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Increasing of High Heating Value of Organic Waste by Microwave-Assisted Drying Pretreatment

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ABSTRACT

Biomass is a promising renewable source for producing various biofuels. This study aimed to improve the high heating value (HHV) of organic waste (vegetable waste) by microwave-assisted drying pretreatment. Organic waste samples, a type of biomass, were obtained from Nonthaburi fresh market: cabbage (Brassica oleracea var. capitata), napa cabbage (Brassica rapa subsp. pekinensis), morning glory (Ipomoea aquatica), kale (Brassica oleracea var. alboglabra) and radish (Raphanus sativus subsp. longipinnatus). The pretreatment was conducted by drying for 1 h, microwave-assisted 450W for 5 min and drying for 1 h, microwave-assisted 800W for 5 min and drying for 1 h and drying for 3 h, all conditions were conducted at 105°C. The results showed that the high initial moisture content of organic waste samples of 90% to 96% after pretreatment shows the high moisture removal content percentages of about 90–96% after microwave-assisted 800W and drying for 1 h and increasing its HHVs were 13.83–15.51 MJ/kg. Moreover the %HHV comparison by microwave-assisted drying pretreatment was higher than conventional drying. In addition, cabbage showed that the highest of its HHV was 16.15 MJ/kg after drying for 3 h. Hence, the results of HHVs of organic waste samples indicated a possible ability to be utilized as biofuel.

1. INTRODUCTION

There have been numerous biomass resources for the production of biofuel. Biofuels are usually classified as follows: food crops, organic waste and agricultural residues (such as wheat straw [1], rice straw and rice husks [2], corn cobs, coconut shells [3], fruit peels [4]) and algae, since algae can accumulate lipids, capture CO_2, some types of algae have a calorific value at level of wood [5], [6], microbes and microalgae, CO_2 capture or other advanced technologies [7], [8], [9]. Organic waste (vegetable waste) also known as biodegradable waste/biomass, is produced mainly from living organisms, either plants or animals [10], [11].

Due to an increase of population and limitation of landfill facility, composting and conversion are the most common ways to manage organic waste safely [12], [13]. In economic terms, organic waste can be converted into a source of heat generation electricity, hot water, and steam or in form of biofuel production [14]. In the past nine years, the information of municipal solid waste (MSW) of Nonthaburi Province in Thailand trends increased and was around 0.73 million tons in 2021. Because of restriction of landfill areas; therefore, waste management for usefulness and a sustainable basis is necessary [15], [16].

Limitation parameter of organic waste and high moisture content biomass is higher moisture content (in vegetable waste around 88 to 94%) [5], [6] (in aquatic biomass around >98%) [17], [18]. Moisture content in organic waste is an important parameter in thermal pre-treatment (a type of physical pre-treatment) for converting organic waste into fuel energy by reducing the moisture content [14], [19], [20].

Microwave processing has exhibited its potential for drying and pre-treatment method [21]-[24]. Thermal pre-treatment was used as a potential method for organic waste pre-treatment, and microwave pre-treatment has been found to be effective in organic waste stabilization [21]. Moreover, microwave-assisted technology has been applied for biochar production in many research which informed of microwave-assisted hydrothermal carbonization [25], [26]. The use of microwave information of drying worked with organic waste to produce biochar was absent. In this study, vegetable wastes, which lignocellulosic biomass wastes, were taken as a pre-treatment to study for increasing the high heating value by using the household microwave for drying and converting biomass.

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2. MATERIALS AND METHODS

2.1 Raw Material and Preparation

Organic waste samples (vegetable wastes) of top 4 types, i.e., cabbage (Brassica var. capitata), napa cabbage (Brassica rapa subsp. pekinensis), morning glory (Ipomoea aquatica) and kale (Brassica oleracea var. alboglabra) were selected by systematic sampling of organic waste from Nonthaburi fresh market, Mueng Nonthaburi district, Nonthaburi province [20]. Radish (Raphanus sativus subsp. longipinnatus) is root vegetable, was also investigated because of difference in morphology.

The fresh organic waste was collected in the early morning then cut of size 1x1 cm±0.17×0.24 cm. After cutting, the remainder was kept in the refrigerator before use in further experiment. Only not over two weeks-old material was used as raw material.

2.2 Experimental Procedure

Organic waste samples with size of 1x1 cm±0.17×0.24 cm, weighed 10 g per sample and placed in each ceramic container. Drying process for moisture removal was conducted by a universal oven (Memmert Universal Oven UF55, Germany) and microwave-assisted drying by household microwave (Samsung ME711K Microwave Oven, Malaysia). The pre-treatment was conducted in 4 conditions as shown in Table 1. For each condition was repeated three times.

Table 1. Pretreatment conditions.

Pretreatment	Conditions
Drying (D)	1) 1 h
	2) 3 h
Microwave-assisted	1) 450 W 5 min+ drying 1 h
+ Drying (MW+D)	2) 850 W 5 min+ drying 1 h

2.3 Characteristic Analysis

To compare the drying condition and microwave-assisted drying condition on moisture removal, proximate analysis, fiber analysis, and ultimate analysis were analyzed. The analysis methods with the results in this section were taken from [20]. The proximate analysis provides moisture content (ASTM E 871-82) [27]), volatile matter (ASTM E-872 [28]), ash content, and fixed carbon content (ASTM D 1102 [29]). Fiber analysis, cellulose, hemicellulose, and lignin contents were analyzed according to [20]. AOAC Official Method 2002.04, 2016 [30], AOAC Official Method 973.18, 2016 [31] and AOAC Official Method 973.18, 2016 [31]). The ultimate analysis gives element percentages of C, H, N, O, and S was analyzed according to [20] (ISO 16948:2015 with CHNS/O Analyzer with FlashSmart model, Thermo Scientific, Thermo Quest).

2.4 High Heating Value Determination

The high heating value (HHV) of biochar product was analyzed by bomb calorimeter model LECO AC500 using ASTM standard D-2015 [32]. Product from microwave-assisted pre-treatment was wet therefore it was necessary dried in hot air oven (Memmert Universal Oven UF55, Germany) at 105°C for 1 h before analyzing of HHV by bomb calorimeter. The HHV of some organic waste which has stalk and leaf can be calculated by using heating value of each portion according to Equation 1:

$$\text{HHV}=\left(\text{HHV}\times\left(\frac{\%\text{weight of stalk}}{100}\right)\right)+\left(\text{HHV}\times\left(\frac{\%\text{weight of leaf}}{100}\right)\right) \quad (1)$$

2.5 Calculation

Removed moisture of the biomass after thermal pretreatment was calculated with the following Equation 2:

%Removed moisture =

$$\left(\frac{\text{weight before drying} - \text{weight after drying}}{\text{weight before drying}}\right)\times 100 \quad (2)$$

Removed-moisture comparison was calculated percentage deviation which was based on the removed moisture percentage of 105°C 1 h drying with the following Equation 3:

%Removed-moisture comparison =

$$\left(\frac{\left(\begin{matrix}\%Removed\ moisture\ at\ each\ condition\ - \\ \%Removed\ moisture\ after\ 105\,℃\ 1\ h\ drying\end{matrix}\right)}{\%Removed\ moisture\ after\ 105\,℃\ 1\ h\ drying}\right)\times 100 \quad (3)$$

HHV comparison was calculated percentage deviation which was based on HHV of 105°C 1 h drying with the following Equation 4:

%HHV comparison =

$$\left(\frac{\left(\begin{matrix}HHV\ at\ each\ condition\ - \\ HHV\ after\ 105\,℃\ 1\ h\ drying\end{matrix}\right)}{HHV\ after\ 105\,℃\ 1\ h\ drying}\right)\times 100 \quad (4)$$

3. RESULTS AND DISCUSSION

3.1 Characteristics of Organic Waste

All vegetable wastes contain high initial moisture contents, more than 90% (Table 2 which was modified from [20]). The results obtained show a high initial moisture content that settled in space within the cell that requires high fuel and large equipment dimension usage [33], [34]. The HHV (as-dried, after drying at 105°C 1 h) of morning glory (leaf) showed the highest value, followed by kale (leaf) and cabbage were 18.78, 17.35, and 16.85 MJ/kg, respectively. Morning glory showed the highest percentage of lignin and HHV were about 4.31% and 18.78 MJ/kg, respectively (Table 2), consistent with reports of [34], [35], [36], [37], HHV of biomass fuels increases as increase lignin contents. In addition, other factors such as chemical elements also C and H tend to raise the heating value while oxygen decreases [34], [38]. Moreover, Table 2 shows HHV (as received), minus means additional heat was applied to material for dehydrating water content before acting like fuel.

3.2 *Effect of Time and Power of Microwave on Moisture Removal*

The condition of organic wastes, drying in particular, is a prerequisite due to its high initial moisture content [33]. Biomass fuels are composed of biopolymers which consist of cellulose, lignocellulose, hemicelluloses, and lignin [33], [35], [39]. This research demonstrated the effect of microwave-assisted drying pre-treatment conditions compared to conventional drying method at 105°C 1 h in form of percentage of removed-moisture comparison according to Equation 3. Percentage of removed-moisture comparison in Figure 1 showed the highest in radish (95.26%) follows with cabbage, kale, morning glory and napa cabbage, respectively. The results of removed-moisture comparison (%) related with cellulose content in each type of organic waste; radish has the highest cellulose content (62.22% of fiber content) compared to others (kale 60.15%; cabbage 47.08%; napa cabbage 41.67% and morning glory 36.36%). Moreover, when microwave mechanism is taken, the water molecule absorbs microwave more readily than other component [40].

Figure 1 also showed the percentage of moisture removal after drying at 105°C of all vegetable type increases when increasing time from 1 h to 3 h and have been found the same in general drying process [20]. For microwave-assisted drying pre-treatment, at the same power increasing microwave heating time increased moisture removal. However, burnt spot was found on the surface of material [41].

Similarly, the percentage of moisture removal after microwave-assisted for 5 min of all vegetable types increases when increasing power of microwave from 450W to 800W (Figure 1). The dehydration was very fast and without any destroying. However, over heating condition occurred of burnt surface, and thus, some chemical reactions were likely to take place as found the same in the previous study [40]. Under high temperatures (also high power of microwave applied), the fresh leaf of the vegetable was decreased in size, reduced the fresh weight because unbound water was removed from the cell surface. During a longer heating time, the color changes to brown because of the browning effect and burning.

Microwave-assisted drying needs less time to reduce moisture content and exhibits the same or higher percentage of moisture removal than the drying method. At the same time, microwave-assisted drying using high power of microwave more effectively removed moisture than using low power of the microwave. Because inhomogeneous of material and/or microwave intensity might result of burnt spot on the surface.

Table 2. Characteristics of organic waste. (Modified from [20]).

	Types							
	Cabbage	Napa cabbage (stalk)	Napa cabbage (leaf)	Morning glory (stalk)	Morning glory (leaf)	Kale (stalk)	Kale (leaf)	Radish
Proximate analysis composition (% wb)								
Moisture	93.33±0.14	96.46±0.37	94.43±0.86	96.22±0.01	92.03±0.67	93.56±0.55	90.04±0.96	96.01±0.11
Ash	0.82±0.04	0.47±0.02	0.67±0.04	0.85±0.06	1.02±0.04	1.17±0.08	0.76±0.17	0.44±0.05
Fixed-carbon	2.40±0.23	2.30±0.21	4.30±0.55	2.20±0.70	5.09±0.21	5.19±0.63	8.57±0.96	3.07±0.28
Volatile matter	1.10±0.05	0.37	1.71±0.21	1.41	0.85±0.17	1.39	0.38±0.00	0.48±0.11
Ultimate analysis (% as received)								
C	38.89±0.80	37.03±1.44		38.73±2.79		37.52±0.67		39.05±0.25
H	5.50±0.13	5.47±0.41		5.31±0.49		5.40±0.41		6.03±0.16
N	3.49±0.01	4.11±0.88		5.23±0.63		3.61±0.50		1.44±0.16
O	37.61±1.41	42.76±1.96		35.98±0.01		42.70±2.55		43.37±0.40
S	1.26±0.19	1.16±0.04		1.04±0.15		0.88±0.01		0.81±0.08
Fiber analysis (%)								
Cellulose	2.42±0.06	0.75±0.1		5.92±0.14		1.63±0.04		0.56±0.01
Hemicellulose	2.02±0.03	0.66±0.01		7.69±0.16		0.70±0.01		0.19±0.02
Lignin	0.70±0.01	0.39±0.00		4.31±0.06		0.38±0.01		0.15±0.00
HHV (MJ/kg) (as-received)	-413.11	-1,678.60		-1,242.50		-1,075.20		-1,750.93

3.3 Effect of Time and Power of Microwave on HHV

The conversion of organic waste into fuel energy depends on the moisture content in organic waste. In generally, moisture in biomass decreases its heating value [20], [33]. The results showed that the HHVs of most vegetable types were conducted by drying at 105°C increase when increasing time from 1 h to 3 h. Similarly, the HHVs of some vegetable types were conducted by microwave-assisted for 5 min increase when increasing the microwave power from 450W to 800W (Figures 2 to 3). Microwave energy can act as many reactions in various phases; dehydration, decarboxylation, tar cracking and oxidation [26], [42].

Microwave-assisted drying needs less time to increase HHV than the drying method. At the same time, microwave-assisted drying using high power of microwave gives more HHV than using low power of microwave. Moreover the % HHV comparison was higher than conventional drying (Figures 2 to 3). HHVs of vegetable waste samples (13.47–15.51 MJ/kg) showed close to and higher than some biofuels currently in use as rice husk and rice straw (14.36 and 12.33 MJ/kg, respectively) [43], [44]. Therefore, microwave-assisted drying pre-treatment vegetable waste is a possibility that it can be used as a biofuel.

3.4 High Heating Value Comparison Pretreatment Method Comparison

The main point of the pre-treatment process is the need to remove this moisture to benefit biofuel production [34]. The results showed that the highest HHVs (as-dried) of most vegetable types are about 13.40-15.50 MJ/kg after microwave-assisted 800 W for 5 min and drying at 105°C for 1 h (Figures 2 to 3).

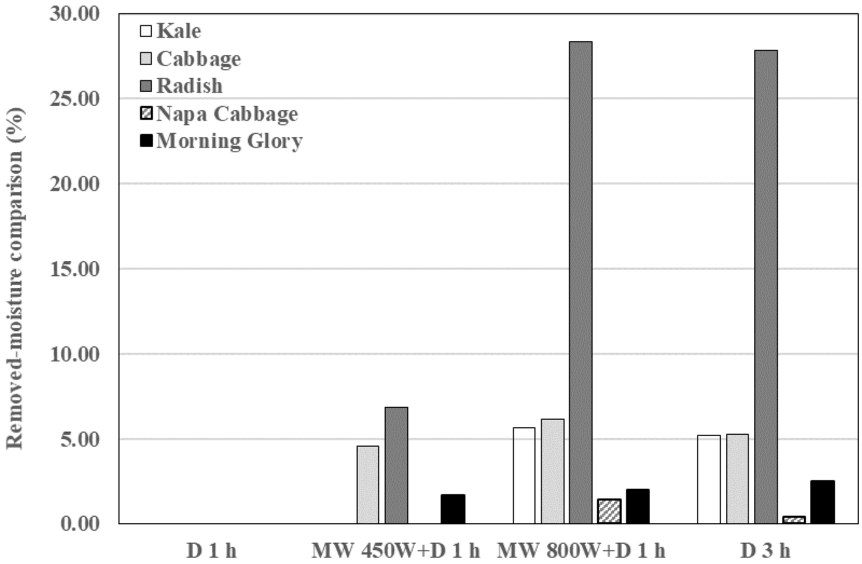

Fig. 1. Percentage of moisture removal comparison.

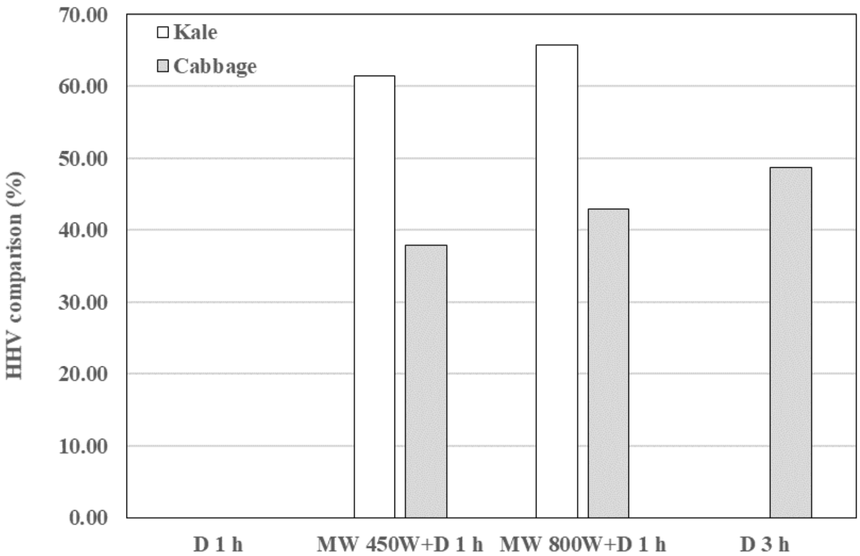

Fig. 2. Comparison of HHVs of kale and cabbage after microwave-assisted drying pretreatment to 1 h drying. (D = Drying, MW = Microwave-assisted).

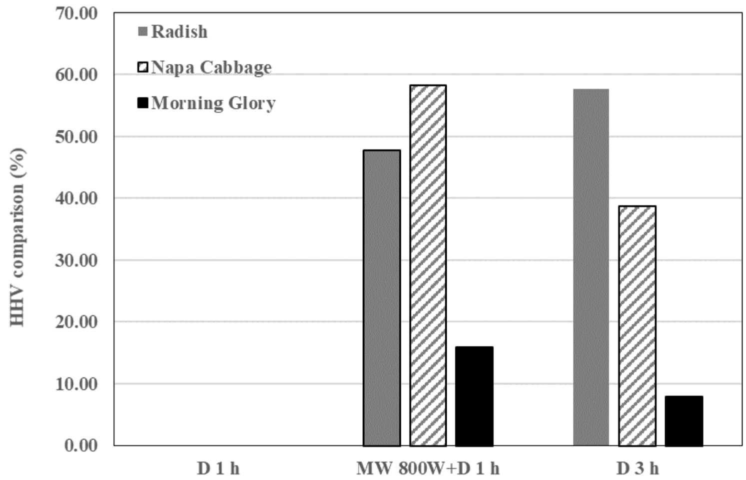

Fig. 3. Comparison of HHVs of radish, napa cabbage, and morning glory after microwave-assisted drying pretreatment after microwave-assisted drying pretreatment to 1 h drying. (D = Drying, MW = Microwave-assisted).

Fig. 4. Physical appearance of organic wastes after drying at 105 °C for 1 h: (a) cabbage; (b) radish; (c) napa cabbage (stalk); (d) napa cabbage (leaf); (e) kale (stalk); (f) kale (leaf); (g) morning glory (stalk); (h) morning glory (leaf).

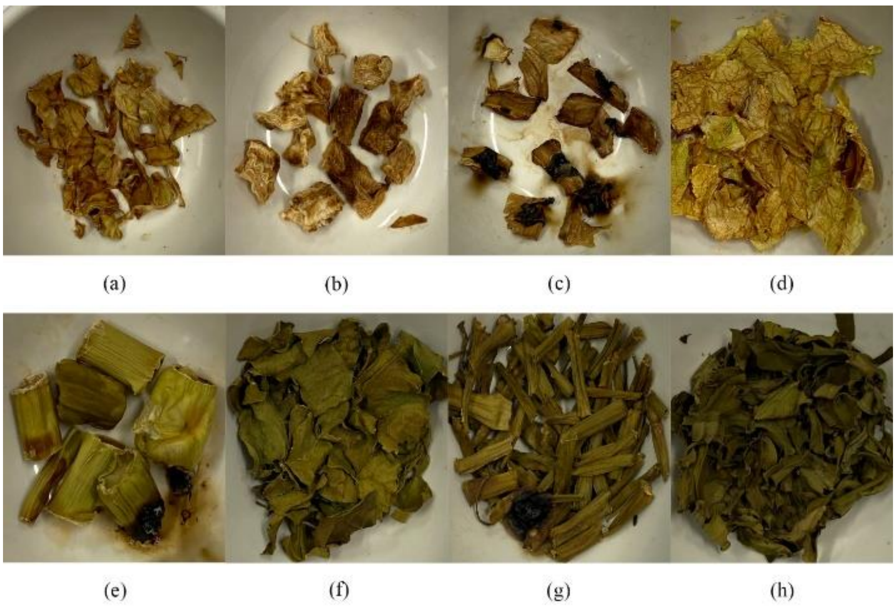

Fig. 5. Physical appearance of organic wastes after microwave assisted 800W for 5 min and drying at 105 °C for 1: (a) cabbage; (b) radish; (c) napa cabbage (stalk); (d) napa cabbage (leaf); (e) kale (stalk); (f) kale (leaf); (g) morning glory (stalk); (h) morning glory (leaf).

The physical appearance of organic waste is illustrated in Figure 5 compared to drying in Figure 4, increasing in high power of microwave enhanced greenish-brown, brown, black color and dry and crispy leaves. In same condition showed that the highest percentage of moisture removal was about 90 to 96% (Figure 1). On the contrary, the lowest HHVs of most vegetable types are about 8.90-11.90 MJ/kg after drying for 1 h at 105°C (Figures 2 to 3). The physical appearance of organic waste was illustrated in Figure 4, drying for 1 h at 105 °C enhanced starting to turn brown color (Figures 4a, 4d) and others were still green color (Figures 4e to 4h) and white color (Figures 4b to 4c), which remained high moisture content. In same condition, the lowest percentage of moisture removal was about 74 to 94% (Figure 1). After thermal retreatment, the color change can be attributed to several reactions: the oxidation reaction, the crosslinking cooperating with condensation reactions, and the enzyme-mediated (Maillard) reactions [45]. As a result, the HHVs of organic waste increase with decreasing moisture content, consistent with the previous study of Demirbas (2007) [33]. Kale showed the highest HHV after microwave-assisted 800W for 5 min with drying 1 h was about 15.50 MJ/kg, followed by microwave-assisted 450W for 5 min and drying at 105°C for 1 h about 15.10 MJ/kg. Napa cabbage and morning glory showed the highest HHVs after microwave-assisted 800W for 5 min and drying at 105°C for 1 h about 14.20 and 13.83 MJ/kg, respectively, followed by drying at 105°C for 3 h about 12.44 and 12.88 MJ/kg, respectively. In contrast, cabbage and radish showed the highest of HHVs after drying for 3 h at 105°C were about 16.15 and 14.37 MJ/kg, respectively, followed by microwave-assisted 800W for 5 min and drying for 1 h at 105°C about 15.51 and 13.47 MJ/kg, respectively (Figures 2−3). The drying method needs a longer time to increase HHV and gives the same amount of energy for some vegetable types compared to the microwave-assisted drying method. In comparison, the microwave-assisted method needs the high power of the microwave and less time to increase HHV compared to the drying method. Consequently, the microwave-assisted drying method is more energy efficient than the drying method.

3.4 Specific Energy Consumption (*SEC*)

SEC of the drying process was calculated according to Equation 5.

$$SEC = \frac{E}{m_{biomass}} \qquad (5)$$

where E is energy used for drying process and $m_{biomass}$ is weight of biomass product.

SEC based on biomass weight in the experiment for drying process were 66.17 (1 hour 105°C) and 128.56 (1 hour 300°C). SEC for microwave-assisted drying were 0.05 (5 min 450 W) and 0.12 (5 min 800 W). Wang *et al.* (2008) insisted that microwave drying had more potential technology than conventional heated air drying [40].

4. CONCLUSION

This paper study thermal pre-treatment using the microwave-assisted drying method to increase the high heating value (HHV) of organic waste. When comparing the drying method and microwave-assisted drying method, the process with microwave-assisted drying, 800W for 5 min and drying at 105°C for 1 h condition has more removing moisture content from an organic waste sample (90 to 96%) and can increase its HHVs (13.47 to 15.51 MJ/kg). Moreover, cabbage showed that the highest of its HHV was 16.15 MJ/kg after drying at 105°C for 3 h. Hence, the microwave-assisted drying method could be used as an alternative approach to conventional heating for sample pre-treatment due to the heating of the waste occurring more quickly and efficiently, shorter processing time and more energy efficiency. Through microwave-assisted drying pre-treatment, abundant vegetable waste can be valorized into biofuels. Due to the problem of organic waste that occurs in large amounts from Nonthaburi city municipality fresh market and the landfill area are limited. Therefore, it is necessary to study for production of biofuel from other organic waste types (different organic waste types shows distinct energy content and element) to reduce the number of organic wastes and be alternative energy in the future.

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