J. Trop. Agric. and Fd. Sc. 51(2)(2023): 61 – 66

The influence of moisture content and raw material size on the mechanical and calorific properties of rice husk pellets

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Abstract

Utilisation of the biomass pellets to generate heat is an alternative source of energy from renewable resources. Rice husk (RH) is biomass that was produced as a by-product from rice mill and has a great potential to be used as an energy feedstock. Nevertheless, the low bulk density (BD) and inconsistent moisture content (MC) of the RH have affected its potential application. Therefore, this study aims to investigate the effects on MC and particle size (PS) of pellet's compound on the quality of RH pellets. The BD, compression strength (CS) and gross calorific value (GCV) of the RH pellets were significantly influenced by the MC of pellet's compound. Particle size of the pellet's compound was not displayed a significant effect in this study unless for CS of the pellets. The range of results for the BD, CS, and GCV were 610 to 687 kg/m^3, 3372 to 7087 kN/m^2 and 14,828 to 15,204 J/g respectively. Combination of the pellet's compound at 12% MC and 6 mm PS has produced the best quality of RH pellet.

Keywords: moisture content, particle size, bulk density, densification, rice husk pellet

Introduction

Rice husk (RH) is a biomass that is produced as a by-product from rice mill and it has a great potential to be used as energy feedstock due to its chemical properties and availability in large quantity (Bakari and Ngadi 2013). The amount of RH can be estimated based on the ratio of rice grain to rice husk which is 1:0.22 depending on the variety, climate condition and geographical location (Ugheoke and Mamat 2012; Zhang et al. 2012). Based on the total figure of rice produced in Malaysia in 2020 the amount of RH generated is around 518,320 mt (MAFI 2020). Currently, most of the RH was burnt and dumped in open fields and a small amount was used as fuel for boilers and electricity generation. It is because the RH has a low-bulk density and usually below 200 kg/m^3 (Yank et al. 2016).

The densification process can be used to increase the bulk density of the RH. It also may increase the volumetric energy density and uniform size and quality. Hence, it might improve and facilitate handling, storage and transportation of the RH in bulk (Kaliyan and Morey 2010). Densification process can be divided into two methods which are mechanical densification and pyrolysis (Savage et al. 2013). Mechanical densification involves applying pressure to densify the material mechanically. Meanwhile, pyrolysis involves heating the biomass in the absence of oxygen.

A biomass densification system consisted of three major unit operations namely, drying, size reduction and pelletising. However, the drying process was less important in densification system of the RH. Normally, the MC of RH was not too high and can accommodate the size reduction operation. Size reduction was an important treatment of RH for energy conversion and densification process (Vijay 2012). It enhances the total surface area, the pore size of substance and the sum of contact points for inter-particle bonding in the compaction process. These were essential for the densification process.

Therefore, a study on the effect of MC and PS in production of rice husk pellet via densification process was conducted to determine the behaviour for each factor. The best combination of MC and PS for each type of testing will be obtained by analysing the experimental results.

Article history
Received: 20.6.2023
Accepted: 5.11.2023

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Materials and method

Materials

The sample of RH was obtained from MARDI's rice mill in Serdang, Selangor. It was supplied by using plastic drums that covered with a tight cap to keep the sample in good condition. Meanwhile, the glycerine has been used as binder and lubricant to assist in pellet formation.

Particle size reduction of rice husk

The laboratory cutting mill (Retsch 100, Germany) was used to reduce PS of 3 kg of RH sample for each cutting treatment. The sample of RH at specified wetness level was manually fed into cutting chamber through a hopper. The PS reduction treatment of RH was shown in *Table 1*.

Pelletising process of rice husk

Pellet compound preparation

The preparation of pellet compound before the pelletising process was conducted according to treatment matrix as exhibited in *Table 2*.

The sample of ground RH, water and glycerine were weighed by using digital weight balance (AND GF-3000, United Kingdom). In this study, the total amount of glycerine that was utilised in each pellet's compound was 20% (wet weight) of the total weight of ground RH. A transparent 20 x 40 mm plastic bag was used for each treatment of pellet during blending process. The pellet compound was manually stirred to disperse the ingredients. The MC of the pellet's compounds were verified and measured by using moisture analyser (AND MX-50, United Kingdom) prior to the pelletising process.

Pelletising process

The Pellet Press (Szetech SP300B, China) that powered by a 22kW electric motor and equipped with 6 mm of die hole diameter was utilised in this study. The pellet compound was manually fed into the pelletiser through a hopper. The temperature of pellets after exiting the die was around 80°C due to particle friction between pelletiser's roller and die. Then, it was cooled down to ambient temperature prior to conditioning process and quality assessment. The RH pellets were kept and conditioned in the laboratory for a week with temperature of 27 °C and humidity 50% to stabilise their properties (Liu et al. 2016).

Quality evaluation for rice husk pellet

Evaluation of the quality properties for the RH pellets was implemented to evaluate the BD, CS and GCV. Each sample that comprises of three groups of MC and PS as indicated in *Table 2* were tested by repeating three times. The average results of testing for each treatment were reported. Determination of BD was conducted by using a measuring cylinder and digital weight balance (AND GF-3000, United Kingdom). The RH pellet was poured into the cylinder from a height of 200 to 300 mm until full, and a debris cone has formed (European Pellet Council 2013). The excess of RH pellet sample was removed by striking a straight stick along the top. Then the mass of the cylinder that contains RH pellet sample was measured. The BD was calculated using the *Equation 1*.

$$BD = (m_2 - m_1)/V \qquad \text{(Equation 1)}$$

Where, m_1 (kg) is mass of the empty container, m_2 (kg) is mass of the full container and V (m^3) is the net volume of the measuring cylinder.

The CS of each RH pellet was determined by using INSTRON Universal Testing Machine 5567 that equipped with a 30 kN load cell. The cylindrical pellet was horizontally placed between two anvils, and compressive force was applied to the cylindrical surface of the pellet at compression speed of 10 mm/min and stopped once the pellet was broken or fractured. The maximum force to break the pellet's structure was recorded to calculate the value of compression strength. The CS was calculated by using the *Equation 2* (Liu et al. 2014):

$$CS = (2F)/(\pi L d) \qquad \text{(Equation 2)}$$

Where F (N) is maximum compression force; L (m) and d (m) are length and diameter of the pellet respectively.

The measurement of GCV for RH pellet was conducted by using oxygen bomb calorimeter (IKA Bomb Calorimeter C6000). Each analysis requires 0.5 g of RH pellet sample for the purpose of GCV measurement (Lu et al. 2014).

Table 1. Treatment of particle size reduction of rice husk sample

Sieve hole diameter SHD (mm)	Moisture content of RH (%)		
	12	16	20
6	Treatment 1	Treatment 2	Treatment 3
4	Treatment 4	Treatment 5	Treatment 6
2	Treatment 7	Treatment 8	Treatment 9

Table 2. Material compound treatment of rice husk pellet

Sieve hole diameter SHD (mm)	Compound moisture content CMC (%)		
	12	16	20
6	Pellet 1	Pellet 2	Pellet 3
4	Pellet 4	Pellet 5	Pellet 6
2	Pellet 7	Pellet 8	Pellet 9

Statistical analysis for rice husk pellet

The multiple regression and Two-Way ANOVA were conducted to each quality point of RH pellets by using Minitab 16 software. The relationship equation for each quality properties for RH pellet was obtained from the result of the multiple regression analysis.

From the Two-Way ANOVA, the significant factor that influenced the quality properties was achieved by comparing the mean value of each factor. The P-value from the analysis was referred to justify the significant level of each factor at confidence interval (CI) of 95%.

Results and discussion

Quality evaluation of rice husk pellet

a. Bulk density

The result of BD analysis for RH pellets is exhibited in *Table 3*.

The highest BD of the RH pellets was 687 kg/m³ from a combination of pellet's compound at 12% moisture content (MC) and 6 mm particle size (PS). Meanwhile, the lowest BD of RH pellets exhibited by the combination at 20% MC and 2 mm PS with the value of 610 kg/m³. The results obtained from this study were higher than the results as reported by Widjaya et al. (2019) which is 511 kg/m^3 that was produced via flat-die roller type of pelletiser. The densification process has increased tremendously the BD of RH pellet as compared to the BD of RH.

The BD has displayed a negative correlation with MC of the pellet's compound. The trend of this findings is similar to the results from Theerarattananoon et al. (2011) and Larsson et al. (2008) as their study using different materials. However, the particle size of the pellet's compound has presented a fluctuated trend of BD. This result was contradicted by the findings obtained by Sudhagar et al. (2006) and Harun and Afzal (2016) due to the variation of pelletising method to produce a pellet. In their study, the single pelletiser unit was used to produce pellets from other biomass.

Table 3. Result of bulk density for rice husk pellet

Moisture content, MC (%)	Particle size, PS (mm)	Average bulk density of RH pellet (kg/m^3)	Standard deviation, SD (kg/m^3)
12	6	687	12.2
12	4	678	13.1
12	2	676	11.3
16	6	645	11.4
16	4	644	13.2
16	2	646	10.6
20	6	621	13.9
20	4	630	10.1
20	2	610	12.5

Compression strength

The result of CS analysis for RH pellets was illustrated in *Table 4*. In general, the CS displayed a negative correlation as the MC of pellet's compound increased. These findings were similar to the results as published by Missagia et al. (2011) as their study using the same type of biomass and the pellet was produced via laboratory compactor. They have conducted the study at 17%, 19% and 20%; 2 mm, 4 mm and 6 mm of the compound moisture content and particle size respectively. Their study has concluded that pellets with lower moisture content and finer particle size exhibited a higher degree of hardness.

Table 4. Result of compression strength for rice husk pellet

Moisture content, MC (%)	Particle size, PS (mm)	Average compression strength (kN/m^2)	Standard deviation, SD (kN/m^2)
12	6	7,087	335
12	4	5,258	241
12	2	5,069	234
16	6	4,555	210
16	4	4,663	198
16	2	3,992	185
20	6	4,333	208
20	4	4,358	192
20	2	3,372	168

However, the particle size of pellet's compound had shown a positive relationship with the CS as it increasing. This result was contradicted of Missagia et al. (2011) and Wilson (2010) findings due to different pelletising method. The possible reason was the changes of PS distribution during pelletising process. At bigger particle size of the pellet's compound, the strength was greater because the mixture of particle size could improve inter-particle bonding (Yank et al. 2016).

The highest CS of RH pellets was 7,087 kN/m^2 from the combination of pellet's compound at 12% MC and 6 mm particle size. Meanwhile, the lowest CS of RH pellets was represented by pellet's compound at 20% MC and 2 mm particle size with the value of 3,372 kN/m^2. However, the result of CS obtained by Missagia et al. (2011) was higher that the results from this experiment. At 20% MC, their results of CS were 6,150 kN/m^2, 5,090 kN/m^2 and 5,520 kN/m^2 for 2 mm, 4 mm and 6 mm particle sizes, respectively.

Gross calorific value

The result of GCV analysis for RH pellets was displayed in *Table 5*. The results of GCV of RH pellet for all treatments have passed the minimum calorific value as specified in the Mixed Biomass Pellet standards which is greater than 14,700 J/g (Nunes et al. 2014).

The highest GCV of RH pellets was 15,204 J/g from the combination of pellet's compound at 12% MC and 6 mm particle size. Meanwhile, the lowest GCV of RH pellets was represented by pellet's compound at 20%

Table 5. Result of gross calorific value for rice husk pellet

Moisture content, MC (%)	Particle size, PS (mm)	Average gross calorific value (J/g)	Standard deviation, SD (J/g)
12	6	15,204	421
12	4	15,183	396
12	2	15,136	432
16	6	15,019	520
16	4	15,070	470
16	2	14,950	509
20	6	14,905	385
20	4	15,044	486
20	2	14,828	420

MC and 2 mm particle size with the value of 14,828 J/g. These results were slightly lower than the data as reported by Su X. et al. (2013). They have produced RH pellets using two additive materials namely glycerol palmitate and anthracite. The optimal formulation was displayed by combination of 72% RH, 15% water, 5% glycerol palmitate and 8% anthracite with the calorific value of 17,000 J/g.

The value of GCV showed a downward trend as the MC of pellet's compound increases. This pattern was similar to the findings by Demirbas (2007) and Atnaw et al. (2014) by using various biomass other than rice husk in their study. They have concluded that moisture in the pellet might decrease its calorific value. The particle size of biomass is not directly influencing the result of GCV because the lignin content is considered similar to all pellet's compound. Lignin content in the biomass has displayed a strong correlation on the result of GCV as studied by Dermibas (2001).

Results of the GCV at different particle sizes had shown inconsistent trend. At 12% MC of material compound, the results of GCV have indicated an upward trend while the particle size increase. Dispersion of glycerine as binder material in bigger particle size of pellet's compound is better and resulted to higher value of the GCV. However, trend of the GCV results for pellet's compound at 16% and 20% of MC were inconsistent probably due to uneven dispersion of the glycerine. Sample of the with 4 mm particle size has contained more glycerine and resulted to higher calorific value.

Statistical analysis of rice husk pellet

Multiple regression

The summary result of P-value from multiple regression can be summarised as shown in *Table 6*.

The MC has significantly influenced the relationship for each quality properties. Meanwhile the PS has not significantly affected the relationship for bulk density and gross calorific value. Changes of the PS distribution during pelletising process has mainly affected the result. For the CS, PS has resulted to the significant relationship possibly due mixing of binder material was well distributed. Detailed results for the multiple regression is shown in *Table 7*, *Table 8* and *Table 9*.

Table 6. Summary of P-value for multiple regression analysis

Quality properties	Moisture content (MC)	Particle size (PS)
Bulk density	0.000	0.210
Compression strength	0.007	0.039
Gross calorific value	0.005	0.270

Table 7. Result of multiple regression of BD for RH pellet

Predictor	Coef	SE Coef	T	P
Constant	760.66	11.91	63.86	0.000
CMC	–7.4633	0.6550	+11.39	0.000
SHD	1.837	1.310	1.40	0.210

Table 8. Result of multiple regression of CS for RH pellet

Predictor	Coef	SE Coef	T	P
Constant	7130268	1017968	7.00	0.000
CMC	–222997	55981	–3.98	0.007
SHD	295148	111962	2.64	0.039

Table 9. Result of multiple regression of GCV for RH pellet

Predictor	Coef	SE Coef	T	P
Constant	15466.6	133.5	115.87	0.000
CMC	–31.083	7.340	–4.23	0.005
SHD	17.83	14.68	1.21	0.270

The relationship equation for each quality properties as presented in below equation.

$$BDP = 761 - 7.46\ CMC + 1.84\ SHD,\ (R\text{-}Sq. = 95.6\%) \quad (Equation\ 3)$$

Where, *BDP* (kg/m^3) is *BD* of RH pellets, *CMC* (%) is MC of pellet's compound and *SHD* (mm) is sieve holes diameter that represented particle size.

$$PCS = 7130268 - 222997\ CMC + 295148\ SHD,\ (R\text{-}Sq = 79.2\%) \quad (Equation\ 4)$$

Where *PCS* (N/m^2) is CS of RH pellets, *CMC* (%) is MC of pellet's compound and *SHD* (mm) is sieve holes diameter which represented the particle size.

$$PCV = 15467 - 31.1\ CMC + 17.8\ SHD,\ (R\text{-}Sq. = 76.4\%) \quad (Equation\ 5)$$

Where *PCV* (J/g) is GCV of RH pellets, *CMC* (%) is MC of pellet's compound and *SHD* (mm) is sieve holes diameter which represented the particle size.

b. Two-Way ANOVA

The summary result of P-value from Two-Way ANOVA for all quality properties as indicated in *Table 10.* Meanwhile, the details result of this analysis were displayed in *Table 11*, *Table 12* and *Table 13*.

Table 10. Summary of P-value for two-way ANOVA analysis

Quality properties	Moisture content (MC)	Particle size (PS)
Bulk density	0.002	0.409
Compression strength	0.038	0.145
Gross Calorific value	0.008	0.061

Table 11. Result of two-way ANOVA of BD for RH pellet

Source	DF	SS	MS	F	P
CMC	2	5399.15	2699.57	61.11	0.001
SHD	2	99.57	49.78	1.13	0.409

The results of Two-Way ANOVA have indicated that only MC has significantly influenced the result for each quality. These results can be observed in the main effects plot as displayed in *Figure 1*, *Figure 2* and *Figure 3*.

Generally, the range of mean showed by the effect of MC of pellet's compound was bigger than the effect of PS. Hence, the effect of the MC can be proved as the main factor which influenced the BD, CS and GCV of RH pellets. The best combination to produce RH pellet at optimum quality was represented by pellet's compound at 12% MC and 6 mm of PS. This combination has displayed the highest result for BD and CS.

Table 12. Result of two-way ANOVA of CS for RH pellet

Source	DF	SS	MS	F	P
CMC	2	5.29277E + 12	2.64639E + 12	8.24	0.038
SHD	2	2.09197E + 12	1.04599E + 12	3.26	0.145

Table 13. Result of two-way ANOVA of GCV for RH pellet

Source	DF	SS	MS	F	P
CMC	2	94358	47179.1	20.60	0.008
SHD	2	27900	13950.1	6.09	0.061

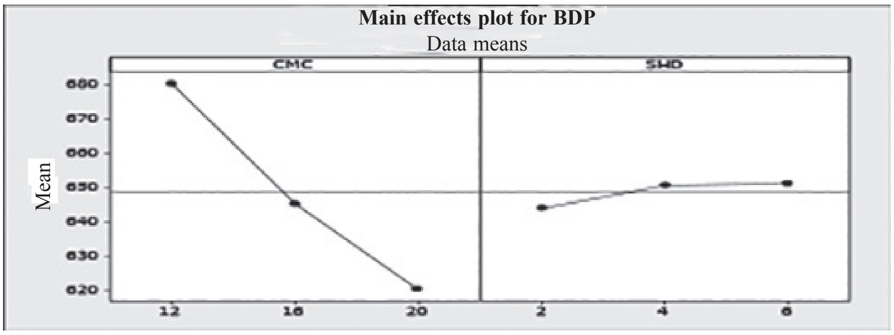

Figure 1. Main effects plot of BD for RH pellets

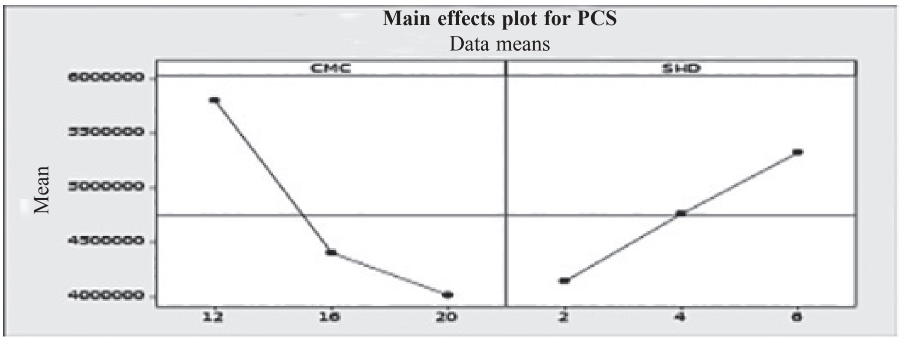

Figure 2. Main effects plot of CS for RH pellets

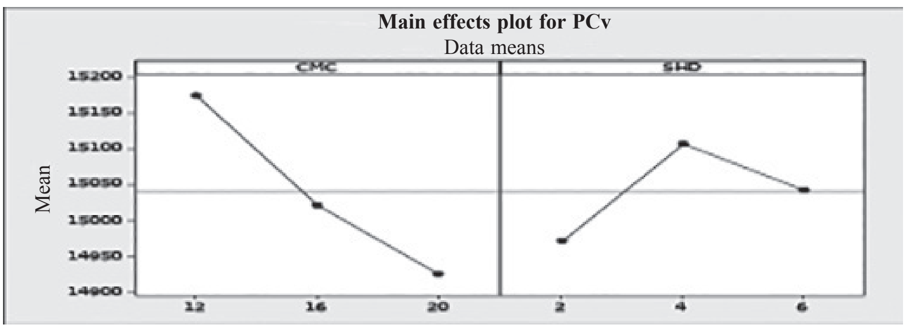

Figure 3. Main effects plot of GCV for RH pellets

Conclusion

Evaluation of the pellets quality has successfully conducted to investigate the influence of moisture content (MC) and particle size (PS) of pellet's compound on its mechanical and calorific properties. Moisture content of the pellet's compound has significantly influenced the bulk density (BD), compression strength (CS) and gross calorific value (GCV) of the RH pellets. These results have indicated a downwards trend as the value of moisture content increased. Meanwhile, the CS also indicated a significant result at different PS by displaying a positive trend as the PS increased. However, the results of bulk density (BD) and gross calorific value (GCV) have not been affected by the PS. Combination of the pellet's compound at 12 % MC and 6 mm PS has produced the best quality of the RH pellet.

Acknowledgement

The authors would like to gratefully acknowledge MARDI and UPM for the laboratory facilities and financial support. In addition, we thank all parties that were directly or indirectly involved in this study.

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