Effect of Portions and Particle Sizes on Ultimate Properties of Oil Palm Fronds

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Abstract. The ultimate properties are important to determine the percentage of constituent elements of material which contributes to combustion. Combustion is one of the important elements to determine whether a material is suitable to be used as a solid fuel or not. Thus, the objective of this study is to evaluate the effect of portions and particle sizes on the ultimate properties of oil palm fronds. The ultimate analysis parameters are carbon, hydrogen, nitrogen, sulphur, and oxygen. The carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) elements were determined using a CHNS/O Analyzer, Perkin Elmer 2400 Series II base on ASTM D3176 standard, while oxygen (O) was determined by the difference of other percentages from 100%. The average percentage of carbon of bottom, middle and top portion of oil palm fronds for smaller particle size (0.5mm) were 43.46±0.10%, 43.37±0.04% and 43.32±0.04% respectively. On the other hand, the average percentage of carbon of the same portion of oil palm fronds for bigger particle size (1.5mm) were 44.30±0.04%, 43.82±0.02% and 43.69±0.04% respectively. Meanwhile, the average percentage of hydrogen of the same portion of oil palm fronds for smaller particle size (0.5mm) were 5.41±0.02%, 5.38±0.02% and 5.34±0.01% respectively. The average percentage of hydrogen of the same portion of oil palm fronds for bigger particle size (1.5mm) were 5.50±0.04%, 5.43±0.02% and 5.33±0.01% respectively. The average percentage of nitrogen of the same portion of oil palm fronds for smaller particle size (0.5mm) were 0.44±0.02%, 0.45±0.02% and 0.48±0.02% respectively and for bigger particle size were 0.40±0.01%, 0.46±0.01% and 0.47±0.02% respectively. The average percentage of sulphur of the same portion of oil palm fronds for smaller particle size (0.5mm) were 0.31±0.02%, 0.34±0.01% and 0.35±0.01% respectively and for bigger particle size were 0.32±0.02%, 0.33±0.01% and 0.34±0.01% respectively. Finally, the average percentage of oxygen of the same portion of oil palm fronds for smaller particle size were 50.38±0.01%, 50.51±0.02% and 50.51±0.02% respectively and for bigger particle size were 49.58±0.02%, 49.96±0.02% and 50.17±0.03% respectively. Based on the results of the ultimate analysis above, it can be concluded that oil palm fronds have the potential to be utilised as solid fuel.

INTRODUCTION

According to the Integrated Taxonomy Information System (ITIS), palm belongs to a family of plants called Arecaceae. It consists of 200 genera and 3,000 species, and oil palm comprises in species of *Elaeis guineensis* Jacq.

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[1]. The term of Elaeis comes from Greek words; *elaia,* which means olive and *guineensis,* which refers to its origin from the equatorial Guinea coast. *Elaeis guineensis* Jacq is the primary source of oil palm which is native to Guinea's rainforests in West Africa. This species was first illustrated by Nicholas Jacquin in 1763, and he is remembered in the species' scientific name [2]. Hence its name has become *Elaeis guineeensis* Jacq. In the beginning of the 19th centuries, oil palm cultivation has expanded to the Southeast Asia countries and become an important industrial crop especially in Malaysia, Indonesia and Thailand [3]. While, in Africa, it remained as domestic plant supplying a need for oil and vitamin A for the diet. The oil palm has been grown successfully not only in Africa but also in South America, Southeast Asia, South Pacific and other tropical areas which generally lie between 10º latitude north and south of the equator [4]. The climate features of the main areas are having the average maximum temperature of 29-33ºC and minimum temperature of 22-24ºC. The annual rainfall of 2,000 to 2,500 mm and a humidity of 80 to 90% in the tropical zones are required to maintain continuous supply of moisture content [3]. Ultimately, only 43 countries have the suitable conditions for oil palm to grow well [4]. Malaysia and Indonesia dominate the global production of palm oil with supply around 85% of the palm oil production worldwide [5]. Since the year 2006, Indonesia has surpassed Malaysia to become the world largest palm oil producer. This is mainly influenced by the fast cultivation of oil palm plantation areas in Indonesia and the slow cultivation of the oil palm plantation areas in Malaysia [6].

An oil palm tree can grow up to 20 m tall with its single-stemmed when it is growing spontaneously. In regular plantation, the average of height increases from 30 to 60 cm per year, with the width of the stem differs from 20 to 75 cm, erect, heavy and trunk ringed. Each part of the palm tree has an important role. The stem works as supporting, vascular and storage organ [7]. The trunk plays an important role to hold leaves and transfer mineral nutrients and water from roots upwards and the products of photosynthesis from leaves downward. It also acts as a storage organ with a high amount of starch granules can be found [3]. The leaves are pinnate with 3 to 5 m long. In early five to six years age of the tree, it can produce 30 to 40 leaves in a year. Later, the generation of leaves decreases to 20 leaves in a year [1]. Oil palm fronds are found around the trunk in two spirals which are right-handed or left-handed. Each tree has more than 60 fronds with 120 cm of length per frond [8] and the biomass waste in the form of trunk and frond is generated during palm oil plant production [9]. The economic life of palm oil trees can reach up to 20-25 years [10]. The oil palm frond is known to be the largest contributor to the oil palm residues, providing up to 50.3% of the total residues [11]. Among the Malaysian agricultural sector, which is contributing towards the biomass resources, palm oil wastes contribute the largest with an approximate of 4.5 million hectares plantation area at 5% annual growth [12].

The moisture content of oil palm frond is very high, up to 60% on a wet basis. The leaves are found at the top of the plant arranged like a crown which may contain 40 or more fronds [3]. The fronds lengths decrease from the bottom to the top level of the crown, with an average of about 4 m in length. At the cross-section, the frond shows a triangle shape with the width decreasing from the base to the end of the petiole and from the bottom to the top fronds. A fruiting branch which contains thousands of fruits is held in the axils of the leaves and arranged in a rosette pattern around the crown [13,14]. Pruning activities to get the oil palm fruit by cutting down the fronds has resulted in a lot of fronds residues. This residue, if not managed properly, will be a place for the pest and disease to spread to the oil palm. Thus, in order to ensure that this waste is not harmful, it needs to be reused for a specific purpose such as used as a material for the manufacturing of furniture, i.e., chipboard or use as a solid fuel for biomass energy [15]. To determine whether an agricultural waste can be used as a solid fuel or not, its properties need to be analysed. One of the most important elements is the ultimate analysis. Analysis of biomass using this method reveals the contents of the principal constituent, namely carbon, oxygen, hydrogen, nitrogen, and sulphur. The composition of a wide range of selected biomass fuels is given by [16], and it was reported that oil palm fronds biomass contains relatively high amounts of oxygen and hydrogen as compared to other fuels (such as coal or peat) [17].

MATERIALS AND METHODS

The oil palm fronds that were used for this study was collected from the eastern part of Malaysia, which is in Felda Kemahang 1, Tanah Merah, Kelantan, Malaysia is shown in Fig. 1. The oil palm fronds with no defect and decay-free were selected. Later, they were transported to Universiti Malaysia Kelantan (UMK), Jeli Campus for further processing. The leaflets were removed from the fronds, and then it was divided into three sections which are bottom, middle, and top portion. Then, the fronds skin was peeled and sliced in a longitudinal direction. These sliced fronds were then compressed using a roller type device equipped with a servomotor machine to increase their density before undergoing sun drying. The purpose of the sun drying process is to remove the excess moisture content from the sample. This process can also enhance their durability against fungi and insects' attacks. Each portion of fronds was dried in an oven under the condition of 72º C for 12 hours. The drying temperature of the samples must be moderate to avoid breaking up the lignin structure as well as to keep the moisture content ranging between 9-12%. In addition, this process also helps to increase efficiency in the grinding process. The samples were then ground by disc mill machine to split them into very fine sawdust forms (0.5-2.0 mm particle size). This grinding partially breaks down the lignin, increases the specific area and contributes to the better binding. In this study, only two sizes of particle were selected, which are 0.5mm and 1.5 mm. Generally, the small particle size has a higher specific area, a huge number of contact points and more exposed surface area. Next is the screening process to remove those unwanted materials, undersize and oversize particles. The screening vibrator machine was used to separate the sample. Initially, the machine separates the particles into four different sizes, which are 0.5, 1.0, 1.5 and 2.0 mm. Then, only the required sizes were selected, which were ≤ 0.5 mm and $\geq 1.5 < 2.0$ mm. Particle size ≤ 0.5 mm will be considered as 0.5 mm size and particle size 1.5mm and greater but less than 2.0 mm will be considered as 1.5 mm size.

The ultimate analysis involves the estimation of important chemical elements that make up the biomass, namely carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). The carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) elements were determined using a CHNS/O Analyzer, Perkin Elmer 2400 Series II, while oxygen (O) was determined by the difference of other percentages from 100% [18]. The basic method for doing an ultimate analysis is to burn a sample of biomass in a platinum crucible in a stream of air to produce carbon dioxide and water, the mass fractions of which are determined by gas-analysis procedures. On the other hand, analysis of variance (ANOVA) was carried out to compare the ultimate properties of oil palm fronds based on the different portion and particle size.

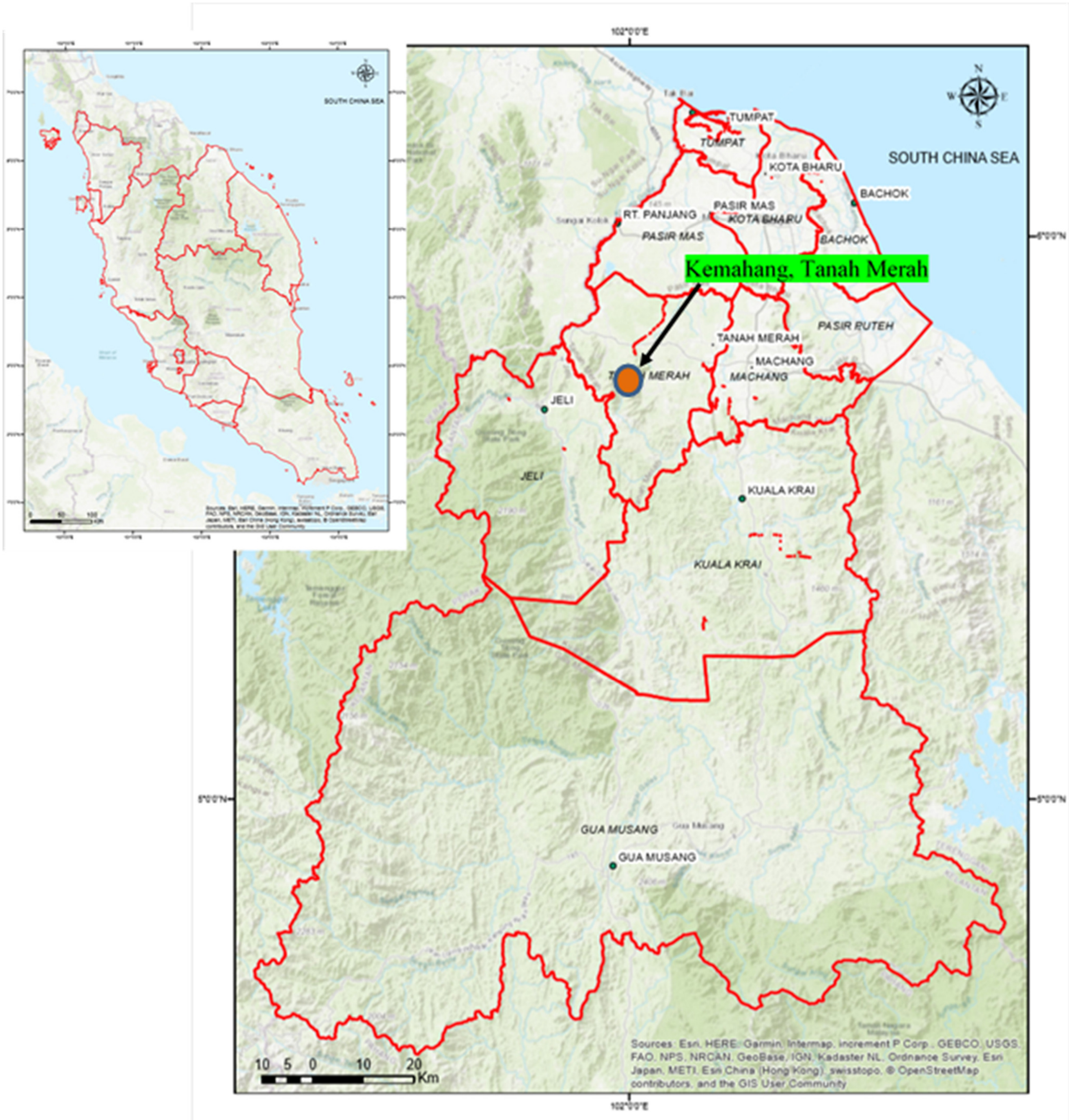

FIGURE 1. Study area.

RESULTS AND DISCUSSIONS

The ultimate properties are important to determine the percentage of constituent elements of oil palm fronds which contribute to combustion. Table 1.0 presents the ultimate analysis of raw oil palm fronds for 5 elements which is carbon, hydrogen, nitrogen, sulphur, and oxygen for each portion.

TABLE 1. Mean value of ultimate properties of oil palm fronds.

Portion	Particle Size (mm)	Ultimate Properties (%)				
		Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
Bottom	0.5	43.46±0.10	5.41±0.02	0.44±0.02	0.31±0.02	50.38±0.01
	1.5	44.30±0.04	5.50±0.04	0.40±0.01	0.32±0.02	49.58±0.02
Middle	0.5	43.37±0.04	5.38±0.02	0.45±0.02	0.34±0.01	50.51±0.02
	1.5	43.82±0.02	5.43±0.02	0.46±0.01	0.33±0.01	49.96±0.02
Top	0.5	43.32±0.04	5.34±0.01	0.48±0.02	0.35±0.01	50.51±0.02
	1.5	43.69±0.04	5.33±0.01	0.47±0.02	0.34±0.01	50.17±0.03

Note: C = Carbon
H = Hydrogen
N = Nitrogen
S = Sulfur
O = Oxygen

Based on Table 1, oil palm fronds have relatively high carbon content which is above 40% in the average, and low content of nitrogen and sulphur, which indicates is a good property for solid fuel. High carbon content is required since it is an important element to facilitate combustion. The low content of nitrogen and sulphur in oil palm fronds is a good thing because it will be minimising the release of nitrogen and sulphur oxides into the atmosphere to reduce environmental pollution [19]. Carbon elements play an important role not only for biomass but also for any organic material. It has a major contribution to the overall heating value of biomass fuel. During photosynthesis, carbon comes from atmospheric CO_2 and becomes a part of the plants. Once the plant undergoes combustion process, it is mainly released back to the atmosphere in the form of CO_2. Figure 2 demonstrates the trend of carbon contents based on portions and the particle size of raw oil palm fronds. It shows the decreasing trend from bottom to the top portion and large particle size tend to have higher value compare to small particle size. The highest value came from the bottom portion of 1.5 mm particle size with 44.30%; meanwhile, the lowest value was observed from the top portion of 0.5 mm particle size with the value of 43.32%. The differentiation of carbon value in raw oil palm fronds from bottom to middle and top portions are significant ($p<0.01$), similarly with the particle sizes. It means that carbon element was influenced by the portions and particle sizes of oil palm fronds.

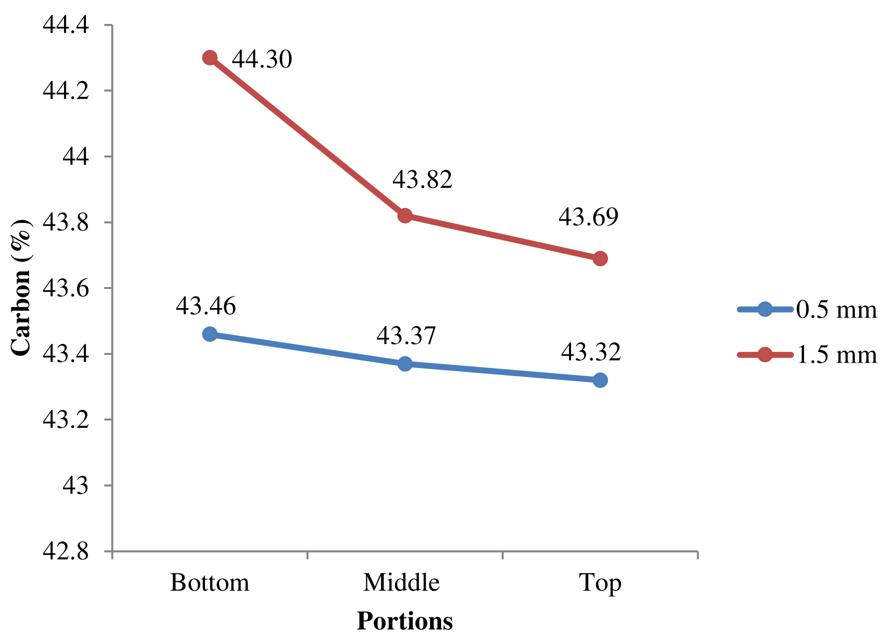

FIGURE 2. Trend of carbon based on portions and particle sizes of raw oil palm fronds.

Hydrogen is another important element of biomass and can be found in the carbohydrates and phenolic polymers. It contributes significantly to the heating value of biomass. Hydrogen is converted to H_2O during combustion. Figure 3 illustrated the trend of hydrogen's portion and particle sizes for raw oil palm fronds where it has decreased from bottom to top portion and large particle tend to have higher value compare to small particle size. The highest value was attained from the bottom portion of 1.5 mm particle size with 5.50% meanwhile the lowest value was observed from the top portion of 0.5 mm particle size with the value of 5.33%. The differentiation of hydrogen value in raw oil palm fronds from bottom to middle and top portions are significant ($p<0.01$), similarly with the particle sizes. It means that hydrogen element was influenced by the portions and particle sizes of oil palm fronds.

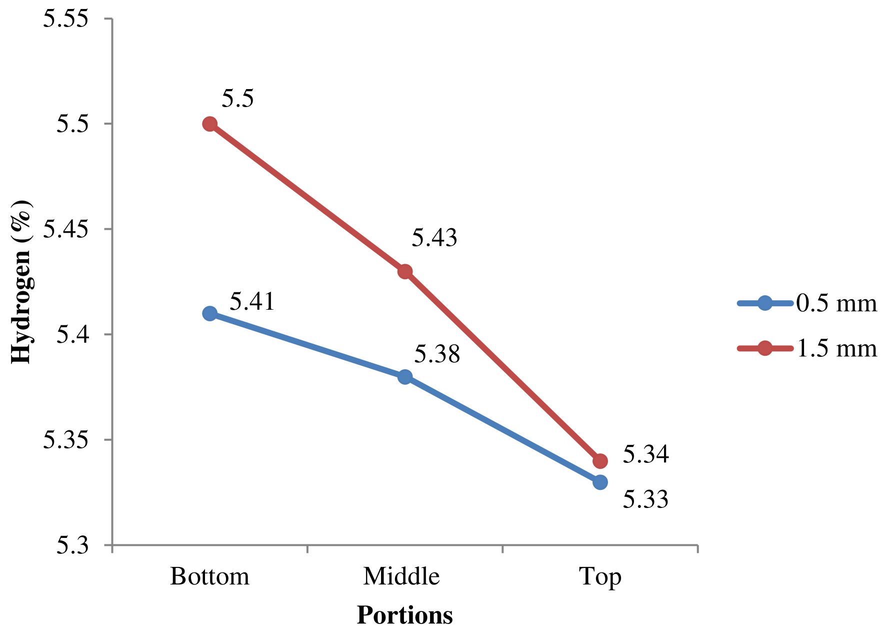

FIGURE 3. Trend of hydrogen based on portions and particle sizes of raw oil palm fronds.

Nitrogen element is related to the plant nutrient. Normally plant absorbs nitrogen from the nutrients in the soil or the fertilisers which were applied to the plant for its growth. Nitrogen partly emitted in oxide forms during combustion, which gives negative effects on global climate and human health. Figure 4 demonstrates the trend on the nitrogen in portions and particle size for raw oil palm fronds where it has increased from bottom to top portion, and small particle tend to have higher value compare to particle size. The highest value came from the top portion of 0.5 mm particle size with 0.48%; meanwhile, the lowest value was observed from the bottom portion of 1.5 mm particle size with the value of 0.40%. The differentiation of nitrogen value in raw oil palm fronds from bottom to middle and top portions are significant ($p<0.01$), but not significant ($P>0.01$) in particle sizes. It means that nitrogen element has influenced by the portions but not particle sizes of oil palm fronds.

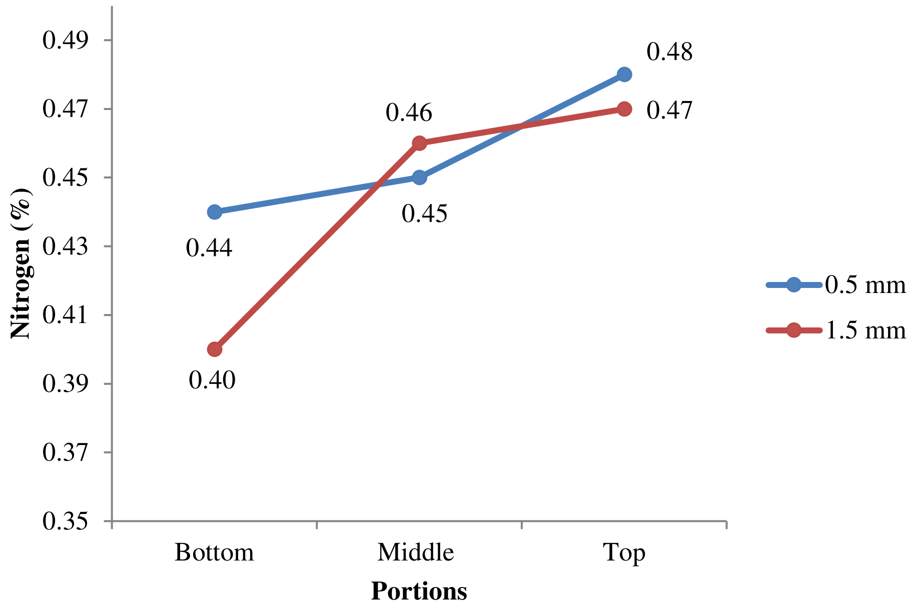

FIGURE 4. Trend of nitrogen based on portions and particle sizes of raw oil palm fronds.

Sulphur is also an important nutrient for plant growth like nitrogen. It has only a small fraction in biomass and presents in some organic structures like amino-acids, protein, and enzymes. During combustion, sulphur is mainly transformed into SO_2 which contributes to aerosol and smog formation, corrosion, and acid rain. Figure 5 demonstrates the trend of sulphur based on portions and particle size for raw oil palm fronds where the trend for both has increased from bottom to top portion, and small particle tends to have higher value compare to large particle size. The highest and lowest value was observed in the same particle size, which is 0.5 mm particle, and the highest value came from the top portion with 0.35%. m\Meanwhile, the lowest value came from the bottom portion with a value of 0.31%. The sulphur value recorded a significant difference ($P<0.01$) between portions but not significant ($p>0.01$) between particle sizes. It means that sulphur element was not influenced by the portions and particle sizes of oil palm fronds.

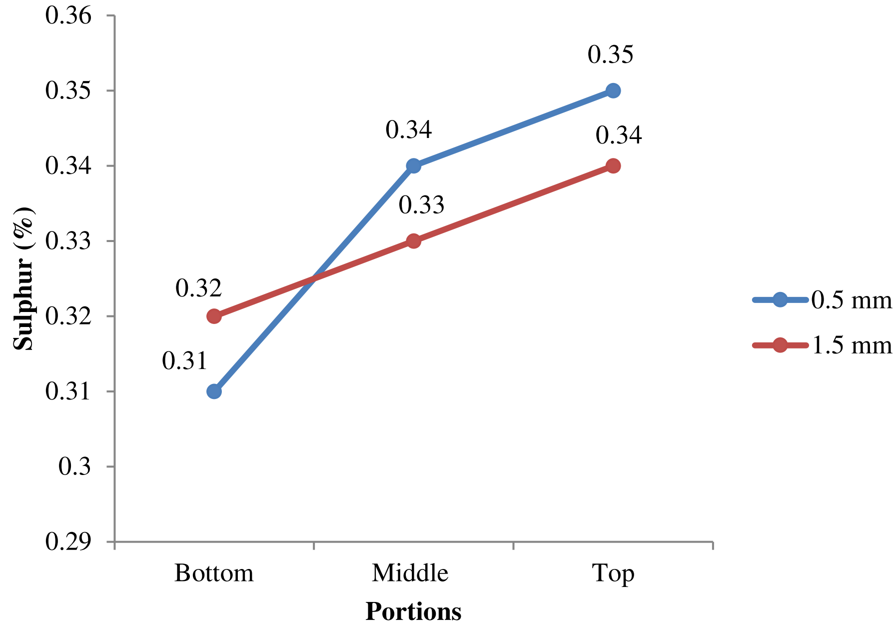

FIGURE 5. Trend of sulphur based on portions and particle sizes of raw oil palm fronds.

The major element of biomass fuels is oxygen. It is presented in all biomass chemical compositions. Oxygen has a negative effect on reducing the heating values of biomass. However, in this study, it was not measured directly, but calculated by subtracting the fractions of all elements in the pellet from 100%. Figure 6 demonstrates the trend of oxygen related to portions and particle size in raw oil palm fronds. It shows that oxygen decreased from bottom to top portion and large particle tend to have higher value compare to small particle size. The highest value was attained from the middle and top portion of 0.5 mm particle size with 50.51%. Meanwhile, the lowest value was observed from the bottom portion of the 1.5 mm particle size with a value of 49.58%. The oxygen value recorded a significant difference ($P<0.01$) between portions and particle sizes. It means that oxygen element was influenced by the portions and particle sizes of oil palm fronds.

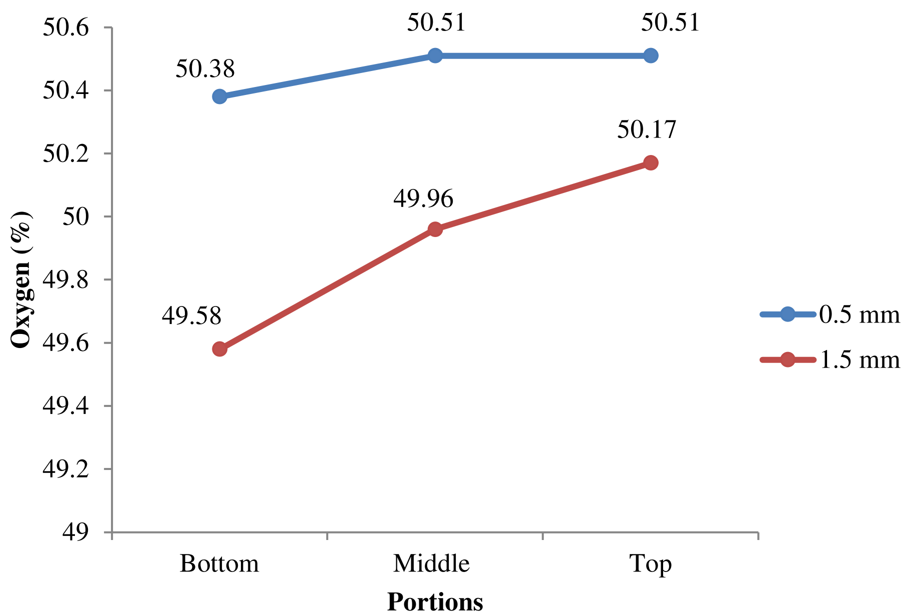

FIGURE 6. Trend of oxygen based on portions and particle sizes of raw oil palm fronds.

Based on the analysis, it is found that carbon and oxygen content was high in raw oil palm fronds, while hydrogen, nitrogen and Sulphur were low. The findings of this study were further strengthened by the finding from [20], in which oil palm fronds have reasonable high carbon content which would be considered as being competitive with their biomass source. Therefore, oil palm fronds can be considered as one of the best options for fuel pellet manufacturing.

CONCLUSIONS

Based on the analysis, it can be concluded that carbon, hydrogen, and oxygen of raw oil palm fronds were significantly influenced by frond portions (bottom, middle and top) as well as particle size. On the other hand, nitrogen and sulphur were only influenced significantly by frond portions but not particle sizes. However, the ultimate properties of oil palm fronds that were recorded in this study show that it has good fuel characteristics to be used as raw materials for solid fuel because it has a high mean percentage of carbon and oxygen contents and low in nitrogen, hydrogen, and sulphur.

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