



Processing of Wild Sunflower with Different Moisture Contents into Solid Bio Fuel

**Fabie T. Dummapi¹, Jacqueline I. Liniasan¹, Marvin T. Valentin^{1*},
Milagros B. Onalan¹, Leonardo D. Dumalhin¹, Marlon N. Galad²,
Daniel Ciolkosz³, Algirdas Jasinskas⁴ and Eva J. Kelly¹**

¹Department of Agricultural and Biosystems Engineering, College of Engineering and Applied Technology, Benguet State University, Philippines.

²Department of Agricultural and Biosystems Engineering, College of Engineering, Central Luzon State University, Philippines.

³Department of Agricultural and Biological Engineering, College of Agricultural Sciences, College of Engineering, The Pennsylvania State University, University Park, PA, USA.

⁴Institute of Agricultural Engineering and Safety, Vytautas Magnus University, Lithuania.

Authors' contributions

This work was carried out in collaboration among all authors. Authors FTD and JIL prepared the samples and gathered data. Author MTV designed the study, supervised the data gathering and wrote the first draft of the manuscript. Author MBO helped in the interpretation of data. Author LDD provided guidelines on the methodology. Author MNG helped in the preparation of the study design. Author DC performed the statistical analyses and helped in the preparation of the manuscript. Author AJ provided guidelines on the specific data gathered. Author EJK managed the literature and helped prepared the study design. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2021/v7i230185

Editor(s):

(1) Dr. Davide Astiaso Garcia, Sapienza University of Rome, Italy.

Reviewers:

(1) Lingesan Subramani, Bharath University, India.

(2) Sunita Kumari, Deenbandhu Chhotu Ram University of Science and Technology, India.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/65762>

Original Research Article

Received 08 December 2020

Accepted 12 February 2021

Published 11 March 2021

ABSTRACT

Wild sunflower with moisture contents of 16%, 12% and 8% was densified without the addition of binding agent. The physical properties of the formed briquettes such as mass, dimensions, volume, density and shattering resistance were evaluated. Thermal properties like ignition time, burning time, ash content, and thermal fuel efficiency by means of boiling test were also evaluated.

*Corresponding author: E-mail: m_valentin14@yahoo.com;

Wild Sunflower stems were gathered and shredded using locally fabricated biomass shredder available at the Research Office of Benguet State University, and were processed into the desired size and moisture contents. Right after the briquetting operation, the physical properties of the briquette were measured and then stored in a zip bag for 24 hours. After the storage, same measurement was conducted.

Results show that the influence of moisture contents on the average mass, dimension, shattering resistance, volume and density was statistically insignificant. The wild sunflower with moisture content of 16% had the highest shattering resistance of 88.85%. Furthermore, the influence of moisture content on the thermal properties like ignition time, burning time and ash content are statistically insignificant. Among the moisture contents, the fastest ignition time of 43.75 sec with longest burning time was recorded under 12%. Ash content was also lowest at 12%.

Keywords: Wild sunflower; moisture content; pressure; briquette; and thermal efficiency.

1. INTRODUCTION

The densification of biomass for use as a fuel in domestic cook stoves and other appliances represent an opportunity for local economic development, energy security and sustainability in many regions [1]. Depending on the circumstances of the local region, these systems could utilize a variety of woody or herbaceous feedstock, employ any of a variety of densification technologies, and provide fuel for either existing or newly designed cook stoves. One such opportunity exists to utilize wild sunflower as a feedstock for briquette production in the Philippines.

Wild sunflower (*Tithonia diversifolia*) plants are shrub-like robust perennial herbs. The stems can grow up to 3 meters tall and are somewhat woody. It grows year-round and is widely available around Benguet and nearby towns in Northern Luzon, Philippines [2]. Proximate analysis of the leaves, stems and roots of *T. diversifolia* [3] indicates 41.85% presence of carbohydrates, 32.79% crude fiber, 9.19% moisture, 8.97% total ash, 5.99% crude protein and 1.19% crude fat in all above ground biomass. Among all the proximate contents, crude fiber is highest in stems. Composition does vary seasonally, with crude fiber, crude protein and ash content higher in September than in May [4]. Wild sunflower produces a nutrient-rich N, K, and P biomass [5] and [6] indicates that P is linked to a plant's ability to use and store energy.

Densification of biomass enhances its transportation, storage, and utilization properties. Briquetting, the creation of large (>25mm diameter) compacts by applying linear force in a cylindrical die, is amenable to developing economies in that the equipment needed can be designed at a variety of levels of complexity and cost, taking advantage of locally available

materials and expertise. Key properties in the densification of biomass include feedstock moisture content, feedstock composition, and applied pressure and duration of pressure.

Feedstock moisture content is an essential property-if it is too low or too high, binding of particles within the compact can be negatively affected, as moisture is necessary to soften the cell walls and activate natural binders that are found in the biomass. The optimum moisture content for briquetting is generally in the range of 8 to 10% [7] and [8]. In general, the moisture content of the final product should be equal to or greater than the equilibrium value; otherwise, swelling might occur in the solid biofuels during storage and transportation.

The most important compositional property of biomass feedstock for most briquetting operations is its lignin content. As reported by [9] lignin has a strong influence on the binding characteristics of briquettes and pellets. It is a natural component of biomass, comprising 20-25% of the mass of most woody species, 10-15% of most herbaceous biomass. A critical property of lignin is its softening temperature. Lignin undergoes plastic deformation upon reaching its softening temperature, which can be as low as 75°C if the feedstock moisture content is optimum [10] and [11]. Ground biomass when heated to its transformation temperature will change from glassy into a rubbery state, allowing adjacent particles to fuse together. This occurring scientific phenomenon is an important aspect to consider when densifying biomass into briquettes to achieve optimum durability of the briquettes.

Pressure in briquetting is applied using a linear piston within a cylindrical die. While under pressure, the biomass particles deform, heat, and fuse together, forming the briquette. The necessary pressure and duration of that pressure

can vary depending on the properties of the feedstock and the briquetting machine. Ideally, a feedstock for briquetting would readily form densified briquettes of high durability that combust well in their intended appliance. Robustness, in terms of sensitivity to variations in moisture content, particle size, or other characteristics, is also a valuable characteristic for a densification feedstock.

The goal of this study, therefore, was to examine the impact of feedstock moisture content on the performance characteristics of *Tithonia diversifolia* briquettes in terms of their density, durability, and thermal performance in a domestic cook stove.

2. METHODOLOGY

2.1 Feedstock Preparation

Wild sunflower was obtained from Balili Riverside, La Trinidad, Province of Benguet and was cleaned by trimming off the leaves leaving the stem for the briquette production. The stems were shredded to a maximum size of approximately 10 mm using a locally fabricated biomass shredder. The shredded materials were subjected to sun drying until the target moisture contents (16%, 12%, and 8%) were achieved in accordance to ASAE S358.2 as calculated using Equations 1 and 2.

$$MC = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

$$M_f = 5(100 - MC) \quad (2)$$

Where: MC is the target moisture content in% (wet basis); M_i is the fresh or initial mass of the shredded sunflower in grams; M_f is the final or dried mass of the shredded biomass in grams.

For each treatment, a quantity of 500 grams of freshly shredded sunflower biomass was dried to the desired moisture content. The mass of the samples was regularly monitored during drying and was stopped upon reaching the desired final dried mass.

2.2 Briquetting

A locally fabricated briquetting molder assembly was used to densify the briquette as shown in Fig. 1. The procedure is further described in Fig. 2. The compacting pressure was supplied with the use of a hydraulic press with a pressure

gauge attached. A total of 500 g of biomass feedstock was used for each briquetting test. The biomass was compressed at a rate of 5.45 kPa s⁻¹ until the final pressure of 195 kPa was reached. This pressure was maintained for 60s prior to releasing the hydraulic press and ejecting the briquette. A total of three replicates were carried out of the briquetting operation for each moisture content.

2.3 Evaluation

Briquette dimensions and mass were measured using a Vernier caliper and digital scale. This was carried out immediately after briquetting, and 24 hours later.

The volume of each briquette was calculated using mathematical equation for the shape of the briquette. In this study, the briquette made was a hollow cylindrical shape. Given such shape the volume was estimated using Equation 3, similar to what was used in [12].

$$V = \frac{\pi}{4}(D_o^2 - D_i^2)h \quad (3)$$

Where: V is the volume of the briquette in m³; D_o is the outside diameter of briquette in inches; D_i is the inside diameter in inches; and h is the height in inches.

Briquette density was calculated following the method used by [13] in which each briquette is weighed then diameter and height are measured (Equation 4).

$$\rho = \frac{m}{v} \quad (4)$$

Where: ρ is the density of the briquette in kg per m³; m is the mass of the briquette in kg; and v for the volume in m³.

Briquette durability was calculated using a drop test. The briquettes were first placed in a sealed plastic bag, then dropped from a height of 1.0 meter onto a flat concrete surface. Each briquette was dropped twice – once while held in a vertical position, and once when held diagonally. The solid and broken particles were weighed. The shattering resistance were calculated using Equation 5 similar to what was used by [14]:

$$PML = 100 * (M_{bd} - M_{ad}) / M_{bd} \quad (5)$$

$$SR = 100\% - PML$$

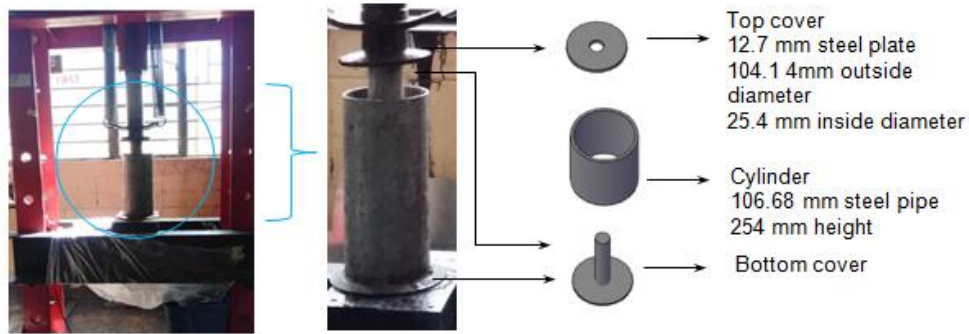


Fig. 1. Briquetting assembly

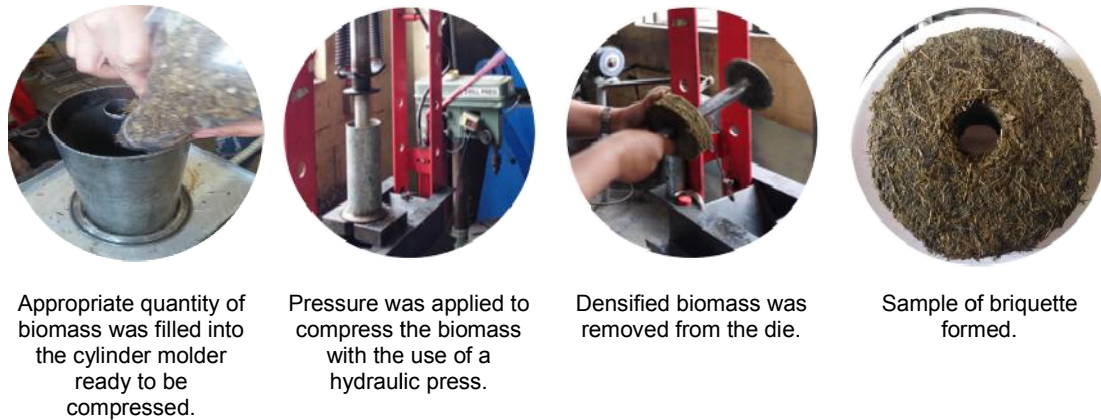


Fig. 2. Densification process

Where: PML is the percentage mass loss; M_{bd} is the mass of briquettes before subjected to shattering test; M_{ad} is the mass after being dropped; and SR is the shattering resistance in percent.

In addition to the physical properties noted above, several thermal properties were also measured. A candle was used as a heat source for the burning of the briquettes. With diagonal orientation the end portion of the briquette was exposed to the fire from the candle until it started to catch fire. The time it took to ignite was recorded. The same source of heat was used for all samples.

Once ignited, the briquette was placed on a metal plate and was allowed to continue to burn. The burning time was recorded by a stopwatch, with the end of the combustion period taken at

the point at which glowing coals were no longer visible. Thus, the burning time is the time for the biomass to either fully or partially combust, as per [15].

The mass of residual material, consisting of mineral ash and uncombusted biomass (if any), was then measured by weighing the ash after cooling the burned briquettes for at least 10 minutes as shown in Fig.3. Ignition time, burning time, and residual mass were measured on briquettes from each moisture content treatment, and the remainder were used to carry out thermal efficiency tests.

2.4 Practical Thermal Efficiency

Thermal efficiency was determined using standard water boiling test. This procedure is similar to what was used by [16] and [15]. 100 ml

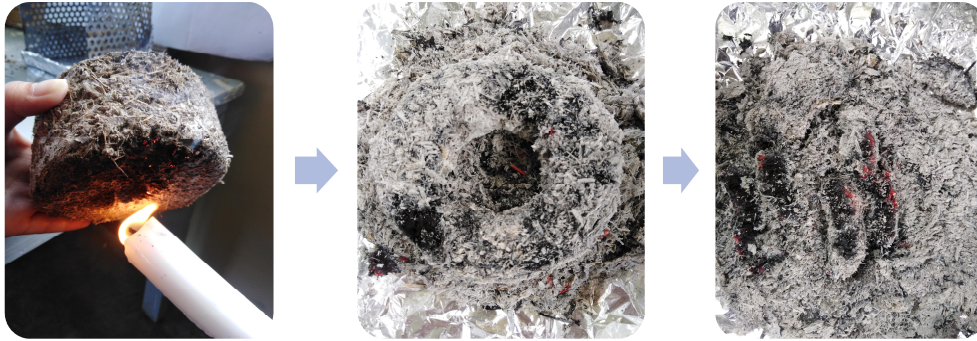


Fig. 3. Burning process

of water at 25°C was placed in a beaker and sealed with aluminum foil to minimize losses by evaporation and was subjected to boiling using a cook stove as shown in Fig. 4.

A briquette was ignited following the procedure noted above for the ignition time test, and was then placed in the stove. The briquette was allowed to burn completely, during which time the water rose to a boil. A thermometer was used to monitor the temperature of the water before and after the test. The following equation was used to calculate thermal efficiency, as per [16]:

$$\eta = \frac{M_w C_p (T_b - T_o) + M_c L}{M_f E_f} \times 100 \quad (6)$$

Where M_w is the mass of water (kg); C_p is Specific heat of water ($\text{kJ}\cdot\text{kg}^{-1}\text{K}^{-1}$); T_b is boiling temperature of water (K); T_o is initial temperature of water (K); M_c is the mass of water evaporated (kg); L is latent heat of evaporation ($\text{kcal}\cdot\text{kg}^{-1}$); M_f is mass of fuel burnt (kg); E_f is the calorific value of fuel ($\text{kJ}\cdot\text{kg}^{-1}$).

2.5 Statistical Tool

Statistical package in excel was used to facilitate the analysis of data.

3. RESULTS AND DISCUSSION

3.1 Dimensions

The average dimensions of the briquettes right after they were densified and after 24 hours of storage are presented in Table 1. Corresponding changes in the dimensions are also computed and presented as shrinkage or swelling percentage. After 24 hours of storage, the

briquettes increased in dimension both in height and the outside diameter. Inside diameter decreased which also indicates that the thickness of the briquettes increased. The smallest change in the dimensions is computed for briquettes with 16% MC. The swelling of the briquettes occurs in all dimensions, but is most pronounced in the longitudinal direction (opposite to the direction in which it was densified). From among the moisture contents, 16% MC briquettes were the most stable in terms giving the smallest change in dimensions corresponding to smallest change in total volume of 34.2%. The changes in volume are statistically different for the three treatments ($p=0.57$). The increase in volume experienced by the samples is likely related to spring back of the individual particles, which has been identified as a potential issue impacting the densification process [12].

The increased volume of the briquettes after densification is not a desirable characteristic of the briquettes, since it would be preferred to be able to immediately store the manufactured briquettes without concern about their swelling while in storage. Further study of this phenomenon, and methods to minimize or control it, would be valuable for increasing overall utility of the densified product.

3.2 Mass

The mass of the briquettes right after densified and after 24 hours storage is presented in Table 2. Percent change in mass is also presented. It was observed that all briquettes have lost certain mass after storage even though they were stored in a zip bag. Highest weight loss of 10.6%. Despite using same mass for each

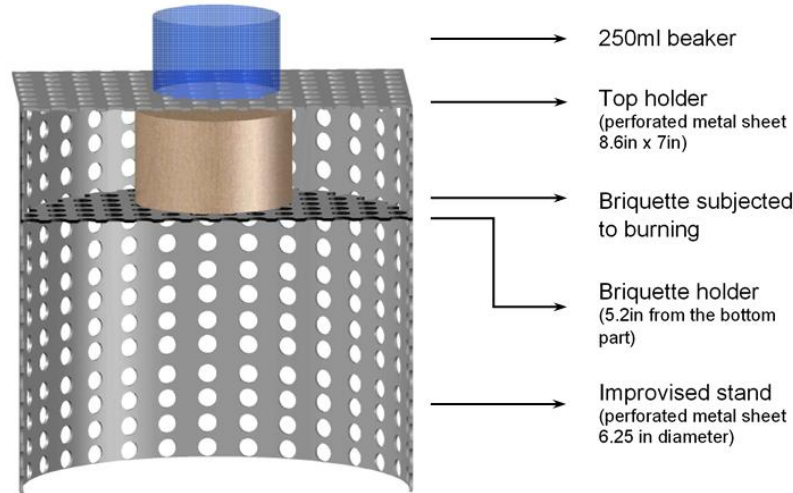


Fig. 4. Setup for boiling test

Table 1. Average dimensions of the briquettes

Treatment (MC, %)	Dimensions (mm)						Shrinkage (sh) Swelling (sw)			Change in Volume (%)
	Right after briquetting			After 24 hours of storage			H	D _o	D _i	
	H	D _o	D _i	H	D _o	D _i				
16	49.1	106.7	25.4	55.9	115.0	24.6	13.8sw	7.8sw	3.2sh	34.2 ^a
12	38.1	106.7	25.4	49.1	115.7	23.2	28.9sw	8.4sw	8.7sh	41.0 ^a
8	48.3	106.7	25.4	55.0	114.7	24.10	14.0sw	7.5sw	5.1sh	37.5 ^a

Table 2. Mass of the briquettes right after the densification process and after storage

Treatment (MC, %)	Right after briquetting	After 24 hours of storage	Mass loss (wl) (%)
	Mean and standard deviation (grams)		
16	215.2	210.5	2.2
12	193.4	192.3	0.6
8	214.1	191.3	10.6

moisture contents, the resulting masses right after the briquetting procedure were not the same. The 8% MC samples exhibited breaking resulting to more mass particles to separate. It the material moisture content is not in the range of the material moisture content interval (8 to 10%), the elements are not consistent ad briquettes fall to pieces [17] Obtaining very high material moisture content leads to the vaporization of the surplus water leading to low self-bonding.

3.3 Density

The overall mean density of briquettes immediately after briquetting was 518.7 kg/m³, and there was no discernable difference in

density between the three treatments as presented in Table 3. After 24 hours, the density of all of the briquettes was notably lower, with reductions in density ranging from 22 to 35%. The average density of all samples after 24 hours was 371.8 kg-m⁻³.

3.4 Shattering Resistance

Average shattering resistance values for the briquettes are presented in Table 4. Sample briquettes with MC of 16% had the highest shattering resistance of 88.9% followed by 12 %MC with 87.3% and 8% MC with 81.0% (p=0.06). Based from the p-value>0.05, the treatment means of the shattering resistance are statistically insignificant. The 8% MC had the

Table 3. Average density of the briquettes

Treatment (MC, %)	Right after briquetting	After 24 hours of storage	Change in density (%)
	Mean (kg-m ⁻³)		
16	524.9 ^a	382.8 ^a	27.1
12	495.9 ^a	384.7 ^a	22.5
8	535.3 ^a	347.8 ^a	35.0

highest broken particles resulting to the highest percentage weight loss with the value of 19.08%. This was likely due to the lowest moisture content sample having insufficient moisture to mobilize the lignin and allow for strong bonding of the biomass particles. As sample moisture content increased, then it appears that the particles more readily bound to each other, allowing the briquettes to resist the impact as it was dropped. The Shattering Resistance for 12% and 16% moisture content samples is not statistically different, suggesting that increasing the moisture content beyond 12% may not yield increases in Shattering Resistance.

Table 4. Average shattering resistance in percent

Treatment (MC,%)	Mean Shattering Resistance
16	88.9 ^a
12	87.3 ^a
8	81.0 ^b

3.5 Thermal Properties

3.5.1 Ignition and burning time

The average time spent to ignite and burn the sample briquettes are shown in Table 5. The overall average ignition time is 47.2 seconds, and there are no statistically significant differences between the three moisture content treatments. Burn time also did not show significant differences, and the overall average burn time was 42.4 minutes.

Table 5. Duration of ignition and burning time in seconds

Treatment (MC, %)	Average Ignition time (s)	Average Burning time (min)
16	45.9 ^a	42.8 ^a
12	43.8 ^a	43.2 ^a
8	51.8 ^a	41.1 ^a

3.5.2 Ash content

The ash content is shown in Table 6. The overall mean ash content for all samples is 6.4%, and there is no statistically significant difference between the three treatments. Ash content, as stated in [18] can be affected by the porosity of the briquette which causes poor combustion resulting to high ash content of fuel.

Table 6. Average ash content of the briquettes

Treatment (MC,%)	Mean
16	6.7 ^a
12	5.7 ^a
8	6.7 ^a

3.6 Practical Thermal Efficiency

The practical thermal efficiency, calculated using Equation 6, is shown in Table 7. The 8%MC samples had the highest thermal efficiency of 14.9% had attained the highest fuel efficiency compared with 16%MC and 12%MC with a mean value of 10.9% and 11.4%, respectively. Analysis of Variance revealed that there is no significant difference among the treatment means.

Table 7. Average thermal fuel efficiency of the briquettes

Treatment (MC, %)	Mean (%)
16	10.9
12	11.4
8	14.9

During the evaluation boiling test method was used to determine the thermal fuel efficiency of the briquette as a result treatment with 8%MC had the fastest time of boiling the water as followed by the 12%MC and 16%MC. Hence, the briquette manufactured using feedstock with the lowest moisture content obtained the highest thermal fuel efficiency. It is likely that these briquettes also had the lowest moisture content when used for the thermal efficiency test, which

would explain why they resulted in a higher efficiency during the combustion test.

4. CONCLUSIONS

Tithonia diversifolia stems successfully densify into cylindrical briquettes with a mean density of 518.7 kg m⁻³ among samples tested in this study. However, the briquettes expand by as much as 40% during the 24 hours following briquetting, primarily through swelling in the longitudinal direction. Density after 24 hours drops to an average of 371.8 kg m⁻³. Feedstock moisture content does not impact briquette density (for feedstock between 8 and 16%), but durability, in terms of shatter resistance, is best for higher moisture contents. Ignition time for the briquettes averaged 47.2 seconds, and burn time averaged 42.4 minutes. Thermal efficiency, measured in a reference combustion appliance, averaged 12.4%, which compares well with values in the literature. Ignition time, ash content, and thermal fuel efficiency were not impacted by moisture content. This implies that briquettes from *Tithonia diversifolia* are relatively insensitive to variations in feedstock moisture content. Further work is needed to optimize process characteristics for briquetting this material, and to address the expansion of the briquettes that occurs after their manufacture.

ACKNOWLEDGEMENTS

This work is supported by Benguet State University.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Yibo Huangfu HL. Effects of moisture content in fuel on thermal performance and emission of biomass semi-gasified cookstove. *Energy for Sustainable Development*. 2014;60-65. DOI: 10.1016/j.esd.2014.05.007
2. Gutierrez RM. The antibacterial property of *tithonia diversifolia* (wild sunflower) extract from baguio-benguet areas in the Phillipines in response to exposure to vehicular traffic. 2014;17(1): 1-2.
3. Bolaji Umar Olayinka DA. hydrochemical and proximate Composition of *Tithonia diversifolia* (Hemsl.). *Annals Food Science and Technology*. 2015;195-200. Available: www.afst.valahia.ro
4. Oluwasola TA. Proximate composition, amino acid profile and some anti-nutrients of *Tithonia diversifolia* cut at two different times. *African Journal of Agricultural Research*. 2016;11(38):3659-3663. DOI:10.5897/AJAR2016.10910
5. Olabode OO. Evaluation of *Tithonia diversifolia* (Hemsl.) a grass for soil improvement. *World J. Agric. Sci*. 2007; 3(4):503-507.
6. Jama BP. *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: A review. *Agroforestry Systems*. 2000;49:201-221. DOI: 10.1023/A:1006339025728
7. Matúš MK. Effects of initial moisture content on the production and quality properties of solid biofuel. *Acta Polytechnica, Journal of Advanced Engineering*. 2015;55(5):335-341. DOI: 10.14311/AP.2015.55.0335
8. K. Rupa-Gadd, a. J. Self-heating properties of softwood samples investigated by using isothermal calorimetry. *Biomass and Bioenergy*. 2018; 111:206-212. DOI: 10.1016/j.biombioe.2017.04.008
9. Adapa P. Compaction characteristics of barley, canola, oat and wheat straw. *Biosystem Engineering*. 2009;104(3):344-355.
10. Back EL. Glass transitions of wood components hold implications for molding and pulping processes. *The Journal of the Technical Association of the Pulp and Paper Industry*. 1982;65(7):107-110.
11. Kaliyan N. Densification characteristics of corn stover and switchgrasses. *Transaction of the ASABE*. 2009;907-920.
12. Wilson M. Optimal compaction pressure, particle size and binder ratio for quality briquettes made from maize cobs, a Master's thesis. Jomo Kenyatta University of Agriculture and Technology; 2016
13. Križan PŠ. A study of impact technological parameter on the briquetting process. *Working and Living Environment al Protection*. 2009;6(1):39-47.
14. Oriabure TE. Density, shatter index and heating value of briquettes produced from leaves of *terminalia mentalis* and

- sawdust od daniela olivera. International Journal of Pure Agricultural Advances. 2017;1(1):38-44.
DOI: 10.20448/813.11.38.44
15. Oyelaran O. Investigating the performance and combustion characteristics of composite bio-coal briquette. Journal of Materials and Engineering Structures. 2018;5:173-184.
16. Onukak EDM. Production and characterization of corncob briquettes from tannery solid waste; 2017
17. Kers JK. Determination of physical, mechanical, and burning characteristics of polymeric waste materials. Estonian Journal of Engineering. 2010;16(4):307-316.
DOI: 10.3176/eng.2010.4.06
18. Ajimotokan HA. Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. Scientific African Elsevier. 2019;5.
DOI: 10.1016/j.scief.2019.e00202

© 2021 Dummapi et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/65762>