Journal of Renewable Energies ICAEEE'24 India (2024) 65 – 81

DOI: https://doi.org/10.54966/jreen.v1i1.1475

Journal of Renewable Energies

Revue des Energies Renouvelables

Journal home page: https://revue.cder.dz/index.php/rer

Conference paper

Experimental investigation on energy potentials and chemical composition of palm kernel briquettes as bio-fuel sources in developing countries

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ARTICLE INFO

Article history:

Received: January 11, 2025

Accepted: July 15, 2025

Available online July 23, 2025

Published: July 24, 2025

Keywords:

Briquettes,

Combustion,

Heating Values,

Proximate Analysis,

Ultimate Analysis.

ABSTRACT

This study experimentally investigates the energy potentials and chemical composition of Palm Kernel Shell (PKS) briquettes as possible bio-fuel sources. The Five different samples briquette produced with varying proportion of PKS powder and cassava starch as binder followed by six days sun drying. The heating value of the PKS briquette samples and raw powder was determined using Bomb Calorimeter. Proximate analysis shows that the moisture contents for both the raw sample and PKS briquettes are within the standard moisture content of biomass fuel. Results of the study show that the higher heating value of the PKS briquette samples varies from 20.62MJ/kg to 22.40MJ/kg while that of pure palm kernel powder is 16.55MJ/kg. The ultimate analysis shows that the Carbon content varies from 60.75% - 66.56%; Hydrogen content 5.55% - 5.98%; Nitrogen content 1.12% - 1.55%; Oxygen content 10.50% - 12.88% and Sulphur content 0.01% – 0.8%. The Energy Dispersive X-ray, Scanning Electron Microscopy and Fourier Transform Infrared Spectroscopy analysis of the briquette samples show the presence of high percentage of carbon content, fractured, porous matrix, and existence of crystalline structure of cellulose which is adequately good for briquette applications in domestic and industrial area due to enhanced binding and combustion characteristics.

1. INTRODUCTION

Nigeria is endowed with a variety of energy resources, including water, fossil fuels, and agricultural waste. Despite the abundance of these energy sources, significant challenges remain in effectively

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ISSN: 1112-2242 / EISSN: 2716-8247

harnessing and converting these energy sources into usable energy. It raises questions as to why Nigeria primarily relies on conventional fuels as the main energy source while neglecting other potential energy options (Emodi and Boo, 2015). This reliance on traditional fuels is believed to have contributed to the ongoing energy crisis in the country, which manifests in inadequate power supply, shortages, and sudden increases in petroleum prices (Akuma, and Charles, 2017). One potential solution to this problem is to embark on the wide range of available energy sources to produce valuable energy output (Abdulrasheed, et al., 2015). Interestingly, many of these energy resources are often considered waste with no secondary use, resulting in disposal being the only alternative (Adeniyi et al., 2014).

There is also significant reliance on fuelwood and charcoal as the primary sources of renewable energy, which has led to severe deforestation and damage to ecosystems in developing countries. Forests have been excessively depleted, causing fuelwood prices to rise notably, which forces women and children to travel lengthy distances for collection. This situation has ultimately resulted in increased prices for kerosene and cooking gas in Nigeria. Numerous researchers are now focusing on alternative renewable energy sources, such as conversion of biomass wastes to briquette for both domestic and small-scale industrial applications. The recent changes in global environmental conditions and the rise in atmospheric levels of carbon and sulfur compounds are driving investigations into such alternative solutions, as the use of fossil fuels poses potential and serious environmental risks due to pollution from greenhouse gases (Jahn et al., 2011).

The alternative source of energy that is recently being researched and developed is biomass fuel from agricultural waste. Biomass from agricultural waste will become a useless material if it doesn't receive further treatment. Otherwise, it can be utilized as a source of alternative energy, especially by converting it into briquette (Mardawati, et al., 2022).

Briquetting is the process of converting agricultural wastes into uniformly constructed briquettes that are simple to use, transport, and store. Pulverized carbonaceous matter is bound together in this procedure, frequently with the help of a binder (Ugwu and Agbo, 2011). Briquetting is the process of compressing materials that are not readily available due to their low density into a convenient solid fuel that may be burned like charcoal or wood (Haggar, 2010). Briquettes have better physical and combustion characteristics than the original waste. Accordingly, briquetting's primary benefits include generating solid fuel with a high thermal efficiency, lowering waste levels, using less energy during production, and environmental preservation (Haggar, 2010).

The two most popular types of briquettes are biomass and coal briquettes. The primary source of biomass briquettes is agricultural wastes. There are several biomass feed stocks that can be used for briquetting, including palm kernel shells. Palm kernel shell is seen as agricultural waste that has the potential to be transformed into a useful energy source. PKS, or palm kernel shells, are carbonaceous solids that are obtained by processing oil palm fruit. According to Adeniyi et al. (2014), it has a high carbon content and can undergo a thermal process that might transform it into a source of heat energy. Depending on their moisture level, the briquettes that are produced might need to be dried before being stored or delivered to customers. These briquettes can be dried in the sun for three to four days at a temperature higher than 25 °C because most developing nations have an excess of sunlight (Blesa et al., 2003; Ngusale et al., 2014). Briquettes may also be kept at room temperature (usually 20 °C) after drying and left to cool for a full day before using (Andrejko and Grochowicz 2007). Higher storage temperatures may cause briquettes to become overly dry and difficult to ignite, whilst lower temperatures would cause the briquettes to become pliable and not long-lasting when burning.

Briquettes are widely used for thermal applications like steam generation in boilers, heating purpose, drying process and gasification plant to replace existing conventional fuel like coal, fire-wood fuel and other expensive liquid fuel like, diesel, Kerosene, black oil, etc. (Ogbuanya, 2005; Tembe et al., 2014).

Use of bio-fuel briquettes as a fuel for green energy has shown very promising results. Also, briquettes are used for domestic purposes such as cooking, house heating, water heating, etc.

This study aims to harness palm kernel shell to make a contribution to the energy mix, with emphasis on evaluating the energy content and chemical characteristics of the resulting briquette produced from palm kernel shells. The findings contribute to a broader understanding of agricultural waste valorisation and support the development of sustainable waste-to-energy strategies.

2. MATERIALS AND METHODS

2.1 Collection of Raw Materials

Palm Kernel shells were collected from Ipokia local government area of Ogun State, South West Nigeria. The starch used as binder in this study was processed from cassava obtained from Ifo local government area of Ogun State, South West Nigeria. Palm kernel shells (about 10 kg) were washed and sun dried for 5-days to remove the moisture contents. The sample was then crushed using a granulator to reduce its size; it was later grounded to powder form and sieved to 25µm -875µm size using Tyler sieves. The palm kernel powder produced was stored in an airtight container to avoid moisture absorption.

2.2 Preparation of Palm Kernel Briquettes

In this study, the binding agent used was cassava starch as it is readily available and ease prepare cassava starch (Oyelaran et al., 2014). In preparation of palm kernel briquette, the collected palm kernel shells were grinded into powder with granulator. The grinded palm kernel was mixed with prepared starch gel and water (hot and cold) in varying proportions. In this study, experiments were done by using 5 variations in the composition of raw materials with adhesive and water as shown in Table 1. Sample A, 170 g of palm kernel powder was mixed 30 g of cassava starch, 50 ml of cold water and 100 ml of hot water. For sample B, 150 g of palm kernel powder, 50 g of cassava starch, 50 ml of cold water and 100 ml of hot water were mixed together. In sample C 130 g of palm kernel powder, 70 g of cassava starch, and 50ml of cold water and 100ml of hot water were mixed together. For sample D, 180 g of palm kernel powder, 20 g of cassava starch, 50 ml of cold water and 50 ml of hot water were mixed together. Sample E, 190 g of palm kernel powder, 10 g of cassava starch, 50 ml of cold water and 50 ml of hot water were all mixed together.

Table 1. Raw Materials used for Proportion of Palm Kernel Briquette Samples

Samples	PKS (*g*)	Starch (*g*)	Cold Water (*ml*)	Hot Water (*ml*)
A	170	30	50	100
B	150	50	50	100
C	130	70	50	100
D	180	20	50	50
E	190	10	50	50

Each briquette samples produced was sun dried for six days at different temperature, ranging from 33^o C to 35^{o}C in order to reduce the moisture content and compactness. Figure 1 and Table 2 show the developed briquette samples and the weight loss recorded of the briquette samples per day.

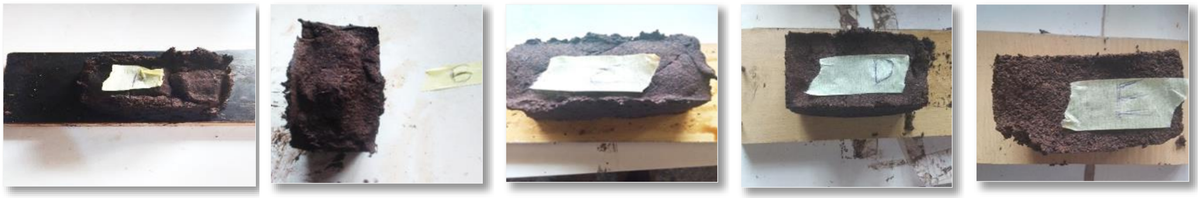


Fig 1. PKS Briquette Samples Produced for Assessment

Table 2. Change in Briquette Sample's Weights During Six Days Drying

Samples	Initial Weight (g)	Day Wise Weight of Dried PKS Samples (g)					
		1	2	3	4	5	6
A	350	250	197	192	184	179	175
B	350	254	192	189	179	174	169
C	350	251	195	189	182	178	175
D	300	240	201	189	180	177	173
E	300	238	205	184	180	179	174

2.3 Briquettes Testing Procedure

The following tests were conducted on the briquette samples after one week sun drying from the date of molding:

- **Proximate Analysis Test**

According to ASTM D-3173, the carbonized palm kernel shells' briquettes moisture content, ash content, volatile matter, and fixed carbon were measured.

- **Ultimate Analysis Test**

Testing for the briquette samples' hydrogen, carbon, nitrogen, sulfur, and oxygen contents is part of this examination. This represents each of the organic material's weight percentages. In biomass, the basic analysis is the determination of Carbon (C), Hydrogen (H), Oxygen (O), Sulfur (S), and Nitrogen (N).

- **Higher Heating Value Test**

A model XRY-1A oxygen bomb calorimeter was used to measure the briquette samples' Higher Heating values.

- **Moisture Content Test**

The MB35 Halogen Ohaus moisture analyzer was used to measure the briquette samples' moisture content.

- **Hardness Test**

The hardness values of the briquette samples were determined by using Vickers hardness machine.

3. RESULTS AND DISCUSSION

This section presents results of the experimental tests carried out in this study. Discussion of the results obtained is also presented.

3.1 Proximate Analysis

The proximate analysis gives the potential efficiency and durability of briquettes that will be produced. The analysis of the raw sample was compared with the analysis of briquette sample A, B, C, D and E. using amount of moisture contents (MC), volatile matter (VM), fixed carbon contents (FC), and the ash contents (AC).

Table 3 shows the average result of the proximate analysis of the raw sample of the palm kernel and that of the analysis of briquette sample A, B, C, D and E. The moisture content of the raw sample was determined to be 4.95% and that of briquettes sample were determined to be 7.6%, 7.52%, 8.50%, 8.55% and 8.94%. Moisture content for cooking fuel ranges from 8-10% and less (Onochie et al., ,2017) The result of the experimental analysis shows that the moisture contents for both the raw palm kernel sample and palm kernel briquettes samples are within the standard moisture content of biomass fuel.

The volatile matter content of the palm kernel raw sample was determined to be 78.75% and that of palm kernel briquette samples A, B, C, D and E are 43.40%, 40.30%, 40.49%, 40.60% and 43.94%. The volatile matters of palm kernel briquette samples are observed to be lower than that of the palm kernel shell raw sample. Biomass with high volatile matter ignite easily but may burn with smoky flame in the absence of oxygen and has a low calorific value (Yin, 2011; Efomha and Gbabo, 2015; Veeresh and Narayana, 2012). Briquette samples A, B, C, D and E have the desirable amount of volatile matter content. The sample A has the highest volatile matter content while the sample B has the lowest.

The fixed carbon content is the percentage of carbon available for combustion (Efomha and Gbabo, 2015) .The percentage of fixed carbon for the palm kernel raw sample was determined to be 14.55% and that of palm kernel briquette samples A, B, C, D and E are 30.75%, 33.70%, 30.09%, 34.30%, and 32.12% .This result indicate that the palm kernel briquette samples have more percentage of fixed carbon content available for combustion than the raw palm kernel sample. Also, the briquette sample D has the highest fixed carbon while the briquette sample C has the lowest fixed carbon content.

The issue of ash content in biomass is complicated. The amount of ash is determined by the amount of inorganic and organic substances as well as any potential contaminants. The sampling location, harvest time, and harvest conditions affect the amount of ash in biomass (Onochie et al., ,2017).The ash content of the palm kernel raw was determines to be 1.75% and that of palm kernel briquette samples A,B,C,D, and E were 18.25%,23.20% ,21.88%, 22.55% and 21.60%. This result indicates that the ash content of the raw palm kernel sample is lower than that of the palm kernel briquette A,B,C,D and E. But for the palm kernel briquette samples A, B, C, D and E, the sample A has the lowest ash content while sample B has the highest.

Table 3. Proximate analysis of PKS Raw (Powder) and PKS Briquette samples

Sample	Moisture contents (%)	Volatile matter contents (%)	Fixed carbon contents (%)	Ash contents (%)
RAW	4.95	78.75	14.55	1.75
A	7.60	43.40	30.75	18.25
B	7.52	40.30	33.70	23.20
C	8.50	40.49	30.09	21.88
D	8.55	40.60	34.30	22.55
F	8.94	43.94	32.12	21.60

3.2 Ultimate Analysis

The ultimate analysis explains and analyze the quantitative distribution of the elemental constituents, namely carbon (C), hydrogen (H), nitrogen (N), and oxygen (O), Sulphur (S), within the designated raw sample of palm kernel shell and the briquette sample of palm kernel shell A, B, C, D and E. Table 4 elucidates the quantitative distribution of the elemental constituents of the briquette samples considered in this study.

The value obtained from the raw sample of the palm kernel shell are carbon (C) 51.90%, hydrogen (H) 8.95%, nitrogen (N) 2.5%, and oxygen (O) 36.60%, Sulphur (S) <0.05%. For the briquette samples A, B, C, D and E, Carbon content varies from 60.75% - 66.56%; Hydrogen content 5.55% - 5.98%; Nitrogen content 1.12% - 1.55%; Oxygen content 10.50% - 12.88% and Sulphur content 0.01% – 0.8%. All the values obtained from ultimate analysis of the briquette samples are within the desirable values but slightly different from that of (Bonsu et al., 2020). The slight difference might have resulted from varying components such method of preparation of briquette, weather condition, percentage moisture content, source of palm kernel sample etc. (Onochie et al., 2017). Comparing the ultimate analysis result of this study (Table 4) and that of Bonsu et al (2020) (Table 5), results of this study show a better performance.

Table 4. Ultimate analysis of PKS Raw (Powder) and PKS Briquette samples

Samples	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulphur (%)
RAW	51.90	8.95	2.5	36.60	<0.05
A	65.70	5.98	1.12	10.80	0.80
B	60.75	5.55	1.55	10.50	0.80
C	65.82	5.98	1. 29	12.88	0.01
D	66.56	5.96	1. 24	10.50	0.01
E	65.80	5.93	1. 26	10.60	0.01

Table 5. Ultimate Analysis of PKS briquette from past study (Bonsu et al., 2020)

Sample	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulphur (%)
Briquette (PKS)	48.90	7	1.02	42.86	0.22

3.3 Higher Heating Values

The higher heating value also called energy value is the amount of heat liberated for a unit mass of a biomass sample (Aina et al, 2009). From Table 6 the higher heating value of the raw sample palm kernel shell obtained is 16.55 MJ/kg while that of the of the palm kernel briquette samples A, B, C, D and E are 20.62 MJ/kg, 20.90 MJ/kg ,22.40 MJ/kg, 20.80 MJ/kg and 20.86 MJ/kg. It is observed that binder concentration has an effect on the higher heating value on palm kernel briquette samples when compare to the raw palm kernel shell without binder. The higher heating values of the briquette sample are higher than that of the raw sample.

The higher heating values of briquette samples A, B, C, D and E are within ASTM standard ranges of briquette with values vary from 18 MJ/kg to 23 MJ/kg (Bonsu et al., 2020). From the samples considered in this study, sample C has the highest heating value.

Table 6. Higher Heating Values r of PKS Raw (Powder) and PKS Briquette samples

Sample	Heating Value (MJ/kg)
Raw	16.55
A	20.62
B	20.90
C	22.40
D	20.80
E	20.86

3.4 Hardness Test Result

The hardness values of the briquette samples were determined by using Vickers hardness machine. The Vickers hardness result of the briquette samples are reported in Table 7, when load of 3 HV, 30 HV and 100 HV were applied on the briquette samples. It can be seen that the higher the number the harder the briquette. The briquette sample C has the highest number after the hardness test was carried out on the samples. This means the samples C is the hardest among the five samples.

Table 7. Hardness test result of Palm Kernel Shell Briquette samples

Sample	HV 3	HV 30	HV 100
A	16.8	26.5	25.5
B	16.5	27.5	28.5
C	19.5	28.7	29.6
D	18.6	26.6	26.7
E	16.5	28.4	28.2

3.5 Fourier Transform Infrared Spectroscopy (FT-IR) Analysis of Briquettes

Fourier transform infrared (FTIR) is an essential analytical tool for researchers. This examination can characterize samples in various forms, including liquids, solutions, pastes, powders, films, fibers, and gases. A researcher suggested that this methodology can also be used to analyze materials on substrate surfaces (Fan et al, 2012).

The briquette samples A, B, C, D and E were characterized by FTIR spectrophotometer analysis. The palm kernel briquette samples were scanned in the wavelength ranging from 400cm^{-1} to 4400cm^{-1}using Perkin Elmer Spectrophotometer and the characteristics peaks were detected and the functional groups were identified. from Figure 2(a) to (e) the peak spectrum of briquette samples A, B, C, D and E were computed to form Table 8 using mid-IR spectrum region for analysis as postulated in (Nandiyanto and Ragadhita ,2019). By comparing values in Table 8 with FTIR standard Table of functional group and its quantified frequencies, it can be seen that samples A, B, C and D single region bond show range comprises bands related to crystalline structure of cellulose. It is related to the valence vibration of H-bonded OH and intramolecular H-bonds while the sample E in the same single region bond (Yahya et al., 2023; Coates, 2000).

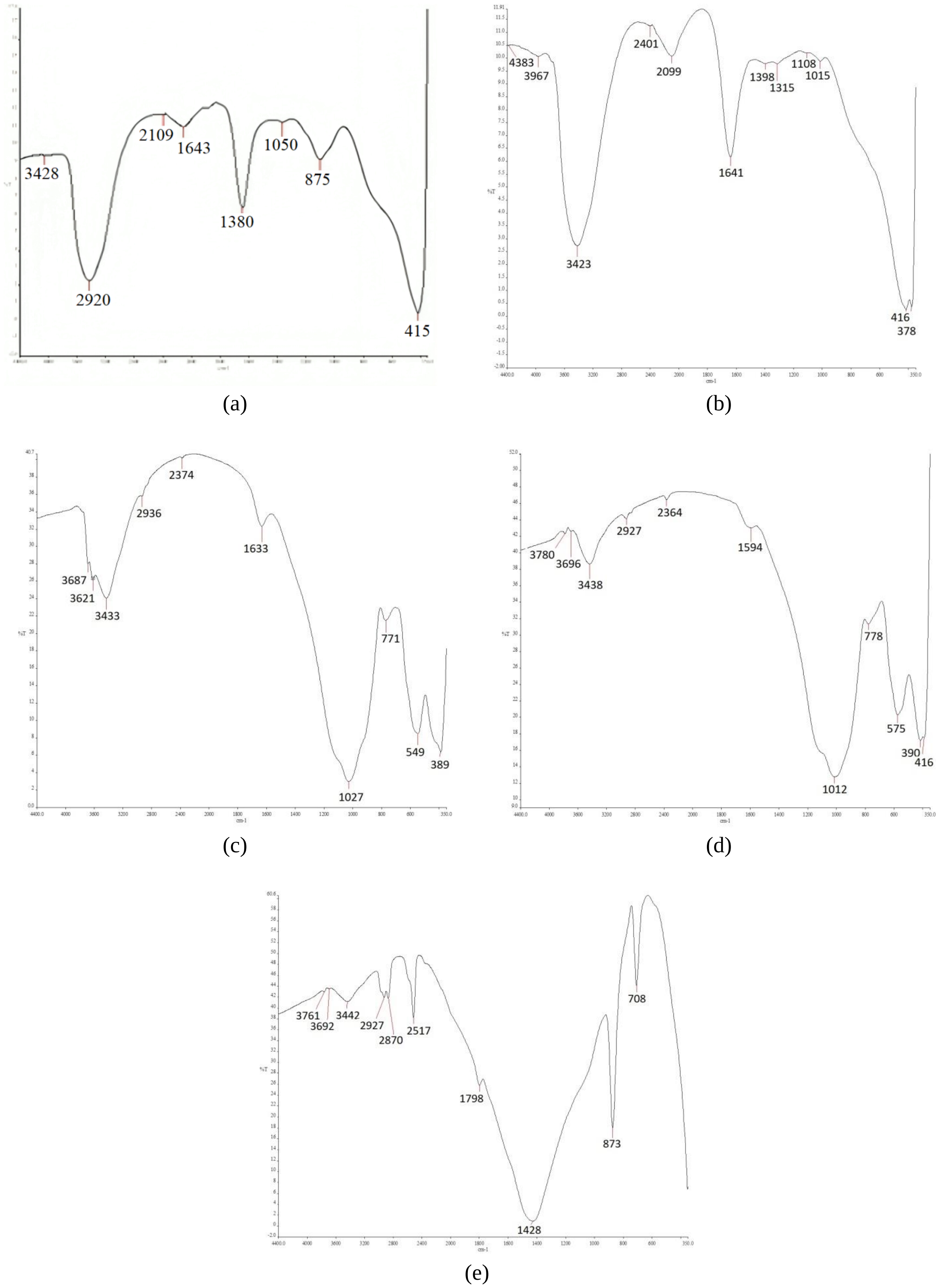


Fig 2. FTIR Analysis of Briquettes

Table 8. FTIR Peak Interpretation of briquette samples

Sample	Properties	Single Region Bond	Triple Region Bond	Double Region Bond	Fingerprint
A	Wavelength (cm^{-1})	3,428.00	2,109.00	1,642.75	415.38
	Intensity	Broad	Medium	Medium	
	Functional Group	Hydroxyl group, H-bonded OH stretch	C ≡ C Terminal alkyne (mono substituted)	Alkenyl C=C stretch	
	Vibrational Mode	Hydrogen-bonded O–H stretching	Symmetric CH_2 stretch	Aromatic ring stretching / Conj. C = O	
B	Wavelength (cm^{-1})	3,423.00	2,099.00	1,640.61	416.37
	Intensity	Broad	Sharp	Medium	
	Functional Group	Hydroxyl group, H-bonded OH stretch	Transition metal carbonyls	Aromatic ring stretching / Conj. C = O	
	Vibrational Mode	Hydrogen-bonded O–H stretching	Carbonyl stretching	Aromatic ring stretching / Conj. C = O	
C	Wavelength (cm^{-1})	3,433.00	2,373.66	1,633.25	388.54
	Intensity	Broad	Sharp and strong	Medium	
	Functional Group	Hydroxyl group, H-bonded OH stretch	Thiols (S-H stretch	Alkenyl C=C stretch	
	Vibrational Mode	Hydrogen-bonded O–H stretching	Asymmetric stretching	Aromatic ring stretching / Conj. C = O	
D	Wavelength (cm^{-1})	3,438.00	2,364.00	1,593.73	416.08
	Intensity	broad	Sharp and strong		
	Functional Group	Hydroxyl group, H-bonded OH stretch	Thiols (S-H stretch)		
	Vibrational Mode	Hydrogen-bonded O–H stretching	Asymmetric stretching		
E	Wavelength (cm^{-1})	2,517.40	Nill	1,427.63	872.86
	Intensity	Broad and weak			Strong
	Functional Group	O–H from COOH groups (carboxylic acids)		Alkanes / lignin side groups	Aromatic rings (para- or mono-substituted
	Vibrational Mode	Stretching vibration		CH_3 bending (asymmetric or symmetric)	C-H out-of-plane bending

3.6 Scanning Electron Microscopy (SEM) Analysis of Briquettes

The SEM analysis was used to examine the internal structure of briquette samples, identifying voids and gaps between particles. Table 9 shows the analysis of the briquettes at different magnifications (Waheed et al, 2022). The examination was carried out on the five palm kennel briquette samples A, B, C, D and E, with each sample photographed at three distinct magnifications: 8000x, 9000x, and 10,000x. The working distance (WD) ranged from 8.4 mm to 10.6 mm, while the horizontal field width (HFW) varied from 120 µm to 130 µm. Particle sizes were around 100 µm, 50 µm, and 20 µm at various magnifications, allowing for a thorough evaluation of surface morphology and pore structure (Bhatia and Sahu 2023).

The overall structures (Figure 3) of palm kernel shell briquette samples A, B, C, D and E show mainly rough and fibrous surface at 8000x magnification. Samples A and C show less heat deterioration and more compact fiber bundles with fewer breaks. Samples D and E, on the other hand, have obvious and visible pores and surface cracks or fractures, which most likely happened as a result of more extensive chemical or high thermal treatment procedures like carbonization (Hamid et al., 2016).

Table 9. SEM Imaging Parameters

Sample	WD (mm)	Mag	HFW (µm)	Size (µm)
A	10.5	9000	126	100
	10.2	10000	125	50
	8.4	8000	130	20
B	10.5	8000	122	100
	10.5	9000	122	50
	9.6	10000	130	20
C	9.6	8000	120	100
	9.8	9000	122	50
	10.2	10000	125	20
D	10.4	8000	126	100
	10.6	9000	125	50
	8.4	10000	130	20
E	10.4	9000	126	100
	10.2	10000	125	50
	8.4	8000	130	20

When 9000x magnification was applied to the briquette samples A, B, C, D and E the morphological differences became more visible (Figure 3). Samples D and E show many empty space and cracks, indicating a breakdown of lignocellulosic structure; the increased porosity in these briquette samples D and E may improve biomass fuel properties by improving air penetration and heat efficiency; notably, Sample E shows a fractured, porous matrix, which is adequately good for briquette applications in domestic and industrial area due to enhanced binding and combustion (Saeed et al., 2021).

At 10000x magnification, the fine features of the surface properties were visible (Figure 3). Microscale structural collapse was seen in briquette sample C, which might have been caused by exposure to too much heat of burning. Samples D and E interconnected pore networks maintained structural integrity, which is beneficial solid fuel like briquettes or charcoal. Furthermore, these interconnected holes may improve densification during production of briquette.

In general, the briquette samples D and E show the best morphological traits for the produced biomass briquettes, such as: elevated porosity of the rough surface and fractured textures microchannel evidence. These characteristics give better compaction, combustion, and energy release. Samples A and B retained more native structure with minimal visible degradation, suggesting lower reactivity or incomplete thermal transformation (Ngangyo et al., 2022).

3.7 Energy Dispersive X-ray (EDX) Analysis of Briquettes

The energy dispersive X-ray spectral presented in Figure 3 show the composition of most common elements detected in each sample of the briquette samples A, B, C, D and E. Sample A composed of 6 elements, sample B, 10 elements, sample C, 11 elements, sample D, 6 elements and sample E, 12 elements. These elements can be group into two, which are organic and inorganic. (Rahmat et al., 2023; Bembenek, 2025).

The organic elements are Carbon (C) which has major energy contributor during combustion, Oxygen (O) which is combines with C to release CO_2 and energy, also Nitrogen (N) which form NOx gases which has emissions issue at high levels. The inorganic elements are subjected to emission and ash quality. The inorganic elements include Chlorine (Cl) which has corrosion effect and dioxin emissions, Sulfur(S) which has SOx emissions, Potassium (K), Sodium (Na) which have slagging and fouling risk (low melting ash) , Iron (Fe),Calcium (Ca), Silicon (Si) which have ash composition, and melting behavior (Anita et al., 2023).

The EDX analysis shows that sample A has 68.5 % of carbon element, which is the highest percentage of carbon among others samples, indicates higher organic content and major energy contributor during combustion. Other organic elements such as oxygen at 12% linked to lignin, cellulose and starch and nitrogen at10.07% which are moderately okay. Inorganic element such as sodium at 2.2%, phosphorous at 1.33% while others like Si, Ti, Fe, Cl, Ca, S, K, Mg, Al are completely absent. In sample B, carbon element has 55%, oxygen 20% and nitrogen 8.7% which are moderately better while the inorganic elements varying in percentage (Yahya,et al., 2023).

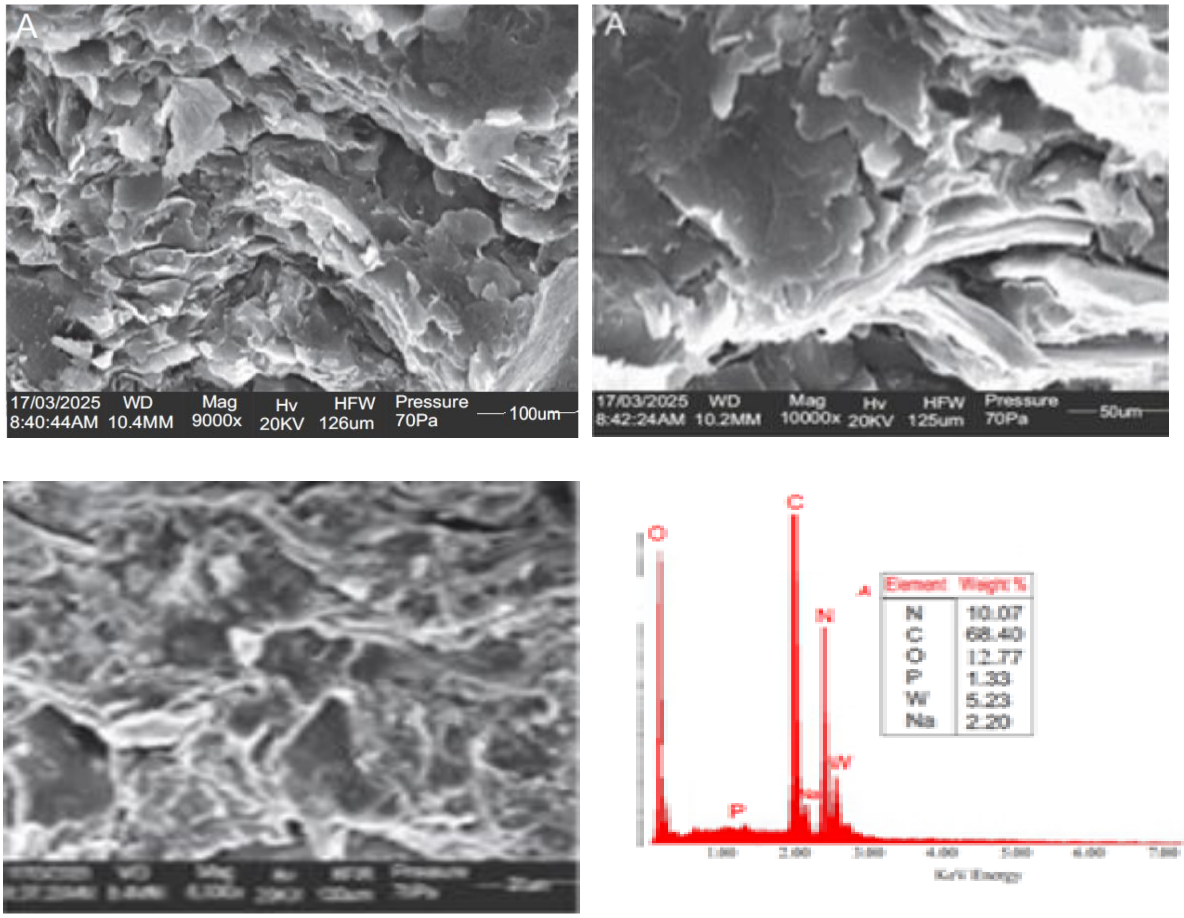
4. CONCLUSION

This study has developed an efficient means of transforming agricultural waste to produce briquettes from biomass as an alternative energy source capable of replacing conventional fuels. The briquette considered in this study was produced by mixing palm kernel powder with cassava starch used as binder at varying proportion. Five different samples were produced and tested: A (170g,30g) B (150g,50g), C (130g.70g), D (180,20g) and E (190g,10g). The experimental results of this study showed that:

- The higher heating values of the briquette simples varied from 20.62MJ/kg to 22.40MJ/kg.
- Ultimate analysis shows that the Carbon content varied from 60.75% - 66.56%; Hydrogen content 5.55% - 5.98%; Nitrogen content 1.12% - 1.55%; Oxygen content 10.50% - 12.88% and Sulphur content 0.01% – 0.8%.

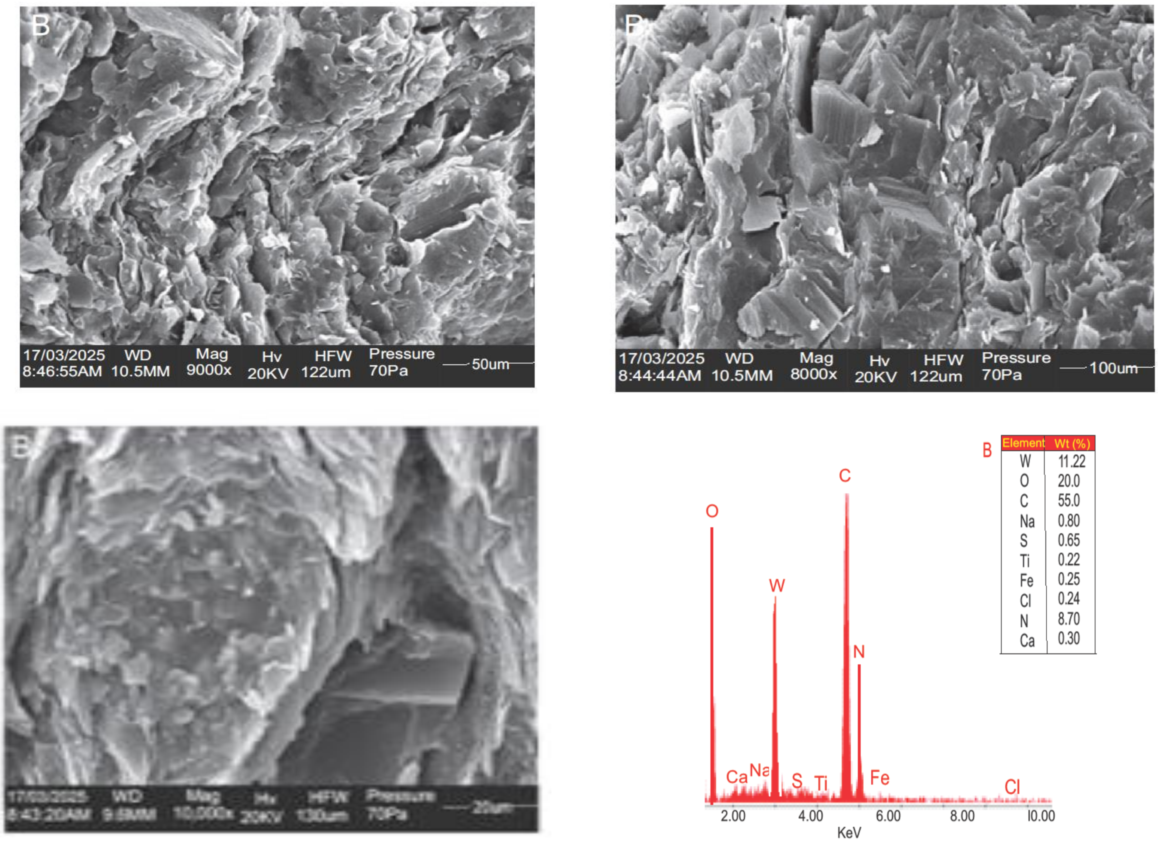
- Proximate analysis shows that the moisture contents, volatile matters ash and fixed carbon contents for the palm kernel briquettes samples are within the aceptable standard of biomass fuel.
- Among the briquette simples tested, sample C (PKS: 130g; Starch: 70g) has the highest heating value (22.40 MJ/kg), Hydrogen content (5.98%), Oxygen content (12.88%) and least Sulfur content (0.01%).
- The briquette sample C has the highest number after the hardness test was carried out on the samples. This means the samples C is the hardest among the five samples.
- The Energy Dispersive X-ray, Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FT-IR) analysis of the briquette samples show the presence of high percentage of carbon content, fractured, porous matrix, and existence of crystalline structure of cellulose which is adequately good for briquette applications in domestic and industrial area due to enhanced binding and combustion characteristics.

Results of this study have shown that the briquettes made from palm kernel shells have good prospects as potentials source of bio-fuel and replacement for conventional fuel.

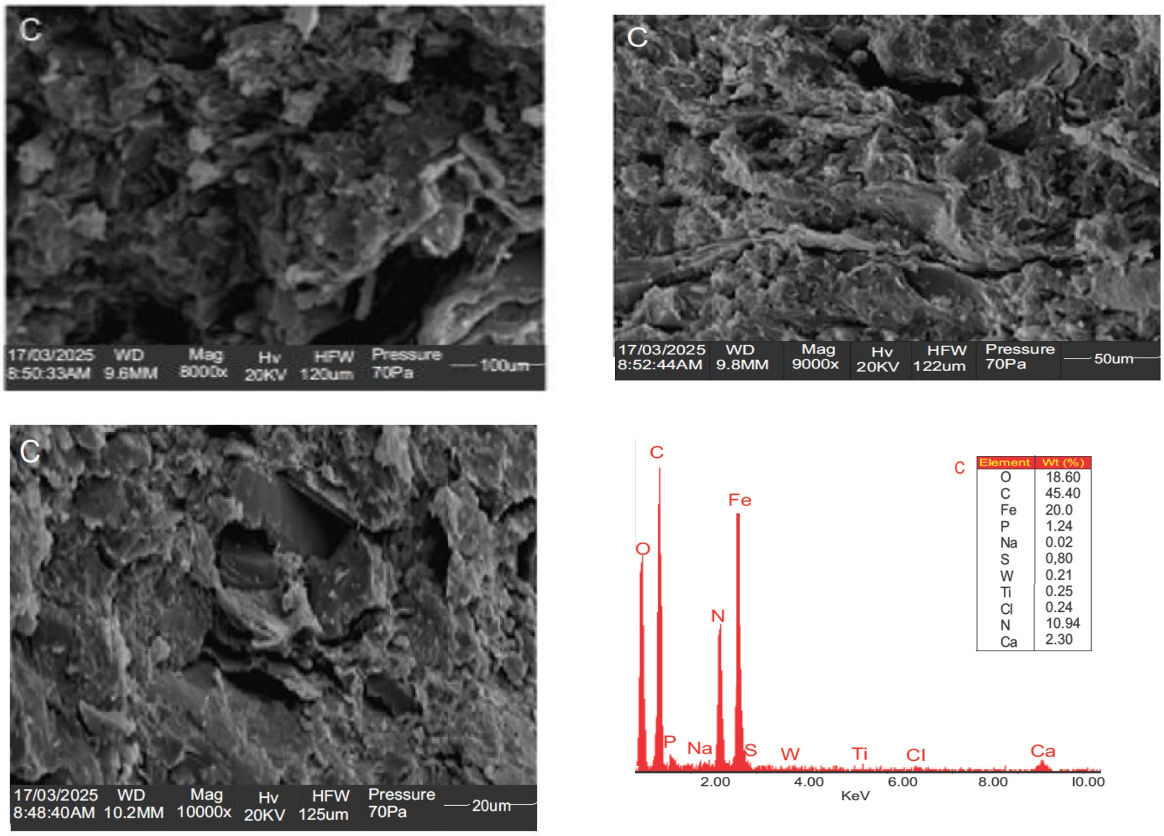


Sample A

Fig 3. SEM-EDX Images of Tested PKS Briquette Samples

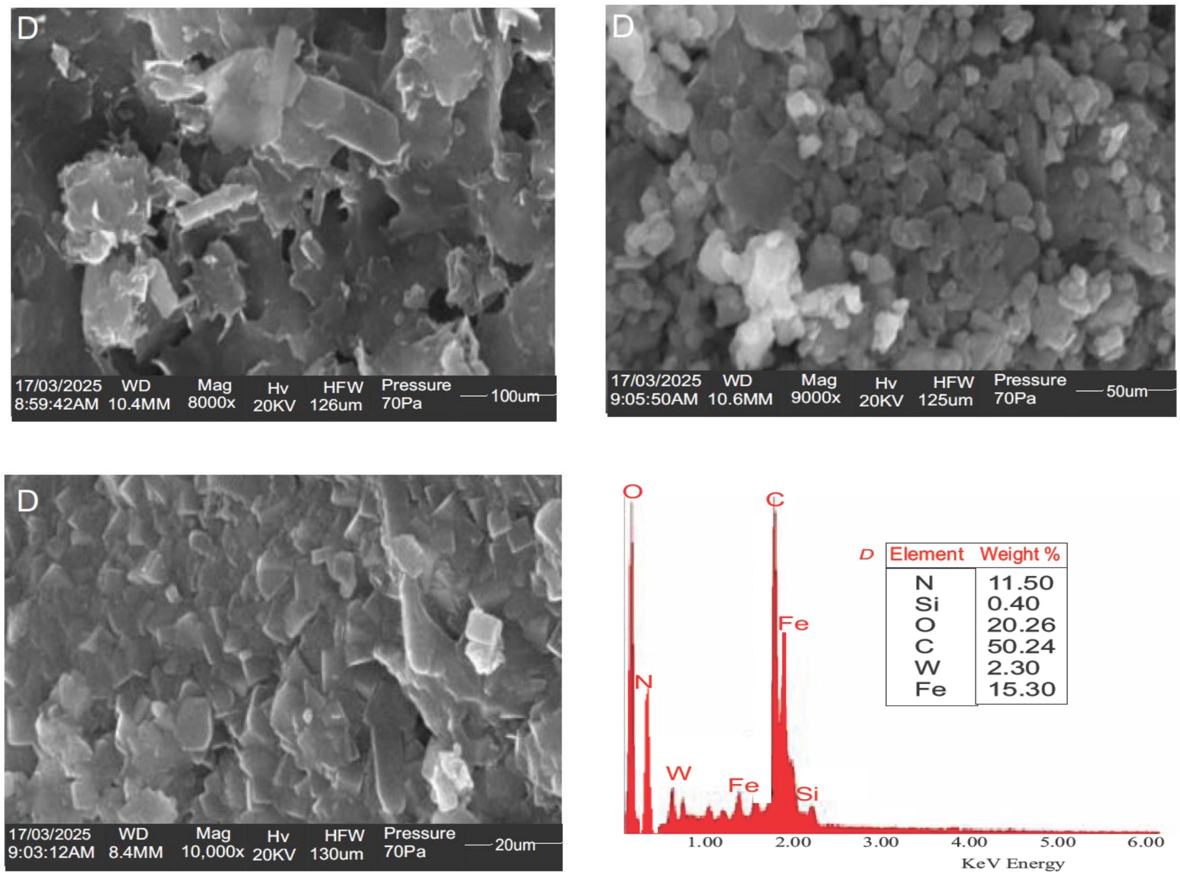


Sample B

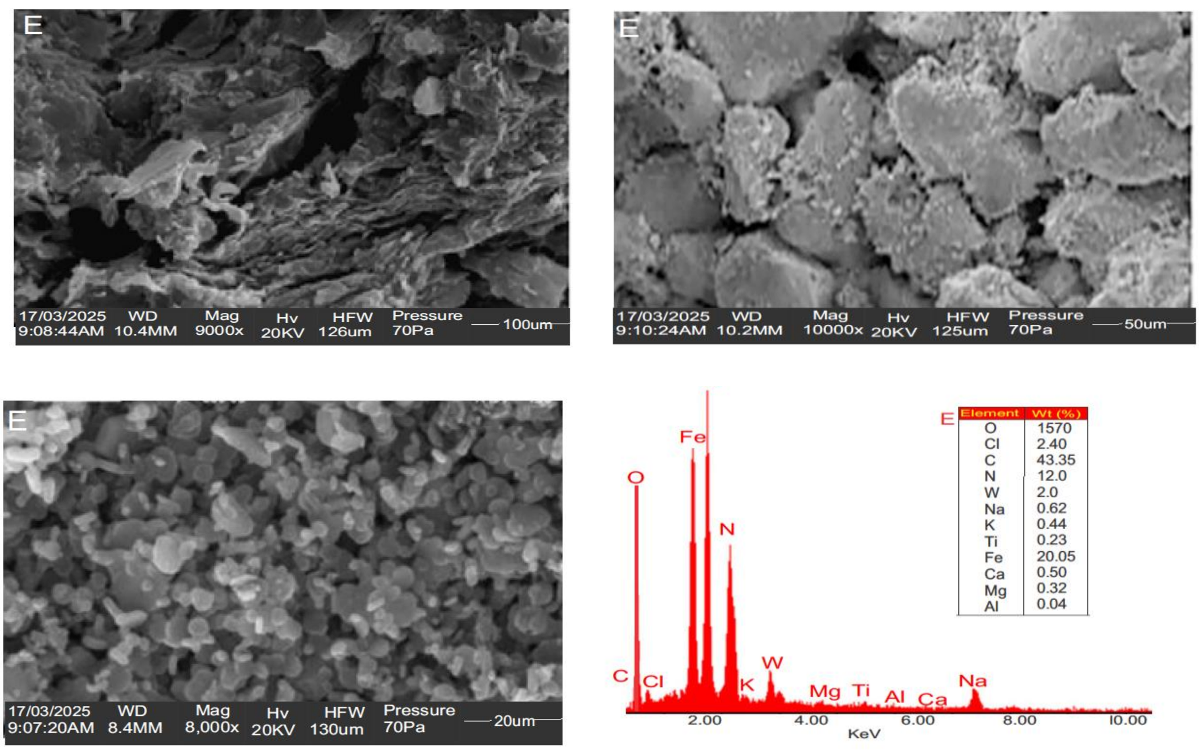


Sample C

Fig 3. SEM-EDX Images of Tested PKS Briquette Samples *(Continued)*



Sample D



Sample E

Fig 3. SEM-EDX Images of Tested PKS Briquette Samples *(Continued)*

NOMENCLATURE

AC	Ash Contents	MC	Moisture Contents
EDX	Energy Dispersive X-ray	PKS	Palm Kernel Shell
FC	Fixed Carbon Contents	SEM	Scanning Electron Microscopy
FT-IR	Fourier Transform Infrared Spectroscopy	VM	Volatile Matter
HFW	Horizontal Field Width	WD	Working Distance

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