ID 10435606

by admin Journal

Submission date: 12-Dec-2023 05:44PM (UTC+0800)
Submission ID: 2256675335
File name: HRPUB_Manu_Template_V1_cek_turnitin.doc (1.39M)
Word count: 5559
Character count: 31846

Evaluation of The Characteristics of Avocado Seed Biochar at Various Pyrolysis Temperatures for Sustainable Waste Management

Ali Rahmat[1], Hidayat Hidayat[1], Lilla Puji Lestari[2], Elfarisna Elfarisna[3], Indriyani Indriyani[4], Mulono Apriyanto[5], Latifa Nuraini[1], Hari Hariadi[1], Abdul Mutolib[6]

[1]National Research and Innovation Agency, 10340, Jakarta Pusat, Indonesia
[2]Technology Laboratory Medic, Faculty Saint Health, University of Maarif Hasyim Latif, 61257, Sidoarjo, Indonesia
[3]Departemen of Agrotechnology, Faculty of Agriculture, University of Muhammadiyah Jakarta, 15419, Tangerang Selatan, Indonesia
[4]Mechanical Engineering Department, Engineering Faculty, University of Sang Bumi Ruwa Jurai, 35118, Bandar Lampung, Indonesia
[5]Departement Food Science, Islamic University of Indragiri, 29212, Indragiri Hilir, Indonesia
[6]Postgraduate Program, University Siliwangi, 46115Tasikmalaya, Indonesia
*Corresponding Author: abdul.mutolib@unsil.ac.id, alirahmat911@gmail.com

Copyright©2021 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract Avocado seeds are produced as a byproduct in households and industrial settings where avocados are used. If not appropriately managed, these seeds become waste, devoid of economic or other advantages. Moreover, there is a need for technology that can transform avocado seed waste into products with economic or practical benefits. One such technology involves converting avocado seed waste into biochar. Biochar has the potential to enhance carbon sequestration, nutrient retention, and water retention in soil. The aim of this research is to examine how different pyrolysis temperatures affect the characteristics of biochar produced from avocado seeds. The results show that pore formation begins at a temperature of 400 °C of pyrolysis, although it is more clearly visible at a temperature of 500 °C. FTIR analysis revealed that the available functional groups in the biochars were O–H, C-H, C=C, and C=O. The C content and C/N ratio of biochar increased with increasing pyrolysis temperature; however, H, O, N, H/C and O/C decreased with increasing pyrolysis temperature. The dominant element content of avocado seed biochar is K_2O, P_2O_5, and SO_3, which are categorized as macronutrients. Through this analysis, the biochar from avocado seeds has the potential to serve as a soil amendment.

Keywords Avocado Seed, Biochar, Characteristics, Waste Management.

1. Introduction

The avocado stands out as a highly significant fruit due to its rich nutritional profile, and it is extensively consumed and cultivated globally [1]. Found abundantly in tropical and sub-tropical regions, the avocado has been historically consumed as a food source [2]. The processing of avocados in various industries results in substantial by-products, including avocado seeds. With an annual estimated production of four million metric tonnes of avocado fruit, the seed comprises approximately 13–18% of the overall fruit [3].

Avocado seeds are produced by households and industrial operations that utilize avocados. If not managed properly, avocado seeds become waste with no economic or no other benefits. Several of these by-products are presently not fully utilized, leading to increased waste disposal expenses through methods such as onsite incineration and landfill disposal. Furthermore, these practices contribute to environmental pollution and pose potential health risks. Avocado organic waste primarily consists of seeds and husks with a small amount of pulp. This waste is often used as fertilizer and a soil improver through landfilling and composting [4]. Avocado industrial processes generate substantial waste, not only from the peel and shell but also from cutting and oil extraction. Avocado seed oil can serve as a feedstock for biodiesel production [5]. Avocado seed waste can be converted into activated carbon, which has been prepared to exhibit relatively good efficacy in reducing ammonium levels in aqueous solutions [6].

As a result, technology is required to convert avocado seed waste into products with economic or other useful benefits. One technology that can be used is converting avocado seed waste into biochar. Biochar is a solid substance generated through the thermochemical conversion of biomass (feedstock) under oxygen-free or limited-oxygen conditions. Avocado seed biochar has the potential to enhance agricultural soils and sequester carbon [7]. The properties of biochar vary depending on the substrate and the production method used; the most common approach involves biomass pyrolysis, a process that requires precise temperature control to ensure the material's desired properties and performance [8]. The addition of biochar to soil improves cation exchange capacity and stabilizes organic carbon in soils containing pyrolyzed carbon [9]. Applying avocado seed biochar to soil represents an alternative technique that enhances soil physicochemical characteristics and soil functioning as part of the ecosystem and the broader environment over the long term [7]. Biochar proves effective in adsorption and construction processes owing to its structural and porous properties [10]. Biochar derived from avocado seeds is produced and utilized primarily as a substitute for soil conditioners [11].

The quality of biochar is influenced by both the type of raw material and the manufacturing process, with one of the key influencing factors being the pyrolysis temperature. Biomass, such as avocado seeds, is processed at temperatures ranging from 400 to 600 °C to produce solid (bio-char) and liquid (bio-oil) products, with or without the use of a catalyst. Optimal conditions for biooil production (37.5%) were found to be at 600 °C with a heating rate of 50 °C/min in the presence of a KOH catalyst. Avocado seed pyrolysis demonstrates potential as a technology for producing sustainable fuels and valuable compounds [12]. Biochars produced at higher temperatures have a more pronounced impact on soil fertility compared to those produced at lower temperatures [13]. Pyrolysis of avocado seeds at 500 °C, with a heating rate of 10 °C/min and a retention period of 20 minutes, resulted in a liquid product (32%), solid product "char" (34%), and gaseous product (34%), with a biomass conversion rate of 67%. Avocado seed pyrolysis shows promise as a method for producing activated carbon, biofuel, and valuable compounds [14].

Pyrolysis biochars (500-600 °C) have demonstrated the potential for use as soil additives and an efficient technique for carbon sequestration, nutrient retention, and water retention. The porous structure of high temperature biochars can support soil microorganism activity, enhance water absorption, and increase soil density. Additionally, the high alkalinity of biochars can help neutralize acidic soil, thereby improving soil fertility and plant growth [15]. Biochar begins to decompose at pyrolysis temperatures below 400 °C, particularly between 220 and 350 °C [16]. Pyrolysis is a process that involves heating organic materials to temperatures exceeding 400-500 °C in the absence of oxygen. This process results in the conversion of the original biomass into solid biochar, condensable oil, and gaseous fractions due to enhanced cracking and carbonization reactions [17]. The pyrolysis of avocado seeds can cause the thermal degradation of the polymeric components of avocado seeds, primarily starch, but also cellulose, lignin, and hemicellulose, at temperatures ranging from 250 °C to 500 °C [18]. Torrefaction and pyrolysis were conducted using a rotary furnace at temperatures ranging from 150 °C to 900 °C to increase the concentration of synthesis gases (H_2, CO) and CO_2 [19]. Therefore, the aim of this study was to investigate the impact of different pyrolysis temperatures on the characteristics of biochar derived from avocado seeds. Where the avocado seeds are a global problem due to the the avocado was comsumed and use as raw material inf food industry globally.

2. Materials and Methods

2.1. Material Preparation

The samples consisted of avocado seeds (*Persea americana*) obtained from traditional markets. These avocado seeds were first washed and cleaned using water to remove dirt, such as soil and husk. Then, they were cut into slices resembling chips and air-dried for 24 hours. Following this initial drying phase, the avocado seeds were further processed by drying them in an oven at 105°C for an additional 24 hours. Avocado seeds that have undergone this oven process are now ready to be used in the production of biochar through a pyrolysis process (Figure 1).

2.2. Pyrolysis Process

Avocado seed samples, prepared for biochar production, are placed into a porcelain cup with a volume of 50 ml and covered with a cup lid. Subsequently, the porcelain cup is wrapped with aluminum foil to suppress material-oxygen interaction during the combustion process. The prepared porcelain cup is then inserted into the muffle furnace, with pyrolysis temperatures ranging from 300, 400, 500 and 600 °C. The muffle furnace temperature gradually increases from room temperature to the desired level, which typically takes 40-60 minutes. The porcelain cup containing avocado seeds is allowed to burn for 4 hours. After this 4-hour period, the muffle furnace is turned off, and the samples/biochar can only be retrieved once the temperature inside the muffle furnace returns to room temperature, which generally takes about 12 hours. The step of producing biochar can be seen in Figure 2.

2.3. Parameter Analysis

In this research, several variables were observed, including images of the surface morphology of biochar, functional groups, crystal conditions, and chemical content such as carbon (C), hydrogen (H), nitrogen (N), and elements contained in biocharhe samples consisted of avocado seeds (*Persea americana*) obtained from traditional markets. These avocado seeds were first washed and cleaned using water to remove dirt, such as soil and

Table 1. The Instrument Used for characteristics of biochar

No	Instrument	Observed variable
1.	Field Emission Scanning	Surface

	Electron Microscopy (FESEM) with the Thermo Scientific Quattro S FESEM	morphology
2.	Fourier Transform Infrared Spectroscopy (FTIR) with the PerkinElmer Spectrum Two equipped with a Universal Attenuated Total Reflectance (UATR) accessory	Functional groups
3.	X-Ray Diffraction XRD 7000 Shimadzu	Crystal condition
4.	Leco CHN 628	Carbon (C), Hydrogen (H), Nitrogen (N) content
5.	Omnian ED-XRF PANalytical Epsilon 3 XLE X-ray fluorescence spectrometer.	Element content

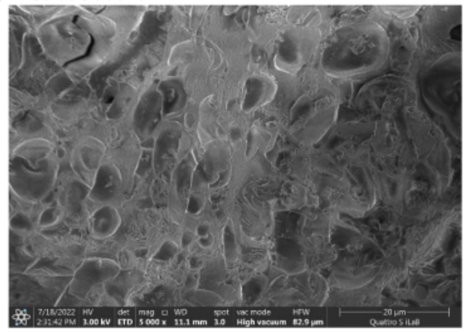
Figure 1. Raw materials.

Figure 2. The flowchart of producing biochar from avocado seed.

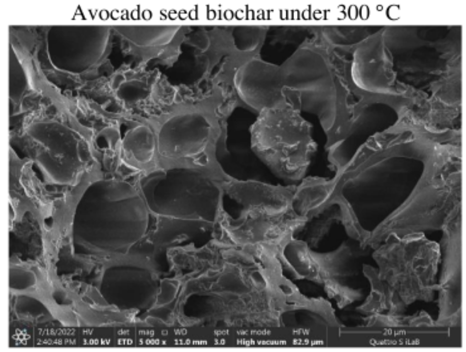
3. Results and Discussions

3.1. Scanning Electron Microscope (SEM)

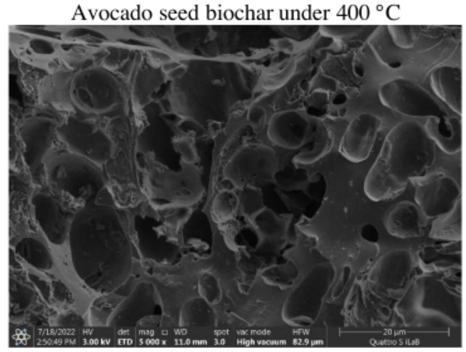
Scanning Electron Microscopy (SEM) is one of the most applicable techniques for estimating the morphological features of materials [20]. SEM can help reveal the surface condition of particles. Previous studies have used SEM to examine porosity, particle distribution of biochar [21, 22]. Figure 3 displays the SEM images of avocado seed biochars at temperatures of 300 °C, 400 °C, 500 °C, and 600 °C, magnified at 5000x.



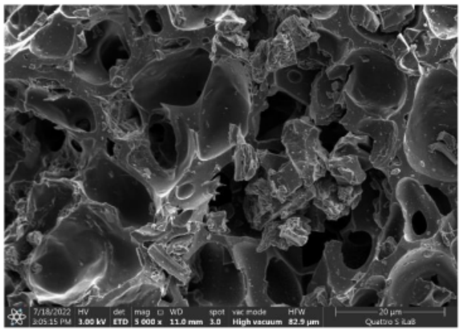
Avocado seed biochar under 300 °C



Avocado seed biochar under 400 °C



Avocado seed biochar under 500 °C



Avocado seed biochars under 600 °C

Figure 3. SEM image surface for biochar avocado seed.

In these images, the focus is on the effect of temperature during pyrolysis on the condition of pores (porosity) in avocado seed biochar. Biochar exhibits high porosity and abundant surface functionalities, enabling it to retain water, nutrients, and pollutants in the soil [23, 24]. Figure 3 shows that variations in pyrolysis temperature affect the surface morphology of avocado biochar. At a pyrolysis temperature of 300 °C, the biochar surface did not display any clear pore formation. However, at a pyrolysis temperature of 400 °C, pores on the surface of the biochar began to form. The formation of pores became more clearly visible at a pyrolysis temperature of 500 °C. At a pyrolysis temperature of 600 °C, cracking started to occur in the pores that had formed. The biochar sample retained its unique macrocellular morphology due to the partial degradation of the lignin component [25].

The structure of biochar appears consistent at pyrolysis temperatures of 400 °C, 500 °C, and 600 °C, but at a temperature of 600 °C, cracking begins to occur within the biochar's pores. These findings align with the results of Mohanty et al. [26] and Mutolib et al. [21].

Cracks in the pores form at 600 °C, and these cracks become more pronounced as the pyrolysis temperature increases. Due to mineral crystallinity and aromatic patterns, the pore structure in biochar becomes more enriched with rising temperatures [27]. The porosity of biochar can have a significant impact on soil microbes. Biochar can act as a microbial habitat, providing a home for beneficial microbes and facilitating microbial colonization [28, 29]. These biochar structures play a vital role in shaping soil physical properties and the availability of nutritional elements for plants [30].

3.2. Fourier Transform Infrared Spectroscopy (FTIR)

From this FTIR spectroscopy it can be seen that there are several important regions and can be interpreted as follows wavenumber (Figure 4). The effect of temperature changes in the pyrolysis process on avocado seed biochar functional groups was determined through FTIR measurements on the sample. The pyrolysis spectrum varies with each increase in heating temperature. The wave number 3264.74 cm^{-1} indicates the presence of free OH absorption. At higher temperatures, the intensity of certain functional groups in the FTIR spectrum may change. Meanwhile, the aliphatic CH strain was determined at a wave number of 2920.64 cm^{-1}, which was supported by a CH3 bending strain in the wave number range of 1440.95 cm^{-1}. It is noticeable that the vibration bands of hydroxyl (O-H) and aliphatic (C-H) groups tend to decrease with increasing temperature, as observed in the FTIR graph. The intensity continues to decrease from a temperature of 300 °C and disappears at a temperature of 600 °C because the decomposition of these groups leads to the formation of melting rings, especially at high pyrolysis temperatures, which consistently result in pore characteristics in avocado samples [31].

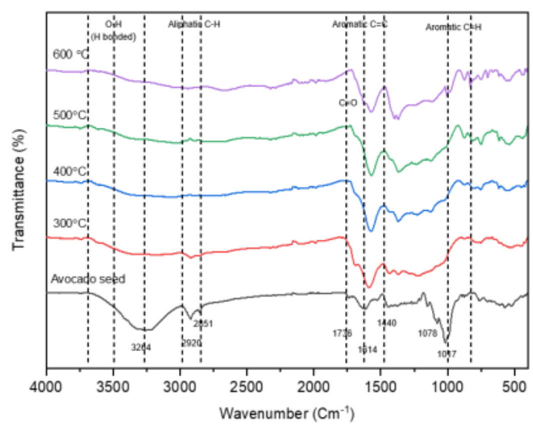


Figure 4. FTIR spectra of biochar avocado seed under different pyrolysis temperatures

The increase in the intensity of the C=C functional group at the wave number 1680-1600 cm^{-1} in the FTIR spectrum with increasing temperature during the pyrolysis process usually indicates changes occurring in the biochar composition and molecular structure. Increasing the temperature from 300 °C to 600 °C during pyrolysis can enhance the intensity of the pyrolysis reaction, leading to the production of more C=C double bonds in the biochar. This heightened intensity reflects the formation of additional double bonds in the biochar during the hotter pyrolysis process. Higher temperatures can also influence the carbonization reaction, which involves the creation of double bonds in the carbon structure, resulting in biochar with an increased number of C=C double bonds. Elevated temperatures can promote the formation of more aromatic carbon structures in biochar. Aromaticity often includes C=C double bonds in the aromatic ring, consequently intensifying the C=C stretching band in the FTIR spectrum. The aromatic structure exhibits greater strength compared to the aliphatic structure [32-33].

Meanwhile, the C=O carbonyl absorption is observed at the wave number 1614.92 cm^{-1}, supported by the C-O-C ester absorption in the wave number range of 1017.44 and 1078.78 cm^{-1}. C=O double bonds in functional groups such as ketones or carboxylic acids also increase in intensity with rising pyrolysis temperature. Changes in the FTIR spectrum can reflect the decomposition and restructuring of organic components in biomass into biochar. Higher pyrolysis temperatures can lead to the formation of a more stable carbon structure in biochar. Some functional groups containing C=O can be transformed into denser carbon structures with stronger bonds, consequently increasing the C=O intensity in the FTIR spectrum [34].

3.3. X-Ray Diffraction Analysis (XRD)

X-Ray Diffraction (XRD) is a method that involves irradiating a material with incoming X-rays and then measuring the intensity and angle of scattering as they exit the material. Materials are identified through XRD analysis based on their diffraction patterns.

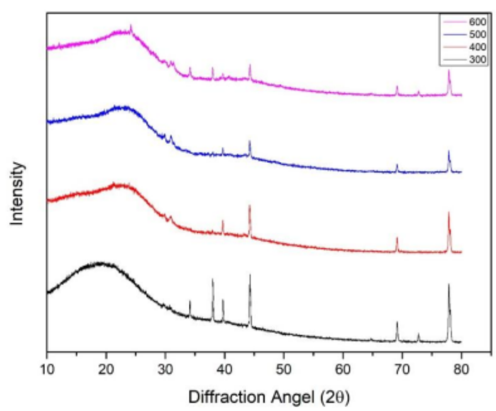


Figure 5. XRD diagram of biochar avocado seed under different pyrolysis temperatures

Figure 5 illustrates the XRD spectra at temperatures of 300 °C, 400 °C, 500 °C, and 600 °C. The pyrolysis process alters the structure of the biochar from amorphous to crystalline as the temperature increases. The results from X-Ray Diffraction (XRD) provide information that the crystal index and amorphous index decrease as the pyrolysis temperature rises and undergo significant changes at 300 °C, 400 °C, and 500 °C. However, at a temperature of 600°C, the sample appears to have reached a saturation point. The diffraction peak of 2-theta at 300 °C is relatively high at 19.4°. After increasing the temperature to 400 °C, 500 °C, and 600 °C, the peak shifted to 23.7°, 23.8°, and 24.1°, respectively. Based on the data, there is no further increase in crystallinity at temperatures of 300 °C, 400 °C, 500 °C, and 600 °C, indicating that the formation of double bonds (C=C) in biochar is not very significant and pointing to a lack of crystalline order in the structure.

XRD analysis of biochar pyrolyzed at 300 °C, 400 °C, 500 °C, and 600 °C shows the presence of relatively wide and less sharp diffraction peaks. These peaks indicate that biochar at these temperatures tends to have an amorphous or semi-amorphous structure [35]. Biochar at these temperatures may possess good adsorption potential for organic and inorganic compounds in waste. Its unique properties can be utilized in environmental restoration, soil quality improvement, and for treating waste due to biochar's ability to interact with various components in the environment, such as pollutants or heavy metals [36-38].

3.4. Ultimate Analysis

In the ultimate analyses, as depicted in Table 2, it becomes evident that with an increase in pyrolysis temperature from 300 °C to 600 °C, there is a notable increase in the carbon content of the biochars, ranging from 63.76% to 74.18%. Conversely, the hydrogen content experiences a decrease from 5.05% to 2.77%, while the oxygen content drops from 16.00% to 8.60%. This observation implies that raising the pyrolysis temperature leads to a higher degree of carbonization in the biochars, causing them to become progressively more aromatic, as indicated by Chen et al. [39]. As a consequence of the pyrolysis process, the biochars exhibit an increase in carbon content compared to the original biomass, accompanied by deoxygenation resulting from the loss of functional groups during pyrolysis. The reduction in hydrogen and oxygen levels corresponds to the breakage of weaker bonds within the structure of the biochar, a change that is favored by higher temperatures. Furthermore, the decrease in hydrogen content can be attributed to the higher proportion of hydrogen compounds in the volatile matter, as discussed by Sánchez et al. [40]. Additionally, the nitrogen contents in the biochar decrease from 1.79% to 1.61% with increasing pyrolysis temperature.

Tabel 2. Ultimate analysis of biochar avocado seed under different pyrolysis temperatures

	Pyrolysis temperature			
	300 °C	400 °C	500 °C	600 °C
C (%)	63.763	69.269	73.394	74.176
H (%)	5.053	3.995	3.359	2.77
N (%)	1.766	1.797	1.751	1.61
O (%)	15.000	16.000	9.100	8.600
H/C	0.079	0.057	0.045	0.037
O/C	0.235	0.230	0.123	0.115

The decrease in H/C ratios and the increase in O/C ratios with rising temperature indicate a growing level of aromaticity in the biochar, as noted in the study by Mui et al. [41]. The O/C ratios of the biochar were at their lowest at 600°C, whereas they were highest at 300°C. This signifies that biochar produced at higher temperatures has lower oxygen content, as discussed in the research conducted by Fu et al. [42].

3.5. Element Content of Avocado Seed Biochar by X-Ray Fluorescence

The elemental composition of biochar determined through XRF analysis is presented in Table 3. The results from XRF analysis detected a total of 8 elements: K_2O, P_2O_5, Fe_2O_3, SO_3, MnO, ZnO, CuO, and Rb_2O. It's important to note that the data represents the percentage of each element rather than the actual concentration. The percentages of elements SO_3, MnO, ZnO, CuO, and Rb2O decreased as the pyrolysis temperature increased. However, K_2O, P_2O_5, and Fe_2O_3 did not show a clear pattern in relation to pyrolysis temperature. The presence of these elements in biochar is influenced by the process of partial diffraction or devolatilization occurring at elevated temperatures, as indicated in studies by Hossain et al. [43] and Claoston et al. [44]. According to the XRF analysis, K_2O, P_2O_5, and SO_3 are the dominant elements among these, and all three are classified as macronutrients.

Tabel 3. Element of biochar avocado seed under different pyrolysis temperatures

Element content (%)	Raw material	Pyrolysis temperature			
		300 °C	400 °C	500 °C	600 °C
K_2O	83.930	88.407	89.200	89.532	88.405
P_2O_5	7.768	6.747	6.413	6.627	7.533
Fe_2O_3	1.174	0.661	0.594	0.625	0.836
SO_3	5.284	3.467	3.176	2.610	2.731
MnO	0.129	0.079	0.067	0.073	0.059
ZnO	0.348	0.200	0.151	0.148	0.099
CuO	0.223	0.140	0.106	0.105	0.073
Rb_2O	0.518	0.295	0.213	0.216	0.140

3.6. Potential Application of Avocado Seed Biochar as Soil Amendment

Land use for diverse activities and purposes is rising and becoming more intensive, affecting the land component's quality [45]. Furthermore, ongoing agricultural intensification with inorganic fertilizers has resulted in a decline in soil quality [46]. To address this problem, soil amendments can be employed, and one such material is biochar.

Biochar, an organic material rich in carbon, results from the heating of organic matter in an oxygen-deprived environment, a process known as pyrolysis. It has been verified that the carbon content in avocado seed biochar falls within the range of 63.76% to 74.18% (as shown in Table 1). Carbon in biochar exhibits remarkable stability, taking more than a century to decompose. Consequently, amending soils with biochar represents an effective means of carbon sequestration. Biochar functions by sequestering carbon, storing it within the soil, and preventing it from undergoing decomposition, as elucidated by Lehmann et al. [47]. Pyrolysis processes, through biochar formation, contribute to reducing the amount of carbon dioxide in the atmosphere [10].

On the other hand, avocado seed biochar also contains essential macronutrients such as Nitrogen, K_2O, P_2O_5, and SO_3. When used as a soil amendment, it enhances various soil attributes, including physical and biochemical properties, soil fertility, and productivity. Over the long term, it contributes to soil improvement by promoting soil aggregation, enhancing water retention, modifying pH levels, and fostering microbial activities. This overall enhancement of soil quality has the potential to reduce the need for chemical fertilizers over time, as discussed in the study by Nepal et al. [48]

4. Conclusion

In this study, we investigated how varying the pyrolysis temperature affects the properties of biochar derived from avocado seed waste (*Persea americana*). The temperature at which pyrolysis occurs plays a crucial role in shaping the characteristics of biochar. At 400°C, pores began to form on the biochar's surface, becoming more pronounced at a pyrolysis temperature of 500°C. As the pyrolysis temperature increased from 300°C to 600°C, we observed an increase in the carbon content and C/N ratio, accompanied by a decrease in H, O, N, H/C, and O/C values. This was expected since higher pyrolysis temperatures lead to greater devolatilization, resulting in biochar that is predominantly composed of carbon. Additionally, FTIR analysis revealed the presence of functional groups in the biochar, including O–H, C-H, C=C, and C=O. The primary elements found in avocado seed biochar are K_2O, P_2O_5, and SO_3, categorized as macronutrients. Based on our analysis, biochar produced from avocado seeds shows potential as a soil amendment.

Acknowledgements

We acknowledge the facilities, scientific and technical support from the National Research and Innovation Agency through E Layanan Sains.

REFERENCES

[1] Ahmad T., Danish M., "A review of avocado waste-derived adsorbents: Characterizations, adsorption characteristics, and surface mechanism," Chemosphere vol. 296, pp. 134036, 2022. DOI: 10.1016/j.chemosphere.2022.134036.

[2] Faris A., "Review on avocado value chain in Ethiopia,"

Industrial Engineering Letters, vol. 6, no. 3, pp. 33–40, 2016.

[3] Tesfaye T., Ayele., Gibril M., Ferede E., Limeneh D. Y., Kong F., "Beneficiation of avocado processing industry by-product: A review on future prospect," Current Research in Green and Sustainable Chemistry, vol.5, pp.100253, 2022. DOI: 10.1016/j.crgsc.2021.100253.

[4] Sánchez F., Araus K., Domínguez M. P., San-Miguel G., "Thermochemical transformation of residual avocado seeds: torrefaction and carbonization," Waste and Biomass Valorization, vol. 8, no. 7, pp. 2495- 2510, 2017. DOI:10.1007/s12649-016-9699-6.

[5] Valensya D., Rozalia I., Syamsuddin Y., "Utilization of avocado seed waste as raw material for producing biodiesel with cao catalyst from eggshell," IOP Conference Series: Materials Science and Engineering, vol. 845, no. 1, p. 012020, 2020. DOI: 10.1088/1757-899X/845/1/012020.

[6] Zhu Y., Kolar P., Shah S. B., Cheng J. J., Lim P. K., "Avocado seed-derived activated carbon for mitigation of aqueous ammonium," Industrial Crops and Products, vol. 92, pp. 34-41, 2016. DOI: 10.1016/j.indcrop.2016.07.016

[7] Demissie H., Gedebo A., Agegnehu G., "Agronomic potential of avocado-seed biochar in comparison with other locally available biochar types: a first-hand report from Ethiopia," Applied and Environmental Soil Science, vol. 2023, pp. 1-15, 2023. DOI: 10.1155/2023/7531228.

[8] Van Y., Jaromír J., Tin C., "Environmental performance and techno-economic feasibility of different biochar applications: An overview," Chemical Engineering Transactions", vol. 83, pp. 469–474, 2021. DOI: 10.3303/CET2183079.

[9] Crowley D., "Biochar as a soil amendment for avocado production," California Avocado Society 2012 Yearbook, 2012.

[10] Chaiwong K., Kiatsiriroat T., Vorayos N., Thararax C., "Study of bio-oil and bio-char production from algae by slow pyrolysis," Biomass and Bioenergy, vol. 56, pp. 600-606, 2013. DOI: 10.1016/j.biombioe.2013.05.035.

[11] Hafiza S., Riaz A., Arshad Z., Zahra S. T., Akhtar J., Kanwal S., Zeb H., Kim J., "Effect of pyrolysis temperature on the physiochemical properties of biochars produced from raw and fermented rice husks," Korean Journal of Chemical Engineering, vol. 40, pp. 1986–1992, 2023, DOI: 10.1007/s11814-023-1465-4.

[12] Durak H., Aysu T., "Effect of pyrolysis temperature and catalyst on production of bio-oil and bio-char from avocado seeds," Research on Chemical Intermediates, vol. 41, pp. 8067-8097, 2015. DOI: 10.1007/s11164-014-1878-0.

[13] Antal MJ., Grønli M., 2003, "The art, science, and technology of charcoal production," Industrial & Engineering Chemistry Research, vol. 42, no. 8, pp. 1619–1640, 2003. DOI: 10.1021/ie0207919.

[14] Yarbay-Şahin RZ., Örenay O., Dolaş Y., Yargıç AŞ., Özbay N., "Experimental study of thermal pyrolysis of avocado seed for liquid fuel production," International Journal of Innovative Approaches in Agricultural Research, vol. 4, no. 4, pp. 447-452, 2020. DOI: 10.29329/ijiaar.2020.320.6.

[15] Dhar S. A., Sakib T. U., Hilary L. N., "Effects of pyrolysis temperature on production and physicochemical characterization of biochar derived from coconut fiber biomass through slow pyrolysis process," Biomass Conversion and Biorefinery, vol. 12, no. 7, pp. 2631-2647, 2022. DOI: 10.1007/s13399-020-01116-y.

[16] Tsai C. H., Tsai W. T., Liu S. C., Lin, Y. Q., "Thermochemical characterization of biochar from cocoa pod husk prepared at low pyrolysis temperature," Biomass Conversion and Biorefinery, vol. 8, pp. 237-243, 2018. DOI: 10.1007/s13399-017-0259-5.

[17] Mohan D., Sarswat A., Ok Y. S., "Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent - A critical review," Bioresource Technology, vol. 160, pp. 191-202, 2014. DOI: 10.1016/j.biortech.2014.01.120.

[18] Elizalde-González M. P., Mattusch J., Peláez-Cid A. A., Wennrich R., "Characterization of adsorbent materials prepared from avocado kernel seeds: Natural, activated and carbonized forms," Journal of Analytical and Applied Pyrolysis, vol. 78, no. 1, pp. 185-193, 2007. DOI: 10.1016/j.jaap.2006.06.008

[19] García-Vargas M. C., Contreras M. D. M., Castro E., "Avocado-derived biomass as a source of bioenergy and bioproducts," Applied Sciences, vol. 10, no. 22, pp. 8195, 2020. DOI:10.3390/app10228195.

[20] Ma X., Zhou, B., Budai A., Jeng A., Hao X., Wei D., Zhang Y., Rasse D., "Study of biochar properties by scanning electron microscope—energy dispersive X-ray spec-troscopy (SEM-EDX)," Communications in Soil Science and Plant Analysis, vol. 47, no. 5, pp. 593-601, 2016.DOI: 10.1080/00103624.2016.1146742

[21] Mutolib A., Rahmat A., Triwisesa E., Hidayat H., Hariadi H., Kurniawan K., Sutiharni S., Sukamto S., "Biochar from agricultural waste for soil amendment candidate under different pyrolysis temperatures," Indonesian Journal of Science and Technology, vol. 8, no. 2, pp. 243-258, 2023. DOI: 10.17509/ijost.v8i2.55193

[22] Rahmat A., Sutiharni S., Elfina Y., Yusnaini Y., Latuponu H, Minah F. N., Sulistyowati Y., Mutolib A., "Characteristics of Tamarind Seed Biochar at Different Pyrolysis Temperatures as Waste Management Strategy: Experiments and Bibliometric Analysis," Indonesian Journal of Science and Technology, vol. 8, no. 3, pp. 517-538, 2023. DOI: 10.17509/ijost.v8i3.63500

[23] Pariyar P., Kumari K., Jain M. K., Jadhao P. S., "Evaluation of change in biochar properties derived from different feedstock and pyrolysis temperature for environmental and agricultural application," Science of The Total Environment, vol. 713, p. 136433, 2020. DOI:

[24] Muzyka R., Misztal E., Hrabak J., Banks S. W., Sajdak M., "Various biomass pyrolysis conditions influence the porosity and pore size distribution of biochar," Energy, vol. 263, p. 126128, 2023. DOI: 10.1016/j.energy.2022.126128

[25] Fuertes A. B., Arbestain M. C., Sevilla M., Maciá-Agulló J. A., Fiol S., López R., Smernik R. J., Aitkenhead W. P.,

Arce F., Macias F., "Chemical and structural properties of carbonaceous products obtained by pyrolysis and hydrothermal carbonisation of corn stover," Soil Research, vol. 48, no. 7, pp. 618-626, 2010. DOI: 10.1071/SR10010

[26] Mohanty P., Nanda S., Pant K. K., Naik S., Kozinski J. A., Dalai A. K., "Evaluation of the physiochemical development of biochars obtained from pyrolysis of wheat straw, timothy grass and pinewood: effects of heating rate," Journal of Analytical and Applied Pyrolysis, vol. 104, pp. 485-493, 2013. DOI: 10.1016/j.jaap.2013.05.022

[27] Kim K. H., Kim J. Y. Y., Cho T. S. S., Choi J. W., "Influence of pyrol-ysis temperature on physicochemical properties of biochar obtained from the fast pyrolysis of pitch pine (Pinus rigida)," Bioresource Technology, vol. 118, pp. 158–162, 2012. DOI: 10.1016/j.biortech.2012.04.094

[28] Mukherjee S., Sarkar B., Aralappanavar V. K., Mukhopadhyay R., Basak B. B., Srivastava P., Marchut-Mikolajczyk O., Bhatnagar A., Semple K. T., Bolan N., "Biochar-microorganism interactions for organic pollutant remediation: Challenges and perspectives," Environmental Pollution, vol. 308, p. 119609, 2022 DOI: 10.1016/j.envpol.2022.11960

[29] Bolan S., Hou D., Wang L., Hale L., Egamberdieva D., Tammeorg P., Li R., Wang B., Xu J., Wang T., Sun H., Padhye L. P., Wang H., Shiddique K. H. M., Rinklebe J., Kirkham M. B., Bolan N., "The potential of biochar as a microbial carrier for agricultural and environmental applications," Science of the Total Environment, vol. 86, p. 163968, 2023. DOI: 10.1016/j.scitotenv.2023.163968

[30] Mullen C. A., Boateng A. A., Goldberg N. M., Lima I. M., Laird D. A., Hicks K. B., 2009, Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis 5, Biomass Bioenerg, vol. 34, pp. 67–74, 2009. DOI:10.1016/j.biomb ioe.2009.09.012

[31] Angın D., Sensöz S., "Effect of pyrolysis temperature on chemical and surface properties of biochar of rapeseed (Brassica napus L.)," International Journal of Phytoremediation, vol. 16, pp. 684–693, 2014. DOI: 10.1080/15226514.2013.856842

[32] Li S., Chen G., "Thermogravimetric, thermochemical, and infrared spectral characterization of feedstocks and biochar derived at different pyrolysis temperatures," Waste Management, vol. 78, pp. 198–207, 2018. DOI: 10.1016/j.wasman.2018.05.048.

[33] Jindo K., Mizumoto H., Sawada Y., Sanchez-Monedero M. A., Sonoki T., "Physical and chemical characterization of biochars derived from different agricultural residues," Biogeosciences, vol. 11, pp. 6613–6621, 2014. DOI: 10.5194/bg-11-6613-2014.

[34] Reza M. S., Islam S. N., Afroze S., Abu Bakar M. S., Sukri R. S., Rahman S., Azad A. K., "Evaluation of the bioenergy potential of invasive Pennisetum purpureum through pyrolysis and thermogravimetric analysis," Energy, Ecology and Environment, vol. 5, pp. 118-133, 2020. DOI: 10.1007/s40974-019-00139-0.

[35] Bardalai M., Mahanta D. K., "Characterisation of biochar produced by pyrolysis from areca catechu dust," Materials Today: Proceedings, vol. 5, no. 1, pp. 2089-2097, 2018. DOI: 10.1016/j.matpr.2017.09.205.

[36] Mohan D., Pittman J. C. U., Steele P. H., "Pyrolysis of wood/biomass for bio-oil: a critical review," Energy & fuels, vol. 20, no. 3, pp. 848-889, 2006. DOI: 10.1021/ef0502397.

[37] Uchimiya M., Wartelle L. H., Klasson K. T., Fortier C. A., Lima I. M., "Influence of pyrolysis temperature on biochar property and function as a heavy metal sorbent in soil," Journal of Agricultural and Food Chemistry, vol. 58, no. 9, pp. 5538-5547, 2010. DOI: 10.1021/jf104206c.

[38] Ahmad M., Lee S. S., Dou X., Mohan D., Sung J. K., Yang J. E., Ok Y. S., "Effects of pyrolysis temperature on soybean stover-and peanut shell-derived biochar properties and TCE adsorption in water," Bioresource Technology, vol. 118, pp. 536-544, 2012. DOI: 10.1016/j.biortech.2012.05.042.

[39] Chen Y., Yang H., Wang X., Zhang S., Chen H., "Biomass-based pyrolytic polygeneration system on cotton stalk pyrolysis: Influence of temperature," Bioresour Technol, vol. 107, pp. 411–418, 2012. DOI: 10.1016/j.biortech.2011.10.074.

[40] Sánchez M. E., Lindao E., Margaleff D., Martínez O., Morán A., 2009, Pyrolysis of agricultural residues from rape and sunflowers: Production and characterization of bio-fuels and biochar soil management," Journal of Analytical and Applied pyrolysis, vol. 85, pp. 142-144, 2009. DOI: 10.1016/j.jaap.2008.11.001.

[41] Mui E. L. K., Cheung W. H., Valix M., McKay G., "Dye adsorption onto char from bamboo," Journal of Hazardous Materials, vol.177, pp.1001–1005, 2010. DOI: 10.1016/j.jhazmat.2010.01.018.

[42] Fu P., Yi W., Bai X., Li Z., Hu S., Xiang J., "Effect of temperature on gas composition and char structural features of pyrolyzed agricultural residues," Bioresource Technology, vol. 102, no. 17, pp. 8211–8219, 2011. DOI: 10.1016/j.biortech.2011.05.083.

[43] Hossain M. K., Strezov V., Chan K. Y., Ziolkowski A., Nelson P. F., "Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar," Journal of Environmental Management, vol. 92, no. 1, pp. 223-228, 2011. DOI: 10.1016/j.jenvman.2010.09.008.

[44] Claoston N., Samsuri A. W., Ahmad-Husni M. H., Mohd-Amran M. S., "Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars," Waste Management & Research, vol. 32, no. 4, pp. 331-339, 2014. DOI: 10.1177/0734242X14525822.

[45] Darma S., Fahrunsyah F., "Effect of soil damage on carrying capacity of biomass production: A lesson from Tanjung Selor District – Tanjung Redeb, Indonesia," Universal Journal of Agricultural Research, vol. 10, no. 6, pp. 682-690, 2022. DOI: 10.13189/ujar.2022.100609

[46] Triharyanto E., Setyaningrum D., Muhammad D. M., Potential of liquid organic fertilizer on flowering, yield of shallots (Allium cepa L. Aggregatum) and soil quality, Universal Journal of Agricultural Research, vol. 10, no.5, pp.526-533, 2022. DOI: 10.13189/ujar.2022.100507

[47] Lehmann J., Gaunt J., Rondon M., “Biochar sequestration in terrestrial ecosystems-A review,” Mitigation and Adaptation Strategies for Global Change, vol 11, pp. 403–427, 2006. DOI: 10.1007/s11027-005-9006-5.

[48] Nepal J., Ahmad W., Munsif F., Khan A., Zou Z., “Advances and prospects of biochar in improving soil fertility, biochemical quality, and environmental applications,” Frontiers in Environmental Science, Vol. 11:1114752. 2023. DOI: 10.3389/fenvs.2023.1114752.

ID 10435606

ORIGINALITY REPORT

14%	13%	11%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	ejournal.upi.edu Internet Source	1%
2	www.tandfonline.com Internet Source	1%
3	link.springer.com Internet Source	1%
4	etheses.whiterose.ac.uk Internet Source	1%
5	Kaifeng Wang, Na Peng, Guining Lu, Zhi Dang. "Effects of Pyrolysis Temperature and Holding Time on Physicochemical Properties of Swine-Manure-Derived Biochar", Waste and Biomass Valorization, 2018 Publication	1%
6	www.hindawi.com Internet Source	1%
7	eacademic.ju.edu.jo Internet Source	1%

8	"Biochar and its Application in Bioremediation", Springer Science and Business Media LLC, 2021 Publication	1 %
9	Submitted to Writtle Agricultural College Student Paper	1 %
10	krishi.icar.gov.in Internet Source	1 %
11	oa.upm.es Internet Source	1 %
12	acikbilim.yok.gov.tr Internet Source	1 %
13	S Sathish, G Narendrakumar, S Vaithyasubramanian, E Sinduri. "Mechanistic model for the batch extraction of oil from avocado seeds available for biofuel production", International Journal of Green Energy, 2021 Publication	1 %
14	bioresources.cnr.ncsu.edu Internet Source	1 %
15	core.ac.uk Internet Source	1 %
16	www.aidic.it Internet Source	1 %

Exclude quotes	Off	Exclude matches	< 1%
Exclude bibliography	On		