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Characterizing Biochar Derived from Palm Kernel Shell Biomass via Slow Pyrolysis for Adsorption Applications

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Pyrolysis,
Palm Kernel Shell Biochar (PKSBC),
Characterizations.

ABSTRACT

This comprehensive study delves into the thorough characterization of biochar derived from palm kernel shells, with a focus on its potential as an environmentally friendly solution to tackle waste management challenges within Malaysia's agro-industry. Employing the (BET) method, the current investigation unveils an impressive specific surface area of 299.7565 m^2/g, complemented by a pore size of 2.17783 nm and a substantial pore volume of 0.1632 cm^3/g, attesting to its extraordinary adsorption capacity. Assessment of thermal stability through (FESEM) imaging underscores its resilience, FTIR spectroscopy unravels distinct peaks within the stretching region. XRD analysis introduces a characteristic pattern for palm kernel shell-derived biochar (PKSBC), marked by a prominent, broad peak observed at approximately $2\theta = 20\text{-}30°$ and $2\theta = 40\text{-}50°$, indicative of crystalline and semi-crystalline phases, respectively. Elemental analysis assumes a pivotal role in assessing biochar quality, with a particular emphasis on carbon content, instrumental in identifying potential impurities or contaminants that could compromise its effectiveness in critical applications, including water treatment, air purification, and gas adsorption. This study not only underscores the substantial promise of palm kernel shell-derived biochar in addressing environmental challenges but also provides invaluable insights into its exceptional properties. These findings have the potential to redefine sustainable practices and drive environmental stewardship, offering innovative solutions to the pressing issues of our time.

1. INTRODUCTION

The persistent environmental concerns, escalating petroleum prices, energy crises, depletion of fossil fuels, and growing need for energy are significant factors driving the urgent demand for alternative sustainable energy sources [1,2]. The key attributes of biomass, including environmental friendliness, sustainability, and biodegradability, have positioned it as a leading contender for the production of bio-energy [3,4]. The investigation of conversion technologies presents viable avenues for exploring the economic viability of bio-resources [5]. Biofuels and bio-chemicals are produced via thermochemical conversion processes, encompassing pyrolysis, gasification, liquefaction, and combustion [6,7]. Pyrolysis is a highly important method for the conversion of biomass into bio-fuels [8,9,10]. During the process of biomass pyrolysis, the residual feedstock releases volatiles and semi-volatiles, resulting in the production of gases, bio-oil, and chars. Moreover, the production of bio-char might involve the re-condensation of vapor into the bio-char material, a process that is influenced by the duration of vapor residence. This phenomenon contributes to the enhancement of bio-char products [11,12,13]. Figure 1 presented below describes the steps that are involved in the production of biochar obtained from palm fruit.

a-Palm Fruit- PF b-Palm Kernel Shell-PKS c-Palm Kernel Shell Biochar-PKSBC

Figure 1 shows the (a) PF (b) PKS (c) PKSBC.

The PKS, which are a type of lignocellulose biomass, currently lack any significant utilization beyond their direct combustion in furnaces [14,15,16]. Consequently, they are often disposed of in open places. The aim research is to examine the physiochemical and thermochemical properties of biochar derived from hard (PKS). The determination of the surface area of biochar is crucial in order to propose specific applications for this material. The heating rates are employed for Thermogravimetric (TG) analysis. In addition, the analysis of biochar involves the utilization of scanning electron microscopy, X-ray diffraction, and Fourier transform infrared spectrometry. These techniques are employed to gain insights into the product profile of biochar samples derived from palm kernel shell specimens. Despite a large amount of research on the understanding of biochar capacity for adsorption in terms of its chemical and physical properties, this particular study stands out for its valuable findings and comprehensive discussions, which contribute to a long-term perspective in the adsorption process. The major goal is to investigate the characterization of biochar for the adsorption process in terms of hardness and porosity,

2- Pyrolysis

Pyrolysis refers to a thermal degradation procedure wherein organic substances are subjected to high temperatures in an oxygen-free environment. This phenomenon results in the degradation of intricate organic molecules into less complicated compounds, encompassing gaseous, liquid, and solid forms. The lack of oxygen hinders the occurrence of full combustion, leading to the generation of byproducts such as biochar, bio-oil, and syngas [17]. During the process of pyrolysis, the organic material undergoes exposure to various temperature zones [18]. The drying zone refers to the initial stage of the process where the moisture content of the material is eliminated due to the increase in temperature. This phase primarily centers on the removal of water and other volatile components, without involving substantial chemical alterations [19]. The pyrolysis zone is defined by the presence of pyrolysis phenomena as the temperature gradually increases. The process of decomposition involves the fragmentation of complex organic compounds into simpler constituents. The resultant products can show variations based on factors such as temperature, pace of heating, and composition of the feedstock. The Char

Formation Zone refers to the geographical area.

3- BIOCHAR

PKSBC is produced by carbonizing the hard outer shells of palm kernel. PKS are a residual material generated as a byproduct of the palm oil business, and their availability is widespread in areas where palm oil and secondly, the possibility of activating it or converting it into activated carbon or Xerogel.

Generating biochar, which is comprised of solid carbonaceous residues, occurs. The prevailing environmental factors within this specific area exert a significant impact on the inherent physical and chemical characteristics of the resultant biochar. The gas and vapor zone is defined by the release of gaseous compounds, including hydrogen, carbon monoxide, methane, and volatile organic compounds. The aforementioned gases have the potential to be gathered and utilized as a source of fuel or as raw materials for chemical production. As gases move out from the high-temperature region, they cool and eventually condense in what is known as the condensation zone. This process gives rise to the formation of a liquid product commonly referred to as bio-oil or pyrolysis oil. The composition of the products derived by pyrolysis is contingent upon various factors, including the temperature, heating rate, residence duration, and inherent properties of the feedstock. Pyrolysis is a versatile process that finds use in diverse domains, encompassing the manufacture of biochar for soil enhancement, bio-oil for energy generation, and syngas for the purpose of heat or electricity production. The process of biomass conversion and waste management is considered crucial due to its capacity to convert organic wastes into valuable goods [20,21,22,23,24,25,26].

Production takes place for example (Malaysia, Indonesia, and India). PKS-derived biochar exhibits numerous advantageous characteristics. The material in question has a high degree of porosity, resulting in a significant surface area. This characteristic renders it particularly

proficient in the processes of adsorption and retention of both nutrients and water within agricultural soils. The application of this technique has the potential to enhance soil fertility, optimize agricultural yield, and decrease reliance on synthetic fertilizers. Furthermore, the utilization of biochar obtained from PKS exhibits the potential to effectively sequester carbon, so contributing to the mitigate of climate change through the long-term storage of carbon within the soil[27,28,29,30].

Table 1 show HHV in previous study.

Materials	HHV	METHODS	Ref.
PKS	27.63 MJ/kg	microwave	https://doi.org/10.1016/j.jclepro.2016.10.176
PKS	24.6 MJkg-1	Pyrolysis	http://dx.doi.org/10.17576/jsm-2017-4612-20
PKS	26 – 30 MJkg-1	Pyrolysis	https://doi.org/10.21894/jopr.2018.0043

4- CHARACTERIZATIONS

This Figure below displays the procedure of characterizing biochar in three primary dimensions: surface morphology, composition, and chemical properties. Each of these factors is systematically treated in a scheduled order [30].

4.1 Surface characterization:

Includes the analysis and evaluation of the Biochar surface physical attributes and characteristics. Tests falling within this particular category may encompass methodologies such as Scanning Electron Microscopy (SEM) with the purpose of visualizing the microscopic surface structure. The importance of this stage lies in comprehending the morphology and porosity of biochar, as these characteristics might influence its efficacy in many applications, such as enhancing soil quality or purifying gases and water [30,31].

4.2 Compositional characterization:

Involves the examination and analysis of the constituent components and compounds that are present in the biochar. Methods such as X-Ray Diffraction (XRD) can be utilized for the purpose of mineral content identification, whereas Fourier Transform Infrared Spectroscopy (FT-IR) may be employed to discover functional groups. The process of compositional characterization plays a crucial role in assessing the chemical composition of biochar, hence influencing its prospective applications in several domains such as carbon sequestration and agricultural improvement [32].

4.3 Chemical characterization:

Includes the examination of many chemical characteristics of biochar, including its pH level, surface functional groups, and chemical reactivity. In this context, analytical techniques like as pH testing and titration methods could potentially be employed. The process of chemical characterization holds significant importance as it offers valuable insights into the potential interactions between biochar and its surrounding environment, hence influencing its applicability for various applications such as pollutant adsorption or soil amendment [38].

In brief, the graph labeled as "Figure 2" provides an in-depth overview of the sequential procedure employed to evaluate the many attributes of biochar, with particular emphasis on its surface features, structure, and chemical structure. Each test within these categories serves an individual purpose in explaining several aspects of biochar characteristics and dynamics, ultimately proving its potential efficiency in distinctsituations.

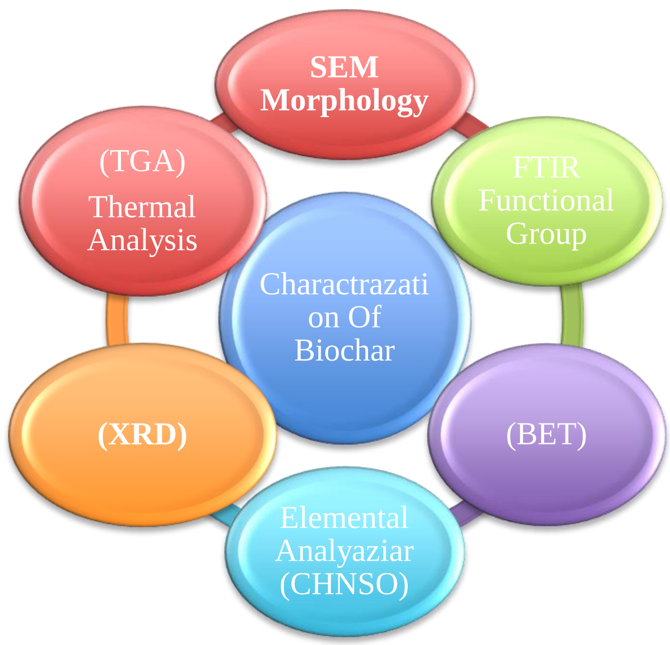
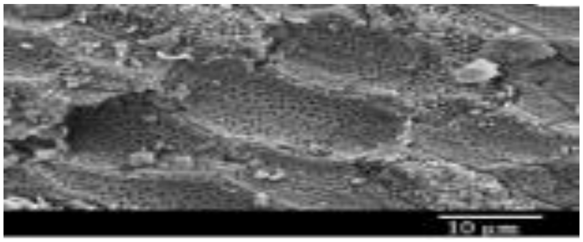


Figure 2. Chemical, Surface, and Structural Characterizations of PKSBC.

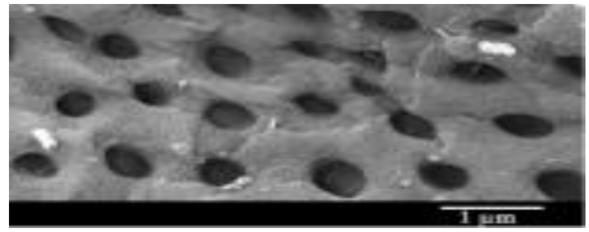
5- RESULT AND DISCUSSIONS

5.1 Scanning Electron Microscopy (SEM)

The utilization of Scanning Electron Microscopy (SEM) is a method employed to acquire high-resolution imagery of a sample's surface. The technique employs a concentrated electron beam to meticulously examine the surface of the specimen, whereby the interaction between the electrons and the specimen produces diverse signals that may be recognized and utilized for the purpose of generating a picture. The scanning electron microscope (SEM) offers comprehensive insights into the sample's topography, morphology, and composition. The utilization of this phenomenon is prevalent across diverse disciplines, including materials science, nanotechnology, biology, and geology [39]. Figure 3 displays the surface morphology of biochar, as observed through scanning electron microscopy (SEM) investigation. The presence of PKSBC (A) exhibits characteristics reminiscent of planner sheet-like formations. The structures display coarse textures and display heterogeneity. However, PKSBC (B) has porous gaps and a rocky-like structure. The findings display similarity to those obtained by researchers in the [40]



A



B

Figure 3 (A and B) display the morphology (SEM) of PKSBC.

The porous structure of PKSBC was shown to have formed well using scanning electron microscopy. This study showed that agricultural waste may be repurposed into marketable porous material.

5.2 Brunauer Emmett Teller (BET)

The Brunauer Emmett Teller (BET) method is a widely employed approach in scientific research for the purpose of quantifying the specific surface area of a given material. The assessment of the porosity and adsorption capacity of biochar samples is a widely employed practice within the field of biochar research. The utilization of palm kernel shell biochar presents an opportunity to gather significant insights into its surface area and capacity to adsorb diverse compounds, including pollutants or nutrients, through the application of BET analysis. The aforementioned data possesses potential utility in the assessment of the appropriateness of palm kernel shell biochar for diverse applications, including but not limited to gas adsorption, water treatment, and soil amendment [41][42][43]. Table 2 displays the BET surface area, pore size, and pore volume of PKSBC. Pore size is 2.17783 nm and pore volume is 0.1632 m3/g, both of which contribute to the PKSBC's large surface area of 299.7565 m2/g. The results obtained from the BET study indicate that PKSC has considerable promise as a precursor for the production of activated carbon and other nanomaterial synthesis.

Table 2 Display the chemical characterization of (PKSBC).

Materials	**SSA (m^2/g)**	**P V (cm3/g)**	**PS (nm)**
PKSBC	299.7565	0.1632	2.17783

4.4928 **Thermo gravimetric Analyzer (TGA)**

The Thermogravimetric Analyzer (TGA) is a scientific device employed for the purpose of measuring variations in the mass of a given specimen in relation to either temperature or time. It is frequently employed in several disciplines, including materials science, chemistry, and environmental science. The (PKS) refers to the hard external covering of the PKF. The substance in the problem is a secondary output of the palm oil sector, which has garnered significant interest as a prospective biomass fuel owing to its considerable calorific value and widespread availability, particularly in nations situated in Southeast Asia [44][45]. To investigate the elemental content and thermal stability of the Biochar, Thermogravimetric Analysis (TGA) was carried out in accordance with ASTM Standard Method D5142-02a. Table 3 presents the measured values of fixed carbon and ash content in palm kernel shell biochar. These findings indicate the considerable amount of high heating value present in the biochar, making it a potentially valuable material for adsorption processes due to its notable adaptability.

Table 3 display the proximate analysis for (PKSBC).

Name of Simples	Stages	Temperature (°C)	Weight loss (mg)	Weight loss rate (wt.%/min)
PKSBC	1st stage Moisture	30.66-147.37	10-8.8784=1.1216	11.92
	2nd stage Volatile	149.33-941.62	8.8784-7.4928=1.3856	13.84
	3rd stage Carbon	946.62-1202	7.4928-1.5368=5.956	58.7
	4th Stage Ash	1202 and so on	1.5368	15.54

Figure 4 presents the Thermogravimetric curves of PKSBC, illustrating the variations in moisture, volatile matter, carbon content, and ash content as a function of temperature. These curves provide valuable insights into the thermal behavior, stability, and composition of the biochar, which are crucial factors for the gases adsorption process. One of the key findings of this study pertains to the structural degradation of biochar derived from palm kernel shells (PKS) under varying pyrolysis temperatures. The analysis revealed that structural changes in the biochar matrix commence at a critical temperature of [970 °C] during the pyrolysis process.

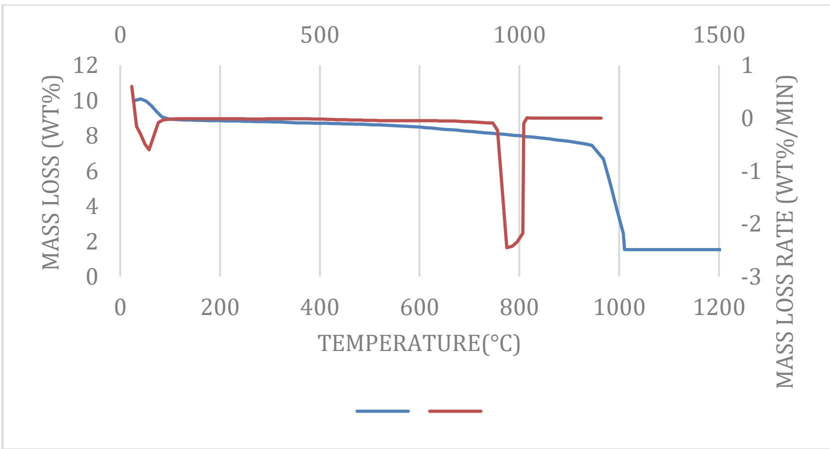


Figure 4 Display Thermogravimetric Analyzer of PKSBC.

5.4 Elemental Analyzer (EA)

The elemental analyzer is an analysis device utilized for the purpose of discovering the chemical composition of a given sample. The utilization of palm kernel shell biochar allows for the examination of several elemental components, including carbon, hydrogen, nitrogen, sulfur, and oxygen [34].

Table 4 Display the Elemental Analyzer of PKSBC.

Raw materials	C	H	N	S	O
PKSBC	35.6931	1.3895	0.7428	0.4294	61.7452

The technique of elemental analysis is employed for the purpose of finding the elemental composition of a given sample. When considering the analysis of PKS, the utilisation of an elemental analyzer can yield numerous advantages:

1- Quantitative analysis involves the utilisation of an elemental analyzer to precisely ascertain the concentration of different elements found in palm kernel shells, including carbon, hydrogen, nitrogen, sulphur, and oxygen.

2- Quality control involves the assessment of the elemental composition of palm kernel shells to ensure their quality and consistency. This analysis is crucial in determining if these shells fit the specific requirements for different uses, including biomass energy production and adsorption processes.

3- Research and development endeavors benefit from the utilization of elemental analysis techniques as they provide a comprehensive comprehension of the chemical characteristics inherent in palm kernel shells. Consequently, this knowledge empowers researchers to delve into novel applications or enhance pre-existing processes associated with these shells.

In relation to potential side effects, it is important to note that elemental analysis of palm kernel shells does not provide any immediate adverse consequences. Nevertheless, it is crucial to acknowledge that the analysis is commonly conducted through burning, a process that has the potential to emit minimal quantities of pollutants into the atmosphere. Typically, these emissions exhibit modest levels and can be efficiently regulated within controlled laboratory environments.

5.5 X-Ray Diffractions (XRD)

The X-ray diffraction investigation was conducted using a RIGAKU XRD diffractometer system, with diffraction measurements taken at 2θ values spanning from 10 to 100°. The X-ray diffraction (XRD) analysis of the extracted silica reveals the presence of a distinct amorphous solid when viewed at an angle of 22.5º, thereby confirming the detection of the amorphous silica phase [46].

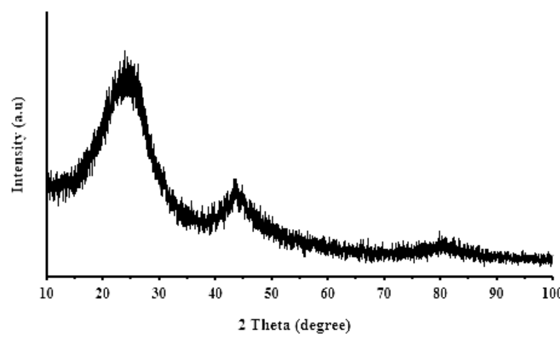


Figure (5) display the patterns of PKSBC.

X-ray diffraction (XRD) is a widely employed methodology for the examination and characterization of the crystal lattice arrangement in various materials. The process is subjecting a specimen to X-ray radiation and quantifying the resulting diffraction pattern that arises from the interaction between the X-rays and the crystal lattice. The diffraction pattern serves as a means to glean insights into the spatial organization of atoms within the material as shown in Figure 6.

X-ray diffraction (XRD) can be employed for the purpose of discerning the existence of distinct crystalline phases or minerals within the palm kernel shell. Additionally, it has the capability to offer valuable insights pertaining to the crystal structure, dimensions of the crystallite, and orientation characteristics of the material.

There are several advantages associated with the utilization of X-ray diffraction (XRD) for the examination of PKS:

1- Phase identification is a crucial step in analyzing the palm kernel shell, as it enables the determination of its distinct crystalline phases. This information is valuable for comprehending the composition and properties of the material. X-ray diffraction (XRD) is a reliable technique employed for this purpose.

2- Quantitative analysis involves the utilization of X-ray diffraction (XRD) to accurately measure the relative proportions of various phases present in a sample, hence facilitating the assessment of the composition of the palm kernel shell.

3- The X-ray diffraction (XRD) technique offers valuable insights into the crystal structure, lattice parameters, and crystallite size of a material, hence facilitating the investigation of its physical and chemical characteristics.

4- Quality control is an essential aspect of maintaining the reliability and integrity of products. In this context, X-ray diffraction (XRD) analysis can be employed as a valuable tool for quality control purposes. Specifically, XRD can be utilized to verify the uniformity and level of impurities in palm kernel shell samples, thereby ensuring their consistency and purity.

5.6 Fourier-transform infrared spectroscopy (FTIR)

The Fourier-transform infrared (FTIR) spectroscopy is a highly effective analytical method employed for the identification and characterization of chemical substances by examining their molecular vibrations.

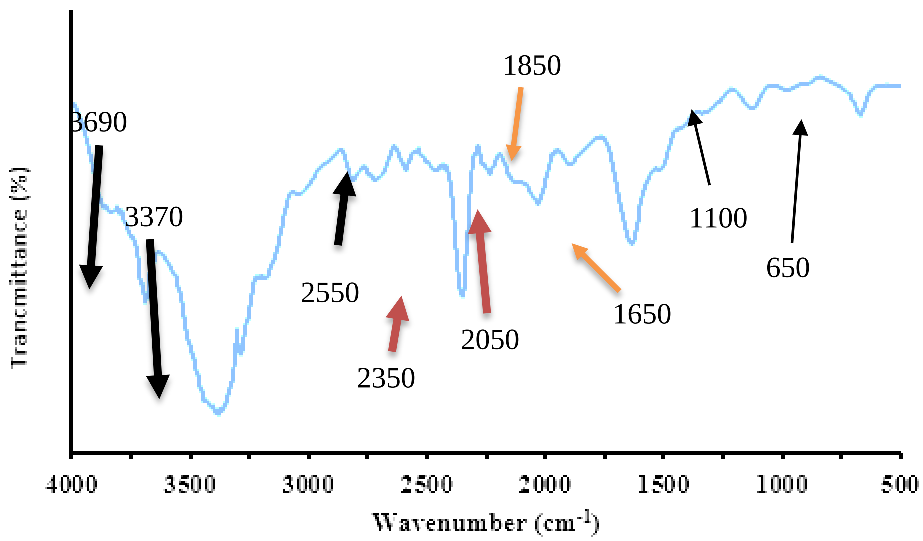


Figure 6 displays the FTIR spectrum of PKSBC.

Each biochar spectrum is classified into four groups: The first group is the O-H functional group, with a wave number range of (2550-3690 cm-1). The second group is the alkyne functional group, with a wave number range of (2050-2550 cm-1). The third group is the main inorganic functional group characteristic of Palm Kernel Shell biochar, with peaks at around (1650 -1850 cm-1), indicating the presence of C=O stretching of aromatic rings and lignin, respectively. The fourth group is also the main functional group characteristic of palm kernel Shell biochar (500-1500 cm-1) For cellulose, it is demonstrated by the presence of C-OH bending at a wavenumber of 1095 cm-1); for alkene, it is demonstrated by the presence of C-H bending at a wavenumber of (650–1100 cm-1).

FTIR spectroscopy has numerous advantages when utilized for the analysis of PKS as appears in Figure 6.

1- The chemical composition of PKS can be determined through the use of FTIR spectroscopy, which enables the identification of several functional groups like hydroxyl groups, carbonyl groups, and aromatic compounds. This material facilitates comprehension of both the chemical composition and structural characteristics of polyketide synthases (PKS).

2-The concentration of certain substances in PKS can be determined through the application of quantitative analysis using FTIR spectroscopy. Through the comparison of absorbance peaks between established standards and PKS samples, it becomes possible to quantify the quantities of different components, including lignin, cellulose, and hemicellulose.

3- The utilization of Fourier Transform Infrared (FTIR) spectroscopy is a viable approach for quality control applications in the manufacture and processing of Palm Kernel Shells (PKS). The consistency and purity of PKS samples can be ensured by monitoring the alterations in chemical composition and structure.

4- The utilization of FTIR spectroscopy in environmental contexts enables the evaluation of the viability of palm kernel shells (PKS) as a sustainable energy source or as a feedstock for the production of

biofuels. Through the examination of the chemical composition, it becomes feasible to ascertain the energy content and appropriateness of palm kernel shells (PKS) for several uses.

5- The utilization of Fourier Transform Infrared (FTIR) spectroscopy has the potential to enhance the optimization of processing parameters for Palm Kernel Shells (PKS), including pyrolysis or gasification techniques. Through the monitoring of alterations in chemical composition throughout these processes, it becomes feasible to enhance factors like temperature, residence time, and catalysts in order to maximize the yield of the intended product.

6- The application of Fourier Transform Infrared (FTIR) spectroscopy offers significant insights and data of great value for research and development endeavors pertaining to Polyketide Synthases (PKS). The comprehension of chemical transformations that transpire during diverse treatments and processing techniques aids in the advancement of novel and enhanced applications for polyketide synthases (PKS).

In general, Fourier Transform Infrared (FTIR) spectroscopy is a multifaceted technique that provides a wide range of advantages for the examination and characterization of palm kernel shells, hence facilitating its effective application in diverse industrial sectors.

CONCLUSION

The utilization of biochar in agriculture and environmental contexts is contingent upon certain characteristics of biochar, such as its specific surface area and surface charge. The initial favorable impact of biochar application on soils, characterized by the inherent addition of nutrients, is expected to diminish over time. Biochar, a very adaptable category of materials, has demonstrated its efficacy across a range of applications. Nevertheless, the existing application of biochar does not prioritize the efficient harnessing of its various benefits, mostly due to the reliance on conventional product schemes. Incorporating novel ideas such as sequential biochar systems can offer utilization strategies that extend beyond single-use scenarios, fostering synergistic relationships between the complex structure of biochar and established agricultural and industrial practices. The use of palm kernel shell has been seen in several applications, such as its implementation as a sorbent in water and gas treatment technology, as well as its use as a filler material within the building industry. Palm kernel shells (PKS) have considerable utility across a diverse array of applications, serving as a viable substitute for direct combustion. The utilization of X-ray photoelectron spectroscopy has enabled the identification of a greater carbon-to-oxygen ratio on the surface compared to the inside of the solid material. This finding suggests that PKS has the potential to be employed as a filler in hydrophobic substances or as a sorbent for pollutants with moderate hydrophobicity. Additionally, there are other findings that provide further evidence for the use of biomass as a filler in construction materials, as well as its potential applications in water treatment and as gas purification agents within the food and beverage industry.

Recommendations for palm kernel shell biochar:

1- Biochar improves soil fertility, water retention, and nutrient availability. It boosts plant growth and production in farms, gardens, and landscaping. It also reduces soil nutrient loss and greenhouse gas emissions.

2- Waste Management: Palm kernel shell waste biochar manufacturing reduces pollution and trash disposal. It sustainably converts agricultural waste into a valuable resource.

3- Carbon Sequestration: Biochar can store carbon in soil for long periods, limiting climate change. Biochar made from palm kernel shells can collect and store carbon dioxide, reducing greenhouse gas emissions and carbon neutrality.

4- Energy Production: Palm kernel shell biochar produces renewable energy. Biofuels or thermal energy feedstock in biomass power plants or industrial boilers can be made from it.

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