Effect of Compaction Pressure, Particle Size and Binder Ratio on Thermo-Physical Properties of Maize Cob Briquettes

Mambo Wilson[1], Kamugasha Dick[2], Adimo Ochieng[3], Nabasirye Margaret[4], and Namagembe Flavia[5]

1 and 3-Jomo Kenyatta University of Agriculture and Technology, P .O. Box 62000-00200, Nairobi, Kenya.

2 and 5-Uganda Industrial Research Institute, P. O. Box 7086, Kampala, Uganda.

4-Makerere University, P. O. Box 7062, Kampala, Uganda.

Corresponding Author: Mambo Wilson, Email address: mambowilson@gmail.com

ABSTRACT

The quality of briquettes varies greatly among small scale producers in Uganda due to the different methods of production, absence of standardization, lack of technical knowledge and quality control procedures. The study aimed at investigating the effect of binder ratio, compaction pressure, and particle size on thermo-physical properties of carbonized maize cob briquettes. A 3×4×5 factorial experiment with four replicates was used. Three particle size levels (small, medium and large), four compaction pressures (P1=2MPa, P2=4MPa, P3=6MPa and P4=8MPa), and five cassava binder ratios (B1=5%, B2=7.5%, B3=10%, B4=12.5%, B5=15%) were used. Briquettes were made from carbonized maize cobs using a manually operated hydraulic briquette press. Proximate analysis, heating value and density were determined. Linear regression models were used to investigate the effect of compaction pressure, binder ratio and particle size on each of the dependent variables. All the independent variables had significant effect on briquette quality. Much as all briquettes met the minimum quality requirements, medium sized particles (4mm to < 6mm), 5% binder ratio and 8MPa compaction pressure produced superior quality briquettes (8.421% ash content, 12.923% volatile matter content, 65.38% fixed carbon content, 13.358% moisture content, 25247.5 J/g heating value, and 409.8824 Kg/m^3 relaxed density). In addition to the high quality briquettes, 5% binder ratio is low enough to minimise food insecurity and the use of smokeless briquettes shall reduce the high death toll caused by indoor air pollution.

Keywords: *Briquette quality, Cassava binder ratio, Compaction pressure, Maize cobs, Particle size.*

◆

1. *INTRODUCTION*

Global fossil fuel deposits are declining at high rate which requires alternative renewable energy sources in order to meet the increasing energy demand for development (Singer, 2011 [1]). Three billion people worldwide are estimated to use traditional biomass for cooking and heating, and majority of them are located in Sub Saharan Africa (Belward et al., 2011 [2]). Biomass accounts for 90% of the energy used in Uganda which can further be partitioned into 70% wood, 16% charcoal and 4% crop residue (Ferguson, 2012 [3]). Maize being the third most important food crop in the country (Haggblade & Dewina, 2010 [4]), it generates large quantities of maize cobs which are normally discarded as waste and pose environmental pollution problem when not well managed. Conversion of the maize cobs into fuel briquettes is environmentally friendly and economically viable (Adetogun et al., 2014 [5]). However, the quality of briquettes varies greatly among small scale producers in Uganda due to the different methods of production, absence of standardisation, lack of technical knowledge and quality control procedures. Sub-standard products undermine briquette potential to tap into available markets (Ferguson, 2012 [3]).

The type and amount of binder affect combustion properties of briquettes. Briquetting using a binder is sufficient at low compaction pressure (Grover & Mishra, 1996 [6]), but particles must bind properly during compression to prevent the briquettes from crumbling. Examples of binders include crude oil, starch, molasses, clay, sodium silicate and cement. Despite the great variety of binders, starch binder results into high quality briquettes. Cassava is a good binder because it has high starch content and is readily available (Ugwu & Agbo, 2013 [7]). However, excessive use of cassava for briquette production has a negative effect on food security (Katimbo et al., 2014 [8]). Knowledge of optimal binder ratio, compaction pressure, and particle size for production of high quality briquettes might be important. The quality of a briquette can be measured from its heating value, density, ash content, volatile matter content, fixed carbon content, and moisture content among others (Sastry et al.,2013 [9]).

This study therefore aimed at investigating the effect of binder ratio, compaction pressure, and particle size on thermo-physical properties of carbonized maize cob briquettes.

2. METHODOLOGY

2.1 STUDY AREA

The research was conducted at Uganda Industrial Research Institute which is located in Nakawa 6.7km along Jinja road.

2.2 STUDY DESIGN

A 3×4×5 factorial experiment was carried out in a completely randomised design with four replications to investigate main effects and interactions of the factors. The three factors were particle size, compaction pressure, and binder ratio. Particle size had three levels (Small (2 to < 4mm), Medium (4 to < 6mm) and Large (6 to < 8mm)), compaction pressure had four levels (P_1=2MPa , P_2=4 MPa, P_3=6 MPa, P_4=8 MPa), and starch binder ratio had five levels (B1=5%, B2=7.5%, B3=10%, B4=12.5%, B5=15%) of the weight of maize cob char. Four replications provided four samples per treatment which were sufficient for all the required experimental tests (Quinn & Keough, 2002 [10]).

2.3 BRIQUETTE PRESS, MATERIAL COLLECTION AND SAMPLE PREPARATION

A manually operated hydraulic briquette press with a capacity of four briquettes was fabricated for the experiment as shown in figure 2.1 below.

Figure 2.1: Manually operated hydraulic briquette press connected to pressure gauge

Each of the cylindrical moulds in the compression chamber of the press had an external diameter of 52.5mm, internal diameter of 20mm, and height of

120mm. The press was powered by a 20 Ton hydraulic jack with 56mm piston base diameter and connected to a pressure gauge of 10MPa capacity using high pressure hydraulic fittings.

Maize cobs collected from farmers in Tiribogo (central Uganda) were sun dried for 5 days to 25% moisture content and then carbonized using a gasifier because it produces homogeneous char. Operating temperatures of the gasifier reactor ranged from 850^{o}C to 1200 ^{o}C, maize cob consumption rate was 30 kg/hr and the char generated was 12% of the raw material by weight (Wabwire, 2014 [11]). Carbonization liberates volatile matter and results into smokeless briquettes of high energy density (Tokan et al., 2014 [12]). Size reduction of the char was achieved by pounding using a mortar and pestle, and then sieved using four different mesh sizes (2mm, 4mm, 6mm, and 8mm) to obtain the required sizes. The particles of size less than 2mm were termed as fine particles, from 2mm to less than 4mm were termed as small particles, from 4mm to less than 6mm were termed as medium particles, whereas from 6mm to less than 8mm were termed as large particles. Then the fine particles were uniformly mixed with each of the three groups of particles (small, medium, and large) in a proportion of 15% by weight to increase strength as specified by Grover & Mishra (1996)[6]. All weights were measured using a digital weighing balance of 0.0001g precision. Cassava tubers of *Nase14* variety were harvested from a farmer in Koboko (North Western Uganda), peeled, washed, grated, sun dried to 10% moisture content, and then ground to produce flour using a grinding machine. Starch paste was prepared using a ratio of 1kg cassava flour to 10 litres of water with continuous agitation and the temperature was raised to 80 ^{o}C. Char of a given particle size was uniformly mixed with starch binder of a given ratio and then compacted using the briquette press at a given hydraulic cylinder pressure and uniform dwelling time of 25 seconds was maintained.

A total of 240 experimental briquette samples were made for evaluation of heating value, moisture content, volatile matter content, ash content, fixed carbon content, and density. Proximate analysis was done using ELTRA Thermostep Thermogravimetric analyzer (Przyborowski et al., 2012 [13]) whereas heating value was determined using IKA KV600 digital bomb calorimeter (Sugumaran & Seshadri , 2009 [14]). Briquette density was computed from their mass and volume (Demirbaş, & Şahin, 1998 [15]).

R-statistical software version 3.1.1 was used for data analysis. Since two of the independent variables (compaction pressure and binder ratio) and all dependent variables (heating value, moisture content, volatile matter content, fixed carbon content, ash content, and density) are continuous, multiple linear regression models were chosen to investigate the effect of compaction pressure, binder ratio and particle size on each of the dependant variables. The multiple regression models also allow for determination of interaction of the factors (Quinn&Keough, 2002 [10]).

3. RESULTS AND DISCUSSION

All the dependant variables (heating value, moisture content, volatile matter content, ash content, fixed carbon content, and density) were normally distributed since histograms and box plots in preliminary analysis were symmetrical. Pearson's correlation matrix shows that particle size, binder ratio and compaction pressure are not correlated (r < 0.014). Table 3.1 below shows p-values for linear regression models of main effects and interactions on each of the dependant variables.

Table 3.1: p-values from linear regression analysis for each of the dependant variables

Effect	Variable(s)		Ash content	Volatile matter content	Fixed carbon content	Moisture content	Heating Value	Density
Main Effects	PS	MP	>0.05	>0.05	>0.05	>0.05	>0.05	<0.0001
		SP	0.00986	>0.05	>0.05	>0.05	0.00079	<0.0001
	BR		>0.05	< 0.0001	< 0.0001	>0.05	<0.0001	<0.0001
	CP		>0.05	>0.05	0.445	>0.05	>0.05	<0.0001
Interactions	PS×BR		>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
	PS×CP		>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
	BR×CP		>0.05	>0.05	>0.05	>0.05	>0.05	0.00059
	PS×BR×CP		>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

Where PS=Particle size, BR=Binder ratio, CP=Compaction Pressure, MP= Medium particles, SP= Small particles, and the reference particle size = Large particles (LP). Level of significance = 5%.

3.1 : Ash Content

Binder ratio and compaction pressure did not have significant effect on ash content at 5% level of significance (p-values > 0.05). Much as compaction pressure increases density which reduces porosity that could limit the amount of oxygen required for combustion (Chirchir et al., 2013 [16]) and result in increased ash content, ELTRA Thermostep Thermogravimetric proximate analyzer uses sufficient amount of oxygen that allows complete combustion. In addition to that, cassava binder only contains 0.2% ash content (Eze & Azubuike, 2010 [17]) which is very negligible at low binder ratios in comparison to 4.2% ash content for char. This explains why compaction pressure and binder ratio never had significant effect on ash content. Particle size had a significant effect on ash content (p-value: 0.00986 <0.05). Ash content of briquettes for the various particles is graphically represented by the bar graph below.

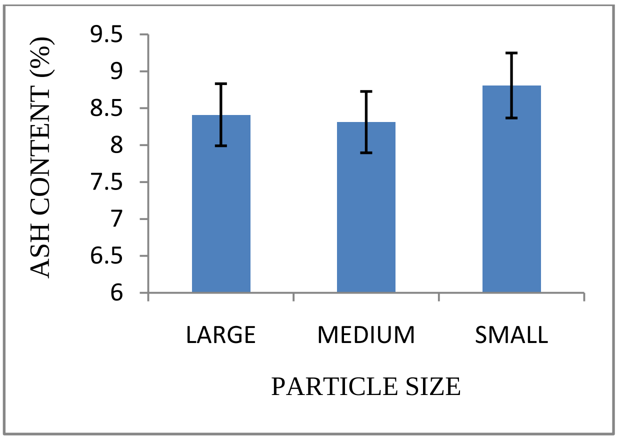

Figure 3.1: Bar plot of ash content for briquettes made from different sizes of particles

Large particles had 8.433% ash content which was not statistically different from that of medium particles (p-value: 0.69357>0.05). Small particles had significantly higher ash content than large particles by 0.421% (p-value: 0.00986<0.05) because of incombustibles such as sand that were retained by the 2mm sieve.

3.2 : Volatile matter content

The fitted simple linear regression model for volatile matter content is as shown by equation one below.

$$VC = 10.723 + 0.407BR \qquad (1)$$

Where;

VC = Volatile matter content on dry basis (%)

BR = Binder ratio (%)

Unlike compaction pressure and particle size, binder ratio had a significant effect on volatile matter content at 5% level of significance (p-value: 3.54×10^{-11}) and it accounts for 38.5% of the total variation in volatile matter content. Low compaction pressure at room temperature does not alter composition of particles (Grover & Mishra, 1996[6]), hence the insignificant effect of compaction pressure on volatile matter content. Maize cobs were carbonized in a gasifier where the high reactor temperatures (850-1200^{o}C) (Wabwire, 2014 [11]) expelled most of the volatile substances. The char particles therefore had very low volatile matter content which explains the insignificant effect of particle size on volatile matter content of the briquettes. Volatile matter content significantly increased with increase in binder ratio as shown by the scatter plot below.

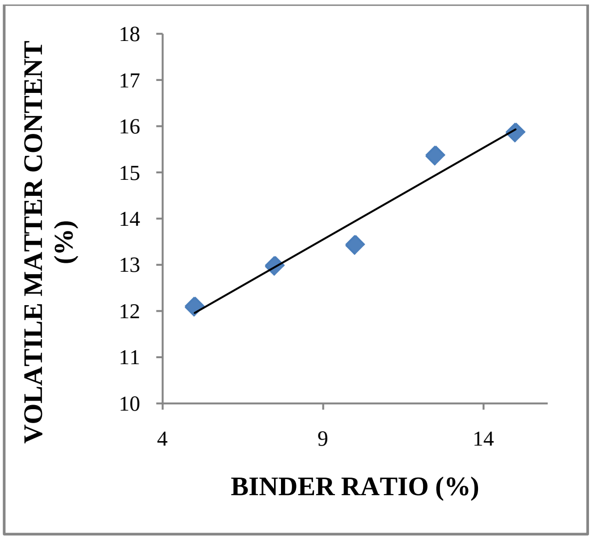

Figure 3.2: Scatter plot of volatile matter content against binder ratio for maize cob briquettes

The volatile matter content of cassava lies in the range of 72-75% (Jarinee & Kiatfa, 2012 [18]) which is higher than 9.4% volatile matter content of maize cob char measured. The higher volatile matter content in cassava than maize cob char explains the increase in volatile matter content with increasing cassava binder ratio.

3.3 : Fixed Carbon Content

The simple linear regression model fitted for fixed carbon content of briquettes is as shown by equation two below.

$$FC = 66.99 - 0.36\,BR \qquad (2)$$

Where;

FC = Fixed Carbon Content on dry basis (%),

BR = Binder Ratio (%)

Unlike particle size and compaction pressure, binder ratio had significant effect on fixed carbon content at 5% significance level (p= 3.37×10^{-08} ***) and it explains 28.5% of the total variation in fixed carbon content.

All the particles were obtained from the same char having uniform fixed carbon content which explains why variation of particle size could not cause any significant effect on fixed carbon content. Low compaction pressures at room temperature do not have any effect on composition of particles (Grover & Mishra, 1996 [6]), hence the insignificant effect of compaction pressure on fixed carbon content. Fixed carbon content decreases with increase in binder ratio as shown by figure 3.3 below.

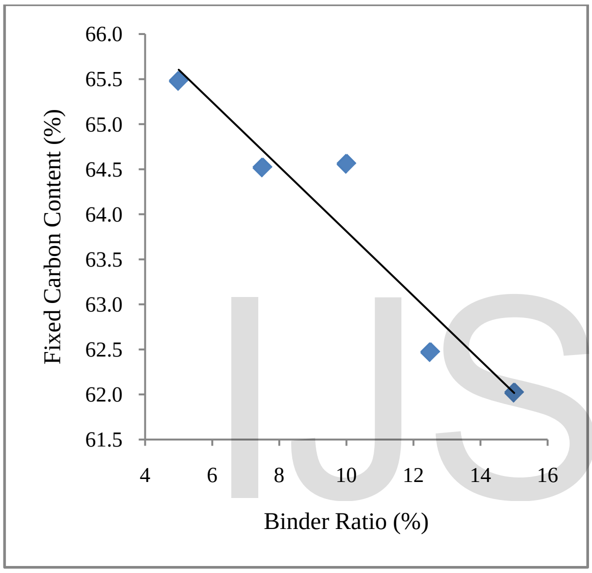

Figure 3.3: Scatter plot of fixed carbon content against binder ratio for maize cob briquettes

The fixed carbon content of maize cob char determined (69.3%) is greater than (9-13%) of cassava (Jarinee & Kiatfa, 2012[18]) which explains the decrease in fixed carbon content as the cassava binder ratio increases.

3.4 : Moisture Content

Compaction pressure, particle size and binder ratio did not have significant effect on moisture content (p-value > 0.05). The drying time and weather conditions were sufficient which released all the free water as evidenced by moisture content of less than 18% (Onchieku et al., 2012 [19]), hence the insignificant effect of the treatment on moisture content. The low moisture content implies that less amount of heat energy is wasted in moisture liberation during combustion which shows that the briquettes produce sufficient heating effect (Grover & Mishra, 1996 [6]).

3.5 : Heating Value

The multiple regression model fitted for heating value is as shown by equation three below.

$$HV = 25340 - 288.2\,SP - 61.99\,BR \qquad (3)$$

Where;

HV = Heating Value (J/g), SP = Small Particles, BR = Binder ratio (%)

Particle size and binder ratio have significant effect on heating value at 5% significance level (p = 1.421×10^{-08}) and explain 36.9% of the total variation in heating value. The graphical representation of heating value is as shown by figure 3.4 below

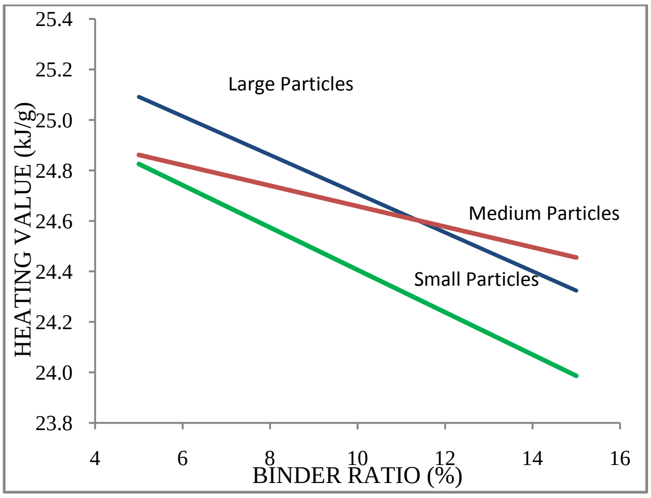

Figure 3.4: Heating value against binder ratio for maize cob briquettes with different particle sizes

The heating value of medium particles at all binder ratios was not significantly different from that of large particles at 5% level of significance (p-value:0.292140). At all binder ratios, small particles had significantly less heating value than large particles (p-value:0.000788). Small particles had 288.2J/g less heating value than large particles due to the presence of sand particles which were retained by the small sieve.

One percent increase in binder ratio reduced heating value by 61.99J/g which agrees with the findings of Chirchir et al., (2013) [16] that increase in binder ratio reduces heating value. The reduction of heating value could be attributed to the reducing fixed carbon content of the briquette as binder ratio increases.

Compaction pressure did not have statistically significant effect on heating value at 5% level of significance (p-value:0.959912) because it only enhances the volumetric calorific value of biomass, but not heating value(Grover and Mishra,1996[6]).

3.6 : Density

The fitted multiple regression model for density of the briquettes is as shown by equation four below

$$D = 226.58 + 20.64\,MP + 41.62\,SP + 7.8\,BR + 19.56\,P - 0.8206 \times P \times BR \qquad (4)$$

Where;

D = Density (kg/ m^3), MP = Medium Particles,

SP = Small Particles, BR = Binder ratio (%),

P = Compaction Pressure (MPa)

Compaction pressure, binder ratio and particle size had significant effect on briquette density at 5% significance level(p-values < 0.05) and account for 78.5% of the total variation. Large un compacted particles had a density of 226.58 kg/m^3. Medium and small particles had higher densities than large particles by 20.64kg/m^3 and 41.62 kg/m^3 respectively because reduction in particle size eases compaction and allows more mass of material for a given volume which increases briquette density (Mitchual et al., 2013 [20]). The interaction between binder ratio and compaction pressure had a negative effect on briquette density. This could be attributed to the displacement of excess binder from the particles at increasing pressure which results into increase in volume, hence decreasing density. However, the resultant effect of pressure and binder ratio on briquette density is positive. One percent increase in binder ratio changes briquette density by (7.8 - 0.8206 Pressure_0) kg/m^3 if all other conditions are kept constant. Where Pressure_0 is the compaction pressure in MPa. Increase in cassava binder ratio increases briquette density (Križan et al., 2011 [21]) because it fills the pores, hence increasing the mass of material in a given volume. Increasing compaction pressure by one mega Pascal alters the density of briquettes by (19.56 - 0.8206 Binder Ratio_0) kg/m^3 while keeping other factors constant. Binder Ratio_0 is the proportion of binder used in percentage. Compaction pressure increases briquette density (Wilaipon, 2009 [22]) because it reduces volume at constant material mass.

Particle size, compaction pressure and binder ratio never had significant interaction on moisture content, volatile matter content, fixed carbon content, ash content and heating value. However, there was significant interaction between compaction pressure and binder ratio on density.

Residual plots for the fitted multiple linear regression models were investigated and therefore the assumptions of independence, homoscedasticity and normality required for linear regression analysis were satisfied.

3.3 : OPTIMAL CONDITION

Factor levels in each model were ranked basing on importance, followed by average ranks of the factor levels in all models, and then the optimal condition was determined by selecting the levels with the best rank for each factor. Much as all treatments satisfied the minimum briquette quality requirements, the fitted linear regression models show that medium sized particles, 5% binder ratio and 8MPa compaction pressure of the hydraulic cylinder produced briquettes with superior quality (8.421% ash content, 12.923% volatile matter content, 65.38% fixed carbon content, 13.358% moisture content, 25247.5 J/g heating value, and 409.8824 Kg/m^3 relaxed density).

The ash content for the briquettes (8.421%) at optimal condition was less than 18% which implies that they burn with little slagging effect and the fixed carbon content (65.38%) is greater than 60% minimum requirement for barbeque use (Zagreb, 2008[23]). Given the fact that volatile matter content is directly proportional to smoke level (Tokan et al., 2014 [12]), the volatile matter content at optimal condition (12.923%) is less than 30% limit for barbeque use (Zagreb, 2008 [23]) which solves the problem of indoor air pollution that has been killing 4.3 million people annually (WHO, 2014 [24]). Heating value of the briquettes at optimal condition (25247.5 J/g) is greater than 17500 J/g requirement for sufficient heating effect (Emerhi, 2011[25]). The moisture content at optimal condition (13.358%) is less than 18% limit for adequate heating without wasting energy to drive extra moisture during combustion (Onchieku et al., 2012 [19]). Relaxed density of maize cob briquettes at optimal condition (409.8824 Kg/m^3) is greater than the bulk density of maize cobs of 50.32Kg/m^3 reported by Oladeji, 2004 [26], which implies that the briquettes occupy 12.25% of the space requirement for storage of maize cobs.

4. CONCLUSION

Compaction pressure, binder ratio and particle size have a significant effect on thermo-physical properties of carbonised maize cob briquettes. Compaction pressure increase significantly increases briquette density. Binder ratio increase significantly increases volatile matter content, reduces fixed carbon content, reduces calorific value, and increases density of briquettes. Particle size increase significantly reduces density, reduces ash content, and increases calorific value of briquettes. Much as all treatments satisfied the minimum briquette quality requirements, the fitted linear models show that 5% cassava binder ratio, medium sized particles (4mm to < 6mm) and 8MPa hydraulic cylinder pressure produced briquettes with superior quality. In a nutshell, the briquettes at optimal condition burn without smoke, leave little ash after combustion, posses high heat intensity, and require little storage space. These briquettes attained good quality requirements for barbeque use and therefore have the potential of reducing wood consumption, hence minimizing deforestation rate.

5. ACKNOWLEDGEMENT

We would like to thank the Almighty God for His providence and protection, RUFORUM for funding the research, Jomo Kenyatta University of Agriculture and Technology for technical guidance and coordination, staff of Uganda Industrial Research Institute (Energy systems division, Mechanical engineering section, Carpentry section, and Chemistry section) for the technical support, staff of Namulonge National Crops Resources Research Institute for guidance on cassava binder, Pamoja Energy limited for carbonisation of maize cobs and all friends who participated in the study.

REFERENCES

1. Singer, S. (2011). The Energy Report: 100% renewable by 2050. *WWF, Ecofys and OMA.*
2. Belward, A., Bisselink, B., Bódis, K., Brink, A., Dallemand, J. F., De Roo, A., ... & Ossenbrink, H. (2011). Renewable energies in Africa. *F. Monforti (Ed.)*, 1-62. Http://Doi.Org/10.2788/1881
3. Ferguson, H. (2012). Briquette Businesses in Uganda The potential for briquette enterprises to address the sustainability of the Ugandan biomass fuel market. *GVEP International*.
4. Haggblade, S., & Dewina, R. (2010, January). Staple food prices in Uganda. In *COMESA policy seminar on variation in staple food prices: causes, consequence, and policy options, African Agricultural Marketing Project (AAMP), Maputo, Mozambique* (pp. 25-26).
5. Adetogun, A. C., Ogunjobi, K. M., & Are, D. B. (2013). Combustion Properties of Briquettes Produced from Maize Cob of Different Particle Sizes. *Journal of Research in Forestry, Wildlife and Environment*, *6*(1), 28-38.
6. Grover, P. D., & Mishra, S. K. (1996). *Biomass briquetting: technology and practices*. Food and Agriculture Organization of the United Nations.
7. Ugwu, K., & Agbo, K. (2013). Evaluation of binders in the production of briquettes from empty fruit bunches of Elais guinensis. *International Journal of Renewable and Sustainable Energy*, *2*(4), 176-179.
8. Katimbo, A., Kiggundu, N., Kizito, S., Kivumbi, H. B., & Tumutegyereize, P. (2014). Potential of densification of mango waste and effect of binders on produced briquettes. *Agricultural Engineering International: CIGR Journal*, *16*(4), 146-155.
9. Sastry, M. K. S., Bridge, J., Brown, A., & Williams, R. (2013). Biomass Briquettes : A sustainable and environment friendly energy option for the Caribbean. In *Fifth International Symposiym On Energy, Puerto Rico Energy Center* (Pp. 1–8). Laccei.
10. Quinn, G. P., & Keough, M. J. (2002). *Experimental design and data analysis for biologists*. Cambridge University Press.
11. Eng, W. A. B. (2014). *Performance Characterisation of A Husk Powered System for Rural Electrification in Uganda* (Doctoral dissertation, Makerere University).
12. Tokan, A., Sambo, A. S., Jatau, J. S., & Kyauta, E. E. (2012). Effects of Particle Size on the Thermal Properties of Sawdust, Corncobs and Prosopis Africana Charcoal Briquettes. *American Journal of Engineering Research*, *03*(08), 369–374.
13. Przyborowski, J. A., Jedryczka, M., Ciszewska-Marciniak, J., Sulima, P., Wojciechowicz, K. M., & Zenkteler, E. (2012). Evaluation of the yield potential and physicochemical properties of the biomass of Salix viminalis× Populus tremula hybrids. *Industrial Crops and Products*, *36*(1), 549-554.
14. Sugumaran, P., & Seshadri, S. (2009). Evaluation of selected biomass for charcoal production. *Journal of Scientific & Industrial Research*, *68*, 719-723
15. Demirbaş, A., & Şahin, A. (1998). Evaluation of biomass residue: 1. Briquetting waste paper and wheat straw mixtures. *Fuel processing technology*, *55*(2), 175-183.
16. Chirchir, D. K., Nyaanga, D. M., & Githeko, J. M. (2013). Effect of Binder Types and Amount on Physical and combustion characteristics. *International Journal of Engineering Research and Science & Technology*, *2*(1), 12-20.
17. Eze, S. O., & Azubuike, A. (2010). Assessment of the physicochemical properties and applications of some cassava varieties. *Research Journal of Applied Sciences*, *5*(4), 309.
18. Jongpluempiti, J., & Tangchaichit, K. (2012). Comparison Proximate Analysis and Heating Value between Cassava Rhizome and Perennial Wood. In *Advanced Materials Research* (Vol. 415, pp. 1693-1696). Trans Tech Publications.
19. Onchieku, J. M., Chikamai, B. N., & Rao, M. S. (2012). Optimum parameters for the formulation of charcoal briquettes using

bagasse and clay as binder. *European Journal of Sustainable Development*, *1*(3), 477-492.

20. Mitchual, S. J., Frimpong-Mensah, K., & Darkwa, N. A. (2013). Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. *International Journal of Energy and Environmental Engineering*, *4*(1), 1-6.
21. Križan, P., Matúš, M., ŠOOŠ, Ľ., Kers, J., Peetsalu, P., Kask, Ü., & Menind, A. (2011). Briquetting of municipal solid waste by different technologies in order to evaluate its quality and properties. *Agronomy Research. ISSN*, 115-123.
22. Wilaipon, P. (2009). The effects of briquetting pressure on banana-peel briquette and the banana waste in Northern Thailand. *American Journal of Applied Sciences*, *6*(1), 167.
23. Zagreb. (2008). *Industrial Charcoal Production*. (D. J. Domac & D. M. Trossero, Eds.) (Vol. 3101). Croatia.
24. World Health Organisation, 2014. " Household air pollution and health" Retrieved from http://www.who.int/mediacentre/factsheets/fs292/en/ at 3:31pm on 7th December 2015.
25. Emerhi, E. A. (2011). Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. *Advances in Applied Science Research*, *2*(6), 236-246.
26. Oladeji, J. T. (2012). A comparative study of effects of some processing parameters on densification characteristics of briquettes produced from two species of corncob. *The Pacific Journal of Science and Technology*, *13*(1), 182-192.