

Effects of Varying Binder Types and Binder Percentages on Mango (*Mangifera indica* L.) Seed Husk Briquettes

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ABSTRACT

The study measured and analyzed the physical and combustion properties of mango seed husk briquettes (MSHBs). The independent parameters included binder type (starch gel, molasses and newspaper paste) and binder percentage (10%, 30% and 50%) that evaluated the effects on bulk density, compressed density, relaxed density, length stability, compression strength, volatile matter, ash content and fixed carbon of MSHBs. Analysis of variance showed that relaxed density, length stability, compression strength and ash content were significantly affected by the two independent factors. Bulk density, compressed density and fixed carbon were solely affected by the binder percentage while volatile matter was affected only by the binder type.

The study revealed that MSHBs produced with newspaper as binder consistently gave superior characteristics such as higher compressive strength (4.03 MPa), lower ash content (9.28%) and higher fixed carbon (8.31%). It is also considered as waste like mango seed husk, the main component of the briquette.

One important edge of MSHBs was the gross calorific value. Mango seed husk briquettes averaged with 17.84 MJ/kg while rice husk was reported to have 15.97 MJ/kg. This study showed the comparative advantage of mango seed husk briquette as an alternative source of energy.

Keywords: mango seed husk, densification, biomass briquette, binder material, binder ratio

INTRODUCTION

Mango (*Mangifera indica* L.) is one of the leading agricultural products processed every year in the Philippines. The Philippine Statistics Authority (2018) reported a GVA of PhP30 billion on mango alone back in 2016. There also exists a huge amount of mango by-products, which is 40-50% of the raw materials by weight (de la Cruz Medina and Garcia, 2002), that must be considered. And nowadays, there is a considerable emphasis on the recovery, recycling and upgrading of wastes particularly for the food and food processing industry in which wastes, effluents, residues, and by-products can be recovered and then upgraded to higher value and

useful products (Laufenberg *et al.*, 2003, Reddy & Yang, 2005 as stated by Garau *et al.*, 2007).

At the same time, there is a need to address climate change and the use alternative renewable energy resources arises. The European Commission and countries outside the EU have set 20-20-20 targets, which requires the production of 20% of energy from renewable sources, including bioenergy, by 2020 (European Commission, 2008). This will replace the use of fossil and conventional fuels.

Doshi *et al.* (2014) noted that the increase in recognition of biomass use as renewable energy source is because it is easy to produce and environment-friendly, and it is generally more

evenly distributed over the world compared to fossil fuels or uranium with less capital-intensive technologies.

Several researches have been made to convert food waste or inedible parts of fruits like peels and seeds into bioethanol. Saifuddin *et al.* (2014) studied the feasibility of bioethanol production from mango waste. The results showed that bioethanol fuel can be produced from mango waste and can be used in petrol engine in combination with pure petrol fuel.

Densification processes such as briquetting, pelleting, cubing and baling are processes of converting residues of low bulk density into a product of higher density compared to the original raw materials (Tumuluru, 2010 and Bhattacharya *et al.*, 2002 as cited by Guial, 2011). It improves the energy content per unit volume, handling and logistics (Rumple *et al.* 2016)

Muazu and Stegemann (2017) noted that adding binders to briquettes improves binding during densification. The quality of briquette binder significantly affects the quality and performance of briquette. Available binders include starch, molasses, lignosulphonates (in animal feed processing), sulfonate salts made from lignin in pulp or biomass wastes that are naturally composed of binding components, such as rice bran and sawdust.

As several characteristics and composition of biomass affect the combustion processes differently, this study aimed to provide characterization of produced mango seed husk briquettes in terms of density, compression strength, proximate analysis (moisture content, ash content, volatile matter) and gross energy measurement as affected by the type and percentage of the binder.

METHODOLOGY

Mango Seed Husk Sample Preparation

Carabao mango seed samples (where the exocarp and mesocarp were already removed) were acquired from a mango processor in Cavite. The endocarp or the stone was removed of any traces of adhering mesocarp. The kernel of the endocarp was separated

with the husk using shears. The mango seed husk samples were oven dried until a moisture content of approximately 10% was achieved. Samples were ground using a hammer mill and were sieved-shaken through a Mesh No. 10 test sieve to obtain a particle size of less than 2mm.

Binder Preparation

Three commonly available binding materials were used to produce mango seed husk briquettes (MSHBs), namely cassava starch, newspaper and molasses.

Cassava Starch

Starch gel was prepared in the laboratory by adding starch powder into water at the ratio of 1:4 and then heating the mixture at 65°C until the solution became sticky and transparent. Continuous stirring of the mixture was done during gel preparation to prevent clump formation.

Molasses

Liquid molasses was directly bought from an animal-feed producer in Silang, Cavite. This type of binder was used directly.

Newspaper Waste

Old newspapers were manually cut to small pieces and soaked in water. Soaking in water was retained for three to five days to get a sticky solution. Before mixing with powdered mango seed husk, soaked shredded newspaper was processed on a blender for 1 minute to produce a paste.

Effects of different binder materials on MSHB were investigated at husk to binder ratio of 5:5, 7:3 and 9:1. Required quantity of manually mixed MSHB and respective binder were weighed to about 25g of mixture.

Briquetting Process

Briquettes were produced in a briquetting machine, developed by Calixto (2015). It is composed of three parts, the mold, the piston and the extruder. The

mold contains eight (8) steel cylindrical dies of dimension 19 cm height and 2.92 cm diameter. Each die was filled with the 25 grams of mango husk and binder mixture and positioned in the Universal Testing Machine (UTM) for compression into briquettes. The mold was placed under the piston, which is actuated through the UTM at the speed of 10 mm/min of piston movement to compress the sample until a maximum load of approximately 20 kN or compacted pressure of 6MPa was reached. A retention time of 10 seconds was done before the pistons were released. The mold was placed on top of the extruder where a 5-ton hydraulic jack was used to push the briquettes inside. A pictorial view of the briquetting machine is shown in Figure 1.

After briquetting, the briquettes were oven dried until no more significant change in weight was observed. They were stored in sealed plastic bags in a desiccator for subsequent analysis.



Figure 1. a) The mold placed under the piston attached to the UTM; b) The mold above the extruder pushed by a hydraulic jack; and c) Briquettes extruded through the machine.

Physical Properties

Density

Bulk density of raw samples (before they are briquetted), compressed density (immediately determined after ejection from the mold) and relaxed density (after 24 hours curing).

The bulk density of the mixed mango seed husk and binder was determined using the weight of a given sample in known volume. An empty graduated cylinder was weighed and filled with the sample. It was tapped on a wooden table approximately 15 times to allow the material to settle down. The weight of the sample and the reading on the graduated cylinder were recorded.

A digital caliper was used to measure the diameter and height while an electronic balance was used for the weight. Compressed density and relaxed density were computed through the following formula:

$$\text{Density} = \frac{\text{weight}}{\pi \left(\frac{\text{diameter}}{2} \right)^2 (\text{height})} \times 100$$

Equation 1

Length Stability

The length of the briquette was measured using a digital caliper at 0, 10-, 20- and 30-minute intervals after briquetting to determine length or dimensional stability.

Compressive Testing

The compression strength of briquettes in cylindrical shape is determined by diametrical compression test (Figure 2).

A single briquette was placed between two flat parallel plates. At a constant rate, an increasing load was applied until the failure on the sample briquette was observed through cracking or breaking. The load at which failure occurred was read and reported as force or stress. A 4.5 kN limit for loading was set to complement the maximum loading of the

crosshead of 5kN. The machine was set to stop upon reading the said load limit.

Combustion Properties

The proximate analysis (including moisture, ash, volatile matter and fixed carbon contents) and the gross energy of the MSHBs were determined.

The moisture content was determined by placing the briquetted samples inside a hot oven at 105°C until constant weight was achieved (Mythili and Venkatachalam, 2013 as cited by Obi, 2015). Equation 2 was applied to determine the moisture content of the samples:

$$\text{Moisture content (wet basis), \%} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

Equation 2

The ash content was obtained as the percentage of residue remaining using a laboratory muffle furnace following the procedure in ASTM-D 3174-04 (2009) as cited by Doshi *et al.* (2014). A 1.0 g of each residual biomass sample was contained in crucible with a known mass and placed in muffle furnace and maintained at $600 \pm 10^\circ\text{C}$ for 4 h. The furnace was cool down then the crucibles were removed and placed in desiccators.

The volatile matter was determined by the procedure in as indicated ASTM-D 3175-07 (2009) as cited by Doshi *et al.* (2014). The residual biomass samples (1.0 g each) was taken in crucible and placed in muffle furnace maintained at $950 \pm 10^\circ\text{C}$ for 7 min. The crucibles were removed from the furnace and placed in desiccators. The difference in weight was expressed as the volatile matter in the samples.

The percentage of fixed carbon was determined by the difference from 100, considering the percentile amounts of moisture, volatile matter and ash.

The gross energy of the dried briquettes was measured using the Parr 6200 calorimeter, a microprocessor controlled, isoperibol oxygen bomb calorimeter. Using an oxygen bomb and oval bucket in a compact calorimeter and a series of



Figure 2. Illustration of the compressive test

standardization tests, the machine automatically generates the sample's energy equivalent (EE) value (Parr Instrument Company, 2019).

Statistical Analysis

The effects of two factors each at three levels to one or more responses have been studied. A full factorial design for two-factor experiments was used. Analysis of variance at 95% confidence level in determining the significant effects of the independent variables with the response variables were performed in all data. Variations in the response were assumed to be due to the effects in the independent factors, with random error accounting for the remaining variation.

Significant differences between calculated values of the physical and combustion properties of the MSHBs were analyzed through two-way ANOVA using the R statistical program.

RESULTS AND DISCUSSION

Effects of different binder types (T1=starch, T2=molasses, T3=newspaper) on mango seed husk briquettes (MSHB) were investigated at varying percentages by weight (10%, 30%, 50%). Required quantity of manually mixed MSHB and respective binder were weighed to about 25g with mixture of ratio of 5:5, 7:3 and 9:1. Samples without any binder, which was used as blank treatment, was also prepared initially. However, resulting briquettes

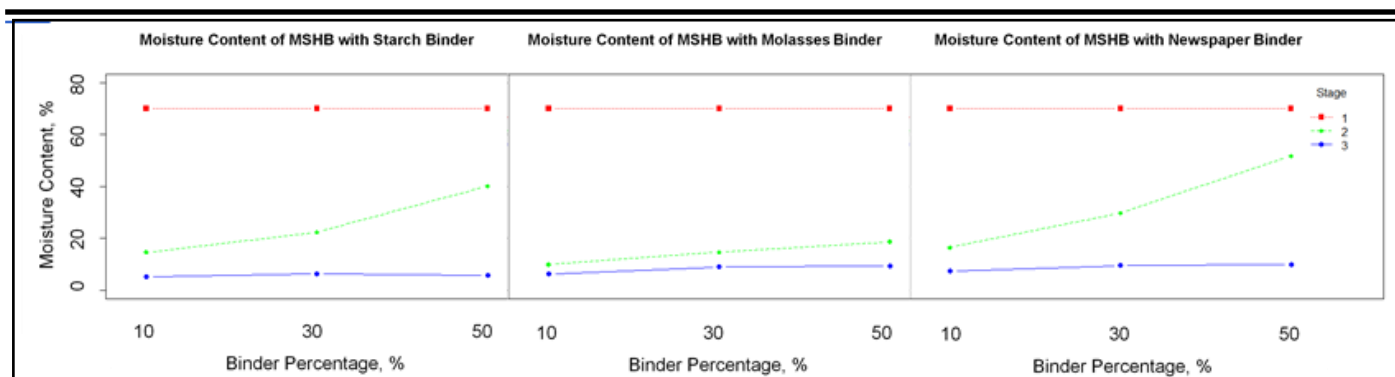


Figure 3. Moisture content of samples at different stages with varying binder types and percentages

easily disintegrated after the molding process therefore were not considered for further tests.

With varying percentages of the three binder types, physical properties and combustion characteristics of MSHBs were determined.

Moisture Content

Mango seed husks obtained from the mango processor had high initial moisture content of 70%. It was mechanically dried until the moisture was reduced to 10%. A range of 8% to 12% was recommended for biomass material used for briquetting (Bhattacharya *et al.*, 2002 as cited by Sen *et al.*, 2016).

Figure 3 shows the different moisture contents of samples at different stages (1=raw mango seed husks, 2=husk and binder mixture before briquetting, 3=MSHB after drying).

Studies have shown that physical and combustion properties of the briquettes have been significantly affected by the type and amount of binder used in briquette formation (Rajkumar and Venkatachalam, 2013 as cited by Sen *et al.*, 2016). With all control parameters of briquetting press and particle size distribution constant, effects on these properties of the type and percentage of binders on the quality of MSHBs (Figure 4) are presented in the succeeding discussions.

Density

One important property that characterizes the briquetting process is density. Since it has a direct

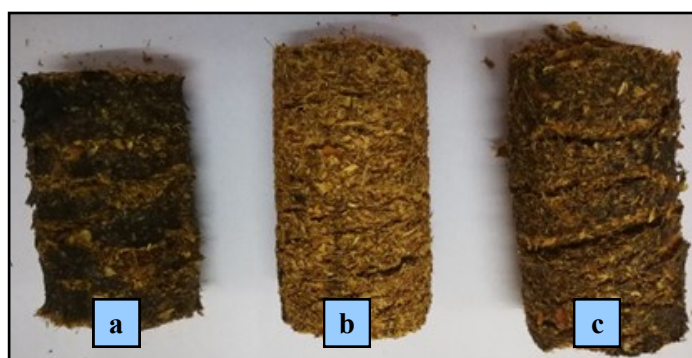


Figure 4. Pictorial view of MSHBs with a) cassava starch; (b) molasses, and (c) newspaper, as binders

relationship with energy/volume ratio, high density products are preferred. Compared with the normal state, densification improves transportation, storage, and handling (Davies and Davies, 2013).

Bulk density (BD) of mango seed husk with all binders before briquetting varies from 0.25-0.39 g/cm³ which improved to compressed density (CD) of 0.54-1.10 g/cm³ after briquetting. Aside from the cost, higher density briquettes also result to longer transport distance and storage period. The average values of compressed densities obtained are more than the minimum recommended value of 0.60 g/cm³ for efficient transportation and safe storage (Mani *et al.*, 2006 as cited by Davies and Davies, 2013).

Relaxed densities (RD) of briquettes with newspaper paste binder ranged from 0.34-0.47 g/cm³, lower than briquettes bonded with molasses binder (0.40-0.69 g/cm³) and starch gel binder (0.48-0.67 g/cm³). Statistics analysis has shown that there is significant difference on compressed and relaxed densities based on the interaction of binder type and binder

percent. Conversely, corresponding results revealed that the binder type had no significant influence on bulk and compressed densities.

Gradual increase in all three densities have also been observed with the increasing binder percent (Figure 5). This implies that bonding of adjacent particles of briquettes improves with increasing binder amount. A similar trend on the effect of binder percentage on relaxed density has been reported on briquettes from sawdust, rice husk, peanut shell, coconut fibre, and palm fibre (Chin and Siddiqui, 2000 as cited by Davies and Davies, 2013).

Length Stability

The effect of binder type and percentage on length stability (LS) was studied and it was observed that the difference in binder type and percentage had significant effect on the length stability of the briquettes. The longitudinal expansions (elongations) were calculated based on the lengths of the briquettes measured at 0, 10, 20 and 30 min after ejection from the die.

Briquettes made from 50% binder had the lowest length average of 28.8mm for a 30-minute period after briquetting, followed by the 30% binder with 45.27mm then the 10% binder with 49.49mm. This phenomenon can be seen from Figure 6, which shows the expansion of the briquettes made of mango husks at different binder percentages.

It was noted that samples with 10% binder had a lower average of 14% moisture content before briquetting compared with 30% and 50% with 22% and 37% moisture content, respectively. Significant expansion was due to the absorption of moisture from the air (Matúš *et al.*, 2015). Aside from the elongation immediately after ejection from the die, significant cracks appeared on the surface.

Compressive Strength

Compressive strength (CS) is the maximum force applied to the face of a briquette before it cracks or breaks (Rajkumar and Venkatachalam, 2013 as cited by Sen *et al.*, 2016). Higher compressive strength makes briquettes more suitable for handling,

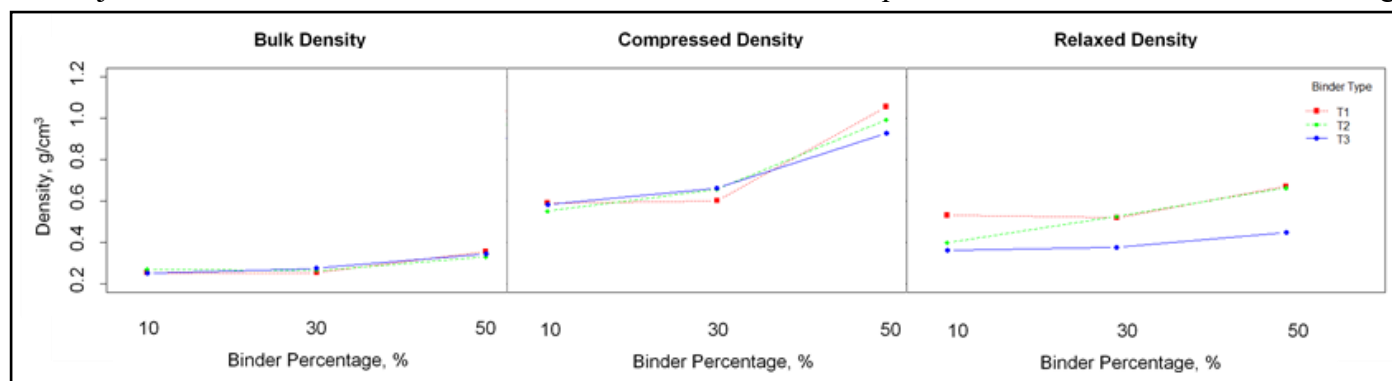


Figure 5. BD, CD and RD of MSHBs with varying binder types and percentages.

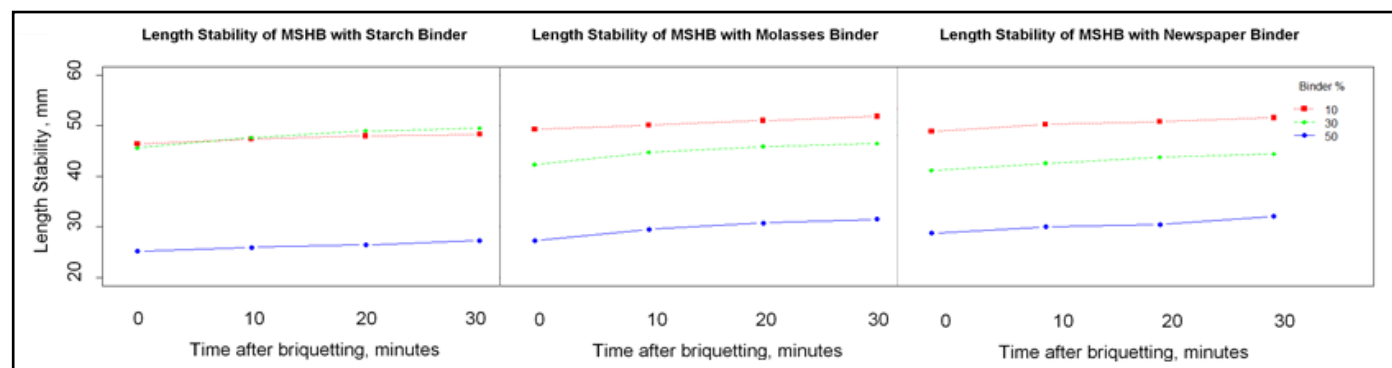


Figure 6. LS of MSHBs with varying binder types and percentages for 30minutes

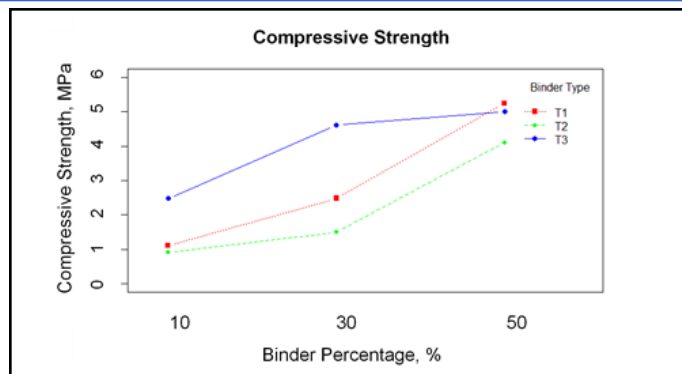


Figure 7. CS of MSHBs with varying binder types and percentages

transporting and storing. It also increases the durability of briquettes by reducing the moisture absorption capacity which causes deterioration of the briquette (Kers *et al.*, 2010 as cited by Sen *et al.*, 2016). The compressive strength of the MSHBs with different binder percentages is presented in Figure 7.

The compressive strength of briquettes with all three binders ranged from 0.77 to 5.33 MPa. Results have clearly shown that compression strength is directly proportional to binder percentage. Briquettes with 10% binder had an average of 1.5 MPa, which could cause rapid disintegration of the briquettes under handling and storage. Briquettes with newspaper as binder showed higher average compressive strength (4.03 MPa) compared with starch binder (2.94 MPa) and molasses binder (2.15 MPa).

Review of related literature showed that higher density briquettes likely possess higher compressive strength than that of lower density (Jamradloedluk and Wiriyaumpaiwong, 2010 as cited by Sen *et al.*, 2016). The same relationship was observed with starch and molasses binders, wherein MSHBs with starch binder resulted to higher relaxed density and compression strength compared with MSHBs with molasses binder. However, this trend was in disagreement with the values reported for starch binders against newspaper binders. Briquettes with newspaper binders exhibited higher compressive strength (except for the 50% binder), though it had lower relaxed density compared with those made with starch binders. This is attributed to the chemical composition of the binder. Paper used for newsprint are normally produced through mechanical pulping. Such process results to lignin

being retained in the pulp and the fibers having high lignin content (El-Haggar, 2007). A lignin derivative has been described to have strong adhesive strength (Zhanga *et al.*, 2018). Enhanced compressive strength of MSHBs with newspaper binder has been accounted to its lignin component.

Proximate Analysis

Proximate analysis is a way of quantifying some physical characteristics of biomass briquettes affecting its combustion characteristics.

Volatile matter (VM) represents the components of carbon, hydrogen and oxygen within a biomass, which when heated is converted to vapor (Tamilvanan, 2013). The volatile matter obtained for the MSHBs at three binder percentages using starch gel, molasses and newspaper as binders averaged between 80–84%, which is within the range recommended by Yang *et al.* (2005). Studies have shown that high volatile matter implies easier ignition of briquettes but produces much smoke, while those with less than 20% volatile substances produce smokeless grade fuels (Obi, 2015).

Ash is the non-combustible component of a biomass. Results showed 9.28–14.30% ash content for MSHBs, which is within the conventional range set by Yang *et al.* (2005). Ash deposits have been known to cause problems in heat transfer surfaces and to increase the rate of corrosion of the metal in the combustion system (Tamilvanan, 2013).

The fixed carbon (FC) of a fuel is defined as the percentage of carbon available for char combustion after all the volatile matter is removed from the biomass (Tamilvanan, 2013). Results showed 5.69–8.31% fixed carbon on the MSHB samples. Highest fixed carbon percentage was observed with MSHBs with newspaper binder. Fixed carbon content has been reported to be dependent on the cellulose content of the selected biomass. A component which comprises nearly 95% of paper (Shyamalee *et al.*, 2015). Figure 8 shows the percent volatile matter, ash and fixed carbon content of MSHBs

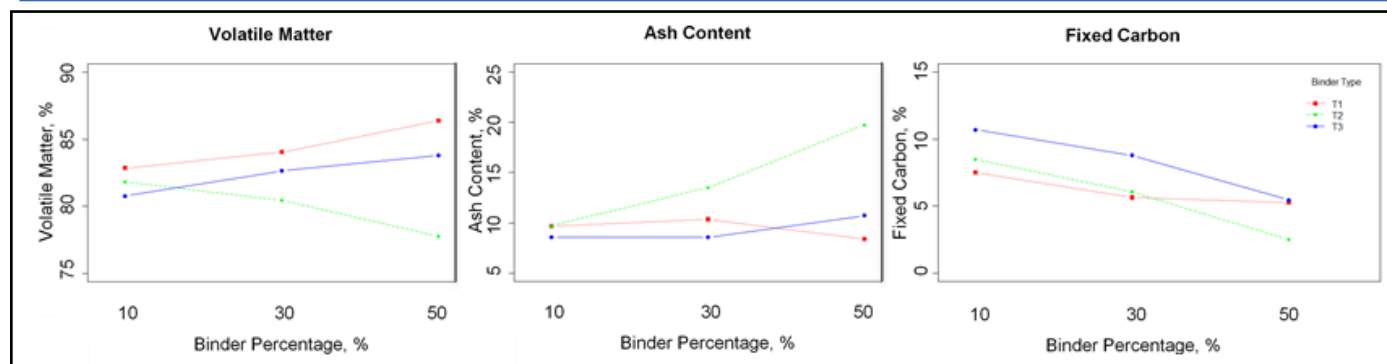


Figure 8. VM, ash and FC of MSHBs with varying binder types and percentages

Calorific Value

Calorific value is an essential property of briquettes. It reveals the energy content of the fuel (Aina *et al.*, 2009 as cited by Sen *et al.*, 2016). For the purpose of this research, gross calorific value (also known as gross energy) has been determined.

The calorific values of briquettes produced from mixture of mango seed husk and binder at different levels are presented in Figure 9. The calorific values of the briquettes ranged between 16.9 MJ/kg and 18.42 MJ/kg. Calorific value of MSHBs without binder was 17.78 MJ/kg. Figure 9 shows that briquettes made from mango seed husk is very ideal as its gross energy is higher than rice husk which is 15.97 MJ/kg (Gravalos *et al.*, 2016). The calorific value of the MSHBs with starch binder (18.18 MJ/kg) and newspaper binder (17.9 MJ/kg) is also within the acceptable range for commercial briquette (>17.49 MJ/kg) (DIN 51731 reported by Singh *et al.*, 2011 as cited by Davies and Davies, 2013).

The mean calorific values reduced from 18.32 MJ/kg to 17.52 MJ/kg at 10% and 50% binders respectively. Low calorific values at high binder percentage can be attributed to lower fixed carbon. High significant correlation between the gross energy of 7 species of biomass shells with their lignin, fixed carbon, and volatile material contents has been reported (Demirbaş, 2003). It can also be due to higher moisture contents which may have absorbed heat liberated during combustion (Sen *et al.*, 2016). Calorific value has been stated to be affected by the type of biomass, chemical composition and moisture content (Josephat and David, 2016).

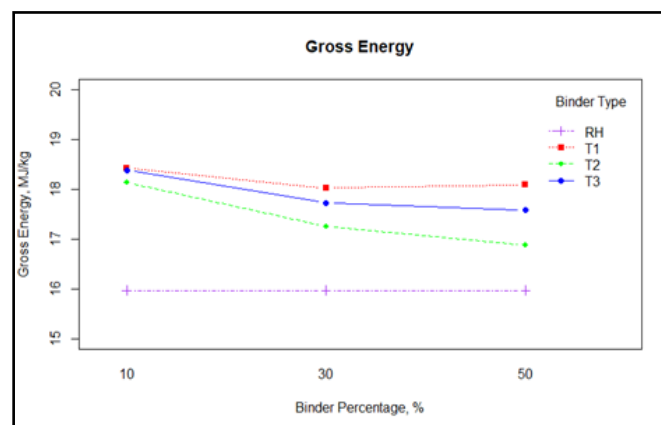


Figure 9. Gross Energy of MSHBs with varying binder types (T1, T2, T3) and percentages as compared to briquettes from rice husk (RH)

Results of statistical analysis on the significant differences between calculated values of the physical and combustion properties of the MSHBs with 95% confidence level in Table 1.

SUMMARY AND CONCLUSION

The study measured and analyzed the physical and combustion properties of mango seed husk briquettes using a 2-factor, 3-level, with 3 replicates experimental design. The independent parameters included binder type (starch gel, molasses and newspaper paste) and binder percentage (10%, 30% and 50%) that evaluated the effects on bulk density, compressed density, relaxed density, length stability, compression strength, volatile matter, ash content and fixed carbon of mango seed husk briquettes. Gross calorific value has also been determined. Analysis of variance showed that relaxed density, length stability, compression strength and ash content were significantly affected by the two

Table 1. Summary of the statistical analysis of MSHBs as affected by varying binder types and percentages

BINDER TYPE	BD ^b	CD ^{bc}	RD ^{abc}	LS ^{abc}	CS ^{abc}	VM ^a	ASH ^{abc}	FC ^b
T1	0.29 ± 0.05	0.75 ± 0.23	0.57 ± 0.08	40.60 ± 10.40	2.94 ± 1.86	84.40 ± 2.34	9.46 ± 1.40	6.12 ± 1.70
T2	0.29 ± 0.03	0.73 ± 0.20	0.56 ± 0.12	41.70 ± 9.06	2.17 ± 1.50	80.00 ± 2.67	14.30 ± 4.47	5.69 ± 3.44
T3	0.29 ± 0.05	0.72 ± 0.16	0.40 ± 0.04	41.20 ± 8.52	4.03 ± 1.24	82.40 ± 2.95	9.28 ± 1.69	8.31 ± 3.65

a=binder type is significant, b=binder percent is significant, c=interaction between binder type and percent is significant

independent factors. Bulk density, compressed density and fixed carbon were solely affected by the binder percentage while volatile matter was affected only by the binder type.

This research revealed that mango seed husk briquettes produced with newspaper as binder consistently gave superior characteristics such as higher compressive strength (4.03 MPa), lower ash content (9.28%) and higher fixed carbon (8.31%) compared to other briquettes produced from other binders. It had an average volatile matter component of 82.4%. Moreover, such material is also considered as waste like mango seed husk, the main component of the briquette. The use of newspaper as binder will also not compete for the use of starch as food and of molasses as animal feed.

One important edge of mango seed husk briquettes was the gross calorific value. Ground mango seed husk briquettes averaged with 17.84 MJ/kg while rice husk was reported to have 15.97 MJ/kg.

This study showed the applicability of mango seed husk briquette as an alternative source of energy. Data gathered can be used for further research and development of mango seed husk briquettes.

RECOMMENDATIONS

Efforts had been made to analyze and quantify the effects of different binder types and binder percentages on the quality of the final mango seed husk briquettes. This study showed the applicability of waste materials such as mango seed husk and newspaper as an alternative source of energy if they are turned to briquettes and binder, respectively. Some recommendations for further studies of mango seed husk briquettes were provided as follows:

1. Design and fabrication of an equipment to aid in the separation of mango kernel from the mango seed husk should be considered.
2. There is a potential improvement of the properties of these briquettes by manipulating operations other than its components. Varying pressure and duration of retention time of briquetting can also be explored.
3. The ultimate analysis which will provide the mass concentrations of the major elements (carbon, oxygen, hydrogen, nitrogen and sulphur) in the briquettes will also provide an in depth discussion on its combustion properties.
4. The heat received during drying also inevitably causes some changes in the physical and combustion characteristics. It is then necessary to find the appropriate technology and the best method of drying.
5. With proper economic analysis, results generated on this study may be used to encourage stakeholders to convert mango seed waste into a valuable and eco-friendly combustible material.

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