Some Properties of White and Torrefied Pellets Obtained from Oil Palm Trunk as Raw Material

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Properties of unheated wood pellets were compared with those of torrefied wood pellets that had been heated to 270, 290, and 310 °C, with raw material taken from two different height levels of oil palm trunk (OPT). The gross calorific value, moisture content, ash content, volatile matter, fixed carbon, density, and weight loss were examined. Air drying or oven drying pretreatment was applied to the raw materials. The results showed that the heating values of samples increased when raw materials were torrefied, depending on the heat treatment temperature. The torrefied pellets were improved by as much as 66.4% in heating value compared with OPT pellet samples. The greatest improvement was found in torrefied pellet samples prepared at 310 °C, using air drying, and height levels of OPT between 0.3 to 1.5 m. The ash content of samples tended to increase when the torrefied temperature was increased, while the volatile matter value was reduced with high temperature. Based on the findings, OPT could be used as a raw material to produce value-added white and torrefied pellets as sustainable solid biofuel.

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Keywords: Wood pellet; Torrefied pellet; Oil palm trunk; Heating value; Volatile matter

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INTRODUCTION

Biomass is a potentially carbon-neutral energy source, and it is the world's fourth largest primary energy resource after natural gas, coal, and crude oil (Saxena *et al.* 2009). Due to heterogeneity in the physical and chemical properties of biomass, high moisture contents, low grindability, low energy density, and biodegradability, there are several restrictions and challenges during biomass utilization (Arteaga-Pérez *et al.* 2017). Efforts are being made to develop upgrading methods that convert biomass into a fuel or bioenergy with excellent logistics and end-use properties (Di Marcello *et al.* 2017).

Oil palm (*Elaeis guineensis*) is now planted in all tropical areas of the world such as Malaysia, Indonesia, and Thailand, and it contributes to the recent economic development of these countries (Siew *et al.* 2008; FAO 2017; Padzil *et al.* 2020; Malinee *et al.* 2021). Oil palms produce the most oil per hectare, and palm oil can be used for a variety of purposes. It is an important species in the region for industrial crops that produce vegetable oil or oleochemical products (Bessou *et al*. 2018). It has primarily been used as a source of cooking oil and a food supplement. In terms of productivity, yields of 4 to 5 metric tonnes of oil per planted hectare (MT/ha) are expected. Because the production cost is lower than that of other oil crops, it may become a necessary feedstock for biofuels such as biodiesel in Southeast Asia (Mukherjee and Sovacool 2014). This species has produced better productivity of fresh fruit bunches (FFB) for 25- to 30-year-old trees (Tareen *et al.* 2021). The harvesting and processing of the yields from these trees, as well as the replantation (1 to 4 years) of oil palm trees, generates a large amount of oil palm biomass in the form of oil palm trunks (Woodham *et al.* 2019). Oil palm trunk (OPT) is a non-woody structure, but it is a lignocellulosic biomass that has a high potential yield in the southern part of Thailand for biofuels and bioenergy applications. The area of oil palm plantation in Thailand was over 0.88 million ha in 2018 (Palamanit *et al*. 2019). Lignocellulosic materials are an important source for renewable fuels and valuable chemicals (Saxena *et al.* 2009). Therefore, OPT can be abundant biomass feedstock and has potential for bioenergy.

It has been predicted that the global energy demand will rise by 28% by 2040, leading to concerns about energy security, global climate change, and the need for sustainable, renewable energy sources (Owusu and Asumadu-Sarkodie 2016; EIA 2017; Manouchehrinejad *et al.* 2021). As fossil fuels have been phased out, renewable energy sources such as wood pellets have grown in importance (Luo *et al.* 2020). Co-firing wood pellets with coal in coal-fired power plants can help the world become less carbon-intensive while still producing enough energy (Visser *et al.* 2020). Wood pellets are the primary solid biofuel used in a few power plants in the UK and Europe (Goerndt *et al.* 2013).

Wood pellet, also known as white pellet, is a densification product made from byproducts of the wood processing industry or lignocellulosic materials through the use of mechanical force to compact particles into pellets (Agar *et al.* 2015; Peng *et al.* 2015). It is a new and expanding heating option in the United States and Europe, with improved combustion characteristics of a homogeneous and energy-dense fuel (McKechnie *et al.* 2016; Buchholz *et al.* 2017). However, some white pellet properties are restricted. Conventional pellets can absorb moisture from their surroundings during transport and storage, have a relatively low energy density, and are difficult to store (Chen and Kuo 2011). As a result, pellet technology has been studied to improve its properties.

Torrefied pellets, also known as black pellets, are typically made from thermally pre-treated raw materials prior to or after pelletization. Torrefaction is a promising method for producing stable wood pellets with higher energy density and hydrophobicity, as well as the lowest global warming potential (Li *et al.* 2012; Chen *et al.* 2021). Torrefaction consists of thermal pretreatment under mild conditions, with temperatures of 200 to 300 °C for 10 min to 3 h of reaction time under various atmospheres (Wang *et al.* 2013; Eseyin *et al.* 2015; Mei *et al.* 2015; García *et al.* 2018). The main goal of torrefaction is to upgrade solid biomass so that it can serve as an alternative to coal (Chen *et al.* 2021). Black pellets have a higher heating value, higher bulk density, and higher bulk energy density than regular wood pellets, which reduces long-distance transportation costs (Alizadeh *et al.* 2022).

Therefore, the purpose of this study was to investigate the properties of this biomass feedstock, in the form of white and torrefied pellets, for energy applications. The products of this experiment demonstrate the potential value-added properties of OPT pellets. The findings could be used to support the use of this biomass feedstock for energy applications.

EXPERIMENTAL

Materials and Methods

Oil palm trunks (OPTs) were selected and cut in July 2021 from an oil palm plantation in Surat Thani, Thailand (9°02'53.8"N, 99°22'32.5"E). These oil palm trees were 30 years old, and therefore their ability to produce oil was diminished and not of economical significance. This study investigated the effects of the height of OPT, namely Low (L) and Medium (M), which represent the stem length of 0.3 to 1.5 m and 1.5 to 3.0 m above, respectively. Both parts of OPT were cut to timber, which then was chipped to small particles as fine as sawdust with lengths of 1 to 4 mm and a diameter less than 4 mm using a sieve with 18 mesh. OPT particles were separated into two categories using air drying and oven drying technique. OPT particles air dried for a week have moisture content (MC) at the average of 14% while oven dried OPT particles has 0% MC.

Both air-dried and oven-dried OPT particles from both part of oil palm stem were torrefied at temperatures of 270, 290, and 310 °C for 10 min in a Muffle Furnaces Stuart 1200 °C range (UK). A total of 250 g of OPT particles were prepared for each torrefaction at atmospheric pressure and in the absence of oxygen. The sample was put in a desiccator for 2 h. An electric flat die wood pellet mill (KN-D-200, China) with 7.5 hp (380v) having pellet mill die in 6 mm was used for pelletization of OPT and torrefied OPT pellets. Before this process, the moisture content was increased to 12 to 15% by adding distilled water to OPT particles. Sixteen conditions of the experiment were produced 3 kg per condition as shown in Table 1.

Table 1. Experimental Conditions of OPT and Torrefied OPT Pellets

Sample Type	Temperature of Heat Treatment (°C)	Pre Oven Drying	Air Drying	Length of OPT from 0.3-1.5 m of stem	Length of OPT from 1.5-3.0 m of stem
1	-	✓		✓	
2	-	✓			✓
3	-		✓	✓	
4	-		✓		✓
5	270	✓		✓	
6	270	✓			✓
7	270		✓	✓	
8	270		✓		✓
9	290	✓		✓	
10	290	✓			✓
11	290		✓	✓	
12	290		✓		✓
13	310	✓		✓	
14	310	✓			✓
15	310		✓	✓	
16	310		✓		✓

Properties Evaluation of Pellets

The density of OPT pellet samples was determined after precise measurements of mass (to 0.01 g) and volume (to 0.01 cm) using the following equation,

$$D = M / V \tag{1}$$

where D is the density of pellet (g/cm^3), M is the mass of the pellet (g), and V is the volume of pellet (cm^3).

Gross calorific value (GCV) of OPT pellet samples was determined using an automatic bomb calorimeter (Leco A-350, MI, USA). A total of 48 samples, accounting for 3 replications of 16 conditions, were randomly selected for the testing, and the results are given as means with standard deviations in MJ/kg (ASTM D 3286-96). The samples were also subjected to proximate analysis to determine the impact of moisture content (MC), volatile matter (VM), ash content (AC), and fixed carbon (FC) in percentage on the gross calorific value.

Energy yield of torrefied pellet was assessed by using gross calorific value of pellet and mass yield (MY),

$$\text{MY} = (M_{\text{tor}}/M_{\text{bef}}) \times 100 \tag{2}$$

where MY is mass yield of OPT (%), M_{tor} is mass after torrefaction (g), and M_{bef} is mass before torrefaction (g).

$$\text{EY} = \text{MY} \times (\text{GCV}_{\text{tor}}/\text{GCV}_{\text{non}}) \tag{3}$$

In Eq. 3, EY is energy yield of torrefied pellet (%), GCV_{tor} is gross calorific value of torrefied pellet (MJ/kg), and GCV_{non} is gross calorific value of non-torrefied pellet (MJ/kg).

The weight loss (WL) of OPT was measured using the following equation,

$$\text{WL} = (A\text{-}B)/A \times 100 \tag{4}$$

where WL is the weight loss of OPT (%), A is the mass of the OPT before heat treatment (g), and B is the mass of the OPT after heat treatment (g).

The Shore A hardness of 48 samples in length of 30 mm was measured by length and width section using a hardness tester HT3000, MonTech, Germany, with 10 N loading. The results are given in the range of 0 to 100 (ASTM D2240-15).

The water absorption (WA) by soaking in distilled water for 5 and 30 min was used to measure the moisture uptake of torrefied and non-torrefied pellets. 48 samples were submerged in a 250 mL beaker with 100 mL of water for 5 min and 48 samples were submerged in a 250 mL beaker with 100 mL of water for 30 min. The sample was poured through filter paper which has pore size of 11 µm and 125 mm in diameter for 10 min. The WA samples was measured by weighed with precisions 0.01 g using the following equation,

$$\text{WA} = (M_{\text{a}} – M_{\text{b}})/M_{\text{b}} \times 100 \tag{5}$$

where WA is the water absorption of pellet (%), M_{a} is the mass of the pellet after soaking (g), M_{b} is the mass of the pellet before soaking (g).

A scanning electron microscope (SEM; FEI Quanta 250, Hillsboro, OR, USA) was employed to examine the morphology of the samples. The SEM was set to 15 kV, and all of the samples were coated with a thin gold layer prior to analysis. The images were carried from cross sections of pellets with a diameter of 6 mm.

For data analysis, a completely randomized design of sample types was used.

Analysis of variance (ANOVA) was used to determine the significant differences between the sixteen types of pellet specimens by using SPSS Statistics version 22 and Duncan's multiple range tests were also used for additional analysis. A p-value of 0.05 was used as the level of confidence.

RESULTS AND DISCUSSION

Table 2 shows the density, moisture content, gross calorific value, fixed carbon, volatile matter, and ash content of OPT pellets and torrefied pellets produced with various conditions. The properties of the pellets produced with 16 different procedures were significantly different at the 95% confidence level ($p \leq 0.001$). The lowest density was reported at 1.16 g/cm^3 for sample type 13 with 310 °C of heat treatment, oven pre-drying, and length of OPT from 0.3 to 1.5 m of the stem. The density of the torrefied samples trended to decrease with increasing temperature of heat treatment. It is believed that mass loss caused the density to drop as temperature rises. As temperature rises throughout the torrefaction process, distinct stages of mass loss take place (Ciolkosz and Wallace 2011; Acharya and Dutta 2013; Acharya *et al*. 2015). The temperature of drying and heat treatment techniques affected the moisture content of the samples. The pellet moisture content can be decreased using high temperatures. The calorific value of the torrefied biomass increases with higher treatment temperatures and longer residence times because hemicellulose is partially degraded, leading to a more hydrophobic solid, and the oxygen-carbon or hydrogen-carbon ratio falls with increasing temperature (Bergman *et al.* 2005; Kiel 2007).

Thermochemical Properties of Pellets

The gross calorific value of the samples is illustrated in Fig. 1. The heating value was significantly affected by pre-oven drying, oil palm trunk height levels, and thermal treatment temperatures ($p < 0.001$).

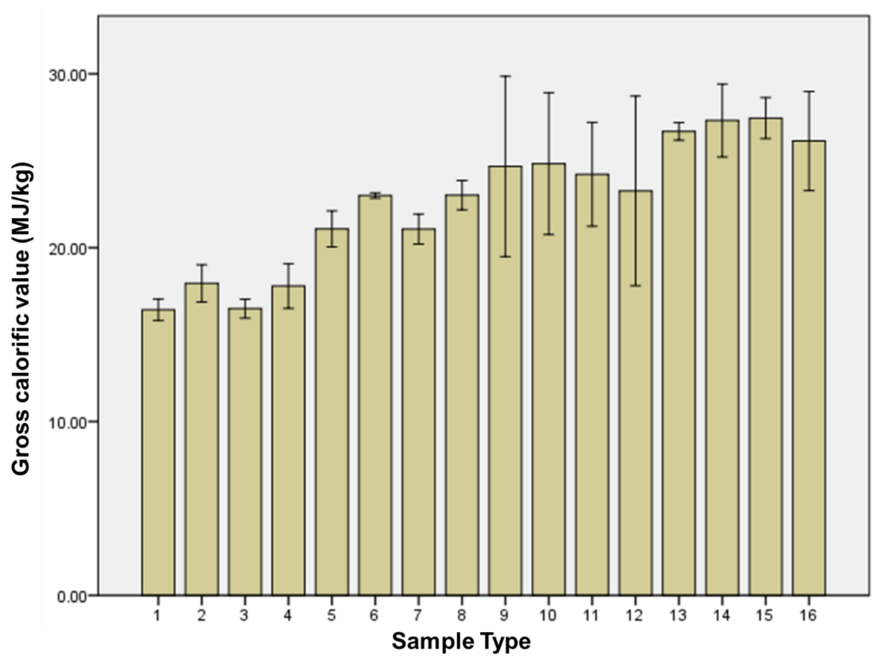

Fig. 1. Gross calorific value of the samples

For the heat treatment temperatures of 270, 290, and 310 °C, respectively, this study reported an improved heating value of OPT by 28.4%, 41.2%, and 56.7% using the torrefaction technique. Additionally, this study discovered that employing OPT height levels between 0.3 and 1.5 m, air drying, and heat treatment of 310 °C improved the heating value of the pellets by 66.4%. According to Ciolkosz and Wallace (2011), hemicelluloses are broken down during the torrefaction process. As the temperature rises, the degradation quickens, and the heating value rises as a result.

Table 2. Density, Moisture Content (MC), Gross Calorific Value (GCV), Fixed Carbon (FC), Volatile Matter (VM) and Ash Content (AC) of OPT Pellets and Torrefied Pellets Produced with Various Conditions

Sample Type	Density** (g/cm^3)	MC** (%)	GCV** (MJ/kg)	FC** (%)	VM** (%)	AC** (%)
1	1.26^{ef} (0.03)	8.59^{g} (0.51)	16.43^{a} (0.25)	3.36^{a} (0.58)	84.57^{gh} (0.68)	5.04^{b} (0.66)
2	1.27^{ef} (0.02)	8.74^{g} (0.75)	17.95^{a} (0.43)	3.43^{a} (0.96)	83.99^{g} (0.77)	5.32^{b} (0.70)
3	1.25^{def} (0.03)	12.46^{h} (0.86)	16.50^{a} (0.22)	2.13^{a} (0.62)	85.94^{i} (0.89)	3.41^{a} (0.47)
4	1.24^{cdef} (0.04)	11.98^{h} (0.51)	17.79^{a} (0.52)	3.36^{a} (1.55)	85.08^{hi} (0.82)	3.09^{a} (0.49)
5	1.27^{ef} (0.02)	5.94^{ef} (0.51)	21.08^{b} (0.42)	6.03^{bc} (1.39)	80.92^{de} (0.64)	5.04^{b} (0.66)
6	1.22^{bcde} (0.01)	5.72^{def} (0.07)	23.00^{c} (0.06)	6.82^{bc} (0.66)	81.05^{de} (0.45)	5.32^{b} (0.70)
7	1.25^{cdef} (0.01)	6.77^{f} (0.80)	21.07^{b} (0.35)	5.81^{b} (1.76)	82.16^{f} (0.29)	5.08^{b} (0.52)
8	1.27^{ef} (0.05)	6.63^{f} (0.45)	23.02^{c} (0.34)	7.00^{bcd} (1.32)	81.78^{ef} (0.21)	5.09^{b} (0.49)
9	1.24^{cde} (0.03)	4.96^{bcde} (0.98)	24.67^{cd} (2.09)	7.94^{cde} (0.69)	79.32^{bc} (0.46)	6.79^{c} (0.30)
10	1.25^{def} (0.02)	4.78^{abcd} (0.43)	24.83^{cd} (1.64)	8.97^{de} (0.43)	78.96^{b} (0.53)	6.34^{c} (0.58)
11	1.30^{f} (0.07)	5.12^{cde} (0.62)	24.22^{c} (1.20)	7.02^{bcd} (0.37)	79.85^{bc} (0.18)	6.37^{c} (0.42)
12	1.22^{bcde} (0.04)	5.34^{de} (0.69)	23.26^{c} (2.20)	6.63^{bc} (0.60)	80.08^{cd} (0.21)	6.66^{c} (0.54)
13	1.16^{a} (0.03)	3.65^{a} (0.64)	26.69^{e} (0.21)	9.08^{e} (1.86)	76.80^{a} (0.36)	8.24^{d} (0.19)
14	1.18^{ab} (0.04)	3.76^{a} (0.60)	27.32^{e} (0.85)	8.84^{de} (1.47)	76.56^{a} (0.56)	8.27^{d} (0.45)
15	1.19^{abcd} (0.04)	4.08^{abc} (0.50)	27.45^{e} (0.48)	9.30^{e} (0.68)	77.41^{a} (0.57)	8.00^{d} (0.14)
16	1.19^{abc} (0.03)	3.91^{ab} (0.37)	26.14^{de} (1.15)	9.79^{e} (0.59)	76.85^{a} (0.90)	7.82^{d} (0.21)

Numbers in parentheses are standard deviation values.
Mean values with the different letters are significantly different.
**Highly significantly different ($P \leq 0.001$).

Torrefaction can increase the fixed carbon value of the pellets. The results are presented in Fig. 2. OPT pellets displayed a low fixed carbon content on average of 3.07% and did not significantly differ from one another, while pre-drying at two distinct heights of oil palm trunks. The sample of torrefied OPT pellets at 270, 290, and 310 °C displayed averages of 6.42%, 7.64%, and 9.26%, respectively. The improvement of biomass fuel quality, which burns with characteristics close to coal, is the main advantage of torrefaction. Coal has various fuel qualities, including a fixed carbon content of 50 to 55% (dry basis), a bulk energy density of 18 to 24 GJ/m^3, a moisture content of 10 to 15%, and a heating value of 23 to 28 MJ/kg (Shankar Tumuluru *et al*. 2011; Koppejan *et al*. 2012).

The volatile matter of the pellets produced with 16 different procedures was decreased when using torrefaction. The highest value of 85.9% was obtained when using length of OPT from 0.3 to 1.5 m of the stem a raw material with air drying process. The lowest value of 76.6% was observed when 310 °C heat treatment was employed using OPT with length from 1.5 to 3.0 m of the stem with pre oven drying process.

When the heat treatment temperature was raised, the ash content of the pellets increased. The greatest value recovered was 8.27% in sample type 14, which is 310 °C heat treated OPT for height level of 1.5 to 3.0 m of stem. The value is slightly low, while using a relatively low temperature for the process. This investigation of white and torrefied OPT pellets showed that the height level of OPT can substantially increase ash content of biofuel.

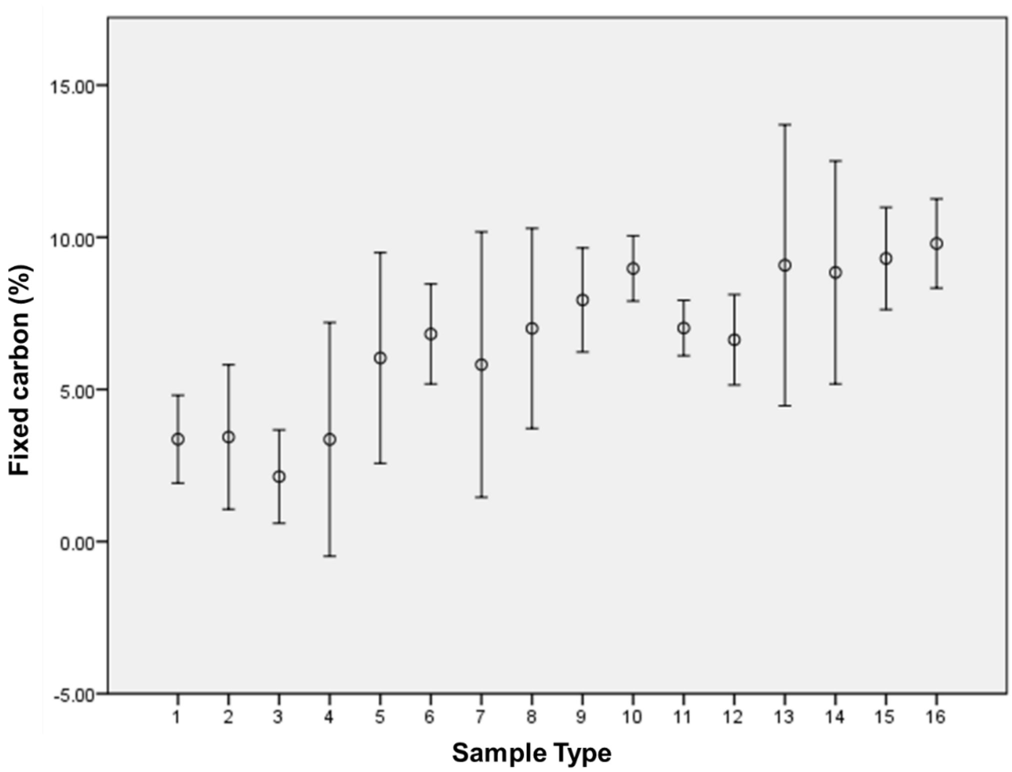

Fig. 2. Fixed carbon of the samples

Physical and Hygroscopic Properties of Pellets

Table 3 displays weight loss, shore A hardness of length and width section, and water absorption of the pellets after soaking in 5 and 30 min. The lignocellulosic materials' original bulk was reduced by heat treatment. This weight loss was dependent on increasing the treatment temperature; at higher treatment temperatures, the weight loss rose sharply. The weight loss was from 60 to 64% for the torrefied OPT sample treated at 310 °C, while heat treatments at 270 and 290 °C resulted in weight loss ranges of 31 to 34 and 50 to 55%, respectively. The weight loss of materials in terms of the thermal degrading properties of biomass was impacted by heat treatment at 200 to 300 °C (Burhenne *et al.* 2013).

Table 3. Weight Loss, Shore A Hardness, and Water Absorption of OPT Pellets and Torrefied Pellets Produced with Various Conditions

Sample Type	Weight Loss** (%)	Energy Yield** (%)	Shore A Hardness Length**	Shore A Hardness Width**	Water Absorption for 5 min** (%)	Water Absorption for 30 min** (%)
1	-	-	80.37^{a} (3.07)	88.23^{b} (1.05)	10.75^{e} (0.61)	38.96^{f} (0.52)
2	-	-	78.37^{a} (5.96)	85.73^{ab} (1.40)	11.24^{ef} (0.99)	39.06^{f} (0.43)
3	-	-	80.90^{a} (1.71)	82.70^{a} (0.66)	9.94^{d} (0.59)	41.16^{g} (0.48)
4	-	-	86.27^{b} (2.61)	88.57^{b} (0.90)	11.70^{f} (0.48)	42.54^{g} (0.88)
5	31.76^{ab} (2.44)	87.56^{e} (2.74)	92.10^{cde} (3.16)	95.23^{cd} (3.57)	7.50^{c} (0.25)	23.79^{de} (0.66)
6	36.63^{b} (1.41)	81.22^{e} (1.63)	93.13^{cde} (2.61)	98.03^{de} (0.50)	7.44^{c} (0.31)	25.27^{e} (0.33)
7	31.26^{a} (3.02)	87.82^{e} (5.05)	89.93^{bcd} (2.58)	96.40^{cde} (1.56)	7.55^{c} (0.25)	24.72^{e} (1.29)
8	33.40^{ab} (3.28)	86.26^{e} (6.15)	94.47^{cde} (2.46)	96.50^{cde} (2.31)	7.82^{c} (0.46)	25.08^{e} (0.53)
9	54.05^{c} (3.26)	69.13^{cd} (9.42)	97.53^{e} (2.14)	98.87^{e} (1.00)	5.64^{b} (0.29)	21.45^{abc} (1.28)
10	50.86^{c} (1.67)	67.96^{bcd} (3.58)	94.10^{cde} (1.85)	98.03^{de} (1.37)	5.77^{b} (0.44)	22.50^{bcd} (0.46)
11	50.85^{c} (2.00)	72.09^{d} (1.49)	88.47^{bc} (5.10)	94.30^{c} (3.47)	5.52^{b} (0.23)	22.98^{cd} (1.51)
12	54.42^{c} (3.18)	70.05^{cd} (2.25)	94.97^{de} (1.67)	95.47^{cde} (1.78)	5.78^{b} (0.42)	22.89^{cd} (1.58)
13	62.00^{d} (3.06)	61.71^{abc} (4.43)	97.03^{e} (5.14)	98.63^{de} (1.87)	3.05^{a} (0.10)	20.68^{a} (0.48)
14	60.24^{d} (2.82)	60.42^{ab} (1.54)	96.90^{e} (2.00)	98.80^{e} (0.35)	3.29^{a} (0.37)	20.49^{a} (1.30)
15	61.01^{d} (3.31)	64.90^{abcd} (5.95)	97.00^{e} (3.05)	93.53^{c} (1.86)	3.49^{a} (0.25)	20.35^{a} (0.87)
16	63.95^{d} (4.43)	58.76^{a} (1.27)	98.23^{e} (2.11)	98.93^{e} (1.85)	3.41^{a} (0.23)	21.08^{ab} (0.54)

Numbers in parentheses are standard deviation values.
Mean values with the different letters are significantly different.
**Highly significantly different ($P \le 0.001$).

Energy yield of torrefied OPT pellet samples was in the range of 58 to 88%. The lowest value of torrefied pellet (58.8%) was in the specimen at 310°C using air drying with length from 1.5 to 3.0 m of the stem. The value of each pellet for various temperature had been reduced when increasing the temperature of heat treatment significantly. It was shown that white pellet has higher energy yield than those of torrefied pellets (Park *et al.* 2020).

Mass yield and energy yield of heat treated OPT pellets were decreased, but their gross calorific values of sample were increased so that there were significant difference between non-torrefied and torrefied pellets.

Shore A hardness value of the samples was given the hardness of pellets by length and width section (Fig. 3). Based on the findings this study, shore A hardness value of the samples with length section ranged from 78 to 86 for OPT pellets, 89 to 94 for 270 °C torrefied OPT pellets, 88 to 97 for 290 °C torrefied OPT pellets, and 96 to 98 for 310 °C torrefied OPT pellets.

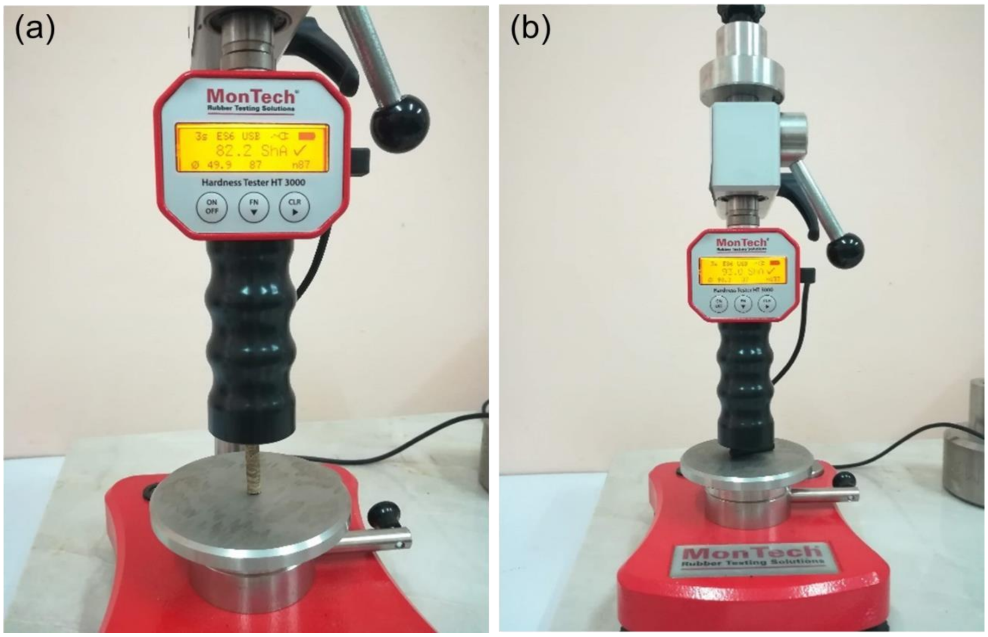

Fig. 3. Shore A hardness testing of the sample, (a) with length section and (b) with width section

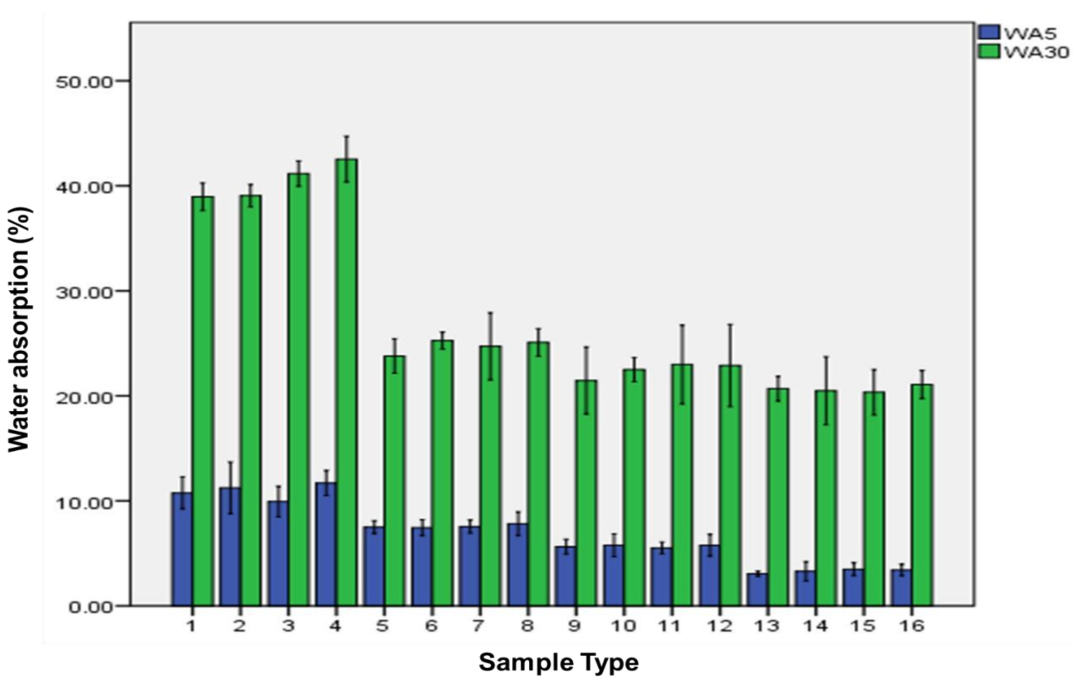

Fig. 4. Water absorption of the pellet samples produced with various conditions, WA5 (water absorption for 5 min) and WA30 (water absorption for 30 min)

The shore A hardness value of the samples with width section showed a scale in 82 to 88 for OPT pellets, 95 to 98 for 270 °C torrefied OPT pellets, 94 to 98 for 290 °C torrefied OPT pellets, and 94 to 99 for 310 °C torrefied OPT pellets. The findings revealed how their hardness behaved, showing that a pellet's width section is harder than its length section. Additionally, torrefied OPT's properties had enhanced with increased temperature. Water absorption value of the samples produced with various conditions was significantly different in this work.

Figure 4 displays the comparison of WA of the samples after soaking in distilled water for 5 and 30 min. The heat treatment technique improved the resistance of the pellets towards WA. In comparison to conventional OPT pellets, heat-treated pellets at 310 °C exhibited resistance of 69.7% and 48.9% after soaking 5 and 30 min, respectively. According to this experiment, white pellets are less water resistant than black pellets. Torrefied pellets were still intact, while the OPT samples became degraded when submerged in water for a longer period of time.

The morphology of untreated OPT pellet and torrefied OPT samples was investigated by scanning electron microscope, as shown in Fig. 5. The surface of the untreated OPT pellets was coarse and heterogeneous (Fig. 5a). In contrast, torrefied pellets had a more compact, homogenous structure (Fig. 5b). A similar observation was reported by Mustelier *et al*. (2012).

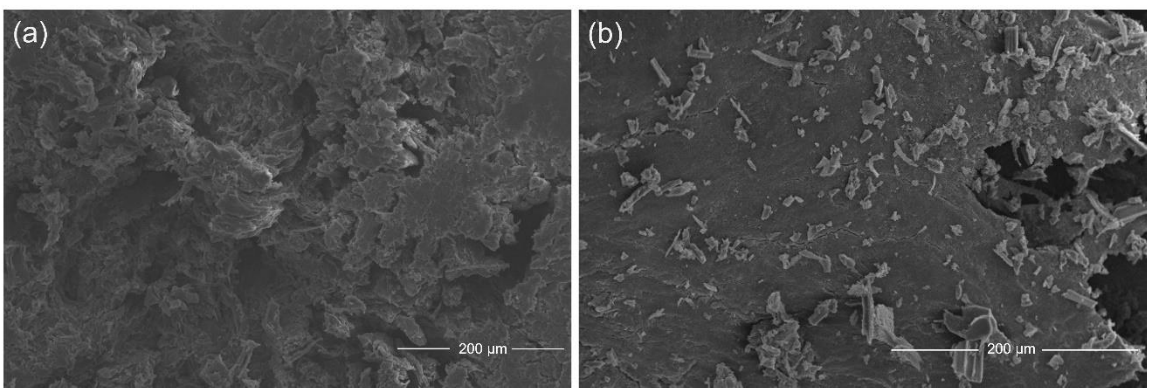

Fig. 5. SEM images of pellet samples, (a) OPT pellet and (b) Torrefied OPT pellet

CONCLUSIONS

1. The torrefaction procedure, which has a connection to volatile matter levels, boosted the samples' gross calorific value up to 66.4%. The maximum treatment temperature (310 °C) used in this investigation revealed the testing results with a considerable difference. Additionally, there was a considerable impact on those attributes from varying OPT height levels. When applying high temperatures, the volatile matter value of the samples was lowered by heat treatment, resulting in low volatile matter values.
2. The water absorption of this experiment was reduced by heat treatment. The highest temperature produced samples with the lowest WA value.
3. Pretreatment drying methods of oil palm trunk, including oven and air drying, resulted in some noticeable differences in the characteristics of pellet samples.
4. According to the findings, oil palm trunk could be a feedstock to product white and torrefied pellets.

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Author Contributions

The manuscript was written through the contributions of all authors. All authors have given their approval to the final version of the manuscript.

Conflicts Of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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