

## The Effects of Additives on the Pelletization of Raw and Torrefied Food Waste

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**ABSTRACT** – This study evaluates the effect of various binders on the pelletization of raw and torrefied food waste (FW) towards its physical properties, including density, moisture reabsorption, and tensile strength of the formed pellets. Three binders; starch, lignin, and vegetable oil, were used to make the raw and torrefied FW pellets. It was found that the addition of lignin helps to improve the density of both, raw and torrefied FW pellets by 40% for raw FW pellets and up to 27% improvement for the torrefied FW pellets. In addition, increasing the concentration of lignin may also reduce moisture reabsorption from 48% to 40% of raw FW pellets, and the sorption was further reduced for the torrefied FW pellets. The addition of lignin improves the tensile strength, mainly the torrefied FW pellets. Results show that lignin inclusion demonstrates significant enhancement to the physical properties of FW pellets.

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## INTRODUCTION

Biomass is an organic matter that can be harvested as a source of renewable energy. Today, biomass contributes to 14% of the total world energy consumption, which is the fourth source of energy globally [1]. The biomass energy is mostly obtained from wood-related waste (64%), municipal solid waste (MSW) (24%), agricultural waste (5%), and landfills gases (5%) [2]. In addition, food waste (FW) that usually ends up as MSW consists of one-third of still-edible food produced in the world [3]. This domestic FW has not been thoroughly investigated as an energy source, despite being organic and holds the potential to be utilized. Hence, FW remains a relatively untapped biomass resource used in both developed and developing countries. The under exploration of FW creates the opportunity to utilize FW as a possible source of renewable energy production. The characterization of FW from our earlier work [4] is shown in Table 1, which shows the composition of raw FW.

**Table 1.** Proximate (PA) and Ultimate Analysis of Raw FW.

Proximate Analysis (wt%)	[4]
Moisture Content (wt%) <sup>a</sup>	55.74
Moisture Content (wt%) <sup>b</sup>	8.86
Volatile Matter (wt%) <sup>c</sup>	60.53
Fixed Carbon (wt%) <sup>c</sup>	25.58
Ash (wt%) <sup>c</sup>	13.90
Ultimate Analysis (wt%)	
C	33.93
H	8.87
N	4.95
O <sup>d</sup>	52.24
HHV (MJ/kg) <sup>e</sup>	13.18

<sup>a</sup> raw FW, <sup>b</sup> food waste after drying which used for torrefaction, <sup>c</sup> dry basis, <sup>d</sup> by difference, <sup>e</sup> Average value of HHV

However, the use of FW as a renewable energy material is hampered by several technological challenges. This is mainly due to the FW characteristics that bear high moisture content, low energy density, and high hydrophilicity [5]. These limitations slightly offset the potential of FW and utilization as the pre-treatment would incur high handling cost, storage space and containment, and reduction in the energy conversion process [6]. Therefore, as a solution, the physical properties of FW needs to be enhanced before it can be employed as an energy source efficiently. The two most widely patented technologies that can improve the physical characteristics of biomass, specifically FW, are torrefaction and pelletization, which involve the enhancement of energy and volumetric densities of raw biomass [6].

Torrefaction is carried out in an inert condition with nitrogen (N<sub>2</sub>) at a temperature range of 200 to 300°C [7]. During torrefaction, the moisture contained in the biomass and other low molecular weight components is reduced drastically due to partial removal of volatile matter [8]. As a result, the remaining hydrophobic solid is produced, with high calorific

value as the content of fixed carbon is increased [8]. The torrefied biomass possesses coal-like properties and may potentially replace coal as solid fuel in the future. There have been many studies on biomass torrefaction [8], especially the ones focusing on FW [4], [9], [10]. However, these studies focused solely on the torrefaction, having determined that like other biomass, the fuel properties improved with increasing temperature, though they are not too affected by the residence time of more than 30 minutes.

In addition to torrefaction, pelletization or densification of biomass is equally important, as it addresses the logistic issues, mainly transportation and storage of the biomass. It is considered as a mechanical pre-treatment of biomass that compress the FW into solid particles of uniform size and shape [11]. However, pelletization without the addition of binders was found to form pellets with lower tensile strength compared to pellets formed with a binder such as water [12], starch [13], lignin [14], and waste vegetable oil [15]. This study focusses on the agricultural waste biomass and forest residues. To the best of our knowledge, there has not been an attempt to evaluate the FW torrefaction and pelletization, especially on the effect of different types of binders used to improve the properties of the pellets. Hence, in this study, the effects of various additives, namely starch, lignin, and vegetable oil on the physical and mechanical properties of raw and torrefied FW, were investigated.

## MATERIALS AND METHODS

### Materials

FW was collected from a cafeteria in Universiti Malaysia Pahang (UMP) during lunch hours to obtain sufficient samples for the experiment.

### Food Waste Pre-Treatment

FW was dried in an oven at FTKKP laboratory of UMP. They were placed in an aluminium foil and placed in the oven for drying. The sample was heated at 105°C until constant weight was obtained. Next, the samples were ground using a blender and subsequently sieved to get a consistent particles size of 0.1 mm [10].

### Torrefaction and Pelletization

The raw FW samples were torrefied using a tubular reactor. 20 g of FW was placed inside the reactor for each run. Next, the reactor was purged with 2mL/min of N<sub>2</sub> for 10 minutes to create an inert atmosphere. Next, the torrefaction process was carried out at 300°C for 30 minutes. The reactor was then allowed to cool down to atmospheric temperature and the final weight of the sample was taken.

After enough torrefied FW samples were obtained, they were turned into pellets. The pellets were made using the single pellet press. The binders selected to form the pellets were starch, lignin, and vegetable oil at various compositions of 10%, 15%, and 20% wt./wt. of the FW. The starch and lignin were mixed with water 60°C, where the former formed a gelatine and the vegetable binder was mixed with biomass at slightly higher than 80°C. Raw and torrefied FW pellets were fabricated without any binder as a reference sample. The pellets were completely filled in the die, while the lever was pressed and held for 3 minutes to maintain constant pressure in the pellets and to ensure uniformity.

### Analysis

Three analyses which are density, moisture reabsorption, and tensile strength were carried out to raw and torrefied FW pellets. The density of the FW pellets was determined by measuring the mass and volume of the pellets. The aim of the torrefaction was to improve the innate drawbacks of the biomass. The water uptake tests were conducted to determine the moisture reabsorption of the pellet, where the pellets were submerged in water for 5 minutes at room temperature and subsequently, each pellet was lifted gently and the remaining water was wiped off carefully with a dry cloth prior to being weighed [16]. The moisture reabsorption was calculated using the following formula:

$$\text{Moisture reabsorption} = \frac{m_f - m_i}{m_f} \times 100 \quad (1)$$

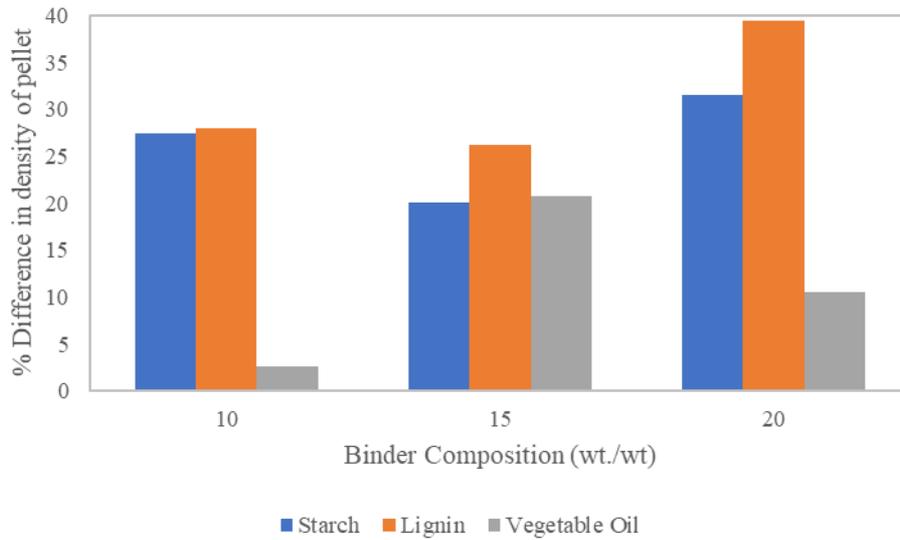
Where  $m_f$  and  $m_i$  are the final and the initial weight of the pellet, respectively. The properties of fabricated pellets were further investigated via tensile strength analysis. The FW pellets were pressed with 50 kN force until the pellet breaks. The pellets were placed directly below the beam of the Brookfield Texture Analyzer at 5 cm away. Once the pellets break, the beam stop applying pressure and move back to its original position, with the values of the applied forces recorded.

## RESULTS AND DISCUSSIONS

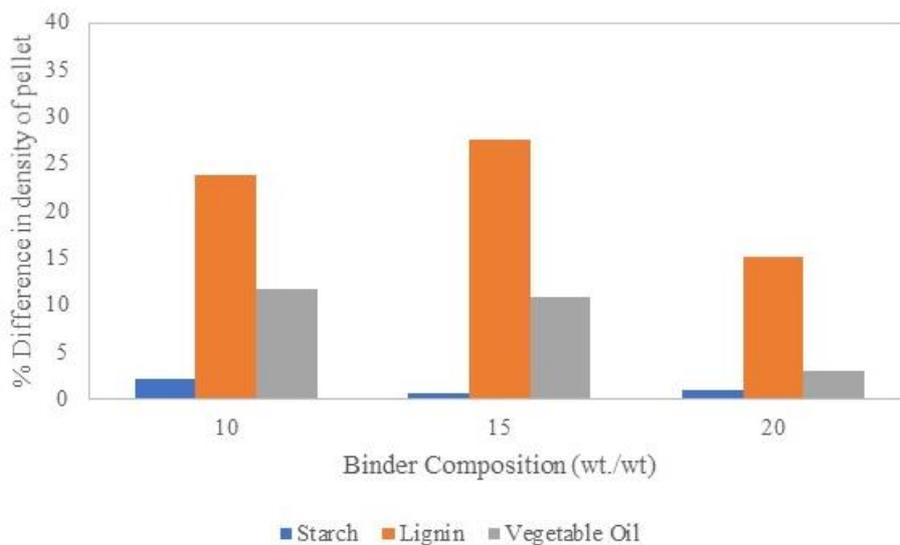
### Pellet Density

The density of the pellets is presented in form of percentage of improvement in comparison to the pellets without any binders. Figure 1 illustrates the improvement in the density of pellets formed from raw FW, while Figure 2 illustrates the improvement in the density of pellets from torrefied FW using different binders. It can be observed that, in general, the density of all pellets formed from raw and torrefied FW improved at various degrees compared to pellets without any binders. Untreated FW pellets in Figure 1 shows that increasing binder content improves the pellet density, except for vegetable oil. The highest degree of improvement was achieved when lignin was added at 20 wt.%. Despite of all binders' compositions resulted in the improvement of the pellet density when FW was torrefied, as shown in Figure 2, it was not in the linear trend. It was observed that pellets made with 15 wt.% lignin achieved the highest degree of improvement.

The torrefaction process turns the remaining solid to be hydrophobic as its fixed carbon content increases [8] from partial removal of volatiles. This process increases the density of the pellets, as the residual solids consist only the heavy components. In addition, the presence of binders further enhanced the density by 15 wt.% for lignin, as the further addition is undesirable. Similar observation was reported for raw and torrefied biomass, with [18] and without addition of binders [17].



**Figure 1.** Percentage Difference in Density of Raw FW Pellet with Various Binders



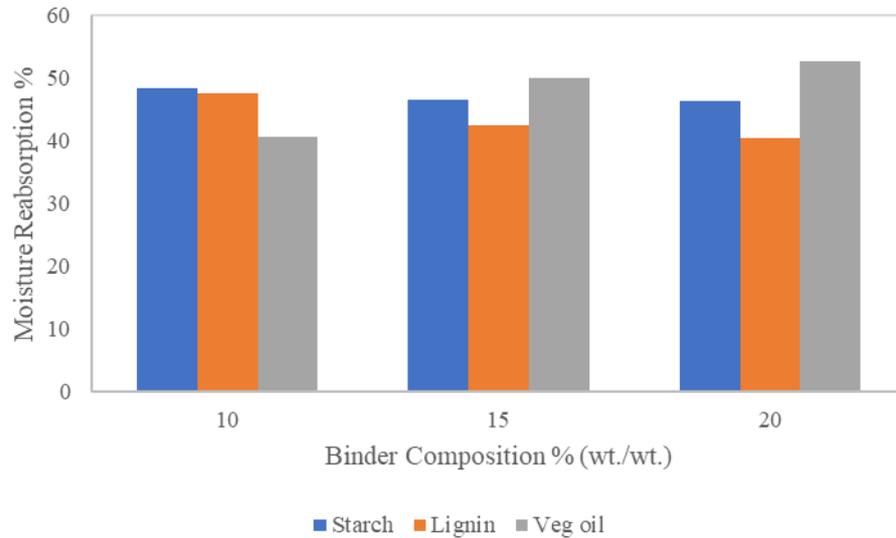
**Figure 2.** Percentage Difference in Density of Torrefied FW Pellet with Various Binders

### Moisture Reabsorption

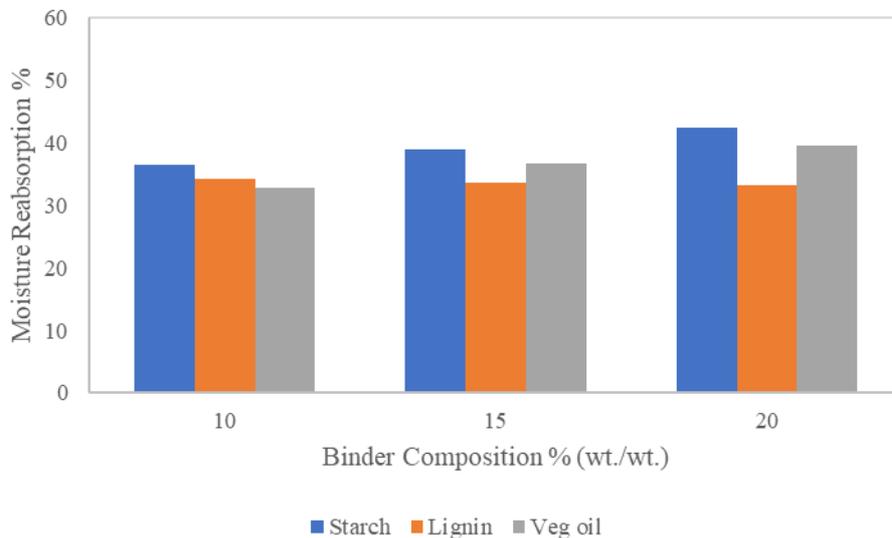
The hygroscopic nature of FW results in its tendency to absorb moisture, especially from its surrounding. The presence of moisture in the pellets serves as a breeding ground for microorganisms, hence creating the medium for mould growth. Therefore, reducing its hygroscopicity may reduce the costs of storage, handling, and lengthening its life span while maintaining their properties [19]. Figure 3 and 4 illustrate the moisture reabsorption capabilities of raw and torrefied FW

pellets respectively. The average moisture reabsorption of raw and torrefied FW pellets is less than 50% and 40%, respectively, as shown in Figure 3. The torrefaction process, intensifies the hydrophobicity of the material by removing the hydroxyl groups in the biomass particles [20].

The moisture reabsorption of raw FW pellets with starch shows no changes with the increasing concentration. In contrast, for vegetable oil, higher concentration causes higher water absorption. Lignin appears to be the most promising binder for raw FW pellets as it effectively reduces the moisture reabsorption. For torrefied FW, as shown in Figure 4, both starch and vegetable oil indicate the tendency of moisture reabsorption when the binder concentrations were increased. On the other hand, lignin consistently shows high performance by exhibiting reducing trend of moisture reabsorption when the concentration was increased. This result is in agreement with previous work [18], which the presence of binders in the pellets improves the moisture reabsorption.



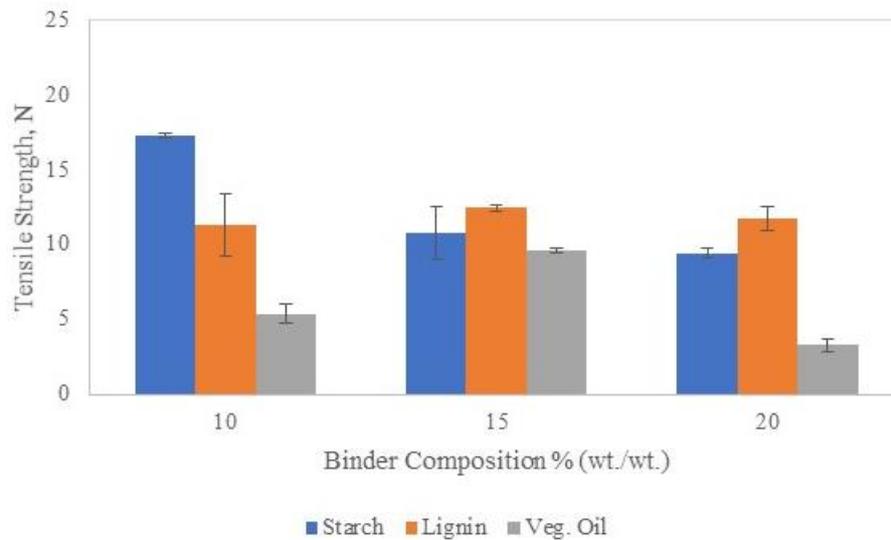
**Figure 3.** Moisture Reabsorption of Raw FW Pellet



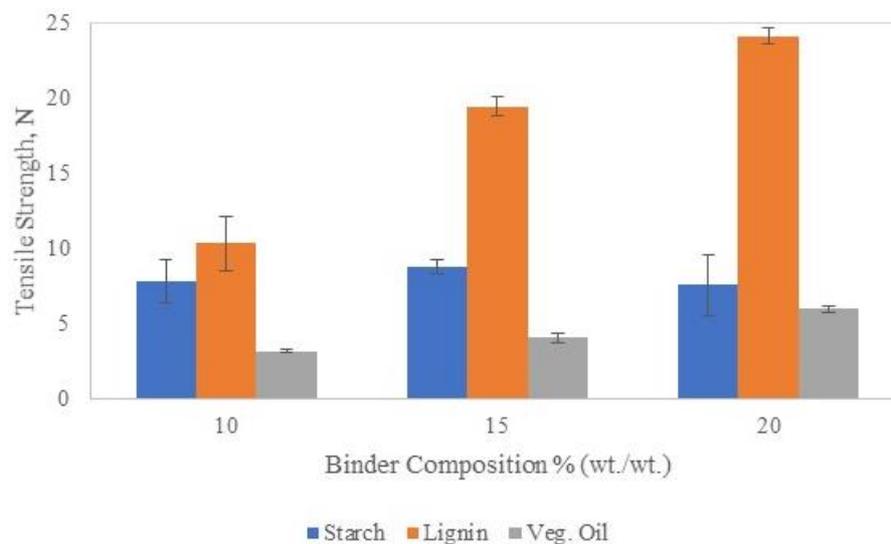
**Figure 4.** Moisture Reabsorption of Torrefied FW Pellet

### Tensile Strength

Figure 5 and 6 illustrate the tensile strength of raw and torrefied FW pellets respectively. The highest tensile strength for raw FW pellet was obtained with starch-binding percentage of 10 wt.% and any further addition of binder composition reduces the strength. Pellets bound by lignin were not significantly affected by the changes of concentration. The optimum binder concentration for vegetable oil was recorded at 15 wt.%. Binder concentration affects the tensile strength of torrefied FW pellets. Firstly, pellets with starch were not affected with the changes of concentration, as compared to torrefied FW pellets with vegetable oil binder which demonstrated a slight improvement. The most apparent changes in tensile strength depicted by the torrefied FW pellets, see Figure 5, as a result of an increase of lignin concentration. This trend is well supported by the findings from the previous work, which found that, increasing binder concentration improves the strength of the torrefied biomass pellets [18].



**Figure 5.** Moisture Reabsorption of Raw FW Pellet



**Figure 6.** Moisture Reabsorption of Torrefied FW Pellet

## CONCLUSION

This work investigates the use of binders to improve the quality of raw and torrefied FW pellets. The density of raw and torrefied FW pellets was significantly improved with the addition of lignin compared to pellets bound by starch and vegetable oil. In the moisture reabsorption analysis, it was found that pellets impregnated with starch and vegetable oil demonstrated higher absorption compared to lignin-based pellet, which in essence is not desirable, as more moisture may reduce the quality of the pellets. In addition, pellets made with lignin exhibits the highest tensile strength against other pellets made with starch and vegetable oil, which further confirms the superiority of lignin as the best binder for both raw and torrefied FW pellets.

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