International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 2 (February 2025), PP 01-11

Impacts of rice starch, cassava starch, and molassesbinders on the combustion yield and durability of eucalyptus charcoal fines briquettes

Ravo Andrianirina [1,2], Michaël Temmerman[2], E. J. R. Sambatra[1, 3], McGordon RANAIVOSON[2]
[1]*Ecole du Génie Industriel, Institut Supérieur de Technologie d'Antsiranana*
[2]*Eco Consulting Group GmbH & Co. KG HersfelderStraße 17 36820 OberaulaAllemagne*
[3]*EDT Energies Renouvelables et Environnement, Université d'Antsiranana*
[1]*Corresponding Author: ravo.andrianrina@gmail.com*

ABSTRACT

In this study, the impact of using different proportions of rice starch, cassava starch, and molasses as binders with eucalyptus charcoal fines briquettes was compared. The proportions considered were 5%, 7.5%, and 10% for rice and cassava starch, whereas for molasses, 5%, 10%, and 15% were used due to its high concentration and moisture content. Cooking tests of 3 liters of water with 15 MJ of usable calorific value (PCI) for each sample were first conducted. Subsequently, durability or impact resistance tests for each sample were carried out. At the conclusion of the testing series, it was observed that overall, the type of binder influences the combustion yield, which was 22.36%, 26.81%, and 27.30% for briquettes made with molasses, rice starch, and cassava starch, respectively. With varying proportions of binder, it was found that as the proportion of binder increases, the combustion yield tends to decrease. The relationship between yields and binder proportions is linear for starches and follows a power equation for molasses. Furthermore, between the two starches, very slight variation in combustion yield was observed, regardless of the binder proportion. Regarding the durability of the briquettes, it was observed that overall, the type of binder has little impact on the durability of the briquettes (74% for rice, 77.5% for cassava, and 76% for molasses). The durability of the briquettes is lower when the proportion of binder is low, following a linear equation regardless of the type of binder used. However, briquettes with molasses are more fragile than briquettes with starch for proportions below 10%. For the two starches, a slight difference in durability was observed as the binder proportion increased.

Keywords: *cooking energy, environment, bio combustible, energy yield, binder, durability*

Date of Submission: 20-01-2025 Date of acceptance: 05-02-2025

I. INTRODUCTION

Biomass is defined as any organic matter derived from forestry and agricultural resources, including livestock effluents, that is available sustainably (OECD/IEA, 2015; FAO, 2004; IEA, 2004). The European Union directive (2001) provides a more energy-oriented definition: biomass is the biodegradable fraction of products, waste, and residues from agriculture (including plant and animal substances), forestry, and related industries, as well as the biodegradable fraction of industrial and municipal waste. It can be used for energy purposes, hence the term "bioenergy." It is part of renewable energy through the conversion of biofuels, which can be in solid form (wood, charcoal, briquettes, pellets, etc.), liquid form (biofuels such as ethanol, biodiesel, etc.), and gaseous form (biogas, etc.).

In developing countries, cooking energy is considered one of the most important components of household energy consumption (AK Pandey et al, 2012). It is primarily sourced from the use of biofuels. Moreover, biomass, an abundant source of natural domestic energy, is one of the alternatives for adapting to climate change caused by greenhouse gas emissions (Bain, RL, 2004). When produced sustainably, it can be considered CO2 neutral. Additionally, biomass, particularly wood, often contains lower levels of pollutants (such as sulfur) compared to mineral coal (Srivastava NSL et al, 2014).

In Madagascar, energy consumption is dominated by the use of biomass, accounting for 79% across all types of consumers. This percentage rises to 96% when considering domestic cooking in households, which is almost exclusively done using wood energy (MEEH,2017). Cooking stoves used by households are still largely traditional, consuming significant amounts of firewood or charcoal (MEEH, 2019). At the national level, the demand for wood energy far exceeds legal and sustainable production. This leads to the illegal overexploitation of natural forest reserves, with impacts exacerbated by the use of traditional carbonization techniques that exhibit low mass yields (12% to 20%). Inefficient consumption of wood energy results in overexploitation of resources and low-yield carbonization, contributing to the degradation of forest ecosystems and significantly increasing greenhouse gas (GHG) emissions in the country (euei, 2015).

Large volumes of biomass, including residues from agricultural production (such as peanut and coconut shells, corn cobs, for example) and urban waste, are generated each year in developing countries. These residues represent a burden for those who produce or collect them. They are often either left in place and slowly degrade, generating nuisances for the surrounding community, or incinerated, usually without heat recovery (Mwampamba TH et al 2013; Ferguson H 2012) . Charcoal fines, a by-product of its production and marketing chain, are generally underutilized and accumulate at handling and marketing sites. Madagascar is no exception, even though no exact official figures have been released to date. However, these residues can be valorized for energy purposes, among other things, for briquette production as an alternative to charcoal.

In the briquetting or agglomeration process, production machines can be classified into three categories based on the applied pressure: low-pressure briquetting ($0 < P < 5$ MPa) requiring the use of a binder; medium-pressure briquetting (5 MPa $< P <$ 100 MPa); and high-pressure briquetting ($P \geq 100$ MPa) that does not require the use of a binder (yousif A. et al 2006; OYEDEMI T. I, 2012). From this classification, briquetting technologies are grouped into two machines: i) briquetting press machines (hydraulic, piston, rollers) and ii) extruder machines, which are based on the principle of a screw without typically requiring a binder (JS Tumuluru, 2010).

When valorized through agglomeration, residues generally lead to the production of briquettes characterized by low density. Several studies have been conducted on this subject, taking into account the energy performance of briquettes, as well as economic aspects related to transportation, storage, and usage (J.S. Tumuluru, 2010; Sokhansanj, S. and Fenton, J. 2006; Mitchell, P. et al 2007). Therefore, there is interest in the densification technique, which allows density to be increased up to 600 to 1200 kg/m³ (Phani A. et al, 2011; Holley CA, 1983; Mani, S, et al 2003; McMullen, J., et al 2005; Obernberger, I. and G. Thek, 2004) . Indeed, densification improves handling, reduces transportation costs, and, importantly, increases the energy content per unit volume of fuel, which also gains in homogeneity and stability [23][24] (Granada, E. et al 2002; Kaliyan, N. et R. Morey, 2006). The briquettes can take various forms (cubic, cylindrical, conical, spherical, and prismatic), and unlike pellets, are primarily intended for household cooking (Grover., PD and SK Mishra, 2006; K. Demirbaş, A. Şahin–Demirbaş, 2009).

Technically, the production of briquettes for domestic use generally requires the use of binders to enhance the cohesion of materials, even though most biomass contains natural elements that can be used as binders (Shaw M, 2008). Furthermore, due to densification, the use of binders reduces energy costs (Rukayya I.M., 2017) and wear on production equipment [29] (JS Tumuluru et al 2011), thereby implicitly lowering production costs.

Binders can be classified according to their function (matrix type and film type) and their characteristics (organic, inorganic, and composite) (W.H. Chen *et al, 2015;*. Chou C., 2009; Kaliyan, N., Morey RV, 2009; Mwampamba, TH et al, 2013; Njenga, M et al 2014; Rezania, S. et al 2016; Roy MM,, 2012), In terms of comparison, briquettes produced with an inorganic binder (such as clay) exhibit excellent thermal capacity but have low fixed carbon content and also lower combustion yield, while ash content is high. Briquettes with organic binders show better cold resistance, high volatility, mechanical strength, and thermal stability that can vary at high temperatures. Composite binders consist of multiple binders that combine all the advantages of the different types (G. Zhang et al, 2018).

In addition to technical criteria, the choice of a binder in practice also responds to other considerations: availability, cost, and competition with agricultural materials intended for food. According to G. Zhang et al. (2018), the main properties of a binder can be summarized as follows: solid bonding, emitted pollution, impact on combustion, usability, and environmental considerations, and it should remain economically accessible.

Currently, many studies have been conducted regarding the impact of binders on the quality of briquettes. For example, a study by Abdu Z. et al. (2014) on carbonized corn cob briquettes using cassava starch as a binder found that as the proportion of binder increases (6%, 10%, 14%, and 19%), the ash content decreases (21.38%, 20.70%, 14.24%, and 11.49%) while the fixed carbon content increases (72.78%, 73.96%, 78.79%, and 81.88%). Another study conducted by Tembe et al. (2014) also showed the impacts of different proportions of cassava binder (15%, 25%, and 35%) on briquettes produced from a combination of three materials: peanut shells, rice husks, and sawdust from *Daniella oliveri*. They concluded that briquettes with higher concentrations of binders are more resistant and that briquettes with 35% binder exhibit better combustion quality.

In the context of this study, the objective is to determine the impacts of three locally available binders—rice starch, cassava starch, and molasses—on eucalyptus charcoal fines briquettes produced using a manual piston press (low pressure). The studied impacts will primarily focus on the combustion yield and mechanical or shock resistance of the briquettes.

II. MATERIALS AND METHODS

2.1. Raw material

For this study, the charcoal fines (CF) used are a by-product of the pyrolysis of eucalyptus wood in a GMDR carbonization oven. The CF represents 9.3% of the total production (Temmerman M.et al 2019) from carbonization oven.

2.2. Different types of binders

Three organic binders are considered in this study:

- Rice flour, available on the local market
- Cassava flour, available on the local market
- Cane molasses, produced by the Ambilobe sugar factory

2.3. Briquette preparation

The briquette production process is described in the following figure.

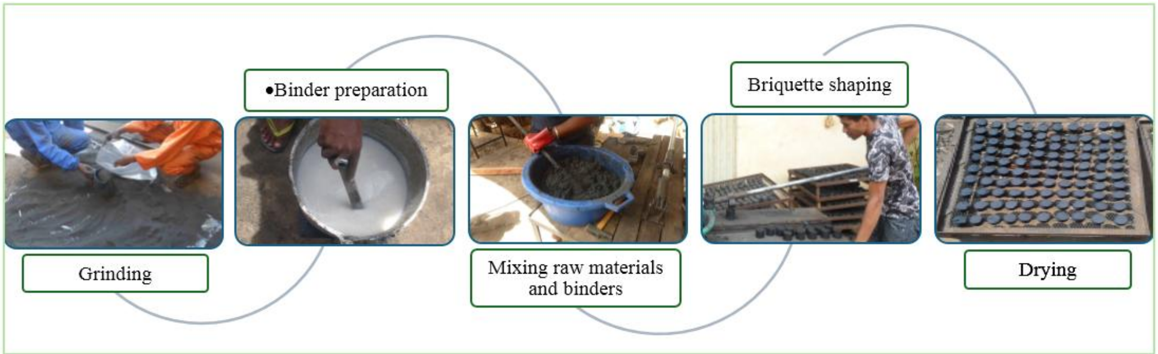


Figure1: Briquette production stage

The grinding of charcoal fines, rice, and cassava to obtain powders was performed using an electric hammer mill (2.2 kW) equipped with a screen with a mesh diameter of 4 mm. As for the shaping of the briquettes, it was done with a manual piston and lever press. At the end of the process, the briquettes were placed outdoors on a metal drying rack until they reached a constant weight.

2.4. Boiling water testing equipment

For determining the thermal yield using the briquette samples, the deployed equipment includes:

- A clay stove of semi-conical shape, weighing 9.5 kg, with a height of 18 cm and a combustion chamber volume of 2,000 cm³. This is the most sold stove model on the market and is produced by a local artisan.
- A thermocouple for measuring temperature changes.
- An electronic precision scale of the Sartorius type with a maximum weight of 20 kg ± 0.5 g.
- A local pot of size No. 24 with a flat bottom, weighing 750 g, with a diameter of 22 cm and a height of 9 cm.

2.5. Composition and masses of briquette sample

The mass proportions of binders studied are 5%, 7.5%, and 10% for the starches (rice and cassava), while for molasses, given its high concentration and significant moisture content (25%), the proportions used are 5%, 10%, and 15%.

The quantity or energy content is set at 15 [MJ] per test to estimate the necessary mass of each sample. In this study, the equipment necessary for measuring the Lower Heating Value (LHV) was not available, which led to the proposal of an alternative method for estimating the useful HHV per sample according to the following general relationship:

$$LHV_{us-sam} = \%_{Material} \,.\, LHV_{us-material} + \%_{binder} \,.\, LHV_{us-binder} \qquad (1)$$

The ash content in the charcoal fines differs from that of the charcoal from which they originate due to the increased ash content resulting from the presence of bark during carbonization, as well as during collection, transport, storage, and preparation of the charcoal fines (mixing with sand, soil, and/or dust, etc.). Thus, in this study, the useful LHV (or the amount of heat that is actually usable) of the material and binders takes into account not only the moisture but also the ash content according to the following formula, derived from literature (Schenkel Y., Temmerman M, 2005):

$$LHV_{us} = LHV.(1 - W)(1 - T_{ash}) - 2{,}4W \tag{2}$$

where:

- LHV_{us-sam} : Useful LHV of the sample or mixture in [MJ/kg]
- $LHV_{us-material}$: Useful LHV of the material used in [MJ/kg]
- $LHV_{us-binder}$: Useful LHV of the binder used in [MJ/kg]
- $\%_{Material}$: Mass proportion of matter in [%]
- $\%_{binder}$: Mass proportion of binder in [%]
- W : Moisture content of the material or binder in [%]
- T_{ash}: Ash content of the material or binder in [%]

The calculation of the necessary mass of each sample per test is a function of the useful LHV and the amount of energy required to be provided for a test series. Therefore, the calculation is done according to the following formula :Q_t

$$m_{sam\,/test} = \frac{Q_t}{LHV_{us-sam}} \tag{3}$$

Or $Q_t$is set at 15[MJ] for each test series.

Below is the table for calculating the useful LHV of each material and the binders for the composition of the briquette samples.

Table 1: Calculated Useful LHVof raw materials and binders used for briquette composition

	CF	*Rice*	*Cassava*	*Molasses*
LHV [MJ/kg]	**30.5** (S. Gaur et TB Reed, 1995)	**17.5** (BM Jenkins et al, 1996)	**14.3** (Glauber C. et al 2020)	**10** (Feedinamic)
Ash [%]	**10.5** (S. Gaur et TB Reed, 1995)	**18**.6 (BM Jenkins et al, 1996)	**1.5** (NNX Dung et al 2002)	**15** (Soder KJ et al 2011)
Moisture [%]	**10**	**5**	**5**	**24.5** (K. Singh et al, 2003)
Useful LHV[MJ/kg]	**24.3**	**13.8**	**13.3**	**5.9**

For carbonized materials, the moisture content is set at 10%, considered as equilibrium moisture or air-dried. Regarding the moisture content of the starch-containing materials used as binders, several authors (Jiang L et al, 2014; Egun I. et al,3013; Xiong HG, 2008) confirm a value range between 4% to 11%. Therefore, the value of 5% is considered for our materials in this study. To provide 15 [MJ] of energy for each test, the tables below show the results obtained in relation to the useful LHVand the necessary mass per repetition for each sample.

Table 2: Estimated useful LHV and corresponding mass of charcoal fines briquettes based on the Type of mixture (proportion and binders used) to deliver 15 MJ

Composition	*% CF*	*% Rice*	*% Cassava*	*% Molasse*	*Estimated useful LHV*	*Mass (kg)*
CF-R-5	95	5			23.8	0.630
CF-R-7.5	92.5	7.5			23.5	0.637
CF-R-10	90	10			23.3	0.644
CF-C-5	95		5		23.8	0.631
FC-C-7.5	92.5		7.5		23.5	0.638
FC-C-10	90		10		23.2	0.646
FC-M-5	95			5	23.4	0.641
FC-Ml-10	90			10	22.5	0.667
FC-M-15	85			15	21.6	0.696

For each composition or sample and for each combustion test series, the quantity described in **Table 2**was produced.

2.6. Conducting Experiments

2.6.1. Determination of Combustion yiedl

The test involves using the same amount of energy for each repetition to raise the temperature of 3 litters of water contained in the pot described in §2.4, through the combustion of the samples prepared for this purpose (Table 2). This means that the mass of each sample is used in the stoves described in §2.4 to raise the temperature of the water in the pot until all the briquettes are completely consumed.

The test is conducted with an uncovered pot, and the energy efficiency is determined by the ratio of the amount of energy required to evaporate the amount of water in the pot to the amount of energy provided by the fuel used. Thus, formulas (1) and (3) are used to determine this efficiency, namely:

The test is carried out with a pot without a lid whose energy efficiency is determined by the ratio of the amount of energy required for the evaporation of the quantity of water in the pot to the amount of energy provided by the fuel used. Thus, formulas (1) and (3) are used to determine this efficiency, i.e.:

$$\eta = \frac{E_u}{E_p} = \frac{m_{wi}\, C_{pw}\, (T_e - T_i) + m_{i,evap}\, H_l}{m_{ech/test}\, PCI_{util\,-ech}} \tag{4}$$

Where:

- E_u [J]: useful energy
- E_p [J]: energy produced by the fuel
- m_{wi} [kg]: initial mass of water
- C_{pw} [kJkg-1°C]: specific heat of water
- $m_{i,evap}$ [kg]: mass of water evaporated during the test
- H_l [kJ kg-1]: latent heat of vaporization of water
- T_e [°C]: boiling temperature
- T_i [°C]: initial water temperature
- $m_{ech/test}$ [kg]: actual mass of fuel used for the test

For this experiment, 10 repetitions for each sample were performed. The average of all the yields obtained from the 10 repetitions is considered the final yield for each sample. This value is subsequently used to analyse the influences of different types and proportions of binders used.

2.6.2. Determination of the mechanical strength of briquettes

The mechanical strength of the briquettes in this study aims to evaluate the binder's ability, according to the defined proportion, to maintain the integrity or keep a large proportion of the briquette mass intact against shocks. The principle involves subjecting a known mass briquette sample to a series of controlled shocks. A simplified device has been designed to carry out the test.

In practice, the sample, contained in a well-sealed plastic bag, is initially weighed to determine its initial mass. It is then placed in the upper compartment of the device to initiate the drop. After 3 consecutive drops, the plastic is opened, and the sample inside is placed in a sieve. All pieces that do not pass through a sieve with diamond-shaped openings of 10 mm on each side are collected for weighing to obtain the final mass after the shocks. It is indeed considered that, in practice, pieces of this size would remain usable for combustion in an improved stove.

Figiure2: Principle of the Briquette Shock Resistance Test

The durability or shock resistance is thus determined by the ratio of the final mass of the sample to the initial mass, that is:

$$DU = \frac{M_2}{M_1} \tag{5}$$

Where:

- DU: Durability or shock resistance in [%];
- $M1$: Initial mass of the sample [g];
- $M2$: Final mass of usable pieces of the sample after the drops [g]

For each briquette composition, 10 samples were tested, constituting 10 repetitions of the test.

III. RESULTS

3.1. Impacts of binders on the combustion efficiency of briquette

3.1.1. Influence of the Nature of the Binder

The results obtained are presented in the following graph.

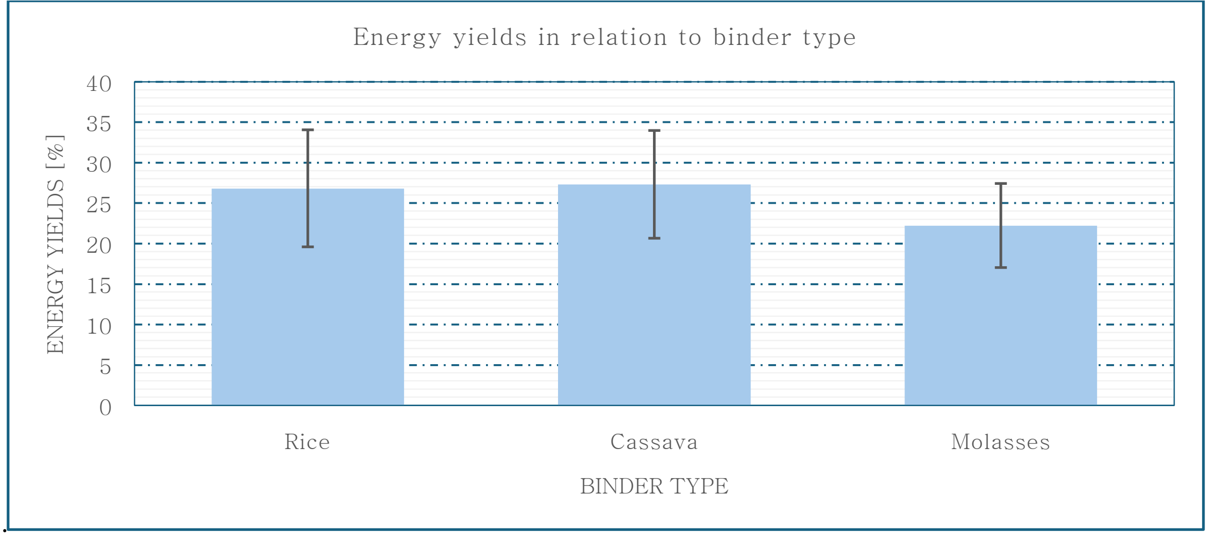


Figure3: Influence of the nature of the binder on the combustion yields of the briquettes

In*Figure3*, the histograms represent the average yields obtained from the 10 repetitions for each briquette based on the type of binder. In contrast, the error bars represent the standard deviations associated with the yields of each briquette.

From ***Figure3***, the following points are noted:

- The yields values are 22.36%, 26.81%, and 27.30% for briquettes with molasses, rice starch, and cassava starch, respectively.
- The briquettes with rice starch and cassava starch show similar energy yields of around 27%.
- The briquettes containing molasses have lower combustion yields than those produced with rice and cassava flours.

3.1.2. Effect of binder proportion on combustion yields

Considering only the 2 types of binders, namely starch and molasses, by grouping rice and cassava into the starch category, the following graph presents the results obtained.

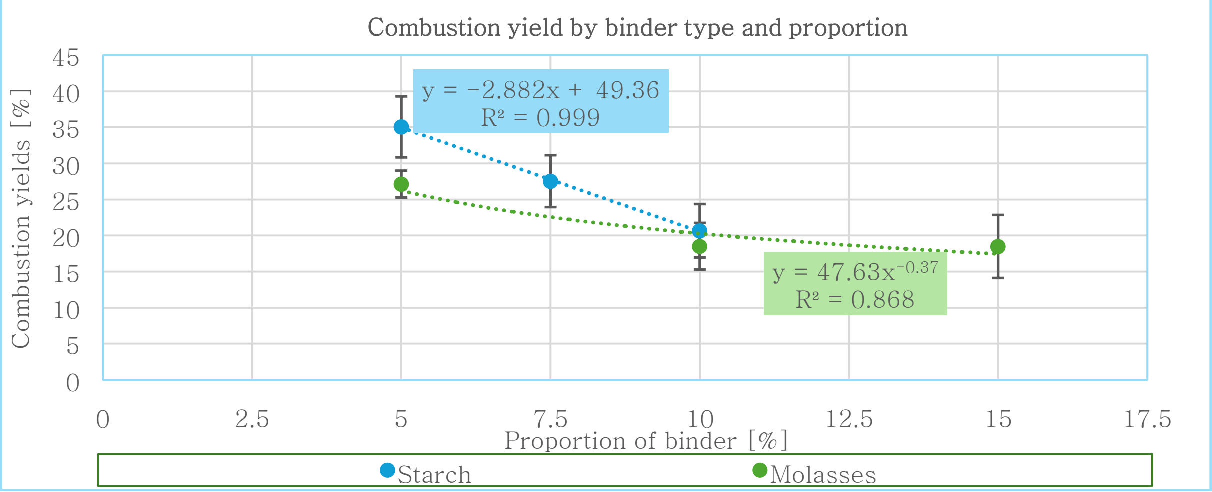


Figure4: Influence of binder proportion on the combustion yields of briquettes

From *Figure4*, it appears that:

- In general, regardless of the type of binder used, briquettes with a low binder content exhibit higher combustion yield compared to those with a higher binder content.
- For the same binder proportion, briquettes with starch have higher combustion yields than those with molasses. Indeed, with a 5% binder content, the briquettes with starch achieve a combustion yield of

35% compared to 27% for briquettes with molasses. With 10% binder, the briquettes with starch have a combustion yields of 20.6% compared to 18.5% for briquettes with molasses.

- The molasses briquettes with 10% and 15% binder have almost the same combustion yields of 18.5%.

The following graph allows us to verify the similar behaviour of the briquettes produced with starch-type binders (rice & cassava).

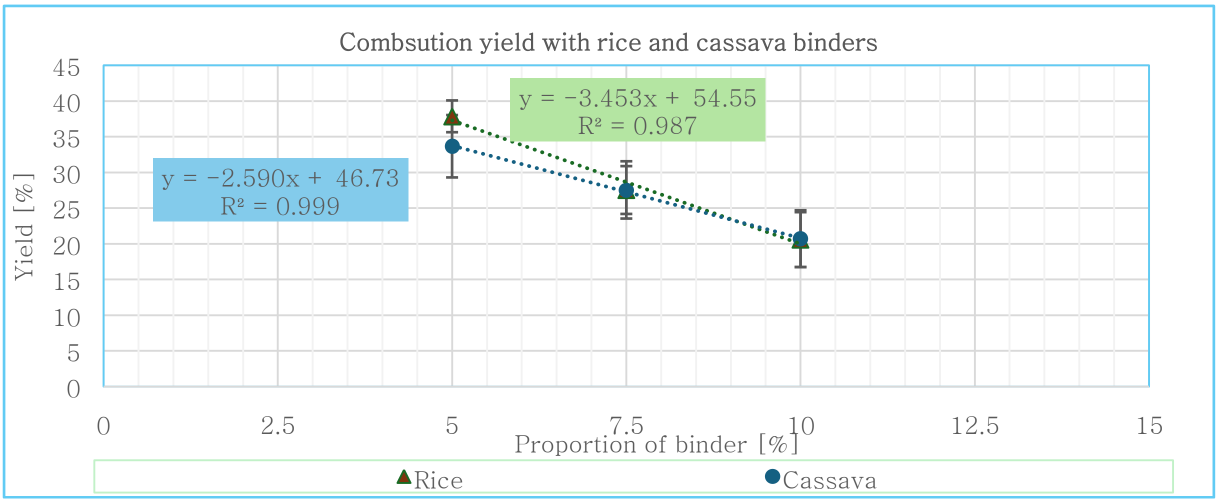


Figure5: Behaviour of briquettes during cooking based on the type and proportion of binder

It can be observed in *Figure5*that a slight difference in combustion yields is particularly noted between the 2 types of starch at a 5% binder content. Indeed, the briquettes with rice starch have a slightly higher yield compared to those with cassava starch, with yields of 39% and 34%, respectively. However, no significant difference in combustion yield is observed for the other binder proportions.

3.2. Impacts of binder on the shock resistance of briquette

3.2.1. Based on the type of binder used

The following graph presents the results obtained from the shock resistance tests of briquettes based on the type of binder used.

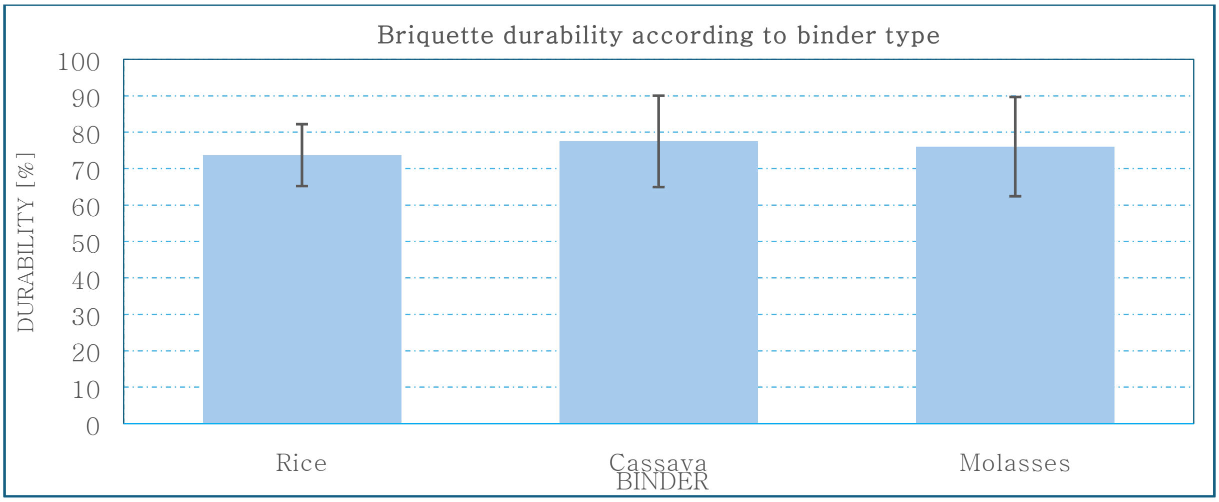
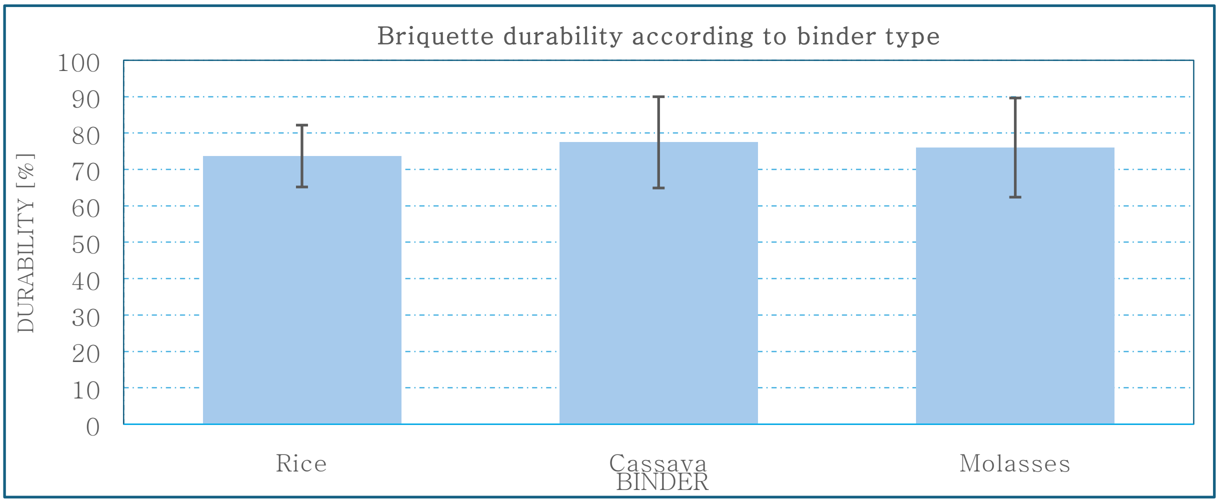


Figure6: Impact of the nature of the binders used on the durability of briquettes



In this Figure6, the histograms represent the average durabilities obtained for each briquette based on the type of binder, while the error bars represent the average standard deviations. It appears that briquettes made with cassava starch exhibit an impact resistance of 77.5%. In second place are the briquettes made with molasses, with a very slight difference in durability compared to cassava starch, showing a value of 76%. The briquettes made with rice starch rank third, with a durability value of 74%. These figures, however, show very slight differences between the durability of the three briquettes.

3.2.2. Based on the proportion of binder

Considering only the two types of binder, namely starch and molasses; by grouping rice and cassava in the starch category, the following graph presents the results obtained.

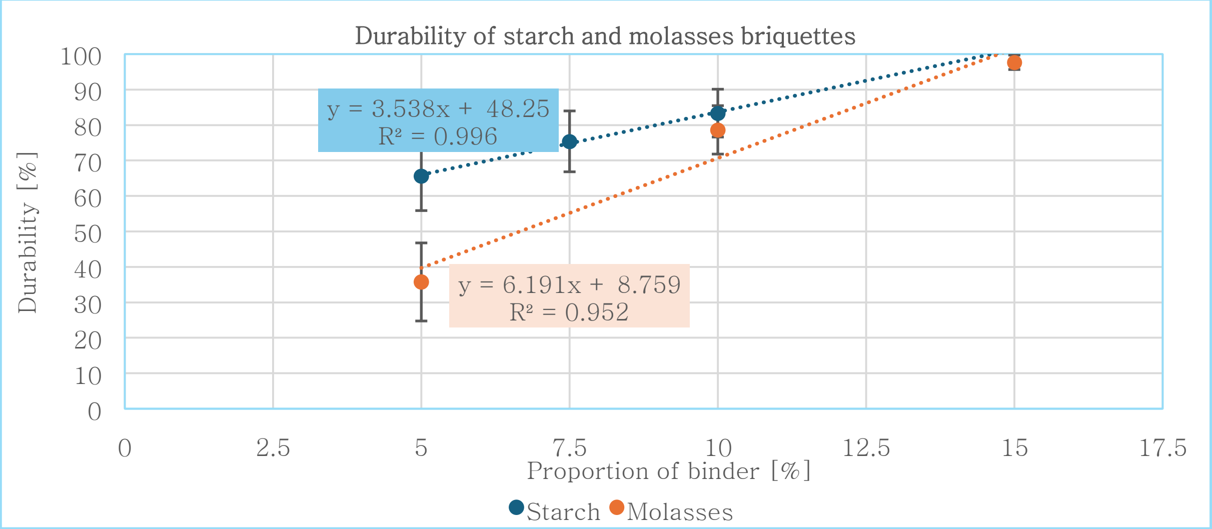
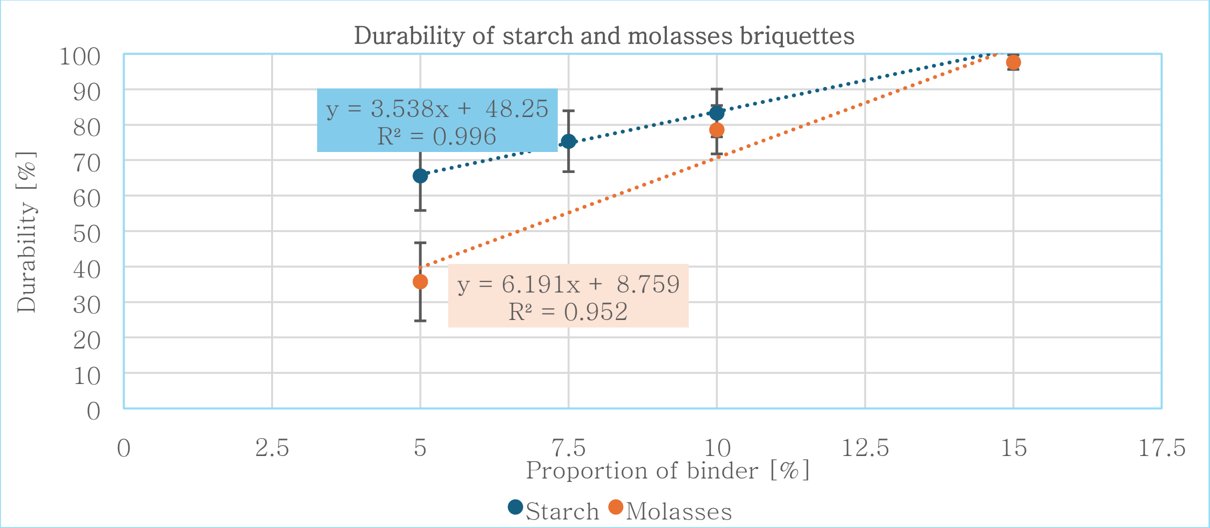


***Figure7*: Impact of the proportion of binder on the durability of briquettes**

From this



, it is observed that:

- Durability is lower when the proportion of binder is low, regardless of the type of binder used. This relationship between the proportion of binder and the durability of the briquettes follows a linear function.
- The evolution of the durability of the briquettes in relation to the proportion of binder is more stable or less sensitive with starch compared to molasses.
- For the same proportions, namely 5% and 10%, the briquettes containing molasses are more fragile than those made with starch. Moreover, the regressions are greater with molasses compared to starch. However, as the proportion approaches 15%, the briquettes with molasses become increasingly compact.

To verify the difference in impact resistance of the briquettes produced with the same type of binder, the following graph shows the results of the comparison between the two starches used in this study

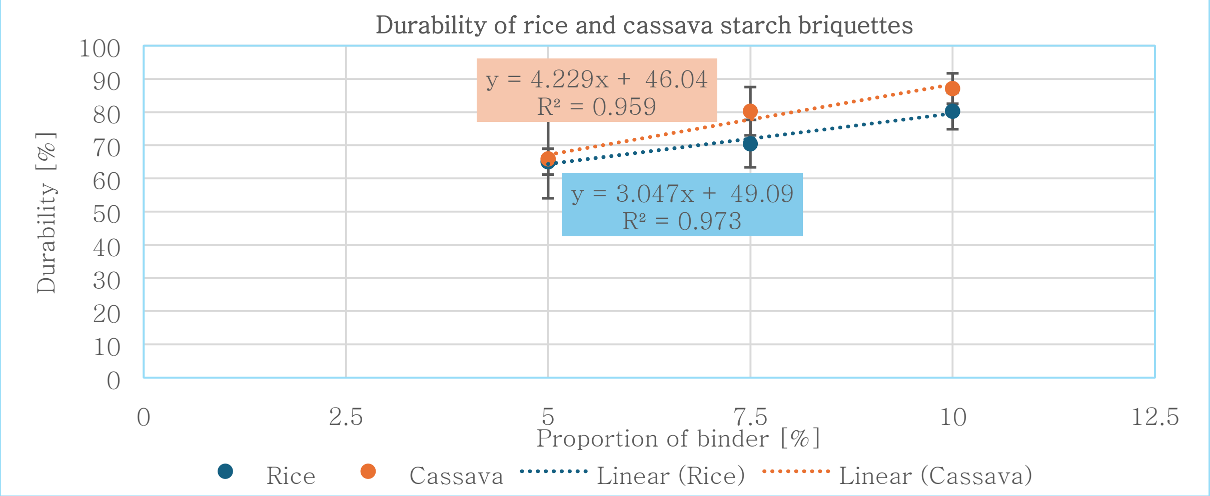


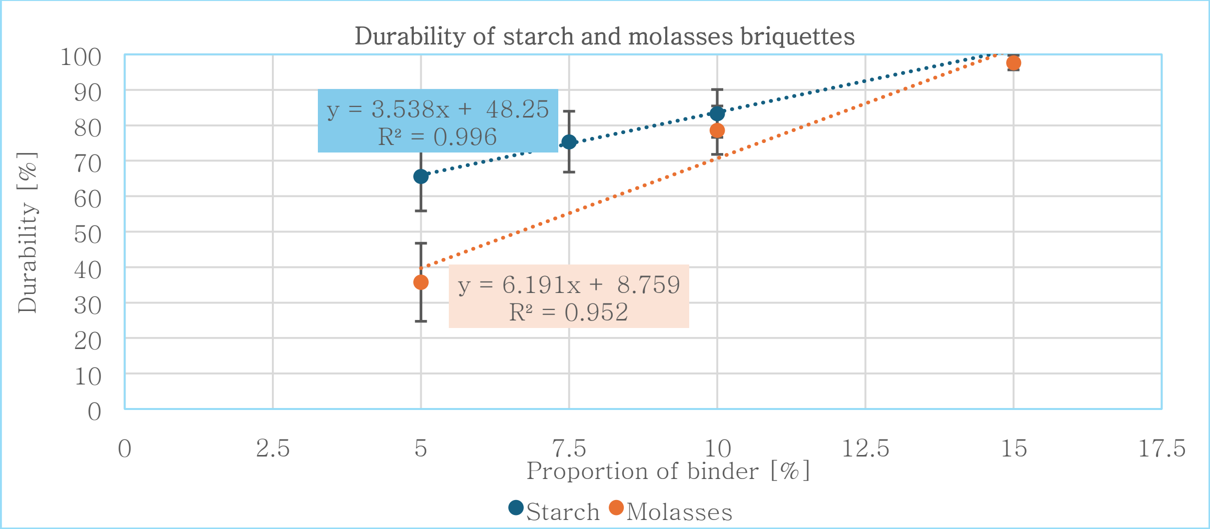
Figure8: Comparison of the impact of the proportion of rice and cassava starch on the durability of briquettes

In thisFigure8, a slight difference can be observed between the durability of briquettes made with rice starch and those made with cassava starch as the proportion of binder increases. That is, briquettes with cassava starch are slightly more compact than those with rice starch as the proportion of binder increases, following a linear function.

IV. DISCUSSIONS

The results presented below allow us to observe the impact of the binder used on the combustion yield of the briquettes. Indeed, the increase in the proportion of binder negatively influences the combustion yield of the briquettes. In this study, mathematical modelling derived from the results allows us to predict the combustion yield of briquettes based on the binder content used, whether it be molasses or starch. For starches, this decrease in combustion yield occurs linearly with the increase in the proportion of binder. In contrast, for molasses, this decrease follows a power equation with the increasing binder content (Figure4). Furthermore, the results demonstrate that binders of different natures, such as starch and molasses in this study, affect the combustion yield of briquettes differently, even when present in the same proportion. This can be explained by the differences in compositions of the binders, particularly the ash content, which negatively influences the combustion behaviour (smothering) of the briquettes. However, binders of the same nature originating from different sources, such as rice and cassava starch in this study, show no significant or negligible difference in combustion yield, regardless of the proportion considered (Figure5).

Regarding the durability of the briquettes, the results of this study demonstrate that an increase in the proportion of binder positively impacts the durability of the briquettes, regardless of the type of binder used. Indeed, the linear functions derived from the results allow predicting the durability of the briquettes based on the binder proportion used for either molasses or starch. Nevertheless, the variation in the durability of the briquettes in relation to the binder proportion is more sensitive with molasses than with starch ().



In several studies involving starch binders, cassava has been the most studied, and the results regarding its impacts on the quality of briquettes are confirmed by this current study. For instance, the study by M. Sawadogo et al. (2018) concluded that briquette B.35 with 10% cassava starch, among the options studied (5 – 10 – 15 – 20 – 25%), represented the best compromise between physicochemical characteristics and mechanical properties. Furthermore, Tembe et al. (2014) demonstrated that as the binder content increases, the briquettes become increasingly resistant to handling and gain stability according to Olorunnisola (2004). Similarly, Oyelaran, O.A. et al. (2014) concluded that for the proportions studied (5 – 10 – 15 – 20%) of cassava starch, proportions of 10-20% yield good briquettes in terms of durability.

Regarding molasses, the study by Singh, A. et al. (1982) confirms that the durability of the briquettes increases with the rising binder content used. The results obtained in these studies would have been more precise if measurements on the characteristics of the materials used were feasible in the field. Thus, values from various publications were utilized.

When making the final choice for the binder, particularly an organic type, it is important to consider food competition and the price related to the dry matter mass to set the price for the briquettes.

Given these previous technical results and the cost in relation to the dry matter mass, the choice of binder type is leaning more towards cassava starch. Indeed, on the local market, 1 kg of dry rice (3900 Ar/kg) is more expensive compared to cassava starch (2800 Ar/kg). As for molasses, it is produced in a sugar factory (SIRAMA Ambilobe) and is not for sale due to its utility in the factory. The choice of cassava is also justified due to food competition, considering that rice is a staple food for Malagasy.

V. CONCLUSION

Regarding combustion yield, it is concluded that:

- Overall, the type or nature of the binder used influences the combustion behaviour or yield. However, for binders of the same type but derived from different materials, the combustion efficiencies of the briquettes are minimally affected.

- The more the binder proportion increases, the lower the combustion efficiency tends to be. For starches, this decrease in combustion efficiency occurs linearly with the increase in binder proportion. In contrast, for molasses, this decrease follows a power equation with the increasing binder content.
- Binders of the same nature, derived from different materials (rice and cassava), show very little variation, if any, in combustion yield.

Regarding impact resistance, it is concluded that:

- Generally, the type or nature of the binder has very little impact on the durability of the briquettes (74% for rice, 77.5% for cassava, and 76% for molasses).
- The increase in the proportion of binder positively impacts the durability of the briquettes, regardless of the type of binder used. However, the variation in the durability of the briquettes based on the binder proportion is more sensitive with molasses than with starch.
- Binders of the same nature, derived from different materials (rice and cassava), exhibit a slight difference in durability, especially as the binder proportion increases.

REFERENCES

[1]. Abdu Zubairu, Sadiq Abba Gana (2014), Production and Characterization of Briquette Charcoal by Carbonization of Agro-Waste-Energy and Power , 4(2): 41-47 DOI: 10.5923/j.ep.20140402.03

[2]. AK Pandey, VV Tyagi, SR Park, SK Tyagi, (2012) ,Comparative experimental study of solar cookers using exergy Analysis, J. Therm. Anal. Calorim. 109 425e431.

[3]. Bain, RL, (2004), An introduction to biomass thermochemical conversion, National Renewable Energy Laboratory, Battelle, p. 17.

[4]. BM Jenkins, RR Bakker and JB Wei (1996), On the properties of washed straw. Biomass and Bioenergy 10 (4) pp. 177-200

[5]. Chen, WH, Peng, J., Bi, XT, (2015). A state-of-the-art review of biomass torrefaction, densification and applications. Renew. Sustain. Energy Rev. 44, 847e866.https://doi.org/10.1016/j.rser.2014.12.039.

[6]. Chou, C.-S., Lin, S.-H., Lu, W.-C., (2009). Preparation and characterization of solid biomass fuel made from rice straw and rice bran. Fuel Process. Technol. 90, 980e987. In:https://doi.org/10.1016/j.fuproc.2009.04.012

[7]. DIRECTIVE 2001/77/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 - Official Journal of the European Communities - L 283/33

[8]. Egun I., Abah AM ,(2013) Comparative performance of Cassava Starch to PAC as Fluid Loss Control Agent in Water Based Drilling Mud, Discovery 3 36-39

[9]. euei, Ministry of Energy and Hydrocarbons (2015) /. Assistance for the Development of a New Energy Policy in Madagascar – Phases 2 and 3.

[10]. FAO (2004) Unified bioenergy terminology. http://www.fao.org/docrep/009/j6439f/j6439f00.htm (8 April 2015).

[11]. Feedinamic - Cane molasses - Syrupy co-product of the crystallization of sugar extracted from sugar cane (Saccharum officinarum L.), https://feedtables.com/fr/content/melasse-de-canne

[12]. Ferguson H (2012) Briquette Businesses in Uganda. The potential for briquette enterprises to address the sustainability of the Ugandan biomass fuel market. GVEP International.

[13]. Glauber Cruz, Alyson da Luz Pereira Rodrigues, Darlan Ferreira da Silva1 (2020)·Wolia Costa Gomes1 Physical–chemical characterization and thermal behavior of cassava harvest waste for application in thermochemical processes

[14]. Granada, E., LM López González, JL Míguez, and J. Moran. (2002). Fuel Lignocellulosic Briquettes, Die Design, and Products Study. Renewable Energy 27: 561–573;

[15]. Grover., PD and SK Mishra..(1996) Biomass Briquetting: Technology and Practices. Regional Wood Energy Development Program in Asia. GCP/RAS/154/NET, Food and Agricultural Organization of the United Nations, Bangkok

[16]. Guojie Zhang, Yinghui Suna, Ying Xua., (2018) Review of briquette binders and briquetting mechanism;

[17]. Holley, CA (1983)The densification of biomass by roll briquetting. Proceedings of the Institute for Briquetting and Agglomeration (IBA) 18: 95-102.;

[18]. IEA (2014) Africa Energy Outlook. A focus on energy prospects in sub-Saharan Africa. (World Energy Outlook Special Report). https://www.iea.org/publications/freepublications/publication/africa-energy-outlook.html.

[19]. Jiang L., Liang J., Yuan X., Li H., Li C., Xiao Z., Huang H., Wang H., Zeng G., (2014) Copelletization of sewage sludge and biomass: The density and hardness of pellet, Bioresource Technology 166 435-443.

[20]. JS Tumuluru, Christopher T. Wright, Kevin L. Kenney and J. Richard Hess, (2010) A Technical Review on Biomass Processing: Densification, Preprocessing, Modelling, and Optimization, ASABE Annual International Meeting

[21]. JS Tumuluru, CT Wright, JR Hess, KL Kenney, (2011), A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application, Idaho National Laboratory, Idaho Falls, ID, USA, j. Biofuels, Bioproducts & Biorefining, 5 683–707.

[22]. K. Demirbaş, A. Şahin–Demirbaş, (2009) Compacting of biomass for energy densification. Energ. Source. Part A. 31(12) 1063–1068. doi:10.1080/15567030801909763

[23]. K. Singh, H. Honig, M. Wermke and E. Zimmer: (2003) Fermentation pattern and changes in cell wall constituents of straw-forage silages, straws and partners during storage. Animal Feed Science and Technology 61(1-4) (1996) 137-153.

[24]. Kaliyan, N. and R. Morey. (2006). Densification Characteristics of Corn Stover and Switchgrass. Presented at the ASABE Annual International Meeting, July 9–12, 2006, Portland, OR, ASABE Paper No. 066174, St. Joseph, MI: ASABE..

[25]. Kaliyan, N., Morey, RV,.(2009) Factors affecting strength and durability of densified biomass products. Biomass Bioenergy 33, 337e359.https://doi.org/10.1016/j. biombioe.2008.08.005

[26]. M. Sawadogo, S. Tchini Tanoh, S. Sidibé, N. Kpai, I. Tankoano, (2018) Cleaner production in Burkina Faso: Case study of fuel briquettes made from cashew industry waste, Journal of Cleaner Production 195 1047e1056,https://doi.org/10.1016/j.jclepro.2018.05.261.

[27]. Mani, S., LG Tabil and S. Sokhansanj. (2003) An overview of compaction of biomass grinds. Powder Handling and Process 15(3): 160-168.;

[28]. McMullen, J., OO Fasina, CW Wood and Y. Feng. (2005). Storage and handling characteristics of pellets from poultry litter. Applied Engineering in Agriculture 21(4): 645-651;

[29]. MEEH, Madagascar Energy Efficiency Master Plan (2019-2040), june 2019

[30]. MEEH, National Energy Report 2017

[31]. Michaël Temmerman, Ravo Andrianirina, Frank Richter; (2019)Technical and environmental performance of the Green Mad Retort carbonization furnace in Madagascar

[32]. Mitchell, P., J. Kiel, B. Livingston, and G. Dupont-Roc. (2007). Torrefied Biomass: A Foresighting Study into the Business Case for Pellets from Torrefied Biomass as a New Solid Fuel. All Energy..

[33]. Mwampamba, TH, Owen, M., Pigaht, M. (2013), Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa. Energy Sustain. Dev. 17, 158e170.https://doi.org/10.1016/j.esd.2012.10.006

[34]. Njenga, M., Karanja, N., Karlsson, H., Jamnadass, R., Iiyama, M., Kithinji, J., Sundberg, C., (2014) Additional cooking fuel supply and reduced global warming potential from recycling charcoal dust into charcoal briquette in Kenya. J. Clean. Prod. 81, 81e88.https://doi.org/10.1016/j.jclepro.2014.06.002.

[35]. NNX Dung, LH Manh and P. Uden: (2002) Tropical fiber sources for pigs--digestibility, digesta retention and estimation of fiber digestibility in vitro. Animal Feed Science and Technology 102(1-4) 109-124.

[36]. Obernberger, I. and G. Thek. (2004). Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. Biomass and Bioenergy, 27: 653-669.

[37]. OECD/IEA (2015) Aboutbioenergy http://www.iea.org/topics/renewables/subtopics/bioenergy/.

[38]. Olorunnisola, AO (2004) Briquetting of rattan furniture waste. Journal of Bamboo and Rattan, Vol. 3, No. 2, pp. 139-149.

[39]. OYEDEMI, TAIWO ISAAC (2012)– these- characterization of fuel briquettes from gmelina arborea (roxb) sawdust and maize cob particles using cissus populnea gum as binder

[40]. Oyelaran, OA, BO, Bolaji, MA Waheed and MF Adekunle, (2014) Effects of Binding Ratios on Some Densification Characteristics of Groundnut Shell Briquettes. Iranica Journal of Energy and Environment, 5(2):167-172. DOI:10.5829/idosi.ijee.2014.05.02.08.

[41]. Phani Adapa, Lope Tabil, Greg Schoenau, (2011) A Comprehensive Analysis of the Factors Affecting Densification of Barley, Canola, Oat and Wheat Straw Grinds

[42]. Rezania, S., Md Din, MF, Kamaruddin, SF, Taib, SM, Singh, L., Yong, EL, Dahalan, FA. (2016) Evaluation of water hyacinth (Eichhornia crassipes) as a potential raw material source for briquette production. Energy 111, 768e773.https://doi.org/10.1016/j.energy.2016.06.026.

[43]. Roy, MM, Corscadden, KW, (2012). An experimental study of combustion and emissions of biomass briquettes in a domestic wood stove. Appl. Energy 99, 206e212.https://doi.org/10.1016/j.apenergy.2012.05.003.

[44]. Rukayya Ibrahim Muazu (2017)-Waste Biomass Densification for Thermochemical Conversion – Thesis of doctor

[45]. S. Gaur and TB Reed; (1995) An Atlas of Thermal Data For Biomass and Other Fuels. NREL/TP-433-7965,

[46]. Schenkel Y., Temmerman M., (2005) The physicochemical characteristics of lignocellulosic materials, Biomass Energy Guide second edition, Schenkel Y., Benabdallah B., IEPF publications

[47]. Shaw M. (2008) Feedstock and Process Variables Influencing Biomass Densification, A Thesis Submitted to the College of Graduate Studies and Research, Department of Agricultural and Bioresource Engineering University of Saskatchewan Saskatoon, Saskatchewan, 1- 102

[48]. Singh, A. and Singh, Y. (1982) Briquetting of paddy straw. Agricultural Mechanization in Asia, Africa and Latin America, autumn, pp. 42-44.

[49]. Soder KJ, Brito AF and Hoffman K., (2011). Effect of molasses supplementation and nutrient value on ruminal fermentation of a pasture-based diet. The Professional Animal Scientist, 27:35-42

[50]. Sokhansanj, S. and Fenton, J. (2006). Cost benefit of biomass supply and pre-processing enterprises in Canada. Biocap, Canada;

[51]. Srivastava NSL, Narnaware SL, Makwana JP, Singh SN, Vahora S, (2014) Investigating the energy use of vegetable market waste by briquetting. Renew Energy ;68:270e5.

[52]. Tembe et al. J.Appl. Biosci. (2014) Density, shatter index and combustion properties of briquettes produced from groundnut shells, rice husks and saw dust of Danielliaoliveri]

[53]. Tembe, ET, Otache, PO and Ekhuemelo, DO, (2014) Density, Shatter index, and Combustion properties of briquettes produced from groundnut shells, rice husks and saw dust of Danielliaoliveri

[54]. Xiong HG, Tang SW, Tang HL, Zou P, (2008) The structure and properties of a starch-based biodegradable film, Carbohydrate Polymers 71 263–268

[55]. YOUSIF A. ABAKR1, AHMED E. ABASAEED (2006), Experimental evaluation of a conical-screw briquetting machine for the briquetting of carbonized cotton stalks in Sudan; Journal of Engineering Science and Technology Vol. 1, No. 2 212-220