International Journal of Technology (2016) 7: 1260-1268
ISSN 2086-9614

EFFECT OF MIXING RATIO AND PELLETING SPEED ON PHYSICAL AND MECHANICAL PROPERTIES OF BIOMASS PELLETS FROM SUGARCANE TRASH

Nirattisak Khongthon[1,2,3,4], Chaiyun Junsiri[1,3,4], Kittipong Laloon[1,3,4], Sakda Champana[3], Somposh Sudajan[1,2,3,4*]

[1]*Department of Agricultural Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand*
[2]*Center for Alternative Energy Research and Development, Khon Kaen University, Khon Kaen 40002, Thailand*
[3]*Postharvest Technology Innovation Center, Commission on Higher Education, Bangkok 10400, Thailand*
[4]*Agricultural Machinery and Postharvest Technology Center, Khon Kaen University, Khon Kaen 40002, Thailand*

(Received: July 2016 / Revised: October 2016 / Accepted: October 2016)

ABSTRACT

The definition of the physical and mechanical properties of sugarcane trash pellets were necessary for the design considerations relating to storage, handling and processing equipment. The mixing ratios of ground sugarcane trash:cassava starch:water content (1.0:0.25:0.85 and 1.0:0.25:1.40 by weight) and pelleting speeds (100, 120, 140, and 160 rpm) were considered to determine their effects on bulk density, true density, porosity, durability and compressive strength. The results show that the mixing ratio by weight of 1.0:0.25:0.85 and pelleting speed of 120 to 140 rpm were optimum for producing the sugarcane trash pellets. At the moisture content of 12.01% (wb), the bulk density, true density, durability and compressive strength of biomass pellets were in the range of 330.93 to 365.00 kg/m^3, 860.38 to 918.43 kg/m^3, 99.34 to 99.46 % and 5.15 to 6.43 MPa, respectively.

Keywords: Mechanical properties; Pellets; Physical properties; Sugarcane trash

1. INTRODUCTION

In Thailand, sugarcane has been widely cultivated on areas of about 1,353,025 hectares with an annual production of about 103.7 million tonnes (FAO, 2014). After sugarcane harvesting, several million tonnes of sugarcane residues are produced annually. Sugarcane biomass or trash is left in the field that can be used as a fuel because it has a heating value of 17.39 MJ/kg and high volume (DEDE, 2012). Sugarcane trash is one of the many demands for fuel for sugar mills and biomass power plants (Khongthon & Sudajan, 2014). Sugarcane residues are very difficult to handle, transport, store, and utilize in their original form, because of high moisture content, irregular shape and sizes, and low bulk density (Theerarattananoon et al., 2011; Adapa et al., 2013).

Densification of sugarcane trash into pellets is one solution for these problems (Emami et al., 2014). Pellets have a low moisture content and due to their uniform shape and size can easily

*Corresponding author's email: somsud@kku.ac.th, Tel. +66-87-2272001
Permalink/DOI: https://doi.org/10.14716/ijtech.v7i7.4753

be handled using existing handling, transport and storage (Mani et al., 2006). The physical properties of pellets are size, bulk density, hardness, strength, durability and other characteristics (Colley et al., 2006; Lam et al., 2008). Information on the physical properties of pellets is essential for the proper design, handling and selection of transportation system or equipment for biomass pellets production (Colley et al., 2006; Zhou et al., 2008; Obernberger & Thek, 2004; White & Jayas, 2001). Many studies were conducted to determine the factors affecting the physical and mechanical properties of biomass pellets, such as the effect of moisture content, particle size and die thickness (Theerarattananoon et al., 2011; Mahapatra et al., 2010). Several studies have been conducted to determine properties of pellets that are produced from plants, such as grasses (Mani et al., 2006), barley, oat, and wheat straw (Donghui et al., 2014; Adapa et al., 2013; Emami et al., 2014), sawdust, bark and logging residues (Lehtikangas, 2001), pineapple waste (Zainuddin et al., 2014), canola and sunflower meal (White & Jayas, 2001). However, there is no published works or information available in the literature about the physical properties of pellets from sugarcane trash pellets and their relationship with mixing ratios and pelleting speeds. Therefore, this study was carried out to determine some physical and mechanical properties of sugarcane trash pellets, such as bulk density, true density, porosity, durability and to investigate the effects of mixing ratios and pelleting speeds on some physical properties of sugarcane trash pellets.

2. EXPERIMENTAL SETTING

2.1. Preparation of Materials

Sugarcane trash variety, Khon Kaen III, was used for this experiment. It was harvested by traditional methods. The moisture content of the trash was determined by the oven-drying method (ASAE, 1993). The average moisture content of sugarcane trash was 12.54% w.b. Sugarcane trash samples were reduced in their size by using a chopper and hammer mill with a 3.0 mm screen opening. The geometric mean diameter (d_{gw}) of the sample was 2.65 mm.

2.2. Pelleting Process

Pelleting experiments were conducted by using a flat die pellet unit (Bhattacharya & Sheatha, 1990). The pellet unit (Figure 1) consisted of 2 rollers with 70×85 mm (diameter×width), pellet die with 235×38.1 mm (diameter×thickness) with 179 holes and 6.0 mm hole diameter. The power was obtained through the power take-off (PTO) of the tractor (Ford-New Holland model 6610), 58.5 kW (78.5 hp).

The ground sugarcane trashes were mixed with cassava starch and water content. The mixing ratio by weight of the ground trash:cassava starch:water content was divided into two groups. Group 1 was the mixing ratio of ground trash:cassava starch:water content of 1.0:0.25:0.85 (moisture content of 40.33% wb). Group 2 was the mixing ratio of 1.0:0.25:1.40 (moisture content of 55.78% wb).

The experiment in a preliminary study showed that a pelleting speed of 140 rpm was optimum for producing sugarcane trash pellets. Therefore, the pelleting speeds of 100, 120, 140 and 160 rpm (0.27, 0.32, 0.37, and 0.42 m/s) were to be studied. After pelleting, the pellet samples were dried by a sun-drying method for five days; the moisture content of each experiment was determined by ASAE method (ASAE, 1993).

The average moisture content of the pellet samples was 12.01% wb. The chosen value of moisture content due to this value was in the range of the Korean wood pellet standard that defined the moisture content of less than 15% wb. and DIN 51731 Standard that defined the moisture content less or equal to 12% wb (WIP, 2009).

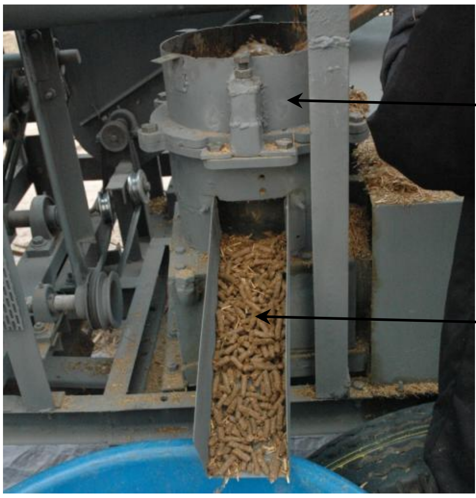

Figure 1 Flat die pellet unit for pelleting experiments

2.2.1. Bulk density

Bulk density of the pellets was determined according to ASABE Standard S269.4 (ASABE, 1993) for cubes, pellets, and crumbles. Bulk density was calculated by dividing the mass by the container volume as shown in Equation 1. The determined bulk density of the pellet was obtained with 10 replications.

$$\rho_b = \frac{m_b}{V_b} \tag{1}$$

where ρ_b is the bulk density (kg/m^3), V_b is the volume of cylinder (m^3) and m_b is the total mass of pellets (kg).

2.2.2. True density

The true density was determined by a direct measurement method. The true density was calculated as the ratio of the mass of the sample of pellets to its volume. Fifty pellet samples were used in the test.

2.2.3. Porosity

The fraction of the volume of voids over the total volume and void spaces in the sugarcane pellet material was a measurement for porosity. The porosity was calculated by the true density and bulk density measured as explained by Equation 2 (Stelte et al., 2011).

$$\text{Porosity} = 1- \frac{\text{Bulk density}}{\text{True density}} \text{ x } 100 \tag{2}$$

2.2.4. Pellet durability

Pellet durability was determined according to ASABE Standard (ASABE, 1993). A sample of pellets was sieved on the appropriate sieve to remove fines. A 100 g sample of sieved pellets was tumbled at 50 rpm for 10 minutes in a tumbling box device. After tumbling, the sample was removed. This test was operated with five replications, then sieved and the percentage of whole pellets was calculated using Equation 3:

$$\text{Durability (\%)} = \frac{\text{mass of pellets after tumbling}}{\text{mass of pellets before tumbling}} \text{ x } 100 \tag{3}$$

2.2.5. Compressive strength

Five samples of the pellets were used to test on the Universal Testing Machine (UTM). The pellet sample was placed on the stationary plate with a horizontal axis (Figure 2). During the downward movement of the crosshead, the movement plate pressed the pellet sample by compressive force until it broke. The diameter of each pellet was measured. The force required for compressing the pellet against time was recorded on the UTM chart recorder. The maximum compressive force (N) of each sample was obtained from the experimental data.

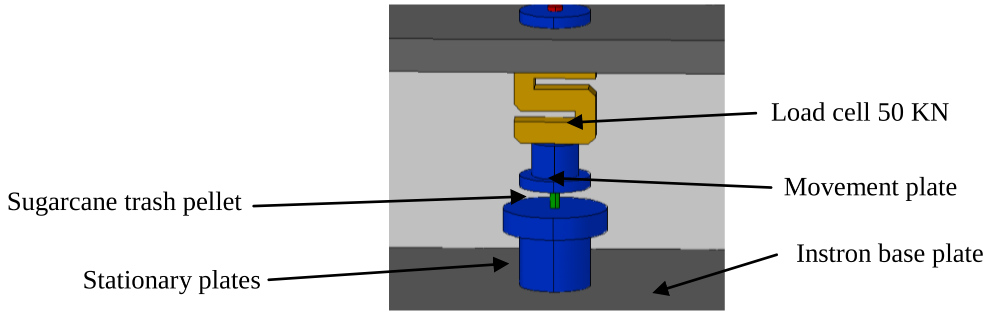

Figure 2 Schematic experimental arrangement for compressive test

The compressive strength was determined from the force-displacement curve for testing pellets that was conducted from different mixing ratios and pelleting speeds using Equation 4:

$$\sigma_s = \frac{F_{max}}{A} \tag{4}$$

where σ_s was the maximum compressive strength, F_{max} was the maximum compressive force and A was the cross sectional area of pellet at the position of compression.

2.2.6. Statistical analysis

This study was planned as a randomized complete block design (RCBD) of a 2×4 factorial experiment. Experimental data were analyzed using an analysis of variance (ANOVA) and the means were compared at the 5% levels of significance using the Least Significant Difference test (LSD) in the SPSS software (ver. 11.5, SPSS, Inc., Chicago, IL, USA, 2008).

3. RESULTS

The analysis of variance for the study of mixing ratios and pelleting speeds on some physical and mechanical properties is shown in Table 1.

Table 1 Analysis of variance of the result of physical and mechanical properties of sugarcane trash pelleting

Source of variation	Bulk density		True density		Porosity		Durability		Compressive strength	
	df	F-value	df	F-value	df	F-value	df	F-value	df	F-value
Replication	9		49		9		2		4	
Mixing ratio (A)	1	2115.29**	1	12095.72**	1	836.40**	1	57.03**	1	1233.20**
Pelleting speed (B)	3	581.80**	3	460.82**	3	133.06**	3	4.71**	3	135.00**
AB	3	184.15**	3	433.92**	3	48.36**	3	4.54**	3	65.76**
Error	72		392		72		16		32	

**Highly significant at 1% level: df, degree of freedom

The analysis of variance showed that mixing ratio (A) and pelleting speed (B) significantly affected bulk density, true density, porosity, durability and compressive strength at 1% levels of significance. It was observed that the effect of mixing ratio was the most significant. The first-order interaction of AB significantly affected bulk density, true density, porosity, durability and compressive strength at 1% levels of significance.

4. DISCUSSION

4.1. Bulk Density

Comparison among treatment mean using LSD showed that at the mixing ratio of 1.00:0.25:0.85 and 1.00:0.25:1.40, the bulk density of 100, 120, 140, and 160 rpm of pelleting speed difference significantly. Figure 3 showed the effect of pelleting speed on bulk density for individual mixing ratios. At mixing ratios of 1.00:0.25:0.85 and 1.00:0.25:1.40, the bulk density increased continuously from 210.59 to 365.00 kg/m^3 and 195.81 to 251.26 kg/m^3 as pelleting speed increased from 100 to 140 rpm, and it decreased rapidly when the pelleting increased to 160 rpm. The bulk density of the mixing ratio of 1.00:0.25:0.85 was higher than the mixing ratio of 1.00:0.25:1.40 throughout the range of pelleting speeds. The bulk density that was obtained from this study had a value close to that of the studied pellets from pineapple waste (Zainuddin et al., 2014). The high value of bulk density was in the range of 330.93 to 365.00 kg/m^3 at a mixing ratio of 1.00:0.25:0.85 and pelleting speed in the range of 120 to 140 rpm.

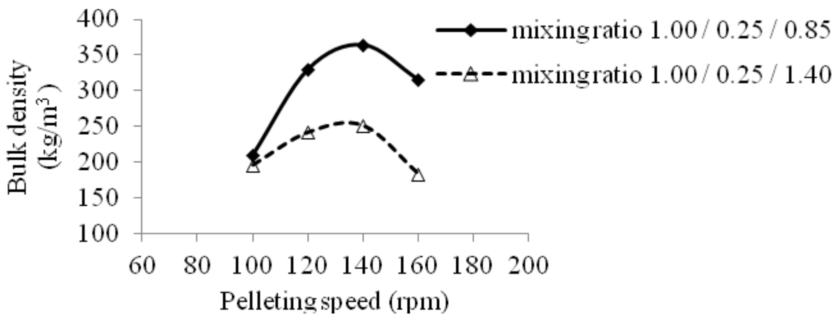

Figure 3 Effect of pelleting speed on bulk density of sugarcane trash pellet at different mixing ratios

The bulk density was important in determining spaces required for transportation and storage and also in determining the working principles of the processing machine.

4.2. True Density

Comparison among treatments mean using LSD showed that at 1.00:0.25:0.85 mixing ratio, the true density of 100, 120, 140 and 160 rpm of pelleting speed difference significantly. At mixing ratio of 1.00:0.25:1.40, the true density of 120 and 140 rpm of pelleting speed did not different significantly but differ significantly for 100 and 160 rpm. Figure 4 showed the effect of pelleting speed on true density for individual mixing ratios. At mixing ratios of 1.00:0.25:0.85, the true density increased continuously from 636.01 to 918.43 kg/m^3 as pelleting speed increased from 100 to 140 rpm, and it decreased rapidly when the pelleting speed increased to 160 rpm. At mixing ratios of 1.00:0.25:1.40, the true density increased slightly from 489.52 to 508.24 kg/m^3 as pelleting speed increased from 100 to 120 rpm, and it decreased slightly when the pelleting increased to 160 rpm. The result indicated that the true density of the mixing ratio of 1.00:0.25:0.85 was higher than the mixing ratio of 1.00:0.25:1.40 at all pelleting speed. The high value of true density was in the range of 860.38 to 918.43 kg/m^3 at mixing ratio of 1.00:0.25:0.85 and pelleting speed in the range of 120 to 140 rpm.

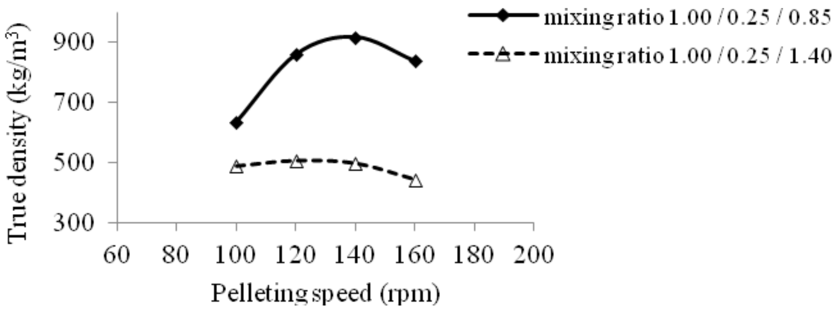

Figure 4 Effect of pelleting speed on true density of sugarcane trash pellet at different mixing ratios

At the mixing ratio of ground trash: cassava starch: water content of 1.00:0.25:0.85, the bulk and true density was higher than the mixing ratio of 1.00:0.25:1.40 due to the moisture content of 1.00:0.25:0.85 mixing ratio was lower. Similarly to the studied of corn stover (Tumuluru, 2015) that increasing the moisture content from 28 to 33% (wb) decreased the density. Similar observations were reported by Mani et al. (2006).

4.3. Porosity

Comparison among treatment mean using LSD showed that at 1.00:0.25:0.85 mixing ratio, the porosity of 120 and 140 rpm of pelleting speed did not different significantly similarly to the result of 120 and 160 rpm of pelleting speed. At 1.00:0.25:1.40 mixing ratio, the porosity of 100, 120, 140 and 160 rpm of pelleting speed did different significantly. Figure 5 showed the effect of pelleting speed on porosity for individual mixing ratios. At the mixing ratio of 1.00:0.25:0.85, the porosity decreased slightly from 66.07% to 59.46% as the pelleting speed increased from 100 to 140 rpm, then showed little difference with further increases of pelleting from 140 to 160 rpm. At 1.00:0.25:1.40 mixing ratio, the porosity decreased continuously from 58.94% to 48.21% as the pelleting speed increased from 100 to 140 rpm, and it increased rapidly from 48.21% to 57.51% when the pelleting speed increased from 140 to 160 rpm. The result indicated that the porosity of the mixing ratio of 1.00:0.25:0.85 at all pelleting speeds was higher than the mixing ratio of 1.00:0.25:1.40. Similar to the studied of coffee (Chandrasekar & Viswanathan, 1999). The reported that porosity decreased with increasing moisture content in the range of 9.9% to 30.6% (wb).

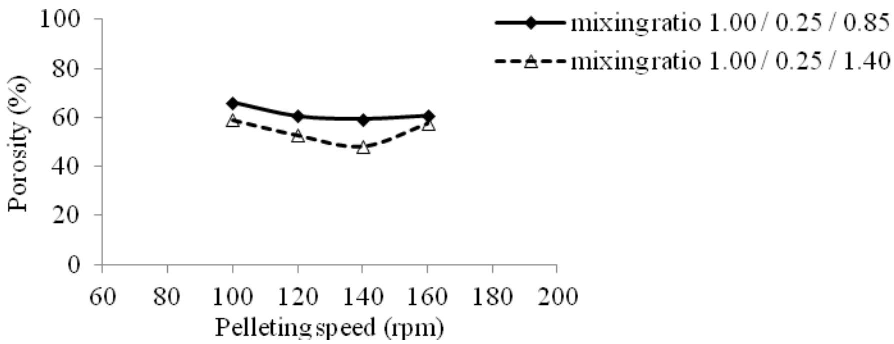

Figure 5 Effect of pelleting speed on porosity of sugarcane trash pellet at different mixing ratios

4.4. Durability

Comparison among treatment mean using LSD showed that at 1.00:0.25:0.85 mixing ratio, the durability of 100, 120, 140, and 160 rpm of pelleting speed did not different significantly.At 1.00:0.25:1.40 mixing ratio, the durability of 100 and 120 rpm of pelleting speed did different significantly but it differenced significantly which 140 and 160 rpm of pelleting speed. Figure 6 showed the effect of pelleting speed on porosity of sugarcane trash pellet for individual mixing ratios. At the mixing ratio of 1.00:0.25:0.85, the durability increased slightly from 98.51% to 99.46% as the pelleting speed increased from 100 to 140 rpm, and it decreased slightly from 99.46% to 98.92% when the pelleting speed increased from 140 to 160 rpm. At 1.00:0.25:1.40 of mixing ratio, the durability increased slightly from 97.11% to 97.21% as the pelleting speed increased from 100 to 120 rpm, and it decreased rapidly from 97.21% to 93.55% when the pelleting speed increased from 120 to 160 rpm. The porosity of the mixing ratio of 1.00:0.25:0.85 was higher than the mixing ratio of 1.00:0.25:1.40 throughout the range of pelleting speeds. The durability that was obtained from this studied had higher value than that of the studied of barley straw pellets (Serrano et al., 2011). The high value of durability was in the range of 99.34% to 99.46% at mixing ratio of 1.00:0.25:0.85 and pelleting speed in the range of 120 to 140 rpm.

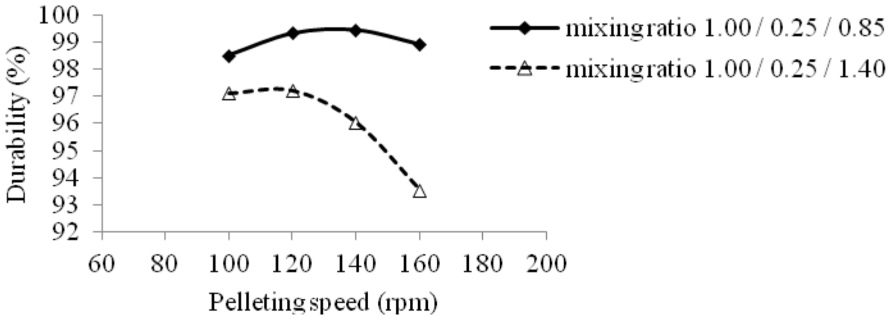

Figure 6 Effect of pelleting speed on durability of sugarcane trash pellet at different mixing ratios

4.5. Compressive Strength

Comparison among treatment means using LSD tests showed that at 1.00:0.25:0.85 mixing ratios, the compressive strength of 100, 120, 140, and 160 rpm of pelleting speeds differed significantly. At 1.00:0.25:1.40 mixing ratio, the compressive strength of pairs of 100 and 160 rpm, and 120 and 140 rpm of pelleting speed did not differ significantly. Figure 7 shows the effect of pelleting speed on compressive strength for individual mixing ratios. At mixing ratios of 1.00:0.25:0.85, the compressive strength increased continuously from 2.18 to 6.43 MPa as pelleting speed increased from 100 to 140 rpm, and it decreased rapidly from 6.43 to 4.06 MPa when the pelleting increased from 140 to 160 rpm. At mixing ratios of 1.00:0.25:1.40, the compressive strength increased slightly from 0.90 to 1.61 MPa as pelleting speed increased from 100 to 120 rpm, and it decreased slightly from 1.61 to 0.84 MPa when the pelleting increased from 120 to 160 rpm. The compressive strength for the mixing ratio of 1.00:0.25:0.85 was higher than the mixing ratio of 1.00:0.25:1.40 throughout the range of pelleting speeds. The high value of compressive strength was in the range of 5.15 to 6.43 MPa at mixing ratio of 1.00:0.25:0.85 and pelleting speed in the range of 120 to 140 rpm.

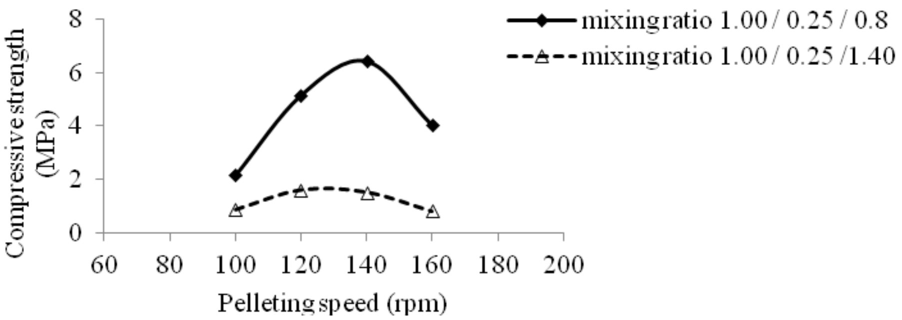

Figure 7 Effect of pelleting speed on compressive strength of sugarcane trash pellet at different mixing ratios

5. CONCLUSION

The results showed that mixing ratios and pelleting speeds significantly affected the bulk density, true density, porosity, durability and compressive strength. It was observed that the effect of mixing ratio was the most significant among all properties in this study.

The results showed that the mixing ratio by weight of 1.0:0.25:0.85 (ground sugarcane trash:cassava starch:water content) and pelleting speed of 120 to 140 rpm were optimum for producing the sugarcane trash pellets. The bulk density, true density and durability of biomass pellets were in the range of 330.93 to 365.00 kg/m^3, 860.38 to 918.43 kg/m^3, and 99.34 to 99.46%, respectively. The compressive strength was in the range of 5.15 to 6.43 MPa.

It was also recommended that other engineering properties be measured or calculated to provide fairly comprehensive information on design parameters involved in the sugarcane trash pellet storage and processing.

6. ACKNOWLEDGEMENT

This research was supported by the Center for Alternative Energy Research and Development, Khon Kaen University, Khon Kaen 40002, Thailand, the Postharvest Technology Innovation Center, Commission on Higher Education, Bangkok 10400, Thailand, and the Agricultural Machinery and Postharvest Technology Center, Khon Kaen University, Khon Kaen 40002, Thailand.

7. REFERENCES

Adapa, P.K., Tabil, L.G., Schoenau, G.J., 2013. Factors Affecting the Quality of Biomass Pellet for Biofuel and Energy Analysis of Pelleting Process. *International Journal of Agricultural and Biological Engineering*, Volume 6(2), pp. 1–12

ASABE Standard S269.4, 1993. *Cubes, Pellets, and Crumbles: Definitions and Methods for Determining Density, Durability, and Moisture Content*. St Joseph, MI

ASAE standard, 1993. *Standards Engineering Practices Data*, 40th eds., American Society of Agricultural Engineering, USA

Bhattacharya, S.C., Sheatha, R.M., 1990. *Biocoal Technology and Economics*, RERIC. Bangkok: Asian Institute of Technology

Chandrasekar, V., Viswanathan, R., 1999. Physical and Thermal Properties of Coffee. *Journal of Agricultural Engineering Research*, Volume 73(3), pp. 227–234

Colley, Z., Fasina, O.O., Bransby, D., Lee, Y,Y., 2006. Moisture Effect on the Physical Characteristics of Switchgrass Pellets. *Transactions of the ASABE*, Volume 49(6), pp. 1845–1851

DEDE, 2012. Available online at: http://www.dede.go.th/ Accessed on May 5, 2013

Donghui, L., Tabil, L.G., Decheng, W., Guanghui, W., Zhiqin, W., 2014. Optimization of Binder Addition and Compression Load for Pelletization of Wheat Straw using Response Surface Methodology. *International Journal of Agricultural and Biological Engineering*, Volume 7(6), pp. 67–78

Emami, S., Tabil, L.G., Adapa, P., George, E., Tilay, A., Dalai, A., Drisdelle, M., Ketabi, L., 2014. Effect of Fuel Addition on Agricultural Straw Pellet Quality. *International Journal of Agricultural and Biological Engineering*, Volume 7(2), pp. 92–100

Food and Agriculture Organization of the United Nations (FAO), 2014. Available online at: http://faostat3.fao.org/download/Q/QC/E, Accessed on January 5, 2016

Khongthon, N., Sudajan, S., 2014. Some Physical and Mechanical Properties of Sugarcane Trash Relating to the Criteria Design of a Sugarcane Trash Chopping Machine. *Advance Materials Research*, Volume 931-932, pp. 1574–1581

Lam, P.S., Sokhansanj, S., Bi, X., Lim, C.J., Naimi, L.J., Hoque, M., Mani, S., Womac, A.R., Ye, X.P., Narayan, S., 2008. Bulk Density of Wet and Dry Wheat Straw and Switchgrass Particles. *Applied Engineering in Agriculture*, Volume 24(3), pp. 351–358

Lehtikangas, P., 2001. Quality Properties of Pelletized Sawdust Logging Residues and Bark. *Biomass and Bioenergy*, Volume 20(5), pp. 351–360

Mahapatra, A.K., Harris, D.L., Durham, D.L., Lucas, S., Terrill, T.H., Kouakou, B., Kannan, G., 2010. Effects of Moisture Change on the Physical and Thermal Properties of Sericea Lespedeza Pellets. *International Agricultural Engineering Journal*, Volume 19(3), pp. 23–29

Mani, S., Tabil, L.G., Sokhansanj, S., 2006. Effect of Compressive Force, Particle Size and Moisture Content on Mechanical Properties of Biomass Pellets from Grasses. *Biomass and Bioenergy*, Volume 30(7), pp. 648–654

Obernberger, I., Thek, G., 2004. Physical Characterization and Chemical Composition of Densified Biomass Fuels with Regard to Their Combustion Behavior. *Biomass and Bioenergy*, Volume 27 pp. 653–669

Serrano, C., Monedero, E., Lapuerta, M., Portero, H., 2011. Effect of Moisture Content, Particle Size and Pine Addition on Quality Parameters of Barley Straw Pellets. *Fuel Processing Technology*, Volume 92(3), pp. 699–706

Stelte, W., Holm, J.K., Sanadi, A.R., Barsberg, S., Ahrenfeldt, J., Henriksen, U.B., 2011. A Study of Bonding and Failure Mechanisms in Fuel Pellets from Different Biomass Resources. *Biomass and Bioenergy*, Volume 35(2), pp. 910–918

Theerarattananoon, K., Xu, F., Wilson, J., Ballard, R., Mckinney, L., Staggenborg, S., Vadlani, P., Pei, Z.J., Wang, D., 2011. Physical Properties of Pellets Made from Sorghum Stalk, Corn Stover, Wheat Straw and Big Bluestem. *Industrial Crops and Products*, Volume 33(2), pp. 325–332

Tumuluru, J.S., 2015. High Moisture Corn Stover Pelleting in a Flat Die Pellet Mill Fitted with a 6 mm Die: Physical Properties and Specific Energy Consumption. *Energy Science and Engineering*, Volume 3(4), pp. 327–341

White, N.D.G., Jayas, D.S., 2001. Physical Properties of Canola and Sunflower Meal Pellets. *Canadian Biosystems Engineering*, Volume 43(3), pp. 49–52

WIP–Renewable Energies, 2009. Available online at: https://ec.europa.eu/energy/intelligent/projects/sites/ieeprojects/files/projects/documents/pelletslas_pellet_standards.pdf, Accessed on Jan 5, 2016

Zainuddin, M.F., Rosnah, S., Mohd Noriznan, M., Dahlan, I., 2014. Effect of Moisture Content on Physical Properties of Animal Feed Pellets from Pineapple Plant Waste. *Agriculture and Agricultural Science Procedia*, Volume 2, pp. 224–230

Zhou, B., Ileleji, K.E., Ejeta, G., 2008. Physical Property Relationships of Bulk Corn Stover Particles. *Transactions of the ASABE*, Volume 51(2), pp. 581–590