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The effect of storage conditions on the characteristics of various types of biomass

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ABSTRACT

In order to determine optimal conditions for maintaining biomass quality during storage, an analysis was conducted to investigate the changes in biomass characteristics in Bangkok, Thailand. The study focused on three types of biomass: Corncob, woodchip, and bagasse, which are valuable renewable energy resources in the region. Each type of biomass was divided into two separate piles: One covered with a plastic sheet and the other left uncovered. Over a storage period of seven months (February-September), various characteristics of the biomass piles were evaluated, including pile temperature, moisture content, ash content, heating value, and dry matter loss. The findings indicate that the utilization of plastic sheets significantly enhanced the quality of corncob and woodchip biomass. This improvement was attributed to reduced moisture content, leading to higher heating values, lower ash content, and decreased dry matter loss in the covered piles compared to the uncovered ones. However, such improvements were not observed in the case of bagasse, as its quality exhibited fluctuations throughout the study period.

1. Introduction

Recently, the Thai government implemented a bio-economy policy to develop the biotechnology industry and increase the utilization of agricultural waste (DEDE, 2018; Awasthi et al., 2020). Therefore, Thailand is currently focused on the development of biomass as a source of renewable energy. This is because it is an agricultural country where a large amount of biomass is generated from agricultural waste material (Waewsak et al., 2020). It serves as a carbon reservoir and is considered to be carbon neutral; this is because carbon dioxide is released through the combustion process and then returns to the carbon cycle. The amount of carbon released during this combustion process is assumed to be in the same range as that in the carbon adsorption process during the growth stages of plants (Deutz and Bardow, 2021). In the past, biomass was considered a waste material that burdened farmers and waste disposal entrepreneurs as its disposal was a time-consuming process, which required resources. However, there was a significant increase in the use of biomass for power generation when the costs of fossil fuels rose. Biomass fuel can be used instead of fossil fuel for power generation and has been acknowledged as being useful for the mitigation of global warming and air pollution reduction (Casal, 2010). Therefore, selling this electricity could increase agricultural entrepreneur income in addition to helping eliminate waste materials and mitigating the effects of climate change in accordance with the global trend of reducing greenhouse gas emissions.

The Department of Alternative Energy Development and Efficiency, Ministry of Energy (Thailand) recently launched the Alternative Energy Development Plan (AEDP) 2018–2037. Its purpose is to increase the proportion of renewable and alternative energy use, with a target of acquiring 5,790MW of power from biomass by 2037. Biomass had the highest proportion of renewable energy use (3,763.77MW) in Thailand in 2021, which was

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30.55% of the total renewable energy consumption (DEDE, 2018). To help develop a local economy and distribute the income generated from owning power plants, the Biomass Community Power Plant has been set up under the Department of Alternative Energy policy guidelines. This policy also encourages the distribution of agricultural waste materials as fuel and for career-building, local community strengthening, immigration reduction, and developing a circular economy.

An important goal of the Biomass Community Power Plant is to ensure that the quality of the biomass used in the combustion process is suitable for power generation. This can be achieved by proper storage of the biomass before combustion. According to Röser et al. (2011) and Parmar (2017), the selling price of biomass is based on its dry weight. In addition, parameters such as the heating value, moisture content, and ash content are used to assess its quality (McKendry, 2002) which may also be affected by seasonal storage and storage time.

The environment of the storage has a profound effect on the quality of biomass and maintaining the quality of biomass would enhance its potential for power generation. To encourage the proper management of biomass storage in each season for each type of biomass. Therefore, we conducted an experiment to identify the characteristic changes in biomass during the storage period, which would help biomass users in community power plants to ensure suitable conditions before use. Three types of biomass that are used as energy fuel widely in Thailand, namely, corncob, woodchip, and bagasse, were chosen for this purpose. The experiment was conducted under two conditions, i.e., when the pile was uncovered and covered with low-density polyethylene (LDPE) plastic sheet.

2. Material and methods

2.1. Storage experimental site

The storage experiment was conducted at Bang Khun Thian, Bangkok, Thailand (13° 34' N, 100° 26' E), which is located in the coastal ecosystem region at a distance of approximately 5km from the Gulf of Thailand (Fig. 1). Daily rainfall and temperature data was collected from the nearest meteorological station, Khlong Toei Station (13° 42'N, 100° 34' E), under the Thailand Meteorological Department (TMD), which is located 20.4km away from the storage experimental site. The accumulated average annual rainfall at this meteorological station over 10 years from 2008 to 2017 was about 1,740 millimeters (mm) and the highest accumulated rainfall was 1,489mm, which was recorded during the rainy season (from May to October). The average minimum and maximum temperatures during these 10 years were 26°C and 33°C, respectively. Fig. 2 shows the weather data for the study period (2008–2017).

Fig. 1: The storage experimental site in Bang Khun Thian district

2.2. Material and experimental piles

The three types of biomass that are commonly available in Thailand were used in this study, including corncob, woodchip, and bagasse. Corncob residue was collected from an animal factory in Suphanburi. *Acacia mangium* wood stems from Suphanburi were comminuted into woodchips, with nominal sizes of 2–50mm. Bagasse residue was obtained from Mitr Phol Danchang, a sugar producer.

The different types of biomass were divided into six piles and stored under two conditions: covered and uncovered. These six piles were uncovered corncob (UC), covered corncob (CC), uncovered bagasse (UB), covered bagasse (CB), uncovered woodchips (UW), and covered woodchips (CW). LDPE plastic sheets were used for the covered piles to prevent penetration by rainwater. The uncovered piles were left open to allow them to react to the environment. The trapezoid-shaped piles of corncob, woodchip, and bagasse were 1m wide, 2m long, and 1m high, with a volume of 1 m^3. These piles were stored on a cement floor at a height of 20cm to avoid moisture penetration and with a gradual slope for better water drainage. The experiment was conducted from March 2020 until September 2020, which spans the summer and monsoon seasons in Thailand.

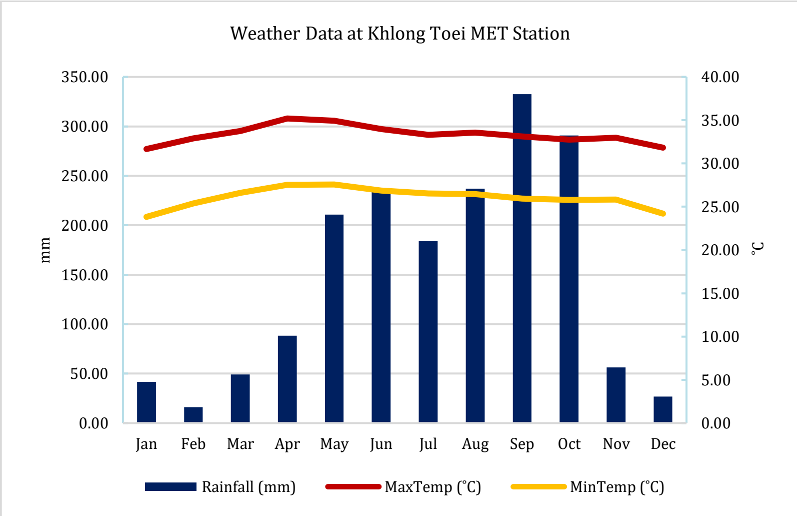

Fig. 2: Weather data obtained from the MET station, Bangkok, averaged over 10 years (2008–2017)

2.3. Sampling technique and parameters studied

In this study, the quality of biomass was defined by 5 parameters: Pile temperature (temperature inside the pile), moisture content, heating value, ash content, and dry matter loss. A type K thermocouple was used to measure the temperature inside the biomass piles through PVC pipes (open/close available) installed at different heights. American Society for Testing and Materials (ASTM) standards were used: E1756–08 for moisture content, D5373–16 for heating value, and E1755–01 for ash content. Dry matter loss was measured to determine the biomass degradation trend during the storage time. The sample was dry by using the oven at 105-degree Celsius and 24 hours before the calculation of dry matter loss (Afzal et al., 2010; Hrčka et al., 2022), as shown in Eq. 1. Further, the ambient temperature and humidity were monitored. The results of this study were summarized as the mean of measurements of the biomass pile that were taken at three heights: 25cm, 50cm, and 75cm (apart from the heating value, which was only collected at a height of 50cm). Biomass samples were collected for analysis in 216 small net bags and 18 large net bags. Inside each pile, there were 36 small net bags (12 bags at each height) and three large net bags (one bag at each height). The small bags had dimensions of 3×4cm and the large ones had dimensions of 30×40cm. Each bag contained varying weights of biomass due to differences in biomass size. All the bags were weighted before they were placed inside the piles. For the laboratory analysis, the moisture content in the small bags was sampled twice a month, the ash content was sampled once a month, and the heating value was sampled once every two months during the experimental period of six months. However, the large bags were collected every three months (in the third and the sixth months of the experimental period) to measure biomass loss. The summarized biomass sampling plan and the amount of biomass used in the laboratory analysis are shown in Table 1. To measure the heating value, elemental analysis was performed using the Carbon-Hydrogen-Nitrogen (CHN) Corder (J-Science, JM10 CHN). The value was then calculated using Dulong's equation, which excludes all moisture and ash (dry ash-free basis; d.a.f.), as shown in Eq. 2.

- Dry matter loss: The change in the mass of the wood substance is the change in the mass of dry wood and it is defined by "dry-matter loss."

$$DML = (1 - \frac{m_{s2}}{m_{s1}})\,(100\%) \quad (1)$$

where, m_{s1} and m_{s2} are the mass of the biomass substance before and after the action of the factor causing the loss of biomass substance. Use a drying oven at 105 °C for 24 hours before calculating.

- Heating value: The higher heating value (HHV) is calculated as:

$$HHV\ (MJ/kg, d.a.f.) = (338.1 \times C + 1441.8 \times H - 180.2 \times O)/1000 \quad (2)$$

where, C, H, and O represent the percentage weights of carbon, hydrogen, and oxygen, respectively.

3. Result and discussion

3.1. Weather conditions

Daily temperature and precipitation data were collected from the nearest meteorological station, Khlong Toei Station. During the storage period, the mean values of the daily temperature ranged between 27˚C and 33˚C, while the accumulated precipitation was 639mm (Fig. 2). The average relative humidity was highest in March and it getting declined during the storage time (Fig. 3). The first and second months of the storage period experienced drought, while rainfall events were concentrated in May–August (the third to sixth month of the storage period).

3.2. Pile temperature

It was observed that the temperature fluctuations in the uncovered storage piles were related to the rainfall trend of the storage period.In particular, the temperature of the bottom layer fluctuated more than that of the middle and top layers of the pile, especially for corncob (Figs. 4–6). It is known that high ambient temperature increases microbial activity. However, during periods with high ambient temperature, the microbial activity of the covered piles was lower than that observed in the uncovered piles because of lower humidity. This phenomenon is evident based on the peak of pile temperature, as shown in Figs. 4–6. Therefore, we can conclude that high rainfall and ambient temperature resulted in higher moisture content and higher biomass degradation due to microbial activity in the uncovered piles.

3.3. Moisture content

The average moisture content of the corncobs, bagasse, and woodchips at time zero (before storage) were 10%, 35%, and 25%, respectively (Fig. 7). During the first two weeks of storage, the moisture content of the covered piles tended to decrease while that of the uncovered piles tended to increase. However, at the end of this period, the moisture content of the uncovered corncob was 11%, which was not significantly different from that of the covered piles. For the two other types of biomass, significant differences in moisture content were observed between the covered and uncovered piles in the first and second weeks of July, when the uncovered bagasse and woodchips both had a moisture content of approximately 56%. In contrast, the covered piles had a moisture content of approximately 10-15% (Fig. 7).

High moisture content was observed during the period of heavy rainfall from May to July. This phenomenon was most evident at the highest level of the uncovered corncob pile, which was the closest to the environmental fluctuations during the storage period. While the moisture content of the covered bagasse pile was largely unaffected by seasonal changes, that of the uncovered pile was significantly affected. Similarly, rainfall or seasonal fluctuations did not significantly affect the moisture content of the covered woodchip pile but affected the uncovered pile.

The moisture content of the corncob pile was lower (about 10–20%) during summer (February to May) in both conditions (covered and uncovered). However, the uncovered corncob pile had the highest moisture content (about 65–80%) from May to September, which was either the rainy season or early winter. The results of this experiment agreed with the findings of Brand et al. (2011), who reported that moisture content fluctuated in accordance with seasons. Hofmann et al. (2018) observed that the moisture content of the woodchip piles was significantly dependent on seasons, storage duration, assortment and sheet cover. Using a sheet to cover the piles was found to decrease the moisture content (Fig. 7).

Table 1: Biomass samples used in laboratory analysis

Analysis	Sampling schedule	Biomass sampling (times) at any height level		
		25 cm	50 cm	75 cm
Moisture content	Twice/month	10	10	10
Ash content	Once/month	5	5	5
Heating value	Once/2 months	-	2	-
Dry matter loss	Start-mid-end of storage period (3 times)	✓	✓	✓

(-): The biomass was not used in the analysis; (✓): The biomass returned to the piles after the measurement

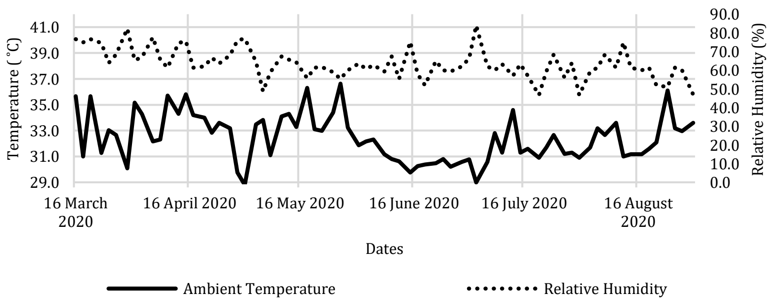

Fig. 3: Ambient temperature and relative humidity at site storage

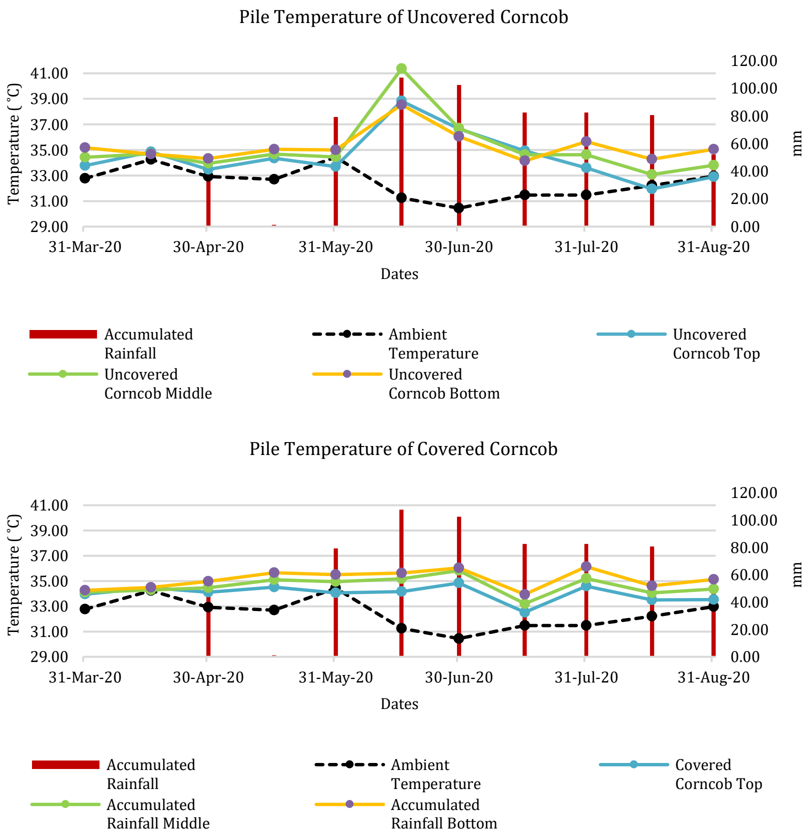

Fig. 4: Temperatures of the uncovered and covered corncob piles

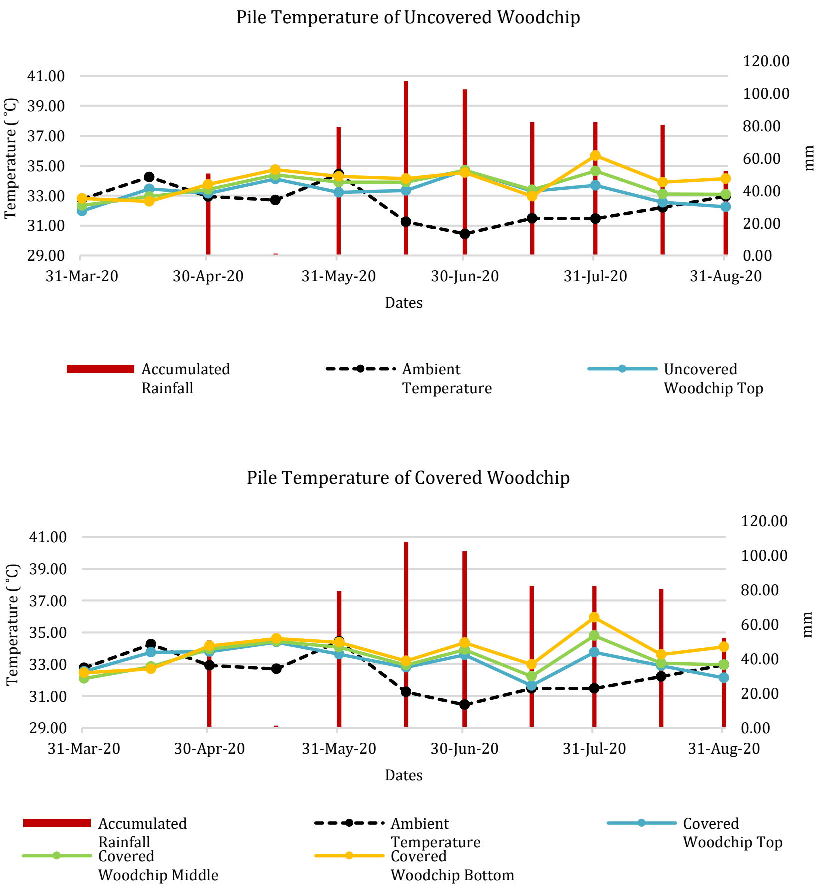

Fig. 5: Temperatures of the uncovered and covered woodchip piles

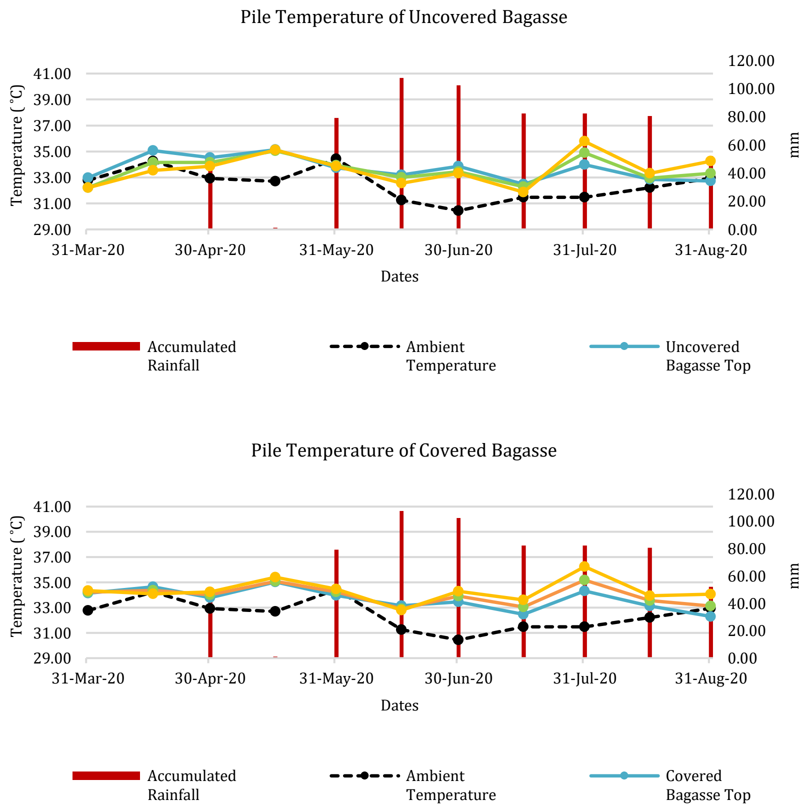

Fig. 6: Temperature of the uncovered and covered bagasse piles

During the month of March, the moisture content of both covered and uncovered piles was similar for all the biomass types (UC=9%, CC=11%, UW=25%, CW=27%, UB=35%, and CB=38%). The plastic sheet cover did not affect the moisture content during the summer period. However, after the rainy season, the moisture content of the uncovered piles, especially corncob, and woodchips, was slightly higher than that of bagasse (UC=68%, UW=54%, and UB=20%). However, the moisture content of the covered piles was still the same as that observed at the starting point (CC=13%, CW=12%, and CB=15%).

Storage of biomass during the rainy season was a challenging task as the characteristics used to evaluate its quality were affected by the rains. However, using LDPE sheets to cover the biomass piles reduced moisture fluctuations and environmental disturbance. Furthermore, the moisture content of the covered biomass piles was reduced during storage and met the fuel quality standard (40% moisture content as per the recommendation from the Department of Alternative Energy Development and Efficiency (DEDE, 2018).

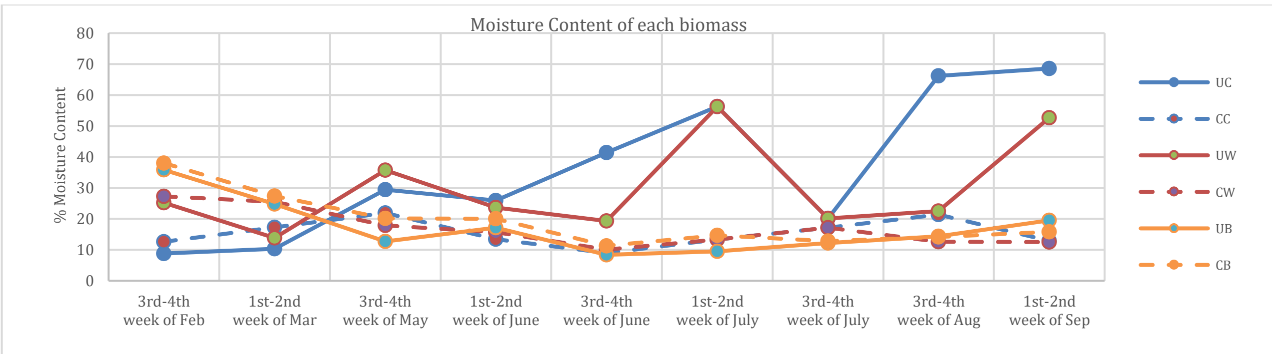

Fig. 7: The moisture content of each biomass pile (UC=Uncovered Corncob, CC=Covered Corncob, UW=Uncovered Woodchip, CW=Covered Woodchip, UB=Uncovered Bagasse, CB=Covered Bagasse)

3.4. Heating value

The oven-drying process was used to measure the heating values of both the uncovered and covered piles. The highest heating value of 16.17MJ/kg was observed in the covered corncob pile in May. The heating value for the uncovered pile was 15.09±0.37MJ/kg and that of the covered corncob pile was 14.92±0.52MJ/kg in September. These values were 1.82% and 2.53% lower than the initial values, respectively. The heating values of the uncovered and covered corncob piles decreased every month. However, their declining trend was observed from July to September (Fig. 8), when there was a large amount of rainfall. This resulted in high moisture content and microbial activity, especially in the uncovered pile. As discussed by Brand et al. (2011), the weather in winter is not appropriate for the degradation of biomass by microorganisms. Microbial activity is an important factor in reducing biomass carbon, which also decreases the heating value.

The heating values of the uncovered and the covered bagasse piles using the oven drying process were 13.84±0.81MJ/kg and 13.90±0.40MJ/kg, respectively, in September, which were lower than the initial values by 9.95% and 1.43%, respectively. The heating values of both the bagasse piles were reduced every month. Although the heating value between the two condition piles has not much difference in the last period of the storage, the heating value of the uncovered bagasse pile decreased more than that of the covered pile since the start of the storage. Moreover, the value of which decreased the most in September during high precipitation (Fig. 8). This study observed that the physical characteristics of the bagasse had a smaller size and dry from precipitation more easily than other types of biomass. According to Jirjis (1995), the small size of biomass had more microbial growth than the bigger. This was probably due to the large surface area of the small size available for microbial growth and in accordance with the higher temperature inside the pile. This allows for continued growth by rendering the internal environment.

The heating values of the uncovered and covered woodchip piles using the oven drying process were 15.24±0.42MJ/kg and 15.73±0.02MJ/kg, respectively, in September, which was lower than the initial values by 10.41% and 7.20%, respectively. The lowest heating value of the woodchip piles was observed in September, which was consistent with the trend observed in the rainy season by Brand et al. (2011). The heating value depends on plant species and their moisture content. An increase in moisture content during storage has a significant negative effect on the heating value (Casal, 2010). The results for the last month of the storage period (September) revealed that the lowest heating value was associated with an increase in moisture content due to rainfall and dry matter loss was the highest due to changes in the biomass composition, as demonstrated previously by Hofmann et al. (2018).

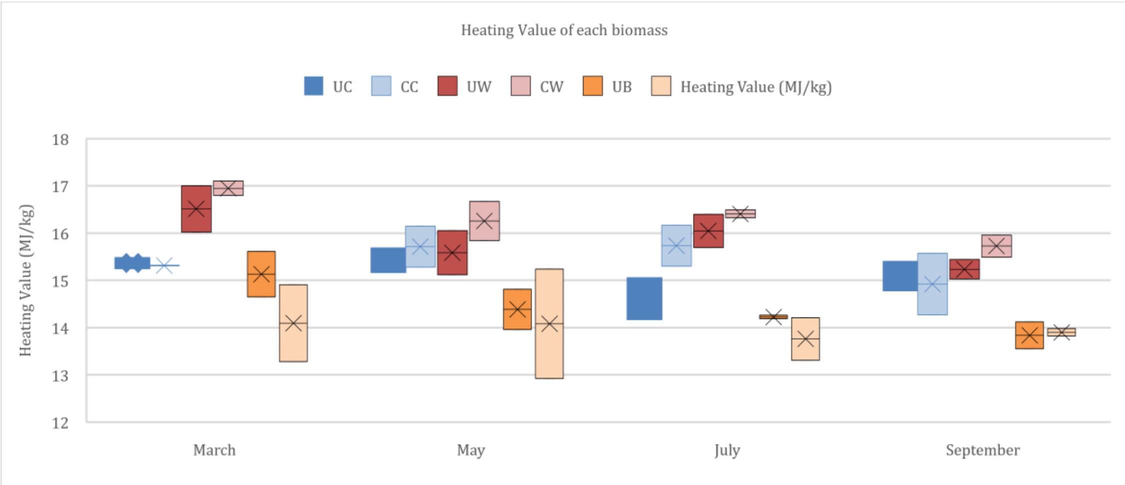

Fig. 8: The minimum, maximum, and average heating values of each biomass pile (UC=Uncovered Corncob, CC=Covered Corncob, UW=Uncovered Woodchip, CW=Covered Woodchip, UB=Uncovered Bagasse, CB=Covered Bagasse)

3.5. Ash content

The ash content of each pile increased throughout the experimental period. The ash content percentage of the covered and uncovered piles did not change much initially; however, it gradually increased in July when there was higher moisture. The higher levels of the piles had the highest ash content percentage, which was much higher in the uncovered piles (Fig. 9).

The uncovered bagasse pile and corncob pile had higher ash content than the covered piles. It is likely that the LDPE sheets used to cover the piles helped protect them from environmental disturbances such as dust particles.

This is corroborated by the findings of Pari et al. (2015), Afzal et al. (2010), and Gejdoš et al. (2015), who suggested that ash content is higher in uncovered piles as contamination occurs easily in such scenarios due to particles of metal, plastic, and so on. According to Jirjis (1995), the main factor responsible for the increase in ash content is the decay of the structural composition of the biomass, especially that of cellulose and hemicellulose. These components decrease throughout the storage period and the dry matter loss can be evidence of such decay.

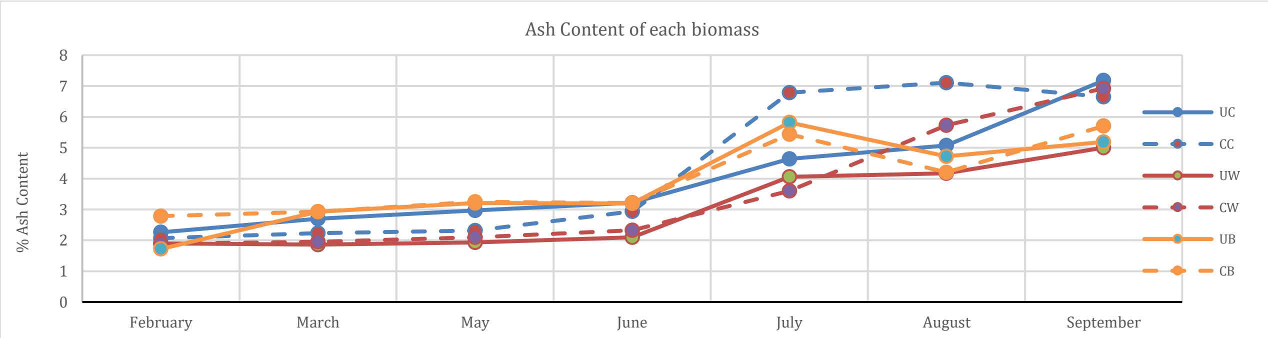

Fig. 9: Ash content of each biomass pile (UC=Uncovered Corncob, CC=Covered Corncob, UW=Uncovered Woodchip, CW=Covered Woodchip, UB=Uncovered Bagasse, CB=Covered Bagasse)

3.6. Dry matter loss

The highest dry matter loss for the uncovered corncob pile was 6.3%, which occurred in the sixth month of the storage period (September). The dry weight of the uncovered corncob pile decreased more than that of the covered pile. According to del Campo et al. (2014), this was related to the biological activity and moisture content when an LDPE sheet was used to cover the pile. The sheet helped reduce environmental disturbances to the pile, such as fluctuations in air temperature, rainfall, and ambient humidity (Fig. 10). However, the changes in dry matter loss were not significant (Wetzel et al., 2017). The results of this study showed that the overall percentage changes in the heating energy due to the combined effect of heating value loss and dry matter loss of the uncovered corncob pile in the third and sixth months of the storage period were 4.58% and 8.03%, respectively. For the covered corncob pile, the percentage changes in heating energy in the third and sixth months were 0.61% and 6.11%, respectively (Fig. 9).

The highest dry matter loss of the uncovered bagasse pile was 8.2% and occurred in the sixth month of the storage period (September). The dry weight of the uncovered bagasse pile decreased more than that of the covered pile. The dry matter loss was high from June to September (Fig. 10). The results of this study revealed that bagasse is the biomass type with the highest dry matter loss. Anerud et al. (2020) pointed out that coverage enhances the drying process and lowers dry matter loss. However, the amount of dry matter loss depends on particle size; a smaller particle size is associated with a higher amount of dry matter loss.

Hofmann et al. (2018) and Pari et al. (2015) studied biomass storage in European countries and found that there was a loss in biomass dry weight over time. The maximum loss was found at the highest level, which was closer to the outer environment, in both the covered and uncovered piles. Röser et al. (2011), Hofmann et al. (2018), and Richardson et al. (2002) suggested that the best season for biomass drying is spring or early summer as the biological degradation during this time is lower as compared to other seasons. Furthermore, coverage is beneficial in autumn and the rainy season because it reduces humidity and degradation of the biomass (Anerud et al., 2020). In this study, a high percentage of dry matter loss was observed in the last month of the storage period (September), which was early winter in Thailand, although it was influenced by heavy rainfall (Fig. 10). These findings suggest that dry matter loss in the rainy season is higher than in summer. These results demonstrate that aerobic digestion of uncovered biomass piles can have a significant effect on the energy and quantity of the biomass.

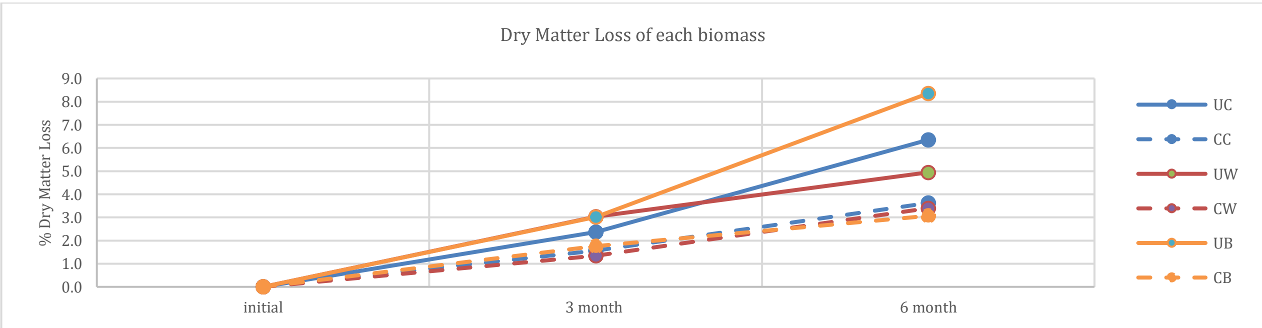

Fig. 10: Dry matter loss of each biomass pile (UC=Uncovered Corncob, CC=Covered Corncob, UW=Uncovered Woodchip, CW=Covered Woodchip, UB=Uncovered Bagasse, CB=Covered Bagasse

3.7. Biomass composition

The hemicellulose and cellulose composition of uncovered corncob decreased each month. On the other hand, the composition of lignin was reaching increased and increased with a decreased proportion of other biomass compositions. Hemicellulose composition was rapidly decreased during June-August when the microbial is growing.

The extractive composition was not stable in the uncovered condition (Fig. 11).

The losses indicate that cellulose and hemicellulose are lost in similar trending. Lignin concentrations were observed to increase over time and the 3 months samples showed a small increase in the percentage of lignin. At 6 months, however, the percentage of lignin in uncovered piles was higher than in covered piles compared to the original. The different increases in the percentage of lignin and decreases in cellulose showed the distinction of the effect of plastic sheet cover to enhance microbial activity (Hofmann et al., 2018).

Lignin is the Lignocellulosic that provides the highest energy. In this study, the covered storage results in a higher lignin composition than the uncovered condition. However, biomass valorization by storage should consider other characteristics, such as the moisture content reduction after the harvesting to increase the energy content of the biomass (Velvizhi et al., 2022; Wang and Lee, 2021; Demirbas, 2002).

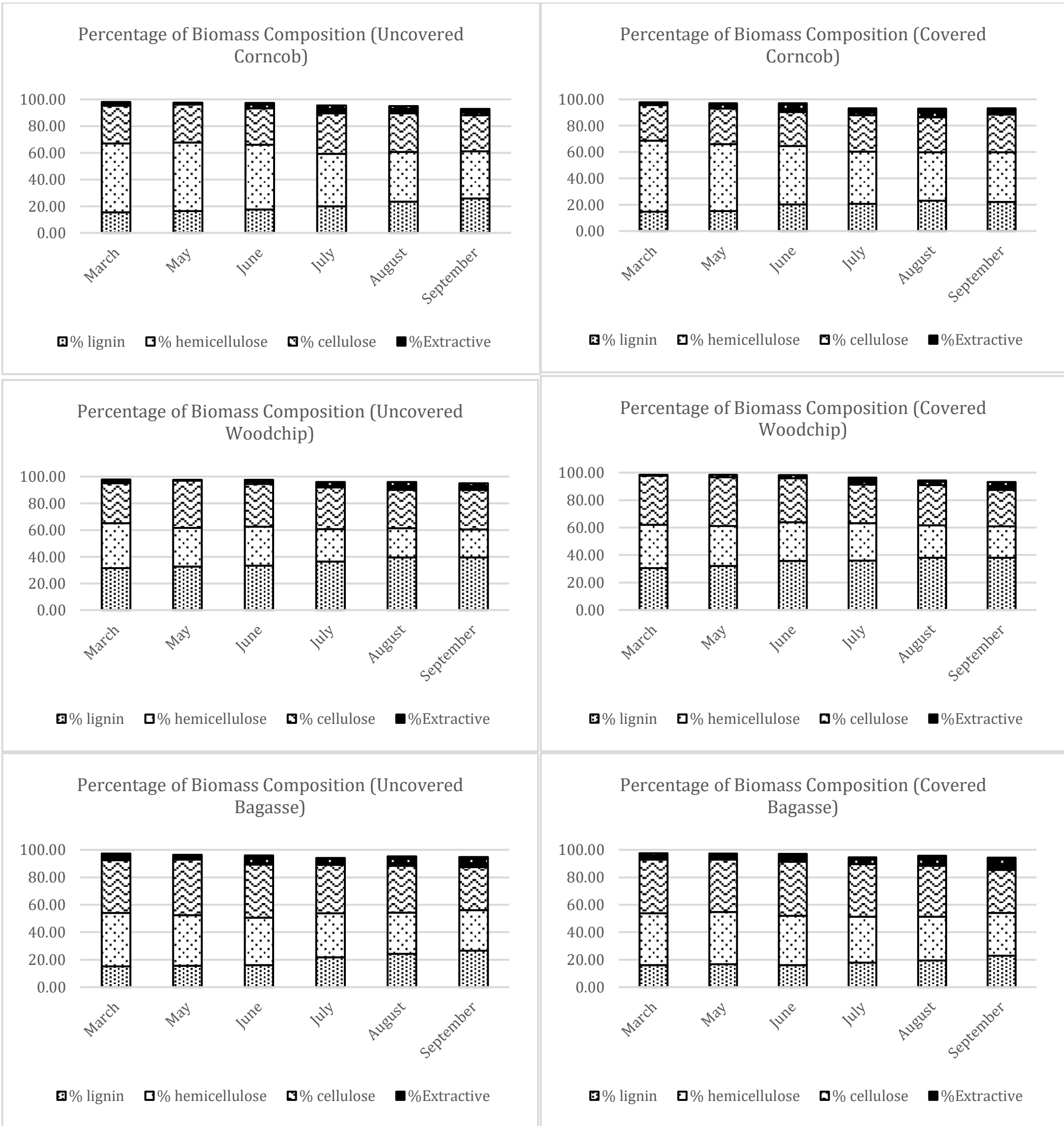

Fig. 11: Biomass composition of each biomass pile

4. Conclusion

This study investigates the impact of weather on biomass quality and its various characteristics, including moisture content, calorific value, dry matter loss, ash content, and biomass composition during the storage period. The findings reveal that while the moisture content of bagasse exhibited limited significance, it notably decreased in July. Notably, the uncovered corncob pile exhibited the highest moisture content during the rainy season or early winter months of May to September. The use of covering sheets during the rainy season was found to be effective in reducing moisture content, but no significant difference was observed between covered and uncovered piles in the summer season. As the highest demand for biomass as fuel in Thailand occurs during summer, this period is deemed the most suitable for biomass storage to enhance its quality. The study further demonstrates that LDPE plastic sheets, when used to cover piles, positively influence energy production from woodchips and corncobs, whereas their impact on bagasse piles was insignificant. Additionally, the type of biomass was found to influence its characteristics during the storage period, with bagasse demonstrating limited potential for reaching high levels of moisture content suitable for energy production even after a six-month storage period from March to September.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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