COMPARATIVE EVALUATION OF THE PELLETIZED BIOMASS FUEL FROM DIFFERENT SOLID WASTES

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Abstract

This research is aimed to convert the vegetable waste into valuable products as an alternative and sustainable fuel source. This study investigated the potential use of fuel pellets that are produced from the wastes such as radish leaf, rice husk and rice husk char. Some physicochemical properties such as moisture content, ash content, bulk density, and chemical composition (N and S %) of different solid waste samples were carried out using appropriate analytical methods. Furthermore, pellets were produced from radish leaf, rice husk and rice husk char using cassava stem and local algae (*Spirogyra sp.)* as a binder. The properties of fuel pellets (compact and relax densities, heating value, energy densities, pellet moisture content) were determined as a function of types and sample composition (60 to 80 % w/w) by applied pressure (1.7 MPa). Also comparative studies of the different samples such as radish leaf (R) with rice husk (H) and rice husk char (C) and their toasted samples (TR, TH and TC) were conducted. The results showed that energy densities ranged from 6.183 to 7.613 $kJcm^{-3}$, 0.366 to 4.387 $kJcm^{-3}$ and 0.909 to 1.648 $kJcm^{-3}$ for the samples R, H and C whereas energy densities ranged from 9.003 to 11.072 $kJcm^{-3}$, 0.369 to 4.760 $kJcm^{-3}$ and 1.116 to 1.876 $kJcm^{-3}$ for the samples TR, TH and TC, respectively. The heating value was also found in the range of 13.188 - 14.336 kJg^{-1}, 13.375 kJg^{-1} and 2.425 - 5.214 kJg^{-1} for samples R, H and C, and 13.737 - 14.010 kJg^{-1}, 12.656 - 13.333 kJg^{-1} and 2.891 - 5.567 kJg^{-1} for samples TR, TH and TC, respectively. From the findings, the radish leaf waste was found to have good pelletizing and combustion characteristics under the conditions considered because of their high density, high heating value and low pellet moisture content. Properties of the densified products (pellets) appeared to be comparable to US PFI requirements.

Keywords: radish leaf, rice husk and rice husk char, physicochemical properties, densification, fuel pellets

Introduction

Agricultural and forest-based industries in developing and emerging economies generate a substantial amount of vegetable solid wastes residue and waste that could, in principle, be used for energy production (Bauen, and Slade, 2013). Vegetable wastes resources are found almost everywhere and can become a reliable and renewable local energy source. Energy produced from vegetable wastes can reduce reliance on an overloaded electricity grid and can replace expensive fuels used in local industries (Armesto *et al*., 2002). Among these vegetable wastes, radish (*Raphanus sativus*) is one of the major vegetable crops grown throughout the country. It is widely grown in different parts of the country mainly by small and marginal farmers.

Rice husk is a by-product of rice milling. The prevalence and year-round production of rice crops on both an industrial and small scale means that rice husks are an attractive biomass fuel because they are not only readily available in large quantities but are also easy to collect. Furthermore, combusting the husk solves the problem of waste husk disposal. A large quantity of rice husks is produced annually in some countries and these residues are left to rot away or they are burned like other agricultural wastes. These residues could however be used to generate heat energy for domestic and industrial cottage applications (Fapetu, 2000).

The conversion of biomass to energy can be achieved through various technologies such as direct/stove, biomass briquette and boiler combustion; thermochemical conversion (which includes

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gasification, pyrolysis and liquefaction); and biochemical conversion (anaerobic fermentation biogas, bioethanol and biodiesel) (Oladeji, 2011 and Qiao *et al.*, 2011).

The major limitations of direct combustion are the low heating efficiency and difficulty in handling, storage and transportation resulting from the low bulk density and high moisture content of the biomass materials (Li *et al.*, 2017 and Tumuluru *et al.*, 2011). Srivastava *et al.*, 2014 converted vegetable market waste to briquettes without pre-treatment and without using any external binders. Therefore, relying on biomass for the production of pellets or briquettes is a potential solution to solid waste problems in developing countries as well as the high dependence on fuel wood.

The PFI is a North American trade association based in Arlington, Virginia, that represents a range of contributors to the pellet industry, including companies that manufacture wood pellets and pellet manufacturing equipment, or provide other products and services to the densified biomass industry at large.

The aim of the present research work is to convert the vegetable waste into valuable products as an alternative and sustainable fuel source. In this work, densification of radish leaf waste was carried out using cassava stem and algae as binding agents and also comparative with rice husk and rice husk char wastes. Effect on properties of the pellets (compact and relax densities, heating value, energy densities, pellet moisture content) were evaluated as a function of types and algae to leaf mixture ratio (60 to 80 % w/w).

Materials and Methods

Collection and Preparation of Solid Waste Samples

Radish leaf wastes were collected from Pyin Oo Lwin Township, Mandalay Region during June and August, 2018. Also rice husk and rice husk char samples were collected from Hle-dan Market, Kamayut Township, Yangon Region during May, 2019.

The radish leaf wastes were cleaned in water, dried naturally in sunlight for at least 5 days. Clean and dried leaf waste were reduced in size using burner and sieved into 40 mesh size. Whereas rice husk sample was naturally dried naturally in sunlight for 1 day, and pulverized with burner to reduce in size. Also rice husk char was dried naturally in sunlight for 1 day, and pulverized with burner to reduce in size and then sieved into 40 mesh sizes.

Moreover, cassava stem was collected from Lashio Township, Northern Shan state and algae (*Spirogyra* sp.) were also collected from Thahton hostel, Yangon University campus. Cassava stem and algae were also dried naturally under the sun by spreading on a steel plate for at least 3 days. After which, they were sieved into 40 mesh size. In this preparation, densifications of different solid wastes were carried out using cassava stem and algae as binding agents.

Determination of the Physicochemical Properties of Raw Materials

The different solid wastes were cleaned in water, dried naturally under sunlight for at least 5 days, and reduced in size. The moisture content (dry basis) of raw materials was determined using the Infrared moisture analyzer method (FD 660). To determine the ash content, the samples were placed in reweighed crucible and ignited in a muffle furnace at 600 ˚C for 2 h until the substance turned into ash (LabTech). After ashing, the crucible was cooled in a desiccator and weighed (AOAC, 2000). For bulk density determination, the graduated cylinder was filled with the dry sample. The cylinder was placed in a tapping box and gently tapped until there was no more reduction in volume and the bulk density was calculated (Tapping method). The sulphur contents of the samples were determined as barium sulphate by precipitation method (AOAC method). Total nitrogen contents of the samples were measured by Dumas Nitrogen Analyzer (NDA 701).

Preparation of Raw Materials for the Fuel Pellets

Pelletizing at moderate conditions may be effective with inexpensive binding agents from natural sources. Prior to densification, blending was performed by weight ratios into 100 % waste samples. Using radish leaf raw materials, three composite samples: (i) 10 % algae, 10 % cassava stem and 80 % radish leaf (R1), (ii) 10 % algae, 20 % cassava stem and 70 % radish leaf (R2), (iii) 10 % algae, 30 % cassava stem and 60 % radish leaf (R3) were prepared. The same ratio as the previous one but pre-toasted at 100 ^{o}C before combination were conducted for samples TR1, TR2 and TR3. Also using rice husk sample, three composite samples: (i) 10 % algae, 10 % cassava stem and 80 % rice husk (H1), (ii) 10 % algae, 20 % cassava stem and 70 % rice husk (H2), (iii) 10 % algae, 30 % cassava stem and 60 % rice husk (H3) were prepared. The same ratio as the previous one but pre-toasted at 100 ^{o}C before combination were conducted for samples TH1, TH2 and TH3. Also using rice husk char sample, three composite samples: (i) 10 % algae, 10 % cassava stem and 80 % rice husk char (C1), (ii) 10 % algae, 20 % cassava stem and 70% rice husk char (C2), (iii) 10 % algae, 30 % cassava stem and 60 % rice husk char (C3) were prepared. The same ratio as the previous one but pre-toasted at 100 ^{o}C before combination were conducted for samples TC1, TC2 and TC3.

Densification Procedure

Each pellet mass loading was approximately 17.0 to 20.0 ± 1.0 g. A compacting (densifying) apparatus used is shown in Figure 1, comprising a piston, a closed-end cylinder and a base. Internal diameter was 27 mm, indicating the resultant pellet size. The compacting apparatus was mounted with 1.7 MPa to the material. Eighteen composite samples with different weight ratios were taken into 250 mL beaker. For each test condition, about 20 mL distilled water was added slowly with constant stirring. A holding time of 1 h was used for each pellet.

Figure 1 Manual densification unit

Determination of the Physicochemical Properties of Fuel Pellet

The resultant pellets were subsequently evaluated for various physicochemical properties, including compact and relax densities, energy density, heating value, pellet moisture content and SEM. The pellet density was determined based on the pellet mass per volume. In this work, the compact and relax densities were used and defined as that of the pellet determined immediately after compaction and that determined after storage for one week, respectively. The energy density (kJ cm^{-3}) used in this work was defined as the product between heating value (kJ g^{-1}) and relax density (g cm^{-3}) of the pellet. The heating value of the pellet was determined using bomb calorimeter (DRI). The pellet moisture content (dry basis) was determined using the infrared moisture analyzer method (FD 660). A scanning electron microscope (SEM) was determined by University Research Center (Jeol JXA- 840 A).

Preparation of Fuel Pellet from Biomass

According to the physicochemical parameters of Lab-Scale Fuel Pellet, mixture ratio of R2 sample was chosen as the most potent sample for further optimization process to fuel pellets production. So, radish leaf (1284.62 g) and algae (153.85 g) were thoroughly mixed and mixed again cassava stem (230. 77 g) with 1000 mL of distilled water. They were thoroughly mixed and heated to obtain syrup, which were sundried for 1 to 2 days. The mixtures were loaded into the pellet mill (Figure 2) for about 15 min. The resultant (densified) pellets were obtained

Figure 2 Pellet Mill

Results and Discussion

Biomass Characteristics

The different solid waste samples in urban areas are seasonally available biomass residues that may potentially be utilized to produce biomass pellets. The biomass pellets comprised many small pieces of leaf packed together and shaped into solid cylinder, holding together by manual densification of solid bridges. Binding agents impart cohesive qualities to powdered material during the production of pellet. In this research work, the different solid waste samples and binding agents are shown in Table 1. Moisture contents, ash contents and bulk density based on the dry solid samples (radish leaf, rice husk and rice husk char) were found 0.16 to 11.85 %, 18.22 to 91.00 % and 0.32 to 0.41 g mL^{-1} whereas sulphur and nitrogen contents were found 0.36 to 0.63 % and 0.42 to 4.64 %, respectively. For the binding agents (cassava stem and algae) the moisture contents, ash contents and bulk density were found to be 0.11- 0.19 %, 18.00 - 76.00 % and 0.10 - 0.39 g mL^{-1} whereas sulphur and nitrogen contents were 0.44 - 0.73 % and 7.46 - 10.63 %, respectively.

Table 1 Some Physicochemical Properties of Different Solid Samples

No.	Sample	Moisture (%)	Ash (%)	Bulk density (g mL^{-1})	Total S (%)	Total N (%)
1	Radish leaf	11.85	18.22	0.37	0.36	3.03
2	Rice husk	0.31	21.00	0.41	0.46	4.64
3	Rice husk char	0.16	91.00	0.32	0.63	0.42
4	Cassava stem	0.09	18.00	0.10	0.44	7.46
5	Algae	0.11	76.00	0.39	0.73	10.63

Physical Appearance of the Fuel Pellets

Figure 3 shows pictorial views of the pellets after one week storage. It was evident that radish leaf pellets (R2) processed at room temperature by applied pressure (1.7 MPa) could retain the pellet form. They would need to be pelletized at higher pressures to form very tight pellets. For processing at room temperature and pre-toasted at 100 °C, all cases were found to be successful in forming pellets. But all cases could not retain the pellet form under low pressure even with binder. From the pictures, the densification of different solid wastes was carried out using cassava stem and local algae as a binder by various mixture ratios and conditions.

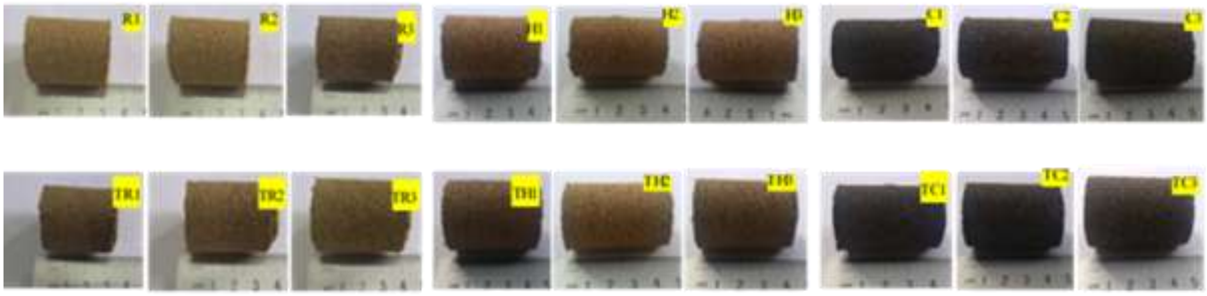

Figure 3 Appearance of fuel pellets densified using different ratio and types of samples

Compact and Relax Densities of Fuel Pellets

Measurement of length and diameter of the pellets was under taken immediately and after storage for one week. This was used to calculate their corresponding volume and density from a fixed mass input. Compacted density was always higher than relaxed density because the expansion of pellet dimension affected change in pellet volume. The results of the experiments carried out on the properties of the radish leaf, rice husk and rice husk char pellets are presented on Table 2. It was observed that change in density of the pellets after storage was rather small for those compressed using radish leaf. Also change in density of the pellets after storage was rather large for those compressed using rice husks and rice husk char. From the finding, it was clear that the ratio of radish leaf had positive impact on the pellet density.

Table 2 Variation in Pellet Densities with Different Conditions

No.	Raw materials	Pellet sample	Compact densities (g cm^{-3})	Relax densities (g cm^{-3})
1.	Radish leaf	R1	0.596	0.572
		R2	0.547	0.531
		R3	0.467	0.453
		TR1	0.832	0.806
		TR2	0.746	0.718
		TR3	0.702	0.651
2.	Rich Husk	H1	0.772	0.366
		H2	0.895	0.385
		H3	0.800	0.328
		TH1	0.737	0.369
		TH2	0.721	0.351
		TH3	0.789	0.357
3.	Rich Husk Char	C1	0.829	0.375
		C2	0.920	0.348
		C3	0.846	0.316
		TC1	0.838	0.386
		TC2	0.767	0.367
		TC3	0.702	0.337

Heating Value, Energy Density and Pellet Moisture of Fuel Pellets

The heating value and energy density of fuel pellets results of this study are as shown in Table 3. A little difference in the energy content of mixture ratios were observed on table 3 using radish leaf with different conditions but more difference in the energy content of mixture ratios were observed using rice husk and rice husk char with different conditions. The energy density (kJ/cm^3) used in this work was defined as the product between heating value (kJ/g) and relax density (g cm^{-3}) of the pellet.

Significant differences in heating values were found between pellet samples. The maximum heating value 14.336 kJ/g of sample R2 and the maximum heating value 14.010 kJ/g of sample TR2 are shown in Table 3. The minimum heating values of R1(13.188 kJ/g) and TR1 (13.737 kJ/g) are shown in Table 3, and the maximum heating values of H3 (13.375 kJ/g) and TH3 (13.33 kJ/g) are also shown in Table 3. The heating values of H1 and H2 and TH1 were not detected. The maximum heating value (5.214 kJ/g) of the sample C3, ranged from 2.425 to 5.214 kJ/g, and that of the sample TC3 (5.567 kJ/g), ranged from 2.891 to 5.567 kJ/g are also shown in Table 3. From the finding, the pellet sample R2 possessed more heating value than other pellet samples that can meet domestic needs such as cooking and water boiling (Tippayawong *et al*., 2018).

The results in Table 3 show that as the moisture content increases the heating value reduces. The minimum moisture contents for pellet samples R2, H1 and TC2 were observed as 2.896 %, 0.510 % and 0.386 % respectively. Higher moisture content implies a lower heating value as each unit mass of fuel contains less oven dry biomass - which is the part of the fuel that actually undergoes combustion to release heat (Tokan *et al*., 2016).

Table 3 Variation in Heating Values, Energy Densities and Pellet Moisture with Different Conditions

No.	Raw materials	Pellet sample	Heating values (kJ g^{-1})	Energy densities (kJ cm^{-3})	Pellet moisture (%)
1.	Radish leaf	R1	13.188	7.544	4.002
		R2	14.336	7.613	2.896
		R3	13.649	6.183	2.834
		TR1	13.737	11.072	2.958
		TR2	14.010	10.059	3.764
		TR3	13.830	9.003	7.302
2.	Rich Husk	H1	ND	0.366	0.510
		H2	ND	0.385	0.512
		H3	13.375	4.387	0.574
		TH1	ND	0.369	1.092
		TH2	12.656	4.442	0.519
		TH3	13.333	4.760	0.949
3.	Rich Husk Char	C1	2.425	0.909	0.415
		C2	4.040	1.406	0.861
		C3	5.214	1.648	0.579
		TC1	2.891	1.116	0.676
		TC2	4.029	1.479	0.386
		TC3	5.567	1.876	0.623

SEM Analysis

The appearance of fuel pellets by grinding mill using raw samples of (a) radish leaf (b) rice husk and (c) rice husk char was indicated by SEM micrograph (Figures 4). In these SEM micrograph, appearance of fuel pellets and rice husk char were observed as similar pattern of pores and attributed on the surface of the all samples. Also rice husk can be seen that stick structure and attributed on the surface of the all samples. The more pronounced morphological character was shown by appearance of fuel pellet samples.

(a) (b) (c)

Figure 4 Scanning electron micrographs of (a) Appearance of fuel pellets by grinding mill, (b) Rice husk and (c) Rice husk char

Comparison of Fuel Pellets with an International Standard

Biomass pellets are currently graded by the US PFI. Pellet quality is a largely dependent on type of feedstock and process parameters. In this work, comparison of our densified products against the US PFI requirement was made for some indicators. Results were shown in Table 4 and Table 5. It can be seen that Radish leaf pellets obtained from this work were in some compliance with the US PFI and German standard requirements.

Table 4 Comparison of Fuel Pellet Properties against PFI Fuel Grade Requirements

No.	Properties	Observed values		PFI premium	PFI utility	PFI standard
		R1 to C3	TR1 to TC3			
1.	Diameter (mm)	27	27	6.35 - 7.25	6.35 - 7.25	6.35 - 7.25
2.	Length (% > 38 mm)	1.2 - 1.5	1.2 - 1.6	≤ 1.0	≤ 1.0	≤ 1.0
3	Energy density (kJ/cm^3)	0.366 - 7.613	0.369 - 11.072	-	-	-
4	Heating value (kJ/g)	2.425 - 14.336	2.891 - 14.010	*15.501 - 19.501	-	* >17.999
5	Moisture (%)	0.415 - 4.002	0.386 -7.302	≤ 8.0	≤ 10.0	≤ 8.0

*Garcia-Maraer and Carpio (2015)

Fuel Pellets Prepared by Commercial Scale

Based on the compact and relax densities, heating value, energy density and pellet moisture content, the densification of radish leaf wastes was chosen for further use as commercial fuel pellets. So, the radish leaf waste, mixture ratio R2 could be suggested for the production of fuel pellet between the different solid wastes (Figure 5). Also commercial pellets obtained from this work were in approximately compliance with the US PFI and German standard requirements.

Figure 5 Appearance of fuel pellets densified by commercial scale

Table 5 Comparison of Commercial Pellet Properties against PFI Fuel Grade Requirements

No.	Properties	Observed values	PFI premium	PFI utility	PFI standard
1	Energy density (kJ/cm^3)	14.329	-	-	-
2	Heating value (kJ/g)	14.803	*15.501 - 19.501	-	* >17.999
3	Moisture (%)	0.312	≤ 8.0	≤ 10.0	≤ 8.0

* Garcia-Maraer and Carpio (2015)

Conclusion

The present work deals with conversion of the vegetable waste into valuable products as an alternative and sustainable fuel source. In converting the radish leaf waste into pellets, the physical and combustion characteristics of the pellets were investigated, and comparative study were also conducted with rice husk and rice husk char pellets in order to establish suitability for use as fuel. The work draws the following conclusion: high efficient and durable solid fuel for domestic use was produced, from radish leaf, with heating value ranging from 12.482 - 14.336 kJ/g on the sample R2 whereas heating value ranging from 12.807 - 14.010 kJ/g on the sample TR2. Also use of radish leaf (60 - 80% w/w) offer any marked improvement of the physical characteristics of the pellets. They were also compared to requirements for fuel pellets in the US PFI in order to assess their potential for future use in pellet firing systems. From the findings between different solid wastes, R2 sample could be suggested for the production of fuel pellet because of their high density, heating value, low pellet moisture content.

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References

A.O.A.C. (2000). "Methods in Food Analysis. Pearson's Chemical Analysis of Foods", *Association of Official Analytical Chemists*. America: 17th Edn., Food Science and Technology

Armesto, L., Bahillo, A., Veijonen, K., Cabanillas, A. and Otero, J. (2002), "Combustion behaviour of rice husk in a bubbling fluidised bed", *Biomass and Bioenergy*. vol. 23(3), pp**.** 171-79

Bauen, A. and Slade, R. (2013). "Biomass Use on a Global Scale", Encyclopedia of Sustainability Science and Technology. pp. 1607-18

Fapetu, O. P. (2000). "Production of Charcoal from Tropical Biomass for Industrial and Metallurgical Process", Nigerian *Journal of Engineering Management*. vol. 1(2), pp. 34-37

Garcia-Maraver, A. and Carpio, M. (2015). "Factors Affecting Pellet Quality", WIT Transactions on State of the Art in Science and Engineering, vol. 85, pp. 26-27

Li, Y., Zhou, L. and Wang. R. (2017). "Urban biomass and methods of estimating municipal biomass resources". *Renewable and Sustainable Energy Reviews*, vol. 80, pp. 1017-1030

Oladeji, J. T. (2011). "Agricultural and forestry wastes and opportunities for their use as an energy sources in Nigeria: An Overview", *World Rural Obs*. vol. 3, pp. 107-112

Qiao, W., Yan, X., Ye, J., Sun, Y., Wang, W. and Zhang, Z. (2011). "Evaluation of biogas production from different biomass wastes with/without hydrothermal pretreatment", Renew. *Energy*. vol. 36, pp. 3313-3318

Srivastava, N. S. L., Narnaware, S. L., Makwana, J. P., Singh, S. N. and Vahora, S. (2014). "Investigating the energy use of vegetable market waste by briquetting", Renew. *Energy*. vol. 68, pp. 270-275

Tippayawong, N., Jaipa, C. and Kwanseng, K. (2018). "Biomass Pellets from Densification of Tree Leaf Waste with Algae", Agricultural Engineering International: *CIGR Journal*, vol. 20(4), pp. 119-125

Tokan, A., Muhammad, M. H., Japhet, J. A. and Kyauta, E. E. (2016). "Comparatitive analysis of the effectiveness of rice husk pellets and charcoal as fuel for domestic purpose", *Journal of MechMechanical and Civil Engineering (IOSR-JMCE)*. Nigeria: vol. 13, Issue 5 ver. VI, pp. 21- 27

Tumuluru, J. S., Wright, C. T., Hess, J. R. and Kenney, K. L. (2011). "A review of biomass densification systems to develop uniform feedstock commodities for bioenergy application", *Biofuel Bioprod. Biorefin*. vol. 5, pp. 683-707