

Production and Characterization of Acid-Base Biofunctional Catalyst from Desert Date (*Balanite aegyptiaca*) Seed Shells (DDSS) for Biodiesel Production

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Abstract

The Nigeria rapid expanding population, security concerns, high cost of fuel, oil theft, pollution caused by fossil fuels and uneven distribution of petroleum among the states has contributed to Nigeria increasing demand for energy. *Balanites aegyptiaca* (desert date) seed shells was used as substrate for the production of acid-base biofunctional catalyst and characterized through energy dispersive x-ray fluorescence (EDXRF), scanning electron microscope (SEM) Brunauer-emmett-teller (BET) and fourier transform infrared spectroscopy (FT-IR) respectively. The EDXRF elemental composition of both biochar and the produced acid-base biofunctional catalyst revealed the presence of , Ca, Fe, Ni, Cu, Zn, Br, Pb and Sr at different concentration while metallic oxides or oxide of metals showed the presence of FeO₃, CuO, Ni₂O, Al₂O₃, ZnO, Na₂O, MgO, SO₃, P₂O₅, CaO, K₂O, MnO, Rb₂O, and SrO at different concentrations. SEM morphology was conducted at magnification range of 500X and 1000X. The desert date (*Balanites aegyptiaca*) biochar DDSS-B showed higher level of porosity, overlapping surface and pores with spongy like structure while the produced acid-base biofunctional catalyst (DDSSAC/KOH/H₂SO₄) showed pores created during calcination filled with the active sites during the impregnation process, resulting in the changed of shape and particle sizes. BET analysis showed an increased in specific surface area, pore volume and pore size from DDSSB to DDSSAC/KOH/H₂SO₄. The functional groups attached to the surface of the DDSS was examined by FTIR at transmission spectra of 4000 – 650Cm³ showing –OH, C–H, C=O, C=C, C–O, S–O and P=O at different wave number among the samples. Based on the results desert date seed shells (DDSS) will be a promising feed stock for catalyst synthesis.

Keywords: Biodiesel, Biofunctional Catalyst, Desert Date, Transesterification

1.0 Introduction

The rising world population and the rate of growing energy production and its consumption has led to severe ecological problems such as the release of greenhouse gases that affect the comfort of humans [1]. The worldwide energy consumed is sourced from charcoal, natural gas and petroleum, which will gradually exhaust in the next centuries [2, 3]. The raise in the price of petroleum products due to the global depletion of fossil fuels has necessitated the need for an alternative renewable and sustainable energy source which is friendly to the environment to replace the fossil fuels [4].

The general concept behind biofunctional heterogeneous catalysis is that two different kinds

of active sites work together to carry out a surface-catalyzed reaction, Biofunctional catalysts can catalyze two different kinds of reactions and have two types of catalytic sites. One special benefit of these catalysts is that they can also change the extremely reactive intermediates that typically result in carbonaceous deposits and yield loss, increasing the selectivity for the intended products [5]. However, in theory, the two sites might take part in the same step, for instance, when distinct components of an adsorbed reactant molecule interact with the catalyst, as in a concerted reaction. Bimetallic catalysts and metal-metal oxide catalysts are the two categories of biofunctional catalysts.

Desert date (*Balanites aegyptiaca*) a family of Balanitaceae is a green tree originated from Africa and part of Middle East, it also grown beyond Africa countries like the Arabian Peninsula, and Southern Asia. Israel, Jordan, Saudi Arabia, North and South Yemen and India [6]. It can tolerate variety of habitat and soils ranging from heavy clay, sand and climatic moisture. It consists of mainly of leaves, stem and roots. The fruit has fleshy mesocarp, brittle epicarp and woody endocarp [7]. In Nigeria it is among the forest resources available, where each tone of whole fruit yielded a half tone of woody shells which are hard and ignitable. The wooden shells can be converted in to activated carbon via carbonization which has been in practice for many centuries [8]. Different countries around the world have made agriculture as the primary industrial sector, there by bringing job opportunity for millions of people, contributing significance quarter to their national income. However this agricultural activities lead to generation of farm waste in sufficient quantity. To overcome this issue, farm waste such as sugarcane bagasse (SCB), coconut husk (CH), corn cobs, wheat straw, rice husks (RH), were converted in to catalyst, activated carbon, biochar and catalyst precursor with less environmental effect [9]. This lignocellulosic biomass has become one of the most common renewable sources of energy and fine chemicals. In recent years due to its less cost, availability globally and less effect to the environment as a result of its low emission of carbon dioxide agricultural wastes materials have gained more attraction for industrial applications. The biomass is often processed with higher heat leading to the formation of gaseous products bio-oil and solid residues [10].

To the best of our knowledge no report have been documented for the use of desert date seed shells for the production of catalyst support used for deposition of active catalytic chemical sites for biodiesel production.

2.0 Materials and Methods

2.1 Sample Collection and Pretreatment

Desert date seeds were obtained at Central Market Sokoto, Sokoto State. The samples were sorted to remove any foreign materials and soaked in an open bowl using clean tap water for 24hrs, then hand dehulled. The dehulled seeds were washed until cleaned and clear from any debris, then dry at room temperature for 72hrs. The dried samples were then crushed using nailing hammer to separate the oily seed and the shell. The shells

were grounded using hammer milling machine in to fine powder, then stored in a dry place for further analysis.

2.2 Production of Desert Date Seed Shells Biochar (DDSB)

The procedures followed Abdullah et al. [11]. Desert date seed shells powder was weighed in to a cleaned 5000 ml beaker soaked in 20% H_3PO_4 and transferred in a furnace and carbonized at 700 °C for three hours. The generated Biochar was washed to a pH of 7, dried in an oven for 12 hrs at 105 °C, and named desert date seed Biochar (DSS Biochar).

2.3 Preparation of Desert Date Seed Shells Acid-Base Biofunctional Catalyst (DDSS-AC/KOH/ H_2SO_4)

The catalyst was synthesized through the method of [11] A mixture of 30 wt% KOH and 15 v/v%, H_2SO_4 (as the basic agent and acidic agents) were added to the weight of DDSS-B, the basic and acidic agents were fixed at 30 wt% and 15 v/v%, respectively. All the chemicals were dissolved in excess distilled water and stirred vigorously for 6 hrs at room temperature until a paste was formed the resulting paste was dried at 105 °C for 24 hrs and activated at 700 °C for 3hrs in tubular furnace. The prepared catalyst was name of DDSSAC-KOH/ H_2SO_4 .

2.4 Fourier Transform Infrared Spectroscopy (FT-IR) Analysis

The catalyst was analyzed using SHIMADZU FTIR-8400S spectrophotometer, using the method of [12] the sample was ground to fine powder and oven dried at 110 °C for 2 hours and turned in to pellet hydrolytically. The pellet was analyzed immediately and the spectra produce were recorded. A pellet prepared with an equivalent quantity of pure KBr powder was used as control the analysis was done by scanning the sample through a wave number range of 600-4000 cm^{-1} .

2.5 Brunauer-Emmett-Teller (BET) analysis

The BET Specific Surface Area and Pore Size Analyzer BELSORP MR1 were used for the analysis using the method of [11]. The evaluations were obtained by performing the N_2 adsorption-desorption isotherm at low temperature (liquid N_2 temperature is -196°C). Briefly, 0.5 g sample was degassed at 150 °C for 12 h. The surface area of the sample was calculated based on BET

equations, while the pore volume diameter was determined by the amount of adsorbed N_2 uptake at 1 atm.

2.6 Scanning Electron Microscope (SEM) Analysis

Surface morphology of a sample was studied using Phenom ProX model, manufactured by Phenom World Eindhoven, Netherlands. The sputter coater used is Q150RES manufactured by Quorum, England. The method of [13] was adopted; the sample was mounted on a stub with a double adhesive which is coated with 5 nm of gold in order to make the samples conductive, and introduced into the column of the machine which is viewed via navigation camera. Scanned images

are taken at an accelerating voltage of 2.00kV to 15.00 kV.

2.7 Energy Dispersive X-ray Fluorescence Spectroscopy

The analysis was conducted using the method of [14] at Umaru Musa Yaraduwa University Katsina central laboratory using XRF machine where by X-rays has been directed towards the seed shell which leads to the formation of diffraction. This diffraction is later send through focusing slit to analyze the seed shell. Photons are diffracted with various wavelengths from the seed shell crystal and collected by the detector which transfers them to the computer for analysis.

3.0 Results and Discussion

Table 1: Level of Element in Desert Date Seed Shells Biochar (DDSSB) and Acid-Base Biofunctional Catalyst (DDSS-AC-KOH/H₂SO₄) obtained in Sokoto

S/N	Metals	DDSSB Concentration (%)	DDSS-AC-KOH/H ₂ SO ₄
1	Fe	0.02806	0.556
2	Cu	0.000555	0.052
3	Ni	0.00469	Not detected
4	Zn	0.002533	0.013
5	Al	0.02887	1.862
6	Mg	0.01904	2.036
7	Na	0.02256	Not detected
8	S	0.08602	11.167
9	P	0.08027	4.656
10	Ca	0.26818	2.240
11	K	0.24288	36.283
12	Mn	0.001331	0.025
13	Cl	0.04368	0.392
14	W	0.0129	0.001
15	Sn	0.52	1.517
16	O	Not detected	37.034
17	Si	Not detected	1.919

Table 2: Level of Metallic Oxides in Desert Date Seed Shells Biochar (DDSSB) and Acid-Base Biofunctional Catalyst (DDSS-AC-KOH/H₂SO₄) obtained in Sokoto

S/N	Metal oxide	Concentration (%)DDSSB	(%)DDSSAC-KOH/H ₂ SO ₄
1	Fe ₂ O ₃	0.04654	0.809
2	CuO	0.001922	0.065
3	Ni ₂ O	0.00275	Not detected
4	ZnO	0.002477	0.016
5	Al ₂ O ₃	0.02871	3.517
6	MgO	0.2001	3.375
7	Na ₂ O	0.0361	Not detected
8	SO ₃	0.19294	27.884
9	P ₂ O ₅	0.14568	10.669
10	CaO	0.3786	3.134
11	K ₂ O	0.3213	43.706
12	MnO	0.001867	0.033
13	Rb ₂ O	0.000767	Not detected
14	SrO	0.0434	Not detected
15	Cr ₂ O ₃	0.00013	0.013
16	WO ₃	0.0098	0.002
17	BaO	0.2544	0.002
18	SnO ₂	0.67	1.926
19	SiO ₂	0.35	4.106
20	Ta ₂ O ₅	0.00289	0.010

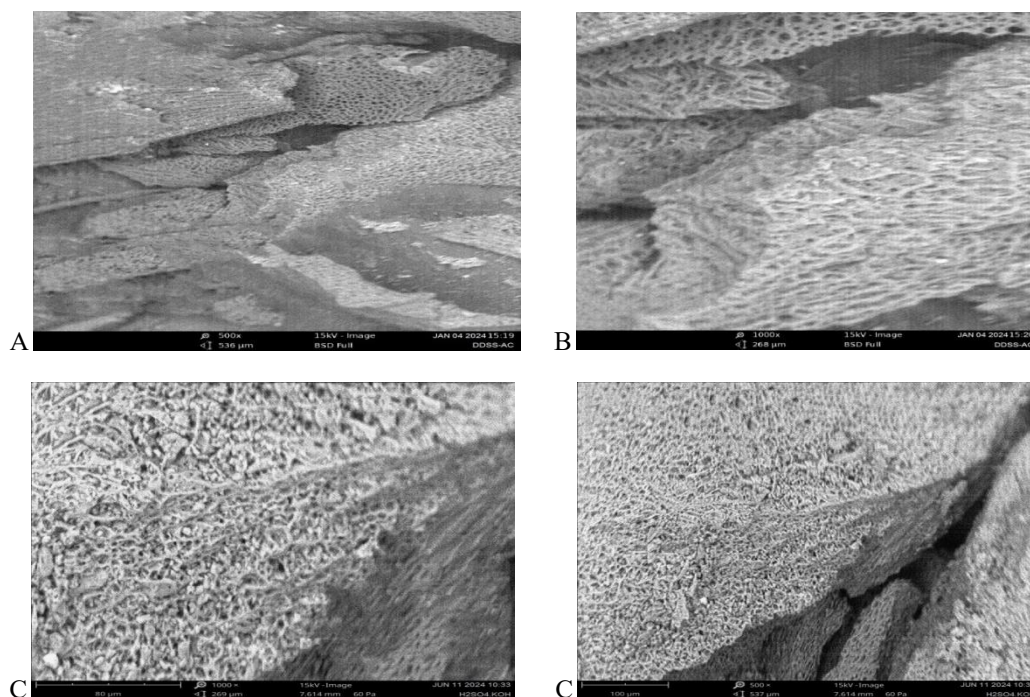


Plate 1: SEM Images of Desert Date Seed Shells, Magnification 500X and 1000X (Source; Authors own elaboration). A and B Images of Desert Date Seed Shells Biochar (DDSSB); C and D images of Acid-Base Biofunctional Catalyst (DDSSAC-KOH/H₂SO₄)

Table 3: Brunauer-Emmett-Teller (BET) analysis of desert date seed shells biochar (DDSSB) and acid-base biofunctional catalyst (DDSS-AC-KOH/H₂SO₄)

	Multi point BET plot Surface area m ² /g	BJH cc/g Pore volume	BJH cc/g Pore diameter
DDSSB	91.468	0.075	1.956
DDSSAC-KOH/H ₂ SO ₄	946.703	0.531	2.128

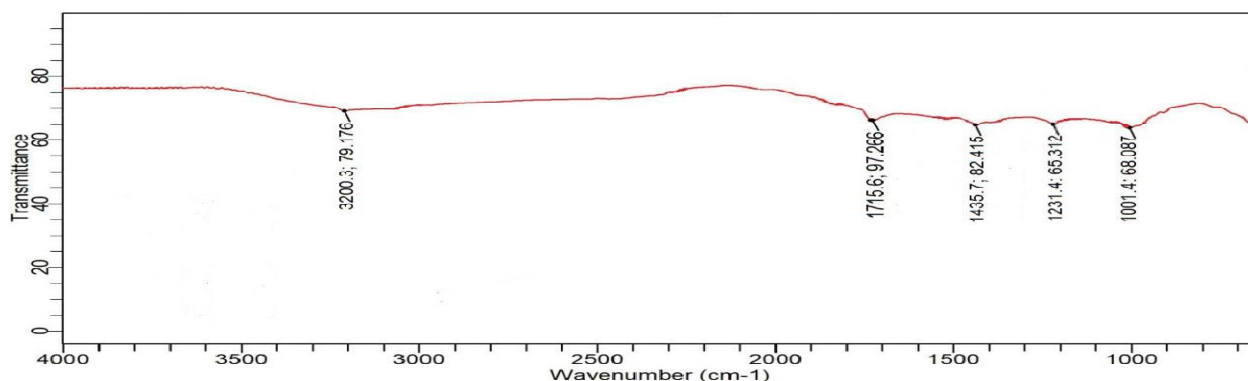


Figure 1: Fourier Transform Infrared Spectrum of Desert Date Seed Shell Biochar (DDSSB)

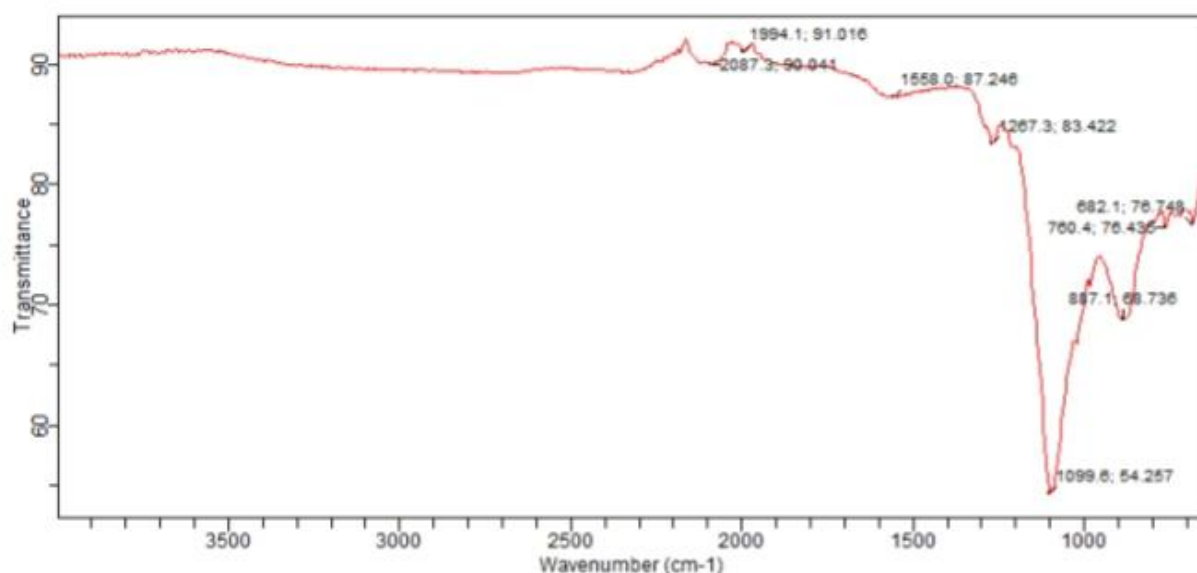


Figure 2: Fourier Transform Infrared Spectrum of Desert Date Seed Shells, Acid-base Biofunctional catalyst (DDSSAC-KOH/H₂SO₄)

3.1 EDXRF Metallic Composition of Desert Date Seed Shells Biochar (DDSSB)

The result was presented in Table 1, demonstrating that calcium has the highest percentage of 0.26818% and Sn with the lowest percentage of 0.006 % this was in agreement with the findings of [15,16] who reported the presence of Al, Mg, P, Ca, Fe and Ag with higher percentage of calcium.

The higher percentage of calcium was due to carbonization of desert date seed shells at higher temperature, which lead to the formation of CaO as a role model for the esterification and transesterification of triglyceride in to free fatty acid methyl ester when the biochar is use as heterogeneous catalyst in the presence of alcohol. Phosphorus was also detected this was due to the pretreatment step design to increase the surface

area of the sample, the present report was in agreement with the findings of [11] who reported the presence of phosphorus after carbonization of the sample.

3.2 The EDXRF Metallic Composition of Produced Acid-Base biofunctional Catalyst (DDSSAC-KOH/H₂SO₄)

The analysis showed the presence of metals at different concentration with oxygen (O) having the highest percentage of 37.034% due to the chemical reaction involving KOH+H₂SO₄ forming KSO₄ + H₂O, followed by potassium (K) with 36.283% this was due to the impregnation of KOH as the active chemical agent that will take part in the esterification and transesterification of oils in the presence of alcohol (methanol) for biodiesel production[17] The other elements found from the analysis have minor or no significance as they are only available in tiny trace amount.

Both the produced biochar and the biofunctional catalyst showed the present of K and Cu which are among the natural constituents of the desert date seed shells.

3.3 EDXRF Metallic Oxides Composition of Biochar

The EDXRF Metallic oxides composition of biochar was presented in Table 2, the analysis showed high percentage calcium oxide of 0.3786 % and low MnO₃ concentration of 0.000095 % respectively. SiO₂ and Fe₂O₃ have a strong coagulant property as reported by [15] as a result, an increase in the reactivity of the catalyst will occur during the esterification and transesterification of oils. Al₂O₃, SiO₂, and Na₂O were also reported by [18]. The most familiar used heterogeneous base catalyst is calcium oxide (CaO) [19], low solubility in a liquid mixture, low-cost, long-lasting, moisture resistant and higher biodiesel yield [20]. CaO is commonly used as a heterogeneous catalyst, and its source from different natural biomass/feedstock such as eggshells, shells, limestone, dolomite, cattle bones [21].

3.4 The EDXRF Metallic Oxides Composition of Produced Acid-Base biofunctional Catalyst (DDSSAC-KOH/H₂SO₄)

The result showed high percentage of potassium oxide K₂O 43.706% followed by SO₃ with 27.889%, P₂O₅ 10.669% and CaO 3.134 % as

shown in table 2. This finding is in line with the report of Sofyan et al. [22]. The higher percentage of K₂O is due to the impregnation of KOH as the active chemical agent during the catalyst preparation while SO₃ was resulted from the reaction of KOH with the H₂SO₄ which both act as the active catalytic chemical agents which will take part in esterification and transesterification of oils for the period of biodiesel production. Pyrolysis of biomass at higher temperatures can increase the alkaline and alkaline earth oxides so that it can be classified as a solid base catalyst [23]. Based on that observable fact, it can be concluded that calcination process (in oxygen-poor conditions) of biomass/feedstocks materials can increase the alkalinity of the catalyst. The concentration of calcium and calcium oxide is increasing accordingly this indicates a promising and reliable catalyst for both the Biochar and the biofunctional catalyst respectively.

3.5 Scanning Electron Microscope Analysis (SEM) of Biochar

SEM analysis revealed the structural characteristics of the catalyst, as illustrated in Plate 1 A and B showcased a heterogeneous pore distribution, higher level of porosity, overlapping surface and pores. The irregular granule structure has led to higher porosity and can facilitate the adsorption of active sites onto the support, this finding is in agreement with the report of Mohammed et al. [15] who reported that 'granule structure is more favourable as far as adsorbing and connecting colloidal particles and further enhancing the sedimentation of flocs.

After the pretreatment with the 20% H₃PO₄ and carbonization in the absence of oxygen the shape and particles size change, there by developing variety of pore sizes as a result of breakdown of the lignocellulosic composition of *Balanites aegyptiaca* seed shells, this was in line with the reports of Abdullah and Maniarasu [11, 24], who's reported that the shape and particle size changed dramatically after treatment with 20% H₃PO₄ and carbonization at higher temperature for 3 hours.

The images also showed a spongy like structure which ensured good dispersion of active sites onto the support during the catalyst preparation as well as increase in reactivity and productivity during the biodiesel production.

3.6 Scanning Electron Microscope Analysis (SEM) of Produced Acid-Base Biofunctional Catalyst (DDSS-AC/KOH/H₂SO₄)

The result was presented in Plate 1 (C and D) revealing further change in structure after doping with $\text{KOH}/\text{H}_2\text{SO}_4$ as the active chemical agents. The pores created during drying and carbonization were filled with the active chemical sites at some stage in impregnation process, resulting in the changed of shape and particle sizes which was in agreement with the studies of [11]. The SEM images obtained before and after the impregnation show a prominent increased in pore availability within the impregnated catalyst when compared with the un- impregnated counterpart, this occurs due to the impregnation process involving KOH . This finding was in agreement with the study of Oni-Adimabua [25] who reported an increase in pore availability by impregnating agricultural waste predominantly composed of CaO .

3.7 Brunauer-Emmert-Teller (BET) Analysis of Desert Date Seed Shells Biochar

The result showed the textural properties of the solid catalysts after carbonization at 700°C for 3hrs, showing that the biochar is a mesoporous structure with a total specific surface area of $91.468 \text{ m}^2/\text{g}$, on multiple-point plot, with BJH pore volume of 0.075 cc/g and pore diameter 1.956 nm as presented in table 3. The higher the surface area the better the adsorption performance [20] the carbonization was done to improve the BET surface area by treatment with H_3PO_4 . After carbonization was completed, the elimination of H_3PO_4 from the surface of biochar allowed immobilization of selected active components during the final calcination process [11].

3.8 Brunauer-Emmert-Teller (BET) Analysis of produced Acid-Base Biofunctional Catalyst (DDSSAC- $\text{KOH}/\text{H}_2\text{SO}_4$)

The analysis revealed high specific surface area, pore size and pore volume as presented in Table 3. A high-quality catalyst possesses a larger surface area, which enhances its capacity for adsorption. According to Peng [26] the use of KOH to activate carbon materials enhances their electrochemical performance and increases their surface area, the result demonstrate that adding KOH positively influences pore development, leading to an increase in specific surface area. Dwiyaniti et al. [27] reported smaller specific surface area SSA in SBC12, about $2136 \text{ m}^2/\text{g}$, and the largest in SBC14, which is $3554 \text{ m}^2/\text{g}$ using KOH as active agent while Kalderis et al. [28] reported high SSA using KOH as an activator on carbon from sugarcane bagasse. The presence of KOH activator will reduce pore diameter and

expand pore volume and surface area [28]. However, the Surface area value obtained in the present study is lower which was $946.703 \text{ m}^2/\text{g}$, even lower than activated carbon from grapheme material that have SSA of $3523 \text{ m}^2/\text{g}$ as reported by [29]. Increasing surface area leads to an increased number of catalytic sites available for reaction, thereby increasing catalyst production, because the active sites are on the surface of a compound and usually, increasing the surface area of catalyst resulting in increasing the number active sites. This implies that if all other factors with regards to reaction are equal, then increasing the surface areas causes increasing activity.

The results presented that surface area and pore volume increased from biochar to the produced acid-base biofunctional catalyst which was in agreement with the report of Manyangadze et al. [30] who reported that, the adsorption performance is improved with the higher surface area. While higher temperature Calcination is necessary to thermally activate metal hydroxides into an active metal oxides catalyst for transesterification reaction [4].

3.9 Fourier Transform Infrared (FT-IR) Analysis of Desert Date Seed Shells Biochar

The functional groups attached to the surface of the carbonized desert sate Seed shells biochar were examined at transmission spectra $4000 - 650 \text{ cm}^{-1}$. five major peaks were determined as shown in Figure 1. A broad band was observed at $3200.36381 \text{ cm}^{-1}$ which was attributed to the hydroxyl group ($-\text{OH}$) while peak at $1715.65742 \text{ cm}^{-1}$ $\text{C}=\text{O}$ due to carboxyl group. The appearance of peak at $1435.39324 \text{ cm}^{-1}$ was indication of $-\text{CH}_2$ bending alkane, absorption at $1001.32678 \text{ cm}^{-1}$ frequency bands corresponds to $\text{P}-\text{O}-\text{C}$ aliphatic phosphates, symmetrical stretching at 1033 cm^{-1} was associated with $\text{Si}-\text{O}-\text{Si}$ stretching band of SiO_2 and peak at 1231.43716 attributed to $\text{P}=\text{O}$ bond for the presence of phosphate. The present study was in agreement of [15].

3.10 Fourier Transform Infrared (FT-IR) Analysis Produced Acid-Base Biofunctional Catalyst (DDSSAC- $\text{KOH}/\text{H}_2\text{SO}_4$)

The analysis provided insights into the molecular composition of the catalyst, where all the peaks correlate to a specific functional group within the compounds, revealing a detailed guideline to their chemical structure. The peak at 760.4 cm^{-1} was

due to C–H (alkane) bending and aliphatic compound vibration. Followed by the double bond region (1500–2000 cm^{-1}) in C=C stretching vibrations at 1558.0 and 1994.1 cm^{-1} next carbon-to-carbon vibrations are found in the triple bond region (2000–2500) at 2087.3 cm^{-1} (Figure 2). This was in line with the studies of Sofyan et al. [22] who closely reported the same using Coconut fiber. Addition of sulfuric acid in the impregnation process causes the formation of S–O (sulfonic) functional groups shown in the wave number 1099.6 cm^{-1} . The stretching vibration at 887.1 cm^{-1} was due to Si–O from Si–OH and Si–O–Si. Conclusively impregnation of sulfuric acid on the biochar catalyst increases the acidity of the catalyst by the appearance of sulfonate functional groups. It also indicates that before and after impregnation treatment, the silica compounds in the material still exist.

4. 0 Conclusion

The result demonstrated the availability of higher specific surface area, pore size and pore volume that are key for a catalytic supported materials, also the higher percentage of calcium oxide in the biochar catalyst along with other metallic oxides that can take part in conversion of oils in to free fatty acids methyl esters (FAME). Therefore utilization of desert date (*Balanites aegyptiaca*) seed shells (DDSS) as feedstock for the synthesis of catalyst support, activated carbon and biochar will be a promising technology for industries in the near future.

5.0 Acknowledgement

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6.0 Conflicts Of Interest

No conflict of interest is declared by the authors.

References

- [1] Leung DY, Wu X, Leung MK. A review on biodiesel production using catalyzed transesterification. *Applied energy*. 2010; 87(4):1083-95.
- [2] Safari A, Das N, Langhelle O, Roy J, Assadi M. Natural gas: A transition fuel for

sustainable energy system transformation?. *Energy Science & Engineering*. 2019 Aug;7(4):1075-94.

- [3] Vasić K, Hojnik Podrepšek G, Knez Ž, Leitgeb M. Biodiesel production using solid acid catalysts based on metal oxides. *Catalysts*. 2020 Feb 17;10(2):237.
- [4] Lee HV, Juan JC, Binti Abdullah NF, Nizah MF R, Taufiq-Yap YH. Heterogeneous base catalysts for edible palm and non-edible *Jatropha*-based biodiesel production. *Chemistry Central Journal*. 2014 Dec;8:1-9.
- [5] Vuori, H., Pasanen, A., Lindblad, M., Valden, M., Niemelä, M. V., & Krause, A. O. I. The effect of iridium precursor on oxide-supported iridium catalysts prepared by atomic layer deposition. *Applied Surface Science*, 2011; 257(9), 4204-4210.
- [6] Chapagain B, Wiesman Z. Variation in diosgenin level in seed kernels among different provenances of *Balanites aegyptiaca* Del (Zygophyllaceae) and its correlation with oil content. *African Journal of Biotechnology*. 2005;4(11).
- [7] Shweta J Sabannavar1 and Vinutha H . (2019) Biodiesel production from the seed kernel of desert date fruit , *Journal of Engineering, Technology And Innovative Research (EIJO-JETIR)*. Volume 6, Issue 3. (ISSN-2349-5162)
- [8] Yunusa U, Bishir U, Ibrahim MB. Kinetic and thermodynamic studies of malachite green adsorption using activated carbon prepared from desert date seed shell. *Algerian Journal of Engineering and Technology*. 2020 Jun 28;2:037-45.
- [9] Lou J, Babadi MR, Otadi M, Tarahomi M, Van Le Q, Khonakdar HA, Li C. Agricultural waste valorization towards (nano) catalysts for the production of chemicals and materials. *Fuel*. 2023 Nov 1;351:128935.
- [10] Mahmood H, Moniruzzaman M, Iqbal T, Khan MJ. Recent advances in the pretreatment of lignocellulosic biomass for biofuels and value-added products. *Current Opinion in Green and Sustainable Chemistry*. 2019 Dec 1;20:18-24.

- [11] Abdullah RF, Rashid U, Taufiq-Yap YH, Ibrahim ML, Ngamcharussrivichai C, Azam M. Synthesis of bifunctional nanocatalyst from waste palm kernel shell and its application for biodiesel production. *RSC advances*. 2020;10(45):27183-93.
- [12] Jerekias, G. & Clever, K. (2011). Chemical extraction and property analysis of marula nut oil for biodiesel production advance in chemical engineering and science. *Journal of Scientific Research*. 1, 96-101
- [13] Magaji BM, Elinge CM, Birnin-yauri AU, Umar S. Article CHARACTERIZATION OF DESERT DATE SEED SHELLS (DDSS) IN PREPARATION OF CATALYST SUPPORT FOR BIODIESEL PRODUCTION. *African Journal of Management, Engineering and Technology*. 2025 Jan 10;3(1):1-0
- [14] Ismail UI, Jamo HU, Usman A, Magama AA, Baban KY, Nura I, Turaki S, Musa FU, Gwadabe SH. Influence of egg shell as heterogeneous catalyst in the production of biodiesel via transesterification of *Jatropha* oil. *Science World Journal*. 2022 Sep 6;17(2):191-5.
- [15] Mohammed, F & Misau, Idris & Gutti, Babagana & Abdulkarim Yusuf, Abdulwadud & Ahmed, Saeed. (2023). characterization and application of balanites aegyptiaca seed (desert date) kernel as natural coagulant and disinfectant for water purification. 24. 69-74.
- [16] Sisca V, Jamarun N. Biodiesel Production from Waste Cooking Oil Using Catalyst Calcium Oxide Derived of Limestone Lintau Buo Biodiesel Production from Waste Cooking Oil Using Catalyst Calcium Oxide Derived of Limestone Lintau Buo. *Archives of Pharmacy Practice*. 2020;11(3-2020):8-14.
- [17] Dwiyaniti M, Barruna AE, Naufal RM, Subiyanto I, Setiabudy R, Hudaya C. Extremely high surface area of activated carbon originated from sugarcane bagasse. In *IOP Conference Series: Materials Science and Engineering* 2020 Dec 1 (Vol. 909, No. 1, p. 012018). IOP Publishing.
- [18] Misau IM, Yusuf AA. Characterization of water melon seed used as water treatment coagulant. *Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences (JABE)*. 2016;3(2):22-9.
- [19] Gimbun J, Ali S, Kanwal CC, Shah LA, Ghazali NH, Cheng CK, Nurdin S. Biodiesel production from rubber seed oil using a limestone based catalyst. *Advances in Materials Physics and Chemistry*. 2012 Oct 26;2(04):138-41.
- [20] Sudsakorn K, Saiwuttikul S, Palitsakun S, Seubsai A, Limtrakul J. Biodiesel production from *Jatropha Curcas* oil using strontium-doped CaO/MgO catalyst. *Journal of environmental chemical engineering*. 2017 Jun 1;5(3):2845-52.
- [21] Niju, P.A. S, Meera Sheriffa Begum KM, Anantharaman N. Utilization of Limestone Derived Calcium Oxide for Biodiesel Production From Non-Edible Pongamia Oil. *Environmental Progress and Sustainable Energy* 2016; 00(00),1–7. DOI: 10.1002/ep.
- [22] Sofyan MI, Mailani PJ, Setyawati AW, Sulistia S, Suciati F, Hauli L, Putri RA, Ndruru ST, Mawarni RS, Meliana Y, Nurhayati N. Use of Sulfuric Acid-Impregnated Biochar Catalyst in Making of Biodiesel From Waste Cooking Oil Via Leaching Method. *Bulletin of Chemical Reaction Engineering & Catalysis*. 2024 Apr 30;19(1):160-70.
- [23] Nurhayati, N., Amri, T.A., Annisa, N.F., Syafitri, F. The synthesis of biodiesel from crude palm oil (CPO) using CaO heterogeneous catalyst impregnated H₂SO₄, variation of stirring speed and mole ratio of oil to methanol. *Journal of Physics: Conference Series* 2020 Oct 1 (Vol. 1655, No. 1, p. 012106). IOP Publishing
- [24] Maniarasu R, Rathore SK, Murugan S. Biomass-based activated carbon for CO₂ adsorption—A review. *Energy & Environment*. 2023 Aug;34(5):1674-721.
- [25] Oni-Adimabua ON, Ifeanyi-Nze FO, Abimbolu AK, Opadokun EO, Omolusi AR, Ezeokolie ED, Udoh EA, Afuape AR, Areola MO, Wokoma PT, Odoh EC. Production, optimization, and characterization of biodiesel from almond seed oil using a bifunctional catalyst derived from waste animal bones and almond shell. *European*

- Journal of Sustainable Development Research. 2024;8(3).
- [26] Peng C, Yan XB, Wang RT, Lang JW, Ou YJ, Xue QJ. Promising activated carbons derived from waste tea-leaves and their application in high performance supercapacitors electrodes. *Electrochimica Acta*. 2013 Jan 1;87:401-8.
- [27] Dwiyaniti M, Barruna AE, Naufal RM, Subiyanto I, Setiabudy R, Hudaya C. Extremely high surface area of activated carbon originated from sugarcane bagasse. *In IOP Conference Series: Materials Science and Engineering 2020 Dec 1 (Vol. 909, No. 1, p. 012018)*. IOP Publishing.
- [28] Kalderis D, Koutoulakis D, Paraskeva P, Diamadopoulos E, Otal E, del Valle JO, Fernández-Pereira C. Adsorption of polluting substances on activated carbons prepared from rice husk and sugarcane bagasse. *Chemical engineering journal*. 2008 Oct 1;144(1):42-50.
- [29] Zhang L, Zhang F, Yang X, Long G, Wu Y, Zhang T, Leng K, Huang Y, Ma Y, Yu A, Chen Y. Porous 3D graphene-based bulk materials with exceptional high surface area and excellent conductivity for supercapacitors. *Scientific reports*. 2013 Mar 11;3(1):1408
- [30] Manyangadze M, Chikuruwo NH, Chakra CS, Narsaiah TB, Radhakumari M, Danha G. Enhancing adsorption capacity of nano-adsorbents via surface modification: A review. *South African Journal of Chemical Engineering*. 2020 Jan 31;31(1):25-32.



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