from paper and coconut husk. Briquettes that fall within this range are grouped as low water absorption briquettes [6].

The effect of binder types on the water resistance capacity of the briquettes is shown in Table 2. The values varied from 51.16±5.65% (B_5) to 102.02±7.21% (B_1) for yam peels, 130.40±12.65% (B_5) to 164.00±10.21% (B_1) for banana peels and 113.20±7.84% (B_5) to 140.00±9.02% (B_1) for cassava peels and the difference in these values was significant (P<0.001). This was an indication that all used binder improved the water resistance capacity of the briquettes. The obtained values were lesser than the range obtained for relative change in the length of briquettes. The implication was that in high relative humidity areas such as Niger Delta, B_5 binder level might be more pliable, suitable and appropriate for production of briquettes. The reason for this observation could be due to particles having inter-particle bonding with nearly no inter-particle pores. This study revealed that short-term exposure to rain would not be detrimental to the physical qualities of the briquettes.

Table 1. *Physical properties of ground feedstock----Please move it up (page 3)to where it is mentioned*

Raw materials (Ground)	Bulk density (kgm^{-3})	Tap density (kgm^{-3})	Equilibrium moisture content (% dry basis)	Geometical mean diameter (mm)
Water lettuce	142.39	154.29	6.9	0.31.
Yam peels	221.26	287.85	10.2	0.23
Cassava peels	208.30	215.07	9.5	0.35
Banana peels	243.54	301.28	11.8	0.29

The relationship between binder levels on the shattering index of the briquettes ranged between 0.55±0.02 (B_1) to 0.98 ±0.05 (B_5) for yam peels, 0.41±0.01 (B_1) to 0.95 ±0.07 (B_5) for banana peels and 0.58±0.02 (B_1) to 0.99 ±0.03 (B_5) for cassava peels (Fig.6). The variations in the values were significant ($P<0.05$). It could be inferred that the amount of binder used have significant influence on the durability rating of the briquettes ($P<0.05$). The briquettes with mean value of shattering index equal or above 0.95 fall within the acceptable range of DIN51731 [36] for production briquettes. It implied that binder B_4 and B_5 for yam peels, B_5 for banana peels and B_4 and B_5 for cassava peels gave optimum binder levels requirements to produce durable, reliable and stable briquettes that stand mechanical handling and transportation, economical feasible and environmentally friendliness. The effect of types of binders and quantity of binder on the durability of briquettes was studied [37]. It was observed 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 0.15 mm and forming pressure of 29.4 MPa [37].

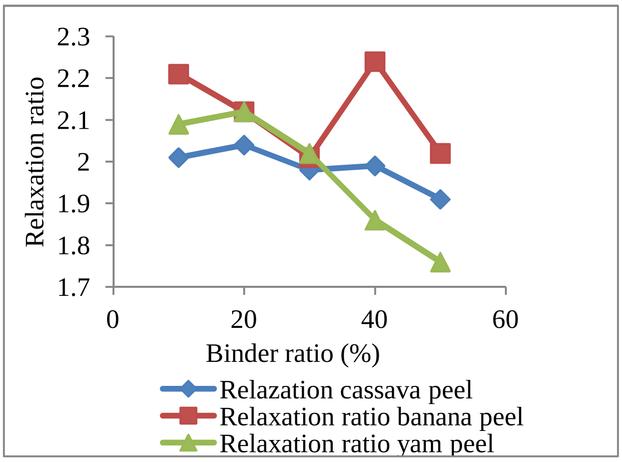

Fig. 5. *Effect of binder concentration on relaxation ratio*

Table 2. *Effect of binder types on the water resistance capacity of the briquettes*

Binder ratio (%)	Relative change in length (%) Yam peels	Relative change in length (%) Banana peels	Relative change in length (%) Cassava peels	Relative change In weight (%) Yam peels	Relative change In weight (%) Banana peels	Relative change In weight (%) Cassava peels
10	10.0	15.2	11.70	102.1	130.4	113.3
20	8.0	10.6	10.6	77.2	143.4	112.2
30	7.0	13.0	8.16	69.5	150.0	106.2
40	5.2	13.6	8	53.4	104.2	138.7
50	3.3	6.4	6.0	51.16	164.0	144

The interaction between crushing strength and binder levels varied from 4.52 ±0.04 MPa (B_1) to 11.10±0.60 MPa (B_5) for cassava peels, 3.04±0.13 MPa (B_1) to 8.30±0.26 MPa (B_5) for banana peels and 4.17±0.09 MPa (B_1) to 9.58±0.19 MPa (B_5) (Fig. 7). The load required to rupture briquettes at different binder ratios and types were significantly different ($P<0.05$). The crushing strength increased with increased binder proportion. This was an indication that banana peels, yam peels and cassava peels can be used as binder. These agricultural wastes have good binding power that competed favourably with binders from other biomass. It could be inferred that the optimum amount of binder require to produce high quality briquettes are 40% (B_4) and 50% (B_5). At these levels of binder, the produced briquettes have the required strength to withstand handling, transportation and storage.

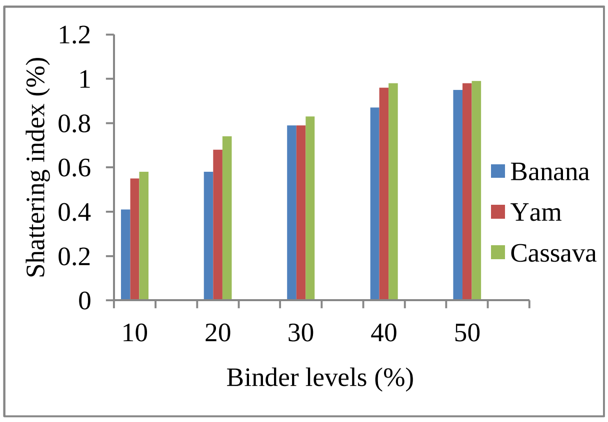

Fig. 6. *Effect of binder levels and types on shattering index of water lettuce briquettes*

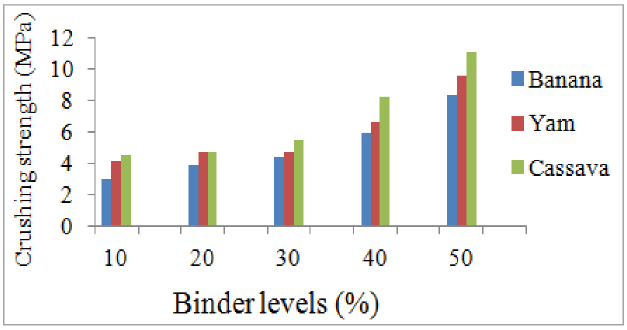

Fig. 7. *Effect of binder levels on crushing strength of the water lettuce briquettes*

The static friction coefficient is important for designing pneumatic conveying systems, screw conveyors and hoppers. The coefficient of static friction of briquettes made with yam peels as binder ranged from 0.13±0.04 (B_5) to 0.23±0.03 (B_1) on fibreglass surface, from 0.21(±0.06) (B_5) to 0.4 ±0.02 (B_1) on rubber, from 0.14±0.02 (B_5) to 0.36±0.03 (B_1) on plywood, and from 0.19±0.03 (B_5) to 0.31±0.01 (B_1) on aluminium sheet (Table 3). The static friction coefficient for all Egyptian onion cultivars ranged from 0.67 to 1.34 and that the highest value was obtained on plywood followed by rubber and galvanized surface [38]. The coefficient of static friction of briquettes made with banana peels as binder ranged from 0.19±0.01 (B_5) to 0.29±0.06 (B_1) on fibreglass surface, from 0.31±0.03 (B_5) to 0.46 ±0.02 (B_5) on rubber, from 0.24±0.02 (B_5) to 0.42±0.03 (B_5) on plywood, and from 0.19±0.03 (B_5) to 0.31±0.01 (B_1) on aluminium sheet. The coefficient of static friction of briquettes made with cassava peels as binder ranged from 0.10±0.02 (B_5) to 0.22±0.03 (B_1) on fibreglass surface, from 0.23±0.02 (B_1) to 0.36 ±0.03 (B_1) on rubber, from 0.21±0.02 (B_5) to 0.33±0.01 (B_1) on plywood, and from 0.29±0.02 (B_5) to 0.10±0.02 (B_1) on aluminium sheet.

At higher binder ratio the briquette becomes more pliable and smoother due to glossy nature of water lettuce. These values were lower than briquettes made from water hyacinth and phytoplankton as binder [23]. Mild steel surface offered less resistance for rolling of briquettes; it is therefore, the material that can be safely used for conveying or transporting of briquettes. The highest [0.56 (B_1)] static coefficient of friction corresponded to rubber sheet. Similar trend was observed for the static coefficient of friction on rubber surfaces having the highest values compared to other surfaces [39, 40, 41].

Table 3. *Coefficient of static friction of briquettes*

Biowaste	Binder ratio	Glass fibre	Plywood sheet	Rubber sheet	Aluminium sheet
	10	0. 23(±0.03)	0.36(±0.03)	0.40 (±0.02)	0.31(±0.01)
	20	0.21(±0.01)	0.32(±0.02)	0.40(±0.03)	0.26(±0.02)
Yam peels	30	0.17(±0.03)	0.31(±0.03)	0.36(±0.01)	0.28(±0.06)
	40	0.15(±0.03)	0.22(±0.04)	0.27(±0.04)	0.22(±0.01)
	50	0.13(±0.04)	0.14(±0.02)	0.21(±0.06)	0.21(±0.03)
	10	0.29(±0.06)	0.42(±0.03)	0.46(±0.02)	0.31(±0.01)
	20	0.27(±0.01)	0.36(±0.02)	0.40(±0.01)	0.27(±0.01)
Banana peels	30	0.24(±0.05)	0.34(±0.03)	0.39(±0.01)	0.28(±0.03)
	40	0.21(±0.01)	0.29(±0.06)	0.33(±0.04)	0.29(±0.05)
	50	0.19 (±0.01)	0.24(±0.03)	0.31(±0.03)	0.29(±0.03)
	10	0.22(±0.03)	0. 33(±0.01)	0. 36(±0.02)	0.29(±0.02)
	20	0.19(±0.04)	0.30(±0.04)	0.32(±0.06)	0.24(±0.01)
Cassava peels	30	0.14(±0.03)	0.30(±0.03)	0.31(±0.01)	0.21(±0.06)
	40	0.12(±0.03)	0.23(±0.03)	0.25(±0.04)	0.20(±0.03)
	50	0.10(±0.02)	0.21(±0.02)	0.23(±0.03)	0.19(±0.02)

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