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# The energy potential evaluation of biomass fuel from weed pellets

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**Abstract** The giant sensitive plant had the most appropriated qualifications for pellet production, as it contained a low content of moisture (3.07%) and ash (2.68%), and a high percentage of fixed carbon (14.13%) and volatile matter (80.12%) with the highest lower heating value of 18,334.08 J/g. It was found that a higher mixing ratio of water for pelletization led to increasing moisture and ash content but resulted in lower volatile matter and fixed carbon. The best mixing ratio for was 8% of water by weight, at which the evaluated properties of the giant sensitive plant pellets: LHV, FC, VM and ash content, were 18,747.46 J/g, 10.92%, 78.77% and 2.24%, respectively. The evaluation of the physical properties of the pellets revealed that a higher amount of water resulted in a larger diameter, greater length and higher fines content. Comparison of pellets from this work with the standard classes of biomass pellets found that the giant sensitive plant pellets could be classified in class I3. It was clearly seen that the weed can be utilized as a useful biomass fuel and formed in a pellet shape for combustion in industrial sectors.

**Keywords:** Biomass pellet, Weed, Heating value, Giant sensitive plant

## Introduction

At present, with energy demand increasing, biomass is being promoted as a source of energy because it helps to reduce greenhouse gases and to balance out $CO_2$ emissions (Pizzi *et al*., 2018; Sirisomboon *et al*., 2020). Generally, agricultural waste such as bagasse, corncobs, rice straw, rice husk, and cassava roots are the most utilized.

However, farmers inevitably encounter weeds among their crops. Some weed species have potential to be used as a source of energy due to having a suitable calorific value, being naturally occurring plants, highly resistant to the

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environment and able to grow quickly. On the other hand, weeds are of concern for reducing crop yields and blocking the water flow of rivers and canals. Farmers usually burn their fields to prepare the land and encourage the growth of the next crop. This method is widely used as it is very cheap and quickly removes competition from weeds, but it is very harmful for both the environment and human beings. It can cause fog and smoke to rise into the atmosphere, generating the PM 2.5 which can cause health effects such as irritation of the eye, nose, throat, and lungs.

It seems useful to utilise the weeds with other aspects instead of eliminating by conventional ways. Yu *et al*. (2017) coverted cattail to be $CO_2$ activated porous to remove malachite greens dye used as supercapacitors. Haque *et al*. (2015) found that the cogon grass provided a good potential for bioethanol after mild alkali pretreatment to enhance the enzymatic hydrolysis. Wongsiriamnuay *et al*. (2008) reported that the giant sensitive plant (*Mimosa pigra* L.) could be utilized through the gasification at relatively moderate conditions and could be used as biofuel. The giant sensitive plant is rich in carbon and volatile matter with relatively high heating values. Wongsiriamnuay and Tippayawong (2010) who studied on thermal degradaion of giant sensitive plant which found that the activation energy was ranged from 235-498 kJ/mol with average of 334 kJ/mol and pre-exponential factor was ranged from $10^{30}$-$10^{33}$ $min^{-1}$.

Therefore, using weeds as fuel in biomass power plant is better than burning out farmers' fields. The forms of biomass weeds utilized for thermal conversion are milled, chip, and pellet. The milled and chip forms are very cheap and easy to prepare, but they involve very difficult and high-cost management for storage and transportation due to the high ratio of volume to weight compared to pellets. In addition, the moisture content (MC) of as-received milled and chip biomass varies depending on the collection procedure. If the raw materials are dried under the sun, this can initially help to reduce the moisture content. High moisture content not only increases the weight of the as-received material but also causes mould and fermentation that produces flammable gas such as methane (Murasawa and Koseki, 2015; He *et al.*, 2020). Therefore, biomass pellets are more suitable for using and providing advantages such as a consistent size, low MC, higher calorific density, and convenience of transportation (Pitak *et al.*, 2020; Pitak *et al.*, 2021). Compared with other forms such as milled and chip, weed pellets can provide increased economic value. Moreover, when weedy grasses are produced and sold, they can bring the added financial value to the farmer. The amount of energy released from burning pellets is around 32 times more than the energy used in processing them. It can be claimed that farm-scale pellet production is found to be a promising opportunity for farmers and landowners who are interested in producing a renewable biomass fuel (Ciolkosz *et al.*, 2017).

In Southeast Asia, four kinds of weed are found including the giant sensitive plant, cogon grass, cattail and neptunia around rivers, canals and lowland areas. However, there have not been many reported on their characteristics and their commercial use. In terms of energy, the gross calorific value and ash content of the giant sensitive plant, cogon grass, and cattail biomass were approximately 17,500 J/g and 3.7% (Wongsiriamnuay *et al.*, 2008), 17,500–18,800 J/g and 7.08–13.91% (Palanca *et al.*, 2018), and 17,300 – 18,200 J/g and 5.47–7.64% (Grosshans, 2017). It showed that the weeds have a useful energy potential and can be used for producing biomass pellets. Using weeds as an energy resource can both limit their spread and utilize them in terms of energy at least for household cooking use.

Thailand is an agricultural country, where the farmland naturally faces the problem of weeds. Therefore, the following types of weeds: giant sensitive plant, cogon grass, cattail, and neptunia, were chosen to evaluate their characteristics in a pellet form. In the pelletization, it was reported that the moisture content (MC) and chemical content, solid density, bulk density, porosity and heating value can influence the quality of the biomass used in thermal processes (Kaewwinud *et al.*, 2016; Lisowski *et al*., 2019; Frodeson *et al*., 2019; Rezaei *et al.*, 2020). Therefore, these properties are restricted for commercial trade. The optimized process for biomass pelletizing differs depending on the biomass characteristics. Therefore, the optimal pelletizing conditions of the four types of weed pellet were investigated in the experiment. After pelletization, the properties of the biomass including the heating value, the proximate analysis, the elemental composition and physical properties were evaluated to select the optimal operating conditions to be suitable for the farming, domestic and industrial sectors.

## Materials and methods

The experiment was carried out to find the best ratio in the selected weed pellets. The overview of the experiment was shown in Figure 1.

### *Sample preparation for examination of biomass properties*

Biomass were used from the four weed types used in this research, namely, Mimosa diplotricha (giant sensitive plant), Imperata cylindrica (cogon grass), Typha latifolia (cattail) and Neptunia javanica Miq. (neptunia) which harvested from farmland in Thailand. First, the weeds were reduced in size by chopping with a wood-chipper. Then, they were sieved to the desired size of 2–5 mm through mesh sieve trays, and dried at 105 ℃ for 24 h in order to preserve and prevent the growth of mould. The prepared samples were used for experiments to determine the biomass properties in terms of moisture content, heating value and proximate analysis.

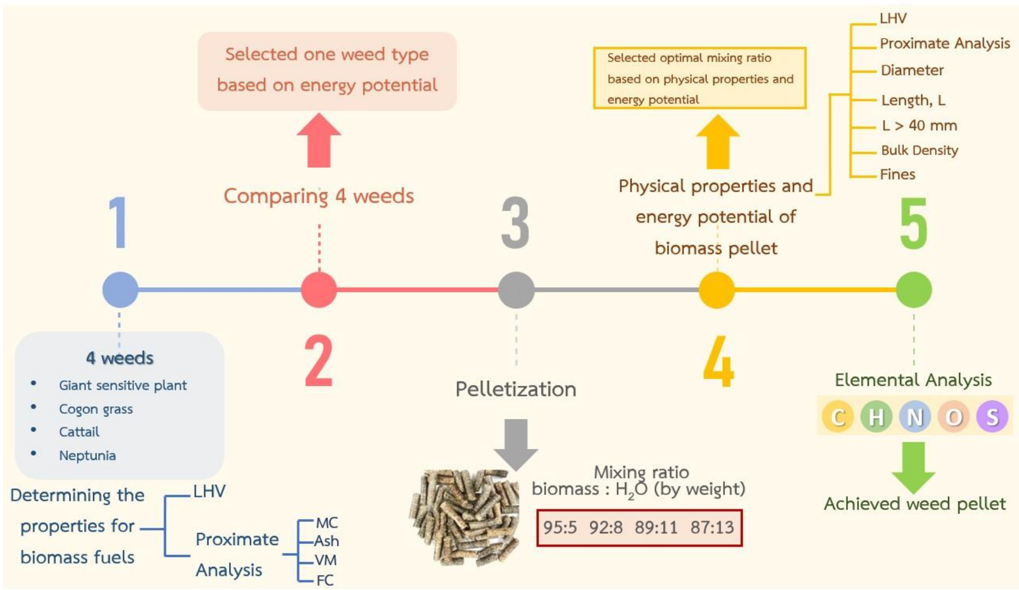


**Figure 1**. The overview of the experimen

***Sample preparation for biomass pelletization***

The prepared biomass samples with sizes of 2–5 mm (as mentioned above) were mixed with water at 5%, 8%, 11% and 13% by weight. The mixed ratio samples were pressed into biomass fuel pellets through an 8 mm diameter die (pellet making machine, Thaisumi, Thailand). The pellet samples with each mixing ratio were determined the properties of the biomass pellet fuel in terms of their moisture content, heating value, proximate analysis properties and physical properties.

***Experiments for determining the properties of biomass fuels***

**Calorific measurement**

The samples weighing 0.6 ± 0.1 g were pressed into bomb pellets with approximately 8 mm diameter and 3 mm thickness by the pressing pellet machine. The pellets were placed on a metal crucible in the vessel of a bomb calorimeter (C200, IKA, Germany) to determine the calorific value of the biomass. The value received from the instrument showed the higher heating value (HHV) in J/g. Then, the lower heating value (LHV) can be determined by subtracting the latent heat of vaporization in the sample from the higher heating value using the following equation:

$$LHV = HHV - mh_{fg}$$

where m is the amount of moisture (g of moisture per g of pellet), and $h_{fg}$ is the amount of enthalpy of vaporization (J/g). In the experiment, the pressure in the vessel was 30 bar, so the heat of vaporization in this condition is 1794.9 J/g (Cengel and Boles, 2015).

**Moisture content measurement**

The moisture content was determined from the weight loss after drying treatment according to ISO 18134-3 (2015). Approximately 1 g of the sample was weighed and placed in a hot air oven at 105 ℃ for 3 h, and the moisture content on a wet basis was determined using the following equation:

$$MC = \frac{m_2 - m_3}{m_2 - m_1} \times 100$$

where MC is the moisture content (%), $m_1$ is the weight of the empty cup with lid (g), $m_2$ is the weight of the cup with lid and sample before drying (g), $m_3$ is the weight of the cup with the lid and sample after drying (g).

**Measurement of volatile matter**

The amount of volatile matter of the biomass is the weight loss after heating according to ISO 18123 (2015). A sample of approximately 1 g was put in a cup with a lid and placed in the furnace at 900 ℃ for 7 min, and then the volatile matter in percentage was calculated:

$$VM = \frac{100(m_2 - m_3)}{m_2 - m_1} - MC \times \frac{100}{100 - MC}$$

where VM is the volatile matter (%), $m_1$ is the weight of the empty cup with lid (g), $m_2$ is the weight of the sample and cup with lid before heating (g), and $m_3$ is the weight of the sample and cup with lid after heating (g).

**Measurement of ash content and fixed carbon**

The determination of the ash content was done according to the ISO 18122 standard (2015) by weighing approximately 1 g of the sample into a cup with lid, and placing it in the furnace at 550 ℃ for at least 2 h. The ash content can be calculated as follows:

$$\text{Ash} = \frac{(m_3\text{-}m_1)}{m_2\text{-}m_1} \times 100 \times \left(\frac{100}{100\text{-MC}}\right)$$

where ash is the ash content percentage (%), $m_1$ is the weight of the empty cup (g), $m_2$ is the weight of the cup and sample (g), and $m_3$ is the weight of the cup and the ash (g). The fixed carbon was determined from the moisture content, ash content and volatile matter as follows:

$$\%FC = 100 - (\%MC + \%Ash + \%VM)$$

***Analysis of experimental results***

One-way ANOVA analysis was used to compare the properties of the weeds in order to select the best pelletizing condition. Multiple comparison was performed to compare the mean of the data in pairs using the least significant difference (LSD) method with the t-test principle. If the difference of any of the means of the pair of data was greater than the LSD, then the mean of that pair was significantly different at the α level (α = 0.05). The LSD calculation is shown in the following equation:

$$\text{LSD} = \overline{X}_i\text{-}\overline{X}_j = t_{\propto},df\sqrt{MSW\left(\frac{1}{n_i}+\frac{1}{n_j}\right)}$$

where $\overline{X}_i$ and $\overline{X}_j$ are the mean of group data i and j respectively, $t_\alpha$ is the t-value obtained from the table t (2-tailed) at df within the group, MSW is the mean square value within the group from the variance analysis table, $n_i$ and $n_j$ are the number of samples in group i and j respectively.

**Determining diameter and length of pellets**

The diameter of the biomass pellet fuel was determined following ISO 17829 (2015). Ten samples were randomly selected and the diameter of each pellet was measured with a vernier caliper to get the average diameter. To determine the length of the pellet, biomass pellets were randomly selected and those with lengths over 40 mm measured with the vernier caliper were separated. The percentage of pellets longer than 40 mm can be calculated as follows:

$$L>40 = \left(\frac{\text{weight of biomass with length} > 40\text{ mm}}{\text{weight of all biomass tested length}}\right) \times 100$$

where L>40 is the percentage of biomass pellet lengths over 40 mm (%).

**Fines content of pellets**

The fines content of pellets, defined as the fines or dust residue of pellets, was determined following ISO 18846 (2016) by using 1,133 g of biomass, weighing a sieve tray (BW), putting the sample on a sieve with a sieve hole size of 0.125 in (3.17 mm) and weighing the sample with the tray again (IW). The biomass sample was sieved 10 times and then the fines were weighed with a fines holder cup (CFW) after weighing only the holder cup (CW). The fines content (%) was calculated as follows:

$$\text{Fines content} = \frac{\text{CFW-CW}}{\text{IW-BW}} \times 100$$

**Bulk density of pellets**

The bulk density test was done following ISO 17828 (2015). A box with dimensions of 150 mm ×150 mm × 150 mm was filled with the pellet sample and then tapped by dropping it 5 times to impact on the floor from a height of 150 mm; having completely filled the box with pellets without any excess overspill, it was then weighed. The bulk density was then calculated as follows:

$$\text{Bulk density} = \frac{\text{box containing biomass pellets - box weight}}{\text{box volume}}$$

A high bulk density means that the pellets contain a high weight to volume ratio. This is useful for storage and transportation.

***Experiments for determining elemental content***

This experiment was carried out to find the best ratio in the selected weed pellets. The elemental analysis was performed to determine carbon, hydrogen and nitrogen following ASTM D5373-16 and sulphur following ASTM D4239-17 (2017) using the elemental analyzer (CHNS-628 Manual, LECO, America).

**Method for determining carbon, hydrogen and nitrogen**

The analyzed sample size of not more than 250 μm was weighed and placed on a furnace containing pure oxygen gas at 900–1150 ℃. The carbon, hydrogen and nitrogen were oxidized to carbon dioxide, water and nitric oxide. The desired gases were evaluated and resulted in the percentage by weight.

**Method for determination of sulphur**

Using the CHNS-628 elemental analyzer connected to the sulphur add-on module, approximately 15 mg to 80 mg of the sample was weighed and placed in a furnace with pure oxygen gas at 1350 ℃. The sulphur in the sample evaporated in the form of $SO_2$, and then flowed through the filter to remove moisture and entered the infrared sulphur measurement cell inside the device. The sulphur content can be calculated by the following equation:

$$M_c = \frac{M_T \times S_{AD}}{S_C}$$

where $M_C$ is the mass of the reference material, $M_T$ is the mass used in the sample test, $S_{AD}$ is the sulphur percentage in the sample test, and $S_C$ is the sulphur percentage in the pure reference material.

## Results

### *Proximate analysis and lower heating value of weeds*

The experiment was determined the properties of biomass pellets from four weed types, namely the giant sensitive plant, cogon grass, cattail and neptunia, in order to select only one type of weed to produce biomass pellets with the most appropriate properties based on the biomass pellet specified in the industry standard (International Organization for Standardization, ISO) as shown in Table 1.

The lower heating value (LHV) of the weeds was calculated after measuring the HHV from the bomb calorimeter. Proximate analysis was conducted to determine the content of ash, VM and FC using the furnace and the moisture content was evaluated using the hot air oven. The results are presented in Table 2. As the results, the giant sensitive plant was the most appropriated for producing biomass pellets.

**Table 1**. Specification of graded wood pellets for industrial use

| Property | Standard | unit | Class I1 | Class I2 | Class I3 |
|---|---|---|---|---|---|
| Diameter, D | ISO 17829 | mm | D08, 8 ±1 | D08, 8 ±1 | D08, 8 ±1 |
| Length, L | ISO 17829 | mm | 3.15 < L ≤ 40 | 3.15 < L ≤ 40 | 3.15 < L ≤ 40 |
| Amount of pellets longer than 40 mm | ISO 17829 | w-% | ≤ 1 | ≤ 1 | ≤ 1 |
| Moisture, M | ISO 18134-3 | w-%, wb | M10 ≤ 10 | M10 ≤ 10 | M10 ≤ 10 |
| Ash, A | ISO 18122 | w-% | A1.0 ≤ 1.0 | A1.5 ≤ 1.5 | A3.0 ≤ 3.0 |
| Fines, F | ISO 18846 | w-% | F4.0 ≤ 4.0 | F5.0 ≤ 5.0 | F6.0 ≤ 6.0 |
| Net calorific value, Q | ISO 18125 | J/g | Q16,500 ≥ 16,500 | Q16,500 ≥ 16,500 | Q16,500 ≥ 16,500 |
| Bulk density, BD | ISO 17828 | kg/m$^3$ | BD600 ≥ 600 | BD600 ≥ 600 | BD600 ≥ 600 |
| Nitrogen, N | ASTM D5373-16 | w-% dry | N0.3 ≤ 0.3 | N0.3 ≤ 0.3 | N0.6 ≤ 0.6 |
| Sulphur, S | ASTM D4239-17 | w-% dry | S0.05 ≤ 0.08 | S0.05 ≤ 0.08 | S0.05 ≤ 0.20 |

**Table 2**. Proximate analysis and lower heating values of weeds

| Biomass | MC (%) | Ash (%) | VM (%) | FC (%) | LHV (J/g) |
|---|---|---|---|---|---|
| Giant sensitive plant | 3.07 ±0.31a | 2.68 ±0.11d | 80.12 ±0.35a | 14.13 ±0.47a | 18,334.08 ± 93.26a |
| Neptunia | 3.40 ±0.35a | 7.52 ±0.06b | 73.91 ±0.23d | 15.17 ±0.35a | 17,423.46 ± 61.19c |
| Cogon grass | 3.20 ±0.61a | 6.85 ±0.09c | 78.27 ±0.40b | 11.68 ±0.81a | 17,597.51 ± 115.84b |
| Cattail | 3.60 ±0.10a | 10.30 ±0.18a | 76.31 ±0.17c | 9.79 ±0.04b | 17,297.88 ± 67.28c |

The same superscript indicates no significant difference from each other ($\alpha = 0.05$)

***Proximate analysis and lower heating value of each water ratio of giant sensitive plant***

The biomass pellets from the giant sensitive plant were tested for four ratios of water percentage by weight of 5%, 8%, 11% and 13%. These ratios were set from the preliminary pelletization test in order to find the minimum and maximum ratio with which the machine could make raw materials in pellet form. The giant sensitive plant pellets were evaluated for the lower heating value, and proximate analysis properties: MC, ash content, VM and FC, showed in Table 3. The MC, FC and LHV of 5% and 8% of water showed not significant difference comparing at 11% and 13% while VM and ash showed significant different value. The possible selection of % water mixing may be either 5% or 8% and the next step of experiment (physical properties) had considered for the section.

**Table 3**. Proximate analysis and lower heating value of giant sensitive plant pellets for different mixing ratios

| Water percentage | MC (%) | Ash (%) | VM (%) | FC (%) | LHV (J/g) |
|---|---|---|---|---|---|
| 5% | 7.52 ± 0.17c | 2.98 ± 0.16b | 77.65 ± 0.57b | 11.85 ± 0.52a | 18,847.42 ± 31.18a |
| 8% | 7.83 ± 0.19c | 2.48 ± 0.01c | 78.77 ± 0.24a | 10.92 ± 0.24ab | 18,747.46 ± 8.23a |
| 11% | 8.44 ± 0.20b | 3.00 ± 0.12b | 77.98 ± 0.59ab | 10.59 ± 0.69b | 18,192.84 ± 104.45b |
| 13% | 9.16 ± 0.31a | 3.65 ± 0.30a | 77.12 ± 0.56b | 10.06 ± 0.45b | 17,549.21 ± 5.12c |

The same superscript indicates no significant difference from each other (α = 0.05)

### *Physical properties of giant sensitive plant pellets*

The physical properties of the biomass pellets from the giant sensitive plant were tested in four ratios, with water–weed ratios of 5%, 8%, 11% and 13%. The results are shown in Table 4. The mixing ratio of 5% revealed the lowest average diameter, average length, and percentage of lengths longer than 40 mm. The ratio of 8% showed the lowest fines content of 3.21% and the mixing ratio of 11% showed the lowest bulk density of 613.83 kg/m$^3$.

**Table 4.** Physical properties of giant sensitive plant pellets

| Water percentage | Diameter (mm) | Length (mm) | Length > 40 mm (%) | Fines (%) | Bulk density (kg/m$^3$) |
|---|---|---|---|---|---|
| 5% | 8.09 ± 0.04c | 28.22 ± 2.64 a | 0.92 ± 3.75b | 3.69 ± 1.09b | 638.98 ± 6.05c |
| 8% | 8.29 ± 0.06b | 29.68 ± 2.05 a | 0.93 ± 0.88b | 3.21 ± 1.15b | 649.19 ± 3.33b |
| 11% | 8.29 ± 0.06b | 29.58 ± 2.22 a | 0.99 ± 1.61b | 3.43 ± 0.26b | 613.83 ± 4.60d |
| 13% | 8.41 ± 0.06a | 31.96 ± 3.34 a | 5.73 ± 0.80a | 5.96 ± 0.28a | 664.08 ± 4.15a |

The same superscript indicates no significant difference from each other (α = 0.05)

The optimal mixing ratio of 8% for pelletization provided an average diameter of 8.29 mm, average length of 29.68 mm, 0.93% of pellets with length exceeding 40 mm, a fines content of 3.21% and the density of 649.19 kg/m$^3$ (Figure 2). These properties were essentially satisfied the requirements for the biomass industry standard as shown in Table 1 (ISO 17225-2, 2014; TISI, 2020).


**Figure 2**. Biomass pellets from giant sensitive plant

### *Elemental composition of giant sensitive plant pellets*

The elemental composition results of the pellets at the optimal mixing ratio of 8% are presented in Table 5.

**Table 5**. Elemental composition of giant sensitive plant pellets

| Element | Test results (%) |
|---|---|
| Carbon (C) | 44.51 |
| Hydrogen (H) | 6.20 |
| Nitrogen (N) | 0.47 |
| Sulphur (S) | 0.20 |
| Oxygen (O) | 46.14 |

## Discussion

From the results of proximate analysis and lower heating values of weeds found that the giant sensitive plant was the most appropriate for producing biomass pellets, having a moisture content of 3.07% wet basis, 2.68% of ash content, 80.12% of volatile matter, 14.13% of carbon content, and the LHV of 18,334.08 J/g. Comparison these data (see Table 6) with the research of Wongsiriamnuay T. and Tippayawong N. (Wongsiriamnuay *et al*., 2010) showed consistently results with a moisture content of 1.6%, 3.7% of ash content, 71.1% of volatile matter, 23.6% of carbon content, and the HHV of 17,500 J/g. The research of charcoal briquette made from giant sensitive plant of Jolanun *et al*. also showed the results of the raw material which consisted of moisture content of 9.06%, 6.30% of ash content, 66.02% of volatile matter, 19.65% of carbon content, and the HHV of 16,700 J/g (Jolanun *et al.*, 2011). These data showed consistently with our research for the same raw material.

The slightly different results may result from the different moisture content of the material. Additionally, comparison other biomass materials such as leucaena leucocephala, eucalyptus, para rubber, rice husk, corn cob and bagasse (see in Table 6) with the giant sensitive plant revealed that the giant sensitive plant provided high potential (heating value, volatile matter and fixed carbon) for using as alternative energy.

The properties of other weeds (Neptunia Cogon grass and Cattail) in this work also were compared, the LHV, MC and ash content of the giant sensitive plant showed the lowest values, while VM and FC showed the highest values. Generally, the efficient biomass should have a high LHV, VM and FC, with low levels of ash and MC in order to get high quality fuel. There was no significant difference in the MC and FC values of all the weed types, except for the FC of the cattail. The ash, VM, and LHV of giant sensitive plant also showed significant differences comparing with the other weeds. Additionally, the study of thermal analysis of giant sensitive plant in Thailand (Wongsiriamnuay *et al*., 2010) using thermogravimetric analysis found that the activation energy was range from 235-498 kJ/mol with average of 334 kJ/mol and pre-exponential factor was range from $10^{30}$-$10^{33}$ $min^{-1}$. The maximum mass loss rate at 326°C was 0.28 %/°C and at 469 °C was 0.19 %/°C. This research also using the same giant sensitive plant in Thailand so that it could be also useful to support in our research in term of kinetic analysis and degradation characteristics of the giant sensitive plant. As the results above, the giant sensitive plant will be selected for further analysis.

The giant sensitive plant was tested for four ratios of water percentage by weight and the giant sensitive plant pellets were evaluated for the lower heating value, and proximate analysis properties: MC, ash content, VM and FC. The proximate analysis and lower heating value of the pellets at 5% water ratio showed the lowest moisture content and the highest FC and LHV. The lowest ash content and the highest VM resulted from the mixing ratio of 8%. The experimental results showed that higher levels of moisture and ash content resulted in lower levels of VM and FC, which were not good for the combustion process. The VM and FC can influence the biological conversion of fuel. VM can represent how easy biomass ignition will be and FC gives an indication of the biomass burning period. Comparison of the different water–weed mixing ratios found that the water percentage of 8% was the most suitable mixing ratio. It provided MC 7.83% wet basis, 2.48% of ash content, 78.77% of VM, 10.92% of FC and the LHV of 18,747.46 J/g. These were the best values according to the standard of biomass pellet properties for industry (ISO 17225-2, 2014; ISO 18134-3, 2015; ISO 18123, 2015; ISO 18122, 2015; TISI, 2020).

**Table 6**. Comparison properties between giant sensitive plant and other biomass materials

| Ref* | Biomass | Proximate analysis (%) | | | | Ultimate analysis (%) | | | | | Heating value (J/g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MC | VM | FC | Ash | C | H | N | O | S | |
| This work | Giant sensitive plant | 3.07 | 80.12 | 14.13 | 2.68 | 44.51 | 6.20 | 0.47 | 46.14 | 0.20 | 18,334 (LHV) |
| Jolanun *et al*., 2011 | Giant sensitive plant | 9.06 | 66.02 | 19.65 | 6.30 | 46.10 | 6.80 | 0.74 | 46.23 | 0.13 | 16,700 (HHV) |
| Wongsiri-amnuay *et al*., 2010 | Giant sensitive plant | 1.60 | 71.10 | 23.60 | 3.70 | 43.90 | 6.00 | 1.40 | 48.70 | - | 17,500 (HHV) |
| Jolanun *et al*., 2011 | Leucaena Leucocephala | 0.63 | 81.00 | 16.59 | 1.78 | 47.55 | 6.55 | 0.38 | 44.51 | 0.01 | 18,800 (HHV) |
| Jolanun *et al*., 2011 | Eucalyptus | 1.14 | 79.00 | 17.22 | 2.64 | 48.93 | 8.05 | 0.52 | 42.48 | 0.02 | 18,500 (HHV) |
| Jolanun *et al*., 2011 | Para rubber | 2.36 | 81.00 | 14.78 | 1.83 | 55.96 | 9.68 | 0.78 | 33.51 | 0.07 | 18,700 (HHV) |
| Güleç *et al*., 2022 | Rice husk | - | 73.00 | 13.30 | 13.7 | 26.69 | 2.88 | 0.21 | 70.05 | 0.17 | 15,900 (HHV) |
| Güleç *et al*., 2022 | Corncob | - | 83.00 | 14.60 | 2.40 | 44.78 | 6.02 | 0.22 | 48.77 | 0.21 | 17,690 (HHV) |
| Das *et al*., 2013 | Bagasse | 9.51 | 74.98 | 13.57 | 1.94 | 43.77 | 6.83 | - | 47.46 | - | 16,800 (HHV) |

According to the physical properties of giant sensitive plant pellets, increasing of the percentage of water mixing resulted in increases of the average diameter, average length and bulk density. In addition, if the amount of water in the mixing ratio is too high, the biomass pellets will be broken or form curved shapes. It leaded to the pellet length exceeding 40 mm, and increased the content of fines. Moreover, longer pellet lengths could be caused by pellets lying close together during combustion which is not desirable in thermal conversion. The water ratio of 13% revealed that the evaluated properties were significantly higher than those specified in the standards (ISO 17225-2, 2014; ISO 17828, 2015; ISO 18846, 2016; TISI, 2020). It was found that if the amount of water in the mixing ratio is too low, this may cause non-firmly binding pelletization, which degraded the pelletization and cause higher fines content.

The elemental composition of giant sensitive plant pellets was shown at the optimal mixing ratio of 8%, the pellets had nitrogen (N) and sulphur (S) contents of 0.47% and 0.2% respectively, which do not exceed the limited specify in the pelletization standard (class I3). In biomass pellet production, the nitrogen content must not be higher than 0.3–0.6% and the sulphur content should not be shown more than 0.08–0.2% (ISO 17225-2, 2014; TISI, 2020). Nitrogen causes the release of nitrogen oxides ($NO_x$) during combustion, which are classified as a type of greenhouse gas. Sulphur is converted to a compound of sulphur oxides ($SO_x$), which are pollutants causing acid rain. (Williams *et al*., 2012, Khan *et al*., 2013, Zheng *et al.*, 2020). If there are too many such elements in the combustion process, it will generate toxic gases and corrosion in component parts of the equipment, which will lead to increased costs of production and be harmful to humans and the environment. (Kato, 1996, Asghar *et al.*, 2021)

In conclusion, the weeds had capability for using as alternative energy instead of getting rid of them without any utilisation. The evaluation of biomass pellet fuel production from selected weed plants in Thailand revealed that the giant sensitive plant could be used as a renewable energy source in the same way as wood due to its high calorific value of 18,334.08 J/g, comparing with the other investigated weeds. The great energy potential for combustion of the giant sensitive plant contributed to producing good biomass pellets. The best ratio of water 8% by weight provided good properties of LHV, FC, VM and ash content of 18,747.46 J/g, 10.92%, 78.77% and 2.24%, respectively. This optimal ratio showed not to high an amount of added water (leading to less added moisture content in pellts) and gave good properties for thermal conversion. Additionally, the pellet made from the best condition of giant sensitive plant could be classified as quality class I3 (ISO 17225-2, 2014) of the biomass pellet fuel which can be used as feedstock in the industrial sector.

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## References

Asghar, U., Rafiq, S., Anwar, A., Iqbal, T., Ahmed, A., Jamil, F., Khurram, M. S., Akbar, M. M., Farooq, A., Shah, N. S. and Park, Y. K. (2021). Review on the progress in emission control technologies for the abatement of CO2, SOx and NOx from fuel combustion. Journal of Environmental Chemical Engineering, 9:106064.

ASTM International (2016). ASTM D5373-16: Standard Test Methods for Determination of Carbon, Hydrogen and Nitrogen in Analysis Samples of Coal and Carbon in Analysis Samples of Coal and Coke, ASTM International.

ASTM International (2017). ASTM D4239-17: Standard Test Method for Sulfur in the Analysis Sample of Coal and Coke Using High-Temperature Tube Furnace Combustion, ASTM International.

Cengel, Y. and Boles, M. (2015). Thermodynamics: An Engineering Approach. 8th ed. New York, McGraw-Hill, pp.907.

Ciolkosz, D., Jacobson, M., Heil, N. and Brandau, W. (2017). An assessment of farm scale biomass pelleting in the Northeast. Renewable Energy 108:85-91.

Das, K, B., Haque, S, M, N., Kader, M, A. and Rahman, Md. S. (2013). Prospects of bagasse gasification technology for electricity generation in sugar industries in Bangladesh. Conference of ICMIME-2013, Rajshahi University of Engineering and Technology, Rajshahi, pp.268-272.

Frodeson, S., Henriksson, G. and Berghe, J. (2019). Effects of moisture content during densification of biomass pellets, focusing on polysaccharide substances. Biomass and Bioenergy, 122: 322-330.

Grosshans, R. (2017). Cattail Harvesting for Nutrient Capture and Sustainable Energy: The Stacked Benefits of Water Retention Green Infrastructure that Drives Economic

Sustainability. North Dakota State University, Fargo, ND. Retrieved from https://www.ag.ndsu.edu/

Güleç, F., Pekaslan, D., Williams, O. and Lester, E. (2022). Predictability of higher heating value of biomass feedstocks via proximate and ultimate analyses – A comprehensive study of artificial neural network applications. Fuel, 320:123944.

Haque, M. A., Barman, D. N., Kim, M. K., Yun, H. D. and Cho, K. M. (2016). Cogon grass (*Imperata cylindrica*), a potential biomass candidate for bioethanol: cell wall structural changes enhancing hydrolysis in a mild alkali pretreatment regime. Journal of the Science of Food and Agriculture, 96:1790-1797.

He, X., Lau, A. K. and Sokhansanj, S. (2020). Effect of Moisture on Gas Emissions from Stored Woody Biomass. Energies, 13(128).

International Organization for Standardization (2014). ISO 17225-2:2014 Solid biofuels - Fuel specifications and classes - Part 2: Graded wood pellets. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2015). ISO 17829:2015 Solid biofuels - Determination of length and diameter of pellets. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2015). ISO 17828:2015 Solid biofuels - Determination of bulk density. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2015). ISO 18122:2015 Solid biofuels - Determination of ash content. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2015). ISO 18123:2015 Solid biofuels - Determination of the content of volatile matter. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2015). ISO 18134-3:2015 Solid biofuels - Determination of moisture content - Oven dry method - Part 3: Moisture in general analysis sample. ISO International Standard, ICS 27.190:75.160.40.

International Organization for Standardization (2016). ISO 18846:2016 Solid biofuels - Determination of fines content in quantities of pellets. ISO International Standard, ICS 27.190:75.160.40.

Jolanun, B., Phutharukchat, A. and Khamtui, C. (2011) Community-based renewable energy from Mimosa Pigra L. charcoal briquettes. KKU Research Journal, 16:20-31.

Kaewwinud, N., Khokhajaikiat, P., Boonma, A. and Chansiri, C. (2016). Effect of moisture content on physical properties of cassava stalk pellets. KKU Engineering Journal, 43:311-313.

Kato, N. (1996). Analysis of structure of energy consumption and dynamics of emission of atmospheric species related to the global environmental change ($SO_X$, $NO_X$, and $CO_2$) in Asia. Atmospheric Environment, 30:757-785.

Khan, Z., Suzana, Y. and Ahmad, M. (2012). Effect of Temperature and Steam to Biomass Ratio on NO and $SO_2$ Formation in Palm Kernel Shell Catalytic Steam Gasification with In-situ $CO_2$ Adsorption. E- Conferences 2nd World Sustainability Forum.

Lisowski, A., Pajora, M., Świętochowskia, A., Dąbrowska, M., Klonowski, J., Mieszkalski, L., Ekielski, A., Stasiak, M. and Piątek, M. (2019). Effects of moisture content, temperature, and die thickness on the compaction process, and the density and strength of walnut shell pellets. Renewable Energy, 141:770-781.

Murasawa, N. and Koseki, H. (2015). Investigation of Heat Generation from Biomass Fuels. Energies, 8:5143-5158.

Palanca, A. G., Leon, R. D. and Jose, W. I. (2018). Torrefied Cogon grass: Effects of torrefaction on fuel properties of solid and condensate products. International Journal of Smart Grid and Clean Energy, 7:1-12.

Pitak, L., Sirisomboon, P., Saengprachatanarug, K., Wongpichet, S. and Posom, J. (2020). Rapid elemental composition measurement of commercial pellets using line-scan hyperspectral imaging analysis. Energy, 220.

Pitak, L., Laloon, K., Wongpichet, S., Sirisomboon, P. and Posom, J. (2021). Machine Learning-Based Prediction of Selected Parameters of Commercial Biomass Pellets Using Line Scan near Infrared-Hyperspectral Image. Processes, 9:316.

Pizzi, A., Toscano, G., Pedretti, E.F., Duca, D., Rossini, G., Mengarelli, C., Ilari, A., Renzi, A. and Mancini, M. (2018). Energy characteristic assessment of olive pomace by means of FT-NIR spectroscopy. Energy, 147:51-58.

Rezaei, H., Yazdanpanah, F., Lim, C. J. and Sokhansanj, S. (2020). Pelletization properties of refuse-derived fuel - Effects of particle size and moisture content. Fuel Processing Technology, 205.

Sirisomboon, P., Funke, A. and Posom, J. (2020). Improvement of proximate data and calorific value assessment of bamboo through near infrared wood chips acquisition. Renewable Energy 147:1921-1931.

Thai Industrial Standard Institute (TISI) (2020). Retrieved from https://www.tisi.go.th

Williams, A., Jones, J. M., Ma, L. and Pourkashanian, M. (2012). Pollutants from the combustion of solid biomass fuels. Progress in Energy and Combustion Science, 38:113-137.

Wongsiriamnuay, T., Phengpom, T., Panthong, P. and Tippayawong, N. (2008). Renewable Energy from Thermal Gasification of a Giant Sensitive Plant (Mimosa pigra L.). 5th International Conference on Combustion, Incineration/Pyrolysis and Emission Control, 466-471.

Wongsiriamnuay, T. and Tippayawong, N. (2010). Thermogravimetric analysis of giant sensitive plants under air atmosphere. Bioresource Technology, 101:9314-9320.

Yu, M., Han, Y., Li, J. and Wang, L. (2017). $CO_2$-activated porous carbon derived from cattail biomass for removal of malachite green dye and application as supercapacitors. Chemical Engineering Journal, 317:493-502.

Zheng, A., Li, L., Tippayawong, N., Huang, Z., Zhao, K., Wei, G., Zhao, Z. and Li, H. (2020). Reducing emission of NOx and SOx precursors while enhancing char production from pyrolysis of sewage sludge by torrefaction pretreatment. Energy, 192:116620.

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