Indonesian Journal of Science & Technology

Journal homepage: http://ejournal.upi.edu/index.php/ijost/

Characteristics of Tamarind Seed Biochar at Different Pyrolysis Temperatures as Waste Management Strategy: Experiments and Bibliometric Analysis

Ali Rahmat[1], Sutiharni Sutiharni[2], Yetti Elfina[3], Yusnaini Yusnaini[4], Hadidjah Latuponu[5], Faidliyah Nilna Minah[6], Yeny Sulistyowati[7], Abdul Mutolib[8,]*

[1]Badan Riset dan Inovasi Nasional, Indonesia
[2]Universitas Papua, Indonesia
[3]Universitas Riau, Indonesia
[4]Universitas Khairun, Indonesia
[5]Universitas Darussalam Ambon, Indonesia
[6]Institut Teknologi Nasional Malang, Indonesia
[7]Universitas Respati Indonesia, Indonesia
[8]Universitas Siliwangi, Indonesia
Correspondence: E-mail: abdul.mutolib@unsil.ac.id

ABSTRACT

Household activities and beverage industries that use tamarind often generate waste in the form of tamarind seeds. Tamarind seeds account for approximately 40% of the total weight of the fruit. If these tamarind seeds are not properly managed, they end up as waste with no economic or other benefits. One effective waste management strategy is to convert tamarind seeds into biochar. This research aims to examine the characteristics of biochar produced from tamarind seeds at different pyrolysis temperatures. The results indicate that as the pyrolysis temperature increases, the fixed carbon content also increases. Pores begin to form on the surface of the biochar at a temperature of 400°C. We have identified functional groups such as C-H, O-H, C≡N, C≡C, C=C, C=O, CH_3, C-O, and C-C in the biochar. The dominant elements in tamarind seed biochar are K_2O, CaO, P_2O_5, SO_3, and MgO, which are part of macronutrients and alkaline elements with the potential to improve soil quality as soil amendments.

ARTICLE INFO

Article History:
Submitted/Received 23 Jul 2023
First Revised 15 Sep 2023
Accepted 18 Oct 2023
First Available online 23 Oct 2023
Publication Date 01 Dec 2023

Keyword:
Agricultural waste,
Biochar,
Tamarind seed,
Psychochemical properties,
Waste management.

1. INTRODUCTION

Tamarind, also known as *Tamarindus indica*, is one of Indonesia's most popular trees. Various parts of the tamarind plant can be used for both food and medicine. Tamarind pulp is not only consumed raw or turned into sweets but is also employed as a raw ingredient in herbal medicine (Putri, 2014). Indonesia holds the potential to produce Javanese tamarind fruit, particularly in the districts of Madura, Mojokerto, West and East Nusa Tenggara, and Central Java (Ariani & Pandanwangi, 2021).

Tamarind fruit offers numerous health benefits for humans, including volatile chemical compounds, vitamins, and fiber. Meanwhile, tamarind pods have a history of use in traditional medicine for treating laxative, digestive, and bile problems. Tamarind seeds are commonly categorized as agricultural waste due to a lack of awareness regarding their potential benefits (Gayathri *et al.,* 2013).

Household activities and beverage industries that use tamarind will produce waste in the form of tamarind seeds. The seed portion of tamarind accounts for approximately 40% of the total weight. If tamarind seeds are not managed properly, they will become waste with no economic or other benefits (Bagul *et al.,* 2015). Therefore, technology is needed to convert this seed waste into materials that have economic value or other useful purposes. One such application is the conversion of tamarind seeds into biochar.

Biochar is a high-energy solid fuel created through the thermal decomposition of biomass, using processes such as pyrolysis and gasification (Nayaggy & Putra, 2019, Pebrianti & Salamah, 2021, Jamilatun *et al.,* 2022). Many research on biochar have been reported (Nandiyanto *et al*., 2023g), such as:

(i) Rice straw (Nandiyanto *et al*., 2017; Nandiyanto *et al*., 2018; Fiandini *et al*., 2020)
(ii) Mangosteen Peel (Nandiyanto *et al*., 2023f)
(iii) Tamarind (Tamarindusindica L) Seed (Nandiyanto *et al*., 2023h)
(iv) Cassava Peel (Yolanda *et al*., 2022)
(v) Lumbricus Rubellus (Nandiyanto, 2019)
(vi) Red dragon fruit (Nandiyanto *et al*. 2020f)
(vii) Pineapple peel waste (Nandiyanto *et al*., 2020e)
(viii) Rice husk (Anggraeni *et al*., 2021)

Due to its lower cost and reduced environmental impact, it can find application in various areas including solid fuel production, soil remediation, greenhouse gas reduction, and waste management (Cha *et al.,* 2016). Biochar is a carbon-based substance produced as a byproduct of pyrolysis, a process that involves heating biomass in a limited or oxygen-free environment. Its chemical and physical properties vary widely due to the different biomass residues used and the specific conditions of pyrolysis. Biochar exhibits significant potential for mitigating carbon emissions through long-term carbon sequestration, while also offering various horticultural benefits (Dunnigan *et al.,* 2018).

Biochar can supply nitrogen (N), increase organic carbon (C), and raise pH levels due to its alkaline nature and high carbon content (Chan *et al.,* 2008). Characterization results for biochar indicate its suitability for various purposes, including use as solid fuel, fertilizer, and bio-adsorbents (Nandiyanto, 2020, Fiandini *et al.,* 2020, Nandiyanto *et al.,* 2020a, Nandiyanto *et al.,* 2020b, Nandiyanto *et al.,* 2020c, Nandiyanto *et al.,* 2020d, Mishra *et al.,* 2020, Nandiyanto et al, 2021, N'diaye *et al.,* 2022, Nandiyanto., 2022). Tamarind seed powder serves as an adsorbent for removing crystal violet dye at different pH levels, offering a treatment option for polluted wastewater (Mopoung *et al.,* 2015; Patel and Vasthi, 2010). Tamarind seed biochar/carbon may present an economically viable alternative as an absorbent (Ishak, 2022).

The type of raw material used and the manufacturing process have a significant impact on the quality of biochar. One of the determining factors is the pyrolysis temperature. Pyrolysis technologies provide an excellent means to utilize lignocellulosic biomass (Subagyono, 2021). However, because pyrolysis can greatly affect both heat transmission and reaction speeds, the optimal operating conditions can vary considerably (Lopez-Velazquez *et al.,* 2013; Sait *et al.,* 2012). Thermal pyrolysis produces varying ash content at temperatures ranging from 450°C to 600°C (Mishra *et al.,* 2020). Results from pyrolysis experiments have revealed an optimum carbonization temperature of 500°C (Akpen *et al.,* 2016). Temperatures between 370°C and 420°C are considered ideal for pyrolysis (Traoré *et al.,* 2016).

As pyrolysis temperature increases, biochar output decreases while BET surface area, and total pore volume increase (Mutolib *et al.,* 2023). Furthermore, increasing the pyrolysis temperature leads to higher percentages of carbon (%C) and ash (%ash) concentrations, while decreasing the percentages of hydrogen (%H), oxygen (%O), and nitrogen (%N) contents in most samples, with the most significant changes occurring in the temperature range of 500°C to 700°C (Chatterjee *et al.,* 2020). According to Al Wabel *et al.* (2013), biochars generated at low temperatures exhibit lower pH and EC values and higher quantities of unstable organic carbon and dissolved organic carbon compared to those produced at high temperatures.

Given the uncertainty surrounding the influence of pyrolysis temperature on biochar characteristics, further research is needed to explore the impact of pyrolysis temperature on specific materials, such as tamarind seeds. Consequently, the objective of this study was to investigate the effects of different pyrolysis temperatures on the properties of biochar derived from tamarind seeds.

2. METHODS

2.1. Bibliometric Analysis

In this analysis, two software applications were used: namely, "Publish or Perish 8" and "VOSviewer." The database utilized for data collection was Google Scholar. The data collection process employed the "Publish or Perish" method, using the keywords "Biochar" and "Pyrolysis," resulting in a total of 1000 articles. Subsequently, the collected data was saved in RIS format. The next step involved running VOSviewer, where "Create" was selected, followed by choosing "Create map based on text data." Then, the option to "Read data from reference manager file" was selected, and the RIS file was uploaded. The specific field from which terms would be extracted was set as the "Title field." Afterward, "Full calculation" was chosen, and a minimum of 10 occurrences was set as the threshold. Finally, the process was completed by clicking "Finish."

2.2. Material Preparation

The samples consist of tamarind seeds collected from the local market. These tamarind seeds are first washed with water to remove any dust or other unwanted impurities. After washing, the samples are air-dried for 48 hours. Once dried, the samples are ready for pyrolysis.

2.3. Pyrolysis Process

Tamarin seeds were subjected to pyrolysis using a muffle furnace. Clean, air-dried tamarin seeds were placed inside a porcelain cup with a volume of 50 mL, which was then tightly sealed and wrapped with aluminum foil. The purpose of coating with aluminum foil was to minimize the interaction of the sample with oxygen during the pyrolysis process. The sample was kept in the furnace for 4 hours, with temperature variations of 300°C, 400°C, 500°C, and 600°C. Following pyrolysis, the sample was allowed to cool to room temperature. Once it reached room temperature, the sample was ground and sieved using a 355 µm sieve (Rahmat, 2021; Rahmat *et al.,* 2022a; Rahmat *et al.,* 2022b; Rahmat, 2022c). The results of the sieve analysis will be used for the characterization of the biochar.

2.4. Parameter Analysis

Proximate biochar content was measured using a TGA 701 Thermogravimetric Analyzer using the ASTM D5142 method (American Standard Testing and Materials). PerkinElmer's Simultaneous Thermal Analyzer (STA) 6000 was utilized for conducting thermogravimetric analysis (TGA). The biochar samples were analyzed over a temperature range of 40 to 1000 °C, employing a continuous heating rate of 10 °C/min. To sustain an inert atmosphere throughout the pyrolysis process, pure nitrogen (N2) gas was consistently introduced into the heating chamber. The TGA curves were devised to evaluate a material's thermal stability by quantifying the weight alteration correlated with temperature variations.

The surface morphology of biochar was examined using Field Emission Scanning Electron Microscopy (FESEM) with the Thermo Scientific Quattro S FESEM. The functional groups of the biochar samples were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) with the PerkinElmer Spectrum Two equipped with a Universal Attenuated Total Reflectance (UATR) accessory. X-ray fluorescence (XRF) spectroscopy was used to characterize the element contents (chemical) of biochar samples. The wavelength dispersion was determined using the Omnian ED- XRF PANalytical Epsilon 3 XLE X-ray fluorescence spectrometer.

3. RESULTS AND DISCUSSION

3.1. Bibliometrics Results

Bibliometrics can be used to identify a data set to understand the connection of one data to another. Many research in bibliometric analysis have reported, presented in **Table 1**.

Figure 1 shows the VOSviewer visualization data. From this, there are 4 clusters based on the proximity of the data.

Based on **Table 2**, it is evident that the four clusters are fundamentally interconnected and maintain a relationship. Some of them even share similar meanings. Research on biochar and pyrolysis is still in the process of exploring various aspects, including the utilization of raw materials (feedstock type), pyrolysis techniques, biochar development, and biochar applications. One of the areas of ongoing research involves investigating biochar's potential use as an adsorbent and as a soil amendment.

Table 1. Previous studies on bibliometric analysis.

No	Title	Ref.
1	Dental suction aerosol: Bibliometric analysis.	Ramadahn *et al.* (2022)
2	A bibliometric analysis of Covid-19 researches using VOSViewer.	Hamidah *et al.* (2020)
3	The latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	Setiyo *et al.* (2021)
4	A bibliometric analysis of management bioenergy research using VOSviewer application	Soegoto *et al.* (2022)
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	Mudzakir *et al.* (20220
6	Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A literature review and bibliometric analysis.	Hamidah *et al.* (2023)
7	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSViewer	Shidiq (2023)

Table 1 (Continue). Previous studies on bibliometric analysis.

No	Title	Ref.
8	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021.	Ruzmetov (2023)
9	Correlation between process engineering and special needs from bibliometric analysis perspectives.	Nordin (2022a)
10	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	Bilad (2022)
11	Computing bibliometric analysis with mapping visualization using VOSviewer on “pharmacy” and “special needs” research data in 2017-2021.	Sudarjat (2023)
12	Nutritional research mapping for endurance sports: A bibliometric analysis.	Firdaus *et al.* (2023)
13	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	Mulyawati *et al.* (2021)
14	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	Nordin (2022b)
15	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	Wirzal *et al.* (2022)
16	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	Solehuddin *et al.* (2023)
17	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis.	Sahidin *et al.* (2023)
18	A bibliometric analysis of materials research in Indonesian journal using VOSViewer	Nandiyanto and Al Husaeni (2021)
19	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	Nandiyanto *et al.* (2023a)
20	Bibliometric analysis of educational research in 2017 to 2021 using VOSViewer: Google Scholar indexed research.	Al Husaeni *et al.* (2023a)
21	Bibliometric analysis of special needs education keyword using VOSviewer indexed by Google Scholar	Al Husaeni *et al.* (2023b)
22	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	Maryanti *et al.* (2022)
23	Computational bibliometric analysis of research on science and Islam with VOSViewer: Scopus database in 2012 to 2022.	Al Husaeni and Al Husaeni (2022a)
24	Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment.	Nandiyanto *et al.* (2022)
25	Bibliometric Analysis of Briquette Research Trends During the Covid-19 Pandemic.	Al Husaeni (2022)
26	Computational Bibliometric Analysis on Publication of Techno-Economic Education.	Ragadhita and Nandiyanto (2022)
27	How bibliographic dataset portrays decreasing number of scientific publications from Indonesia	Nandiyanto *et al.* (2020)
28	Research trends from the Scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review	Nandiyanto *et al.* (2024)
29	Bibliometric analysis of high school keyword using VOSviewer indexed by google scholar	Al Husaeni and Nandiyanto (2023)
30	How to calculate bibliometric using VOSviewer with Publish or Perish (using Scopus data): Science education keywords	Al Husaeni and Al Husaeni (2022a)

Table 1 (Continue). Previous studies on bibliometric analysis.

No	Title	Ref.
31	Bibliometric analysis for understanding “science education” for “student with special needs” using VOSViewer	Nursaniah and Nandiyanto (2023)
32	Bibliometric analysis of research development in sports science with VOSViewer.	Al Husaeni (2023)
33	Bibliometric analysis of engineering research using VOSviewer indexed by Google Scholar	Nandiyanto and Al Husaeni (2022)
34	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSViewer	Al Husaeni and Nandiyanto (2022)
35	Introducing ASEAN Journal of Science and Engineering: A Bibliometric Analysis Study	Nandiyanto *et al.* (2023b)
36	Introducing ASEAN Journal of Science and Engineering Education: A Bibliometric Analysis Study for Understanding Internationalization	Al Husaeni *et al.* (2022a)
37	Exploring Iron Oxide's Role in Hydrogen Production: Bibliographic and Bibliometric Analysis	Nandiyanto *et al.* (2023c)
37	How Technology Can Change Educational Research? Definition, Factors for Improving Quality of Education and Computational Bibliometric Analysis	Al Husaeni *et al.* (2024)
38	Is Universitas Pendidikan Indonesia Ready for Internationalization? A Bibliometric Analysis in The Science and Technology-Related Publications	Nandiyanto *et al.* (2023d)
39	Social Impact and Internationalization of “Indonesian Journal of Science and Technology” the Best Journal in Indonesia: A Bibliometric Analysis	Nandiyanto *et al.* (2023e)
40	Mapping of nanotechnology research in animal science: Scientometric analysis	Kumar(20210
41	A bibliometric analysis of the use of particle technology in computational fluid dynamics	Nandiyanto *et al.*, (2023b)
42	A bibliometric analysis of language teaching to enhance science students' knowledge during laboratory practicum	Fauziah *et al.* (2021)
43	Definition, comprehension-boosting factors for students, and computational bibliometric analysis of language	Al Husaeni *et al.* (2022b)
44	Bibliometric analysis of learning Science by regulating strategy in language education	Suherman *et al.* (2023)

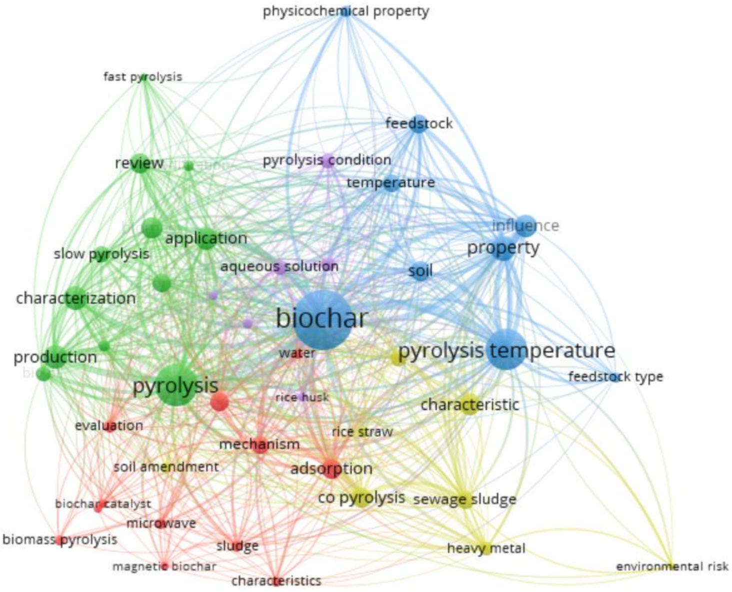


Figure 1. Vosviewer results based on the title with keywords of “Biochar, Pyrolysis”.

Table 2. The cluster from vosviewer analysis.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Adsorption	Application	Biochar	Biochar property
Aqueous solution	Bio oil	Feedstock	Characteristic
Biochar catalyst	Biochar production	Feedstock type	Co pyrolysis
Biomass pyrolysis	Biomass	Physicochemical properties	Environmental risk
Catalytic pyrolysis	Characterization	Property	Heavy metal
Characteristics	Comparison	Pyrolysis condition	Rice straw
Evaluation	Fast pyrolysis	Pyrolysis temperature	Sewage sludge
Magnetic biochar	Modification	Soil	Soil amendment
Mechanism	Preparation	Temperature	
Microwave	Production		
Microwave pyrolysis	Pyrolysis		
Optimalization	Review		
Removal	Slow pyrolysis		
Rice husk			
Sludge			
Water			
Yield			

Based on **Figure 2**, we assessed the relationship between soil amendment and other keywords. Biochar and pyrolysis exhibit a strong correlation with soil amendment. Similarly, pyrolysis temperature is significantly linked to soil amendment. On the other hand, the figure also indicates that research involving biomass, such as sludge and rice straw, has been widely investigated as a material for soil amendment. This research is expected to have an impact on soil quality and the management of heavy metals.

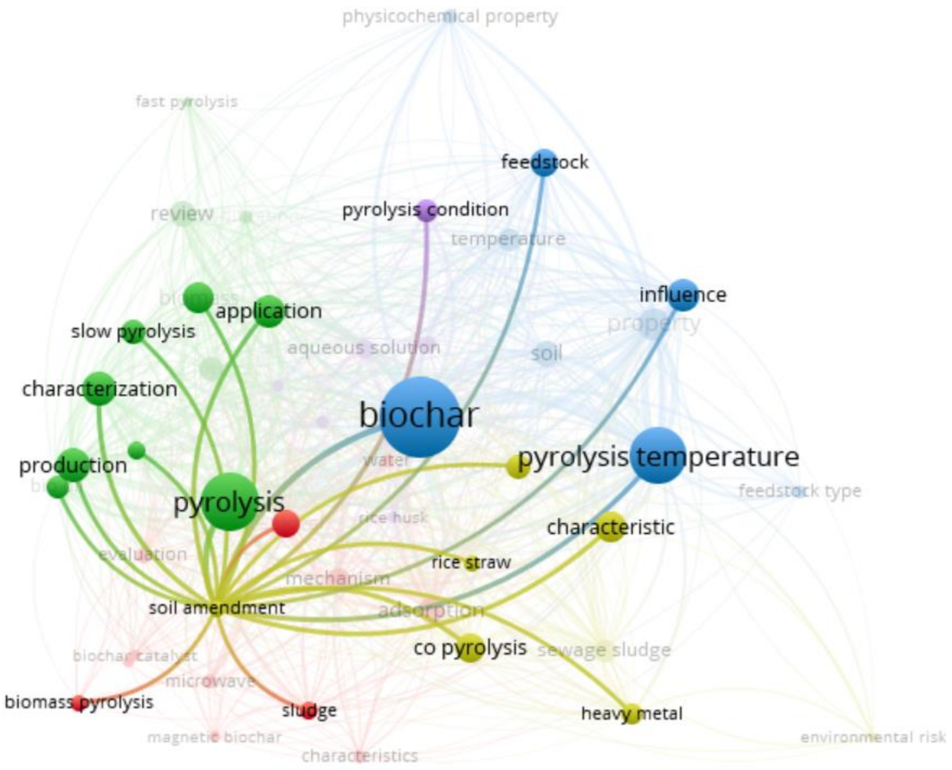


Figure 2. Vosviewer map of soil amendment.

3.2. Proximate Analysis

Proximate analysis provides essential information for characterizing biochar, including parameters such as moisture, volatile matter (VM), fixed carbon (FC), and ash concentration. The ash concentration of biochar is associated with its liming value and inorganic element content, while VM and FC have been used to assess the labile and recalcitrant biochar fractions (Archontoulis *et al.,* 2016). Various factors influence the physical and chemical properties of biochar. Brewer *et al.* (2009) conducted comprehensive biochar characterization experiments and discovered that the chemical and physical properties of biochar vary depending on the biomass feedstock and production techniques. In this experiment, the tamarind seed biochar (TSB) was produced with different temperatures of pyrolysis.

Based on **Table 3**, moisture content and fixed carbon of tamarind seed biochar increase with increasing pyrolysis temperature, whereas volatile matter decreases with increasing pyrolysis temperature. The lowest moisture content is found in TSB-300, at 1.6%, while the highest is in TSB-600, with a value of 9.51%. Similarly, fixed carbon exhibits a similar trend, with TSB-300 having a fixed carbon content of 43.60% and TSB-600 measuring 67.48%. In contrast, volatile matter content in TSB-300 is 50.72%, but it decreases to 18.88% in TSB-600. Regarding ash content, it increases with pyrolysis temperature in TSB-300, TSB-400, and TSB-500, but it decreases again in TSB-600.

According to Sun *et al.,* (2016), the volatile matter concentration of biochar formed at 300°C ranges from 34% to 54%, whereas the volatile matter content ranges from 6% to 19% at 600°C. According to Sun *et al.* (2016), increasing the pyrolysis temperature from 300°C to 600°C increased the fixed carbon content of biochar from 47.3% to 73.1%. Tomczyk *et al.* (2020) discovered that as the pyrolysis temperature increased from 350°C to 700°C, the fixed carbon content of biochar increased from 20% to 80%.

The volatile matter content of biochar reduces as the pyrolysis temperature rises. This is because volatile matter is removed during the pyrolysis process, leaving only the fixed carbon in the biochar. As the pyrolysis temperature increases, the intramolecular and intermolecular chemical bonds in the feedstocks break down, resulting in a steady decrease in moisture and volatile matter content (Sun *et al.,* 2016). According to the search findings, the fixed carbon content of biochar increases as the pyrolysis temperature rises. Fixed carbon is the carbon in biochar that remains after volatile matter is removed during the pyrolysis process (Crombie *et al.,* 2013).

The fixed carbon content in biochar is a key aspect in determining its quality as a soil amendment (Lataf *et al.,* 2022). As the pyrolysis temperature rises and the carbonization process progresses, the organic matter in the feedstocks is broken down into simpler inorganic compounds. This increases the ash content of the biochar and retains more of the feedstock's mineral content as ash (Al Wabel *et al.,* 2013; Qurat-ul-Ain *et al.,* 2021).

Table 3. Proximate data of tamarind seed biochar.

Sample	Moisture content (%)	Volatile matter (%)	Fixed Carbon (%)	Ash content (%)
TSB-300	1.60	50.72	43.60	4.08
TSB-400	7.73	34.00	53.25	5.02
TSB-500	7.66	23.34	62.27	6.74
TSB-600	9.51	18.88	67.48	4.13

3.3. Thermogravimetric Analysis (TGA)

TGA is a type of thermal analysis that analyses weight changes in a material as a function of temperature or time in a controlled environment (Ragadhita & Nandiyanto, 2023). The goal of thermogravimetric analysis is to determine a material's thermal stability and volatile component fraction by monitoring the weight change that occurs while a sample is heated at a constant rate. The stability of biochar is important to be predicted due to the degradation/ decomposition in the natural conditions.

Figure 3 depicts a thermogravimetric analysis (TGA) of biochar generated at various temperatures. Moisture loss is associated with weight loss up to 200°C (Santos *et al.,* 2015). Up to 200°C, around 7-10% weight loss occurs following the moisture content at the proximate data. Temperatures exceeding 300°C to 500°C cause significant weight loss. The evaluated biochar samples were found to be thermally stable below the temperature at which they were formed. After heating to 900°C, the TGA curve reveals a drop in total weight of 46.36%, 35.1%, 25.74%, and 22.37% for TSB-300, TSB-400, TSB-500, and BC600, respectively, indicating that biochar generated at high pyrolysis temperatures is more stable than that formed at lower temperatures.

Kim et al. (2012) obtained similar results after pyrolyzing pitch pine woodchips and Qurat-ul-Ain *et al.,* (2021) for *Parthenium hysterophorus* weed. Sun et al. (2014) also demonstrated that biochar formed at lower temperatures was thermally less stable than biochar formed at higher temperatures due to partial carbonization. Similar findings were discovered in this investigation.

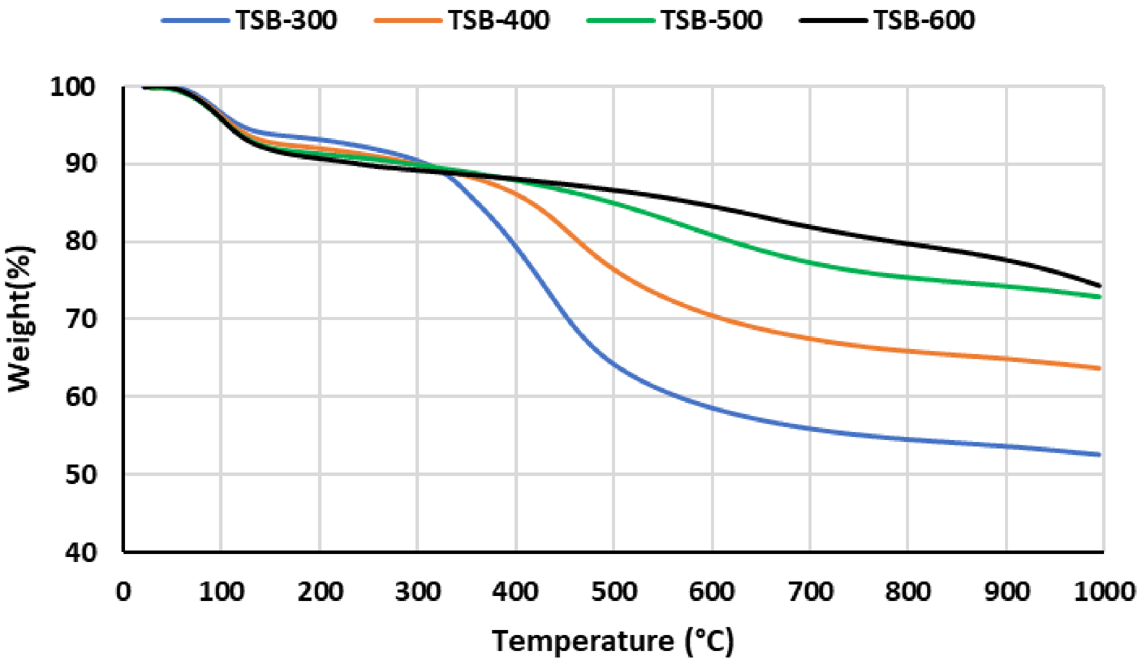


Figure 3. Thermogravimetric analysis of biochar from tamarind seed prepared at different temperatures.

DOI: https://doi.org/10.17509/ijost.v8i3.63500
p- ISSN 2528-1410 e- ISSN 2527-8045

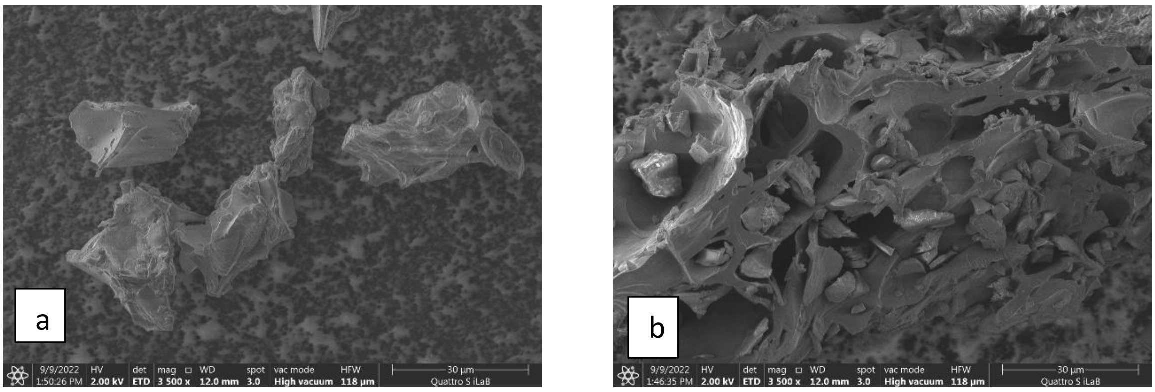
3.4. Scanning Electron Microscope (SEM)

SEM is a type of electron microscope that produces images of a sample by scanning the surface with a concentrated stream of electrons. Electrons interact with atoms in the sample, producing a variety of signals that carry information about the sample's surface topography and composition (Yolanda & Nandiyanto, 2022). The scanning electron microscope (SEM) is used to examine the morphology and microstructure of materials.

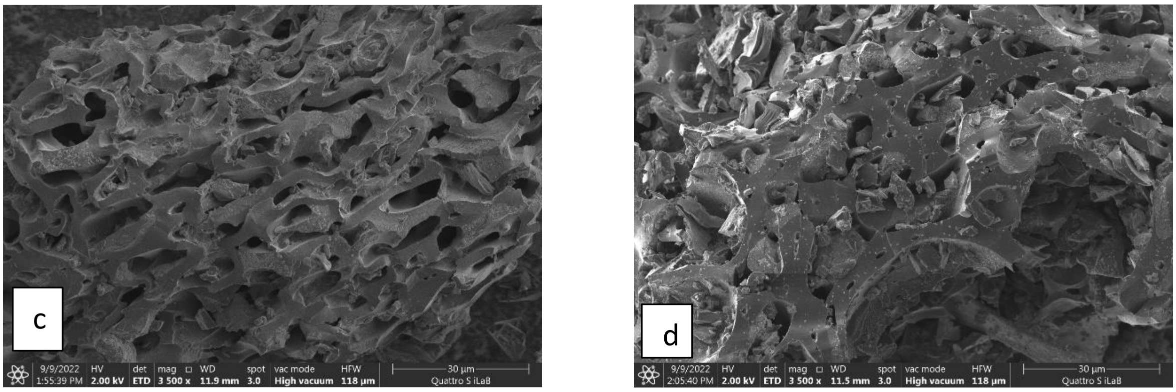
SEM images at 300°C show different visual characteristics compared to treatments at other temperatures. As depicted in **Figure 4**, the tamarin seeds' biochar has not exhibited significant changes; the shape of the tamarin seeds biochar remains consistent, albeit with a shift in color to black. The black hue on the tamarin seeds' surface indicates the presence of organic carbon content, initiating the combustion process. At a temperature of 300°C (**Figure 4a**), carbonization is limited to the surface and has not yet permeated the inner structure of the seeds.

The pyrolysis temperatures of 400°C and 500°C exhibit a nearly identical trend in morphological changes within the tamarin seeds, as illustrated in **Figures 4b** and **4c**. In **Figure 4b**, at a pyrolysis temperature of 400°C, pores begin to emerge in the tamarin seeds biochar. However, these pores are not yet well-defined due to incomplete combustion in some parts of the biochar. In contrast, biochar exposed to 500°C clearly shows distinct pores, indicating complete combustion at this temperature.

Referring to **Figure 4d**, the surface morphology of biochar TSB-600 displays the initiation of pore cracking. Fu *et al.* (2011) contend that pyrolysis at even higher temperatures, specifically 600°C, leads to the formation of a pore network that subsequently collapses and seals the pores.



Tamarin seeds biochar 300°C Tamarin seeds biochar 400°C



Tamarin seeds biochar 500°C Tamarin seeds biochar 600°C

Figure 4. Scanning Electron Micrographs of tamarin seeds biochar.

DOI: https://doi.org/10.17509/ijost.v8i3.63500
p- ISSN 2528-1410 e- ISSN 2527-8045

3.5. Fourier Transform Infrared (FTIR) Spectroscopy

The peak of the wavenumber will present the functional group, **Figure 5** and **Table 4** show the BST have different peaks. Fourier Transform Infrared (FTIR) is an analysis method to characterize the samples by identifying functional groups in the surface of materials (Nandiyanto *et al.,* 2019, Sukamto & Rahmat, 2023, Nandiyanto *et al.,* 2023).

In **Table 4**, the OH (hydroxyl) absorption peak associated with water or other OH groups at wavenumbers around 3220 and 3342 cm^{-1} is still visible at temperatures of 300°C and 400°C, respectively. C-H (carbon-hydrogen) absorption peaks are also observed in the 2920, 2921, and 2972 cm^{-1} regions, representing C-H stretching (Wu *et al.,* 2001). As the temperature increases to 400°C and 500°C, the intensity of the OH and C-H absorption peaks begins to decrease due to decomposition. At a temperature of 600°C, the absorption peaks of the two functional groups disappear, indicating the degradation of cellulose and hemicellulose (Usman *et al.,* 2015). Compounds such as ketones or aldehydes may appear at around 1600-1800 cm^{-1}. The intense peak at 1635 cm^{-1} is the stretching vibration of the carbonyl group (C=O) (Padman *et al.,* 2014).

Absorption peaks representing aromatic carbon C=C (double bonds) can begin to appear at around 1500-1600 cm^{-1}. This may indicate the formation of double bonds in the compounds formed during pyrolysis (Fernandes *et al.,* 2020). The wavenumber range 1527-1635 cm^{-1} indicates the presence of a C=C group on the lignin aromatic ring, with peaks at 1527 and 1523 cm^{-1} included in the C=C bond. As shown in the table, the higher the pyrolysis temperature, the more stable the double bonds of aromatic compounds become, leading to the decomposition of aromatic compounds (Chen *et al.,* 2008). The wavenumber 1366 corresponds to the CH3 bond, while the peak in the range of 1156-1063 is attributed to the CO stretching or CN stretching vibrations of aliphatic primary amines (Chatterjee *et al.,* 2020), and 447 corresponds to the C–C bond.

At higher temperatures, decomposition continues significantly. The intensity of the O-H and C-H absorption peaks is likely to be greatly reduced or even disappear. This event is caused by the degradation and transformation of hemicellulose (300°C), cellulose (400°C), and lignin (500-600°C) in a homogeneous state and a highly aromatic carbon structure (Fernandes *et al.,* 2020).

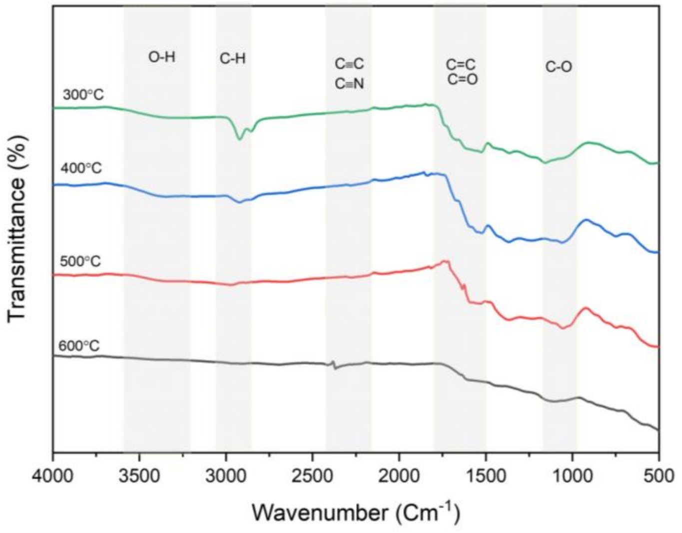


Figure 5. Fourier-transform infrared spectra (FTIR) spectra for biochar from tamarin seeds for different temperatures of pyrolysis

Table 4. Functional group of tamarind seed biochar.

Biochar				Functional Group
TSB-300	TSB-400	TSB-500	TSB-600	
3220	3342	-	-	O-H stretching
2920	2921	2972	-	C-H stretching
-	-	-	2327	C≡C, C≡N stretching
-	-	1635	-	C=O stretching
1527	1523	-	-	C=C aromatic bonds
-	1366	-	-	CH3 bending
1156	1058	1055	1063	C-O bonds
447				C-C bonds

The C≡C (triple bond) absorption peak that appears at 2327 cm^{-1} indicates the formation of alkyne compounds involving triple bonds between carbon atoms, and C=C (aromatic rings) becomes more pronounced at a temperature of 600°C. Both functional groups indicate a higher carbon value and the purity of the carbon produced (Nasution and Rambe, 2013). The peak area at 2327 cm^{-1} also represents the C≡N stretch (Nandiyanto *et al.,* 2019). The application of highly aromatic biochar without functional groups to reduce nutrient loss or remove soil contaminants can be inefficient due to the absence of surface charges capable of interacting with the nutrients or contaminants.

3.6. X-Ray Fluorescence Analysis

The results of X-ray fluorescence Analysis show the percentage of elements that have been normalized to 100%. Based on **Table 5**, at least 14 elements were detected in X-ray fluorescence analysis. these elements are K_2O, CaO, P_2O_5, SO_3, MgO, Fe_2O_3, ZnO, TiO_2, MnO, CuO, Rb_2O, SrO, SnO_2, TeO_2. The five dominant element contents are K_2O, CaO, P_2O_5, SO_3, and MgO. Specifically, the K_2O content ranges from 52% to 55%, the CaO content ranges from 26% to 29%, the P_2O_5 content ranges from 10% to 11%, the SO_3 content ranges from 1.8% to 3.5%, and the MgO content ranges from 2% to 3%. Increasing the pyrolysis temperature does not affect the content of K_2O, CaO, or P_2O_5 elements.

Table 5. Element content of tamarind seed biochar.

Element (oxides)	TSB-300	TSB-400	TSB-500	TSB-600
K_2O	52.29	55.20	52.78	53.12
CaO	29.95	26.64	29,60	28.80
P_2O_5	10.28	11.24	10.89	11.38
SO_3	3.57	2.79	2.02	1.81
MgO	2.38	2.59	2.94	3.43
Fe_2O_3	0.65	0.53	0.52	0.51
ZnO	0.29	0.31	0.38	0.31
TiO_2	0.09	0.09	0.07	0.07
MnO	0.17	0.15	0.16	0.14
CuO	0.17	0.18	0.21	0.16
Rb_2O	0.09	0.11	0.16	0.10
SrO	0.06	0.06	0.11	0.08
SnO_2	-	0.09	0.13	0.06
TeO_2	-	0.02	0.03	0.02

However, increasing the pyrolysis temperature leads to a decrease in the SO_3 content, while conversely, it increases the MgO content. The elemental percentage of biochar varies with temperature due to its volatility and the influence of pyrolysis temperature on the composition and chemical structure of biochar. Additionally, the partial diffraction or devolatilization of these elements at high temperatures affects the concentration of elements in biochar (Hossain *et al.,* 2011; Claoston *et al.,* 2014).

3.7. Potential Application of Tamarin Seed Biochar as Soil Amendment

The USDA classifies red soils as being found in tropical and subtropical zones around the world, covering 6.4109 hectares or 45% of the world's land area. In Indonesia, red soils encompass 51 million ha, which is approximately 27% of the land area. According to Indonesian soil classification, these soils are divided into four primary groups: red-yellow Mediterranean soil, Latosol, Red Yellow Podzolic soil, and Lateritic soil.

They are considered marginal soils with several issues, including low pH and low organic matter (Paiman & Armando, 2010), deficient nutrients (Paiman & Armando, 2010; Sarno, *et al.,* 2004), high aluminum (Al) content and low base saturation (Paiman & Armando, 2010), and low cation exchange capacity, making them susceptible to erosion (Sarno, *et al.,* 2004). Following this problem tamarin seed biochar has potential as soil amendments, where soil amendments can improve the soil conditions.

Based on the proximate analysis, the fixed carbon content ranges from 43% to 67%. This carbon content can enhance the carbon content of the soil. Furthermore, tamarind seed biochar contains K_2O, CaO, P_2O_5, SO_3, and MgO, with these elements categorized as macronutrients. K, Ca, and Mg can also be classified as alkaline elements. Alkaline elements are useful for increasing soil pH through a liming mechanism.

Tamarind seed biochar contains alkaline cations such as Ca^{2+}, Mg^{2+}, and K^+, as confirmed by elemental analysis. When biochar is applied to acidic soil, the alkaline cations within the biochar replace exchangeable H^+ and Al3+ ions. As depicted in Fig. 3, free H+ ions react with OH ions to form neutral water or $CO3^{2-}$ or HCO_3^- ions, generating unstable H2CO3, which readily dissociates to produce CO_2 and H_2O. These liming effects can elevate soil pH and enhance soil fertility, particularly in acidic soils with high levels of harmful aluminum, thereby increasing crop productivity.

4. CONCLUSION

Treatment with varying pyrolysis temperatures affects the proximate data, morphology (pore structure), functional groups, and element content of tamarind seed biochar. The results indicate that as the pyrolysis temperature increases, the fixed carbon content also increases. Pores begin to form on the surface of the biochar at a temperature of 400°C. We have identified functional groups such as C-H, O-H, C≡N, C≡C, C=C, C=O, CH3, C-O, and C-C in the biochar. The dominant elements in tamarind seed biochar are K_2O, CaO, P_2O_5, SO_3, and MgO, all of which are considered macronutrients and alkaline elements that have the potential to enhance soil quality when used as soil amendments.

5. ACKNOWLEDGMENT

The authors acknowledge the facilities, scientific, and technical support from E-Layanan Sains, Badan Riset dan Inovasi Nasional.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

7. REFERENCES

Akpen, G. D., Aho, M. I., and Baba, N. (2016). Preparation and characterization of activated carbons from Albizia saman pod. *Journal of Science and Technology (Ghana)*, 36(3), 44-53.

Al Husaeni, D. F., Al Husanei, D. N., Nandiyanto, A. B. D., Rokhman, M., Chalim, S., Chano, J., Al-Obaidi, A. S. M. and Roestamy, M. (2024). How technology can change educational research? definition, factors for improving quality of education and computational bibliometric analysis. *ASEAN Journal of Science and Engineering*, *4*(2), 127-166.

Al Husaeni, D. F., and Nandiyanto, A. B. D. (2022). Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer. *Journal of Engineering Science and Technology*, *17*(2), 1135-1149.

Al Husaeni, D. F., Nandiyanto, A. B. D., and Maryanti, R. (2023a). Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research. *Indonesian Journal of Teaching in Science*, *3*(1), 1-8.

Al Husaeni, D. N. (2022). Bibliometric analysis of briquette research trends during the covid-19 pandemic. *ASEAN Journal for Science and Engineering in Materials*, *1*(2), 99-106.

Al Husaeni, D. N. (2023). Bibliometric analysis of research development in sports science with vosviewer. *ASEAN Journal of Physical Education and Sport Science*, *2*(1), 9-16.

Al Husaeni, D. N., Al Husaeni, D. F., Nandiyanto, A. B. D., and Al-Obaidi, A. S. M. (2022a). Introducing ASEAN Journal of Science and Engineering Education: A bibliometric analysis study for understanding internationalization. *Data and Metadata*, *1*, 43-43.

Al Husaeni, D. N., and Al Husaeni, D. F. (2022). How to calculate bibliometric using vosviewer with publish or perish (using scopus data): Science education keywords. *Indonesian Journal of Educational Research and Technology*, *2*(3), 247-274.

Al Husaeni, D. N., Nandiyanto, A. B. D., and Maryanti, R. (2023). Bibliometric analysis of special needs education keyword using VOSviewer indexed by google scholar. *Indonesian Journal of Community and Special Needs Education*, *3*(1), 1-10.

Al Husaeni, D. N., Nandiyanto, A. B. D., and Maryanti, R. (2023b). Bibliometric analysis of special needs education keyword using VOSviewer indexed by google scholar. *Indonesian Journal of Community and Special Needs Education*, *3*(1), 1-10.

Al Husaeni, D.F., Al Husaeni, D.N., Ragadhita, R., Bilad, M.R., Al-Obaidi, A.S.M., Abduh, A., Nandiyanto, A.B.D. (2022b). How language and technology can improve student learning quality in engineering? Definition, factors for enhancing students comprehension, and computational bibliometric analysis. *International Journal of Language Education*, *6*(4), 445.

Al-Wabel, M. I., Al-Omran, A., El-Naggar, A. H., Nadeem, M., and Usman, A. R. (2013). Pyrolysis temperature induced changes in characteristics and chemical composition of biochar produced from conocarpus wastes. *Bioresource Technology*, 131, 374-379.

Anggraeni, S., Girsang, G. C. S., Nandiyanto, A. B. D., and Bilad, M. R. (2021). Effects of particle size and composition of sawdust/carbon from rice husk on the briquette performance. *Journal of Engineering Science and Technology, 16*(3), 2298-2311.

Archontoulis, S., Huber, I., Miguez, F., Thorburn, P., Rogovska, N., and Laird, D. (2016). A model for mechanistic and system assessments of biochar effects on soils and crops and tradeoffs. *GCB Bioenergy*, *8*, 1028-1045.

Ariani, A., and Pandanwangi, A. (2021, April). Eco-friendly batik painting wax made from tamarind seed powder (*Tamarindus indica* L*). IOP Conference Series: Earth and Environmental Science*, *737*,012069.

Bagul, M., Sonawane, S. K. and Arya, S. S. (2015). Tamarind seeds: chemistry, technology, applications and health benefits: A review. *Indian Food Industry Magazine*, *34*(3), 28-35.

Bilad, M. R. (2022). Bibliometric analysis for understanding the correlation between chemistry and special needs education using vosviewer indexed by google. *ASEAN Journal of Community and Special Needs Education*, *1*(2), 61-68.

Brewer, C., Schmidt-Rohr, K., Satrio, J., and Brown, R. (2009). Characterization of biochar from fast pyrolysis and gasification systems. *Environmental Progress and Sustainable Energy*, *28*, 386-396.

Cha, J. S., Park, S. H., Jung, S. C., Ryu, C., Jeon, J. K., Shin, M. C., and Park, Y. K. (2016). Production and utilization of biochar: A review. *Journal of Industrial and Engineering Chemistry*, *40*, 1-15.

Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A., and Joseph, S. (2008). Using poultry litter biochars as soil amendments. *Soil Research*, *46*(5), 437-444.

Chatterjee, R., Sajjadi, B., Chen, W. Y., Mattern, D. L., Hammer, N., Raman, V., and Dorris, A. (2020). Effect of pyrolysis temperature on physicochemical properties and acoustic-based amination of biochar for efficient CO2 adsorption. *Frontiers in Energy Research*, *8*, 85.

Chen, B., Zhou, D., and Zhu, L. (2008). Transitional adsorption and partition of nonpolar and polar aromatic contaminants by biochars of pine needles with different pyrolytic temperatures. *Environmental Science and Technology*, *42*(15), 5137–5143.

Claoston, N., Samsuri, A. W., Husni, M. H. A., and Amran, M. S. M. (2014). Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars. *Waste Management and Research*, *32*(4), 331-339.

Crombie, K., Mašek, O., Sohi, S. P., Brownsort, P., and Cross, A. (2013). The effect of pyrolysis conditions on biochar stability as determined by three methods. *Gcb Bioenergy*, *5*(2), 122-131.

Dunnigan, L., Ashman, P. J., Zhang, X., and Kwong, C. W. (2018). Production of biochar from rice husk: Particulate emissions from the combustion of raw pyrolysis volatiles. *Journal of Cleaner Production*, *172*, 1639-1645.

Fauziah, S.P., Suherman, I., Sya, M.F., Roestamy, M., Abduh, A., Nandiyanto, A.B.D. (2021).

Fernandes, B., Mendes, K., Júnior, A., Caldeira, V., Teófilo, T., Silva, T., Mendonça, V., Souza, M., and Silva, D. (2020). Impact of pyrolysis temperature on the properties of eucalyptus wood-derived biochar. *Materials*, *13*(24), 5841.

Fiandini, M., Ragadhita, R., Nandiyanto, A. B. D., and Nugraha, W. C. (2020). Adsorption characteristics of submicron porous carbon particles prepared from rice husk. *Journal of Engineering Science and Technology*, *15*, 022-031.

Firdaus, I. R., Febrianty, M. F., Awwaludin, P. N., Ilsya, M. N. F., Nurcahya, Y., and Sultoni, K. (2023). Nutritional research mapping for endurance sports: A bibliometric analysis. *ASEAN Journal of Physical Education and Sport Science*, *2*(1), 23-38.

Fu, P., Yi, W., Bai, X., Li, Z., Hu, S., and Xiang, J. (2011). Effect of temperature on gas composition and char structural features of pyrolyzed agricultural residues. *Bioresource Technology*, *102*(17), 8211-8219.

Gayathri, R., Thirumarimurugan, M., and Kannadasan, T. (2013). Removal of chromium (VI) ions from aqueous solution using tamarind seeds as an adsorbent. *International Journal of Pharmaceutical and Chemical Sciences*, *2*(2), 984-991.

Hamidah, I., Ramdhani, R., Wiyono, A., Mulyanti, B., Pawinanto, R., Nandiyanto, A., and Rusydi, A. (2023). Biomass-based supercapacitors electrodes for electrical energy storage systems activated using chemical activation method: A Review. *Heliyon, 2023*, 1-30.

Hamidah, I., Sriyono, S., and Hudha, M. N. (2020). A bibliometric analysis of Covid-19 research using VOSviewer. *Indonesian Journal of Science and Technology*, *5*, 34-41.

Hossain, M. K., Strezov, V., Chan, K. Y., Ziolkowski, A., and Nelson, P. F. (2011). Influence of pyrolysis temperature on production and nutrient properties of wastewater sludge biochar. *Journal of Environmental Management*, *92*(1), 223–228.

Ishak, Z., and Kumar, D. (2022). Adsorption of methylene blue and reactive black 5 by activated carbon derived from tamarind seeds. *Tropical Aquatic and Soil Pollution*, *2*(1), 1-12.

Jamilatun, S., Pitoyo, J., Amelia, S., Ma'arif, A., Hakika, D.C., and Mufandi, I. (2022). Experimental study on the characterization of pyrolysis products from bagasse (*Saccharum Officinarum* L.): Bio-oil, biochar, and gas products. *Indonesian Journal of Science and Technology*, *7*(3), 565-582.

Kim, K. H., Kim, J. Y., Cho, T. S., and Choi, J. W. (2012). Influence of pyrolysis temperature on physicochemical properties of biochar obtained from the fast pyrolysis of pitch pine (*Pinus rigida*). *Bioresource Technology*, *118*, 158-162.

Kumar, K. (2021). Mapping of nanotechnology research in animal science: Scientometric anlaysis. *ASEAN Journal of Science and Engineering*, *1*(2), 111-126.

Lataf, A., Jozefczak, M., Vandecasteele, B., Viaene, J., Schreurs, S., Carleer, R., Yperman, J., Marchal, W., Cuypers, A., and Vandamme, D. (2022). The effect of pyrolysis temperature and feedstock on biochar agronomic properties. *Journal of Analytical and Applied Pyrolysis*, *168*, 105728.

Lopez-Velazquez, M. A., Santes, V., Balmaseda, J., Torres-Garcia, E. (2013). Pyrolysis of orange waste: A thermokinetic study. *Journal of Analytical and Applied Pyrolysis*, *99*, 170–177.

Maryanti, R., Rahayu, N. I., Muktiarni, M., Al Husaeni, D. F., Hufad, A., Sunardi, S., and Nandiyanto, A. B. D. (2022). Sustainable development goals (SDGs) in science education:

Definition, literature review, and bibliometric analysis. *Journal of Engineering Science and Technology*, *17*, 161-181.

Mishra, R. K., Kumar, V., and Mohanty, K. (2020). Pyrolysis kinetics behaviour and thermal pyrolysis of Samanea saman seeds towards the production of renewable fuel. *Journal of the Energy Institute*, *93*(3), 1148-1162.

Mopoung, S.; Moonsri, P.; Palas, W.; Khumpai, S. (2015). Characterization and properties of activated carbon prepared from tamarind seeds by koh activation for Fe (III) adsorption from aqueous solution. *The Scientific World Journal*, *2015*, 1-9.

Mudzakir, A., Rizky, K. M., Munawaroh, H. S. H., and Puspitasari, D. (2022). Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis. *Indonesian Journal of Science and Technology*, *7*(2), 291-310.

Mulyawati, I. B., and Ramadhan, D. F. (2021). Bibliometric and visualized analysis of scientific publications on geotechnics fields. *ASEAN Journal of Science and Engineering Education*, *1*(1), 37-46.

Munusamy, K., Somani, R. S., and Bajaj, H. C. (2011). Tamarind seeds carbon: Preparation and methane uptake. *BioResources*, *6*(1), 537-551.

Mutolib, A., Rahmat, A., Triwisesa, E., Hidayat, H., Hariadi, H., Kurniawan, K., and Sukamto, S. (2023). Biochar from agricultural waste for soil Amendment candidate under different pyrolysis temperatures. *Indonesian Journal of Science and Technology*, *8*(2), 243-258.

Nandiyanto, A. B. D. (2018). Cost analysis and economic evaluation for the fabrication of activated carbon and silica particles from rice straw waste. *Journal of Engineering Science and Technology*, *13*(6), 1523-1539.

Nandiyanto, A. B. D. (2019). Amorphous porous carbon microparticles from lumbricus rubellus. *Journal of Engineering Research*, *7*, 13-20.

Nandiyanto, A. B. D. (2020). Isotherm adsorption of carbon microparticles prepared from pumpkin (Cucurbita maxima) seeds using two-parameter monolayer adsorption models and equations. *Moroccan Journal of Chemistry*, *8*(3), 745-741.

Nandiyanto, A. B. D., Al Husaeni, D. F., and Al Husaeni, D. N. (2023e). Social impact and internationalization of “Indonesian journal of science and technology” the best journal in Indonesia: A bibliometric analysis. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *32*(2), 42-59.

Nandiyanto, A. B. D., Al Husaeni, D. N., Al Husaeni, D. F., Hamidah, I., Maftuh, B., and Solehuddin, M. (2023d). Is universitas pendidikan indonesia ready for internationalization? A bibliometric analysis in the science and technology-related publications. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *32*(2), 14-29.

Nandiyanto, A. B. D., Al Husaeni, D. N., and Al Husaeni, D. F. (2023b). Introducing ASEAN journal of science and engineering: A bibliometric analysis study. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *31*(3), 173-190.

Nandiyanto, A. B. D., Al Husaeni, D. N., Ragadhita, R., Fiandini, M., Al Husaeni, D. F., and Aziz, M. (2022). Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment. *Automotive Experiences*, *5*(3), 328-342.

Nandiyanto, A. B. D., and Al Husaeni, D. F. (2021). A bibliometric analysis of materials research in Indonesian journal using VOSviewer. *Journal of Engineering Research*, *9*, 1-16.

Nandiyanto, A. B. D., and Al Husaeni, D. F. (2022). Bibliometric analysis of engineering research using vosviewer indexed by google scholar. *Journal of Engineering Science and Technology*, *17*(2), 883-894.

Nandiyanto, A. B. D., Arinalhaq, Z. F., Rahmadianti, S., Dewi, M. W., Rizky, Y. P. C., Maulidina, A., Anggraeni, S., Bilad, M.R., and Yunas, J. (2020c). Curcumin adsorption on carbon microparticles: Synthesis from soursop (*Annona muricata* L.) peel waste, adsorption isotherms and thermodynamic and adsorption mechanism. *International Journal of Nanoelectronics and Materials*, *13*, 173-192.

Nandiyanto, A. B. D., Biddinika, M. K., and Triawan, F. (2020). How bibliographic dataset portrays decreasing number of scientific publication from Indonesia. *Indonesian Journal of Science and Technology*, *5*(1), 154-175.

Nandiyanto, A. B. D., Fiandini, M., and Al Husaeni, D. N. (2024). Research trends from the scopus database using keyword water hyacinth and ecosystem: A bibliometric literature review. *ASEAN Journal of Science and Engineering*, *4*(1), 33-48.

Nandiyanto, A. B. D., Fiandini, M., Fadiah, D. A., Muktakin, P. A., Ragadhita, R., Nugraha, W. C., and Al Obaidi, A. S. M. (2023f). Sustainable biochar carbon microparticles based on mangosteen peel as biosorbent for dye removal: Theoretical review, modelling, and adsorption isotherm characteristics. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *105*(1), 41-58.

Nandiyanto, A. B. D., Fiandini, M., Ragadhita, R., and Aziz, M. (2023g). How to purify and experiment with dye adsorption using carbon: Step-by-step procedure from carbon conversion from agricultural biomass to concentration measurement using UV vis spectroscopy. *Indonesian Journal of Science and Technology*, *8*(3), 363-380.

Nandiyanto, A. B. D., Fiandini, M., Ragadhita, R., Maulani, H., Nurbaiti, M., Al-Obaidi, A. S. M., and Bilad, M. R. (2023h). Sustainable biochar carbon biosorbent based on tamarind (Tamarindusindica L) seed: Literature review, preparation, and adsorption isotherm. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *32*(1), 210-226.

Nandiyanto, A. B. D., Girsang, G. C. S., Maryanti, R., Ragadhita, R., Anggraeni, S., Fauzi, F. M., Sakinah, P., Astuti, A.P., Usdiyana, D., Fiandini, M., Dewi, M.W., and Al-Obaidi, A. S. M. (2020b). Isotherm adsorption characteristics of carbon microparticles prepared from pineapple peel waste. *Communications in Science and Technology*, *5*(1), 31-39.

Nandiyanto, A. B. D., Girsang, G. C. S., Maryanti, R., Ragadhita, R., Anggraeni, S., Fauzi, F. M., and Al-Obaidi, A. S. M. (2020e). Isotherm adsorption characteristics of carbon microparticles prepared from pineapple peel waste. *Communications in Science and Technology*, *5*(1), 31-39.

Nandiyanto, A. B. D., Maryanti, R., Fiandini, M., Ragadhita, R., Usdiyana, D., Anggraeni, S., Arwa, W.R., and Al-Obaidi, A. S. M. (2020d). Synthesis of carbon microparticles from red dragon fruit (Hylocereus undatus) peel waste and their adsorption isotherm characteristics. *Molekul*, *15*(3), 199-209.

Nandiyanto, A. B. D., Maryanti, R., Fiandini, M., Ragadhita, R., Usdiyana, D., Anggraeni, S., and Al-Obaidi, A. S. M. (2020f). Synthesis of carbon microparticles from red dragon fruit (Hylocereus undatus) peel waste and their adsorption isotherm characteristics. *Molekul*, *15*(3), 199-209.

Nandiyanto, A. B. D., Oktiani, R., and Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology*, *4*(1), 97-118.

Nandiyanto, A. B. D., Putra, Z. A., Andika, R., Bilad, M. R., Kurniawan, T., Zulhijah, R., and Hamidah, I. (2017). Porous activated carbon particles from rice straw waste and their adsorption properties. *Journal of Engineering Science and Technology*, *12*(8), 1-11.

Nandiyanto, A. B. D., Ragadhita, R., Al Husaeni, D. N., and Nugraha, W. C. (2023a). Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis. *Moroccan Journal of Chemistry*, *11*(1), 1-11.

Nandiyanto, A. B. D., Ragadhita, R., and Aziz, M. (2023b). Involving particle technology in computational fluid dynamics research: A Bibliometric analysis. *CFD Letters*, *15*(11), 92-109.

Nandiyanto, A. B. D., Ragadhita, R., and Fiandini, M. (2023). Interpretation of fourier transform infrared spectra (FTIR): A practical approach in the polymer/plastic thermal decomposition. *Indonesian Journal of Science and Technology*, *8*(1), 113-126.

Nandiyanto, A. B. D., Ragadhita, R., Fiandini, M., Al Husaeni, D. N., and Aziz, M. (2023c). The role of iron oxide in hydrogen production: Theory and bibliometric analyses. *Moroccan Journal of Chemistry*, *11*(04), 11-14.

Nandiyanto, A. B. D., Simbara, A. T., and Girsang, G. C. S. (2021). Effects of particle size and composite composition of durian peels and banana midribs' as reinforcement components on resin-based brake pad performance. *Journal of Engineering Research*, *9*, 1-15.

Nandiyanto, A. B. D., Simbara, A. T., Mudzakir, A., and Maryanti, R. (2020a). Improving the learning process in producing bio-charcoal briquettes from durian peels/banana midrib with various particle sizes and composition to high school students. *Journal of Engineering Education Transformations*, *34*, 32-42.

Nasution, Z. A., and Rambe, S. M. (2013). Karakteristik dan identifikasi gugus fungsi dari karbon cangkang kelapa sawit dengan metode methano-pyrolisis. *Jurnal Dinamika Penelitian Industri*, *24*(2), 108-113.

Nayaggy, M., and Putra, Z. A. (2019). Process simulation on fast pyrolysis of palm kernel shell for production of fuel. *Indonesian Journal of Science and Technology*, *4*(1), 64-73.

N'diaye, A. D., Kankou, M. S. A., Hammouti, B., Nandiyanto, A. B. D., and Al Husaeni, D. F. (2022). A review of biomaterial as an adsorbent: From the bibliometric literature review, the definition of dyes and adsorbent, the adsorption phenomena and isotherm models, factors affecting the adsorption process, to the use of typha species waste as adsorbent. *Communications in Science and Technology*, *7*(2), 140-153.

Nordin, N. A. H. M. (2022a). Correlation between process engineering and special needs from bibliometric analysis perspectives. *ASEAN Journal of Community and Special Needs Education*, *1*(1), 9-16.

Nordin, N. A. H. M. (2022b). A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation. *Indonesian Journal of Teaching in Science*, *2*(2), 127-138.

Nursaniah, S. S. J., and Nandiyanto, A. B. D. (2023). Bibliometric analysis for understanding "science education" for "student with special needs" using vosviewer. *ASEAN Journal of Community and Special Needs Education*, *2*(1), 45-54.

Padman, A. J., Henderson, J., Hodgson, S., and Rahman, P. K. (2014). Biomediated synthesis of silver nanoparticles using *Exiguobacterium mexicanum*. *Biotechnology Letters*, *36*(10), 2079-2084.

Paiman, A., and Armando Y. G. (2010). Physical and chemical properties for gnetum gnemon and rubber cultivation development in Jambi Province. *Akta Agrosia*, *13* (1), 89-97.

Patel, H., and Vashi, R. T. (2010). Adsorption of crystal violet dye onto tamarind seed powder. *EJournal of Chemistry*, *7*, 975-984.

Pebrianti, M., and Salamah, F. (2021). Learning simple pyrolysis tools for turning plastic waste into fuel. *Indonesian Journal of Multidiciplinary Research*, *1*(1), 99-102.

Putri, C. R. H. (2014). Potensi dan pemanfaatan Tamarindus indica dalam berbagai terapi. *Jurnal Ilmiah Kedokteran*, *3*(2), 40-54.

Qurat-ul-Ain, Shafiq, M., Capareda, S. C., and Firdaus-e-Bareen. (2021). Effect of different temperatures on the properties of pyrolysis products of Parthenium hysterophorus. *Journal of Saudi Chemical Society*, *25*(3), 101197.

Ragadhita, R., and Nandiyanto, A. B. D. (2022). Computational bibliometric analysis on publication of techno-economic education. *Indonesian Journal of Multidiciplinary Research*, *2*(1), 213-222.

Ragadhita, R., and Nandiyanto, A.B.D. (2023). Why 200°C is effective for creating carbon from organic waste (from thermal gravity (TG-DTA) perspective)?. *ASEAN Journal for Science and Engineering in Materials*, *2*(1), 75-80.

Rahmat, A. (2021). Chemical properties of biochar from date palm seed (Phoenix dactylifera L.) under low temperature pyrolysis as soil amendment candidate. *Applied Research in Science and Technology*, *1*(2), 116–120.

Rahmat, A. (2022c). X-Ray fluorescence analysis of aquilaria malaccensis wood sawdust biochar prepared under low-temperature pyrolysis. *Open Soil Science and Environment*, *1*(1), 1–7.

Rahmat, A., Mutolib, A., and Sukamto, S. (2022b). Elemental content of coffee waste biochar under different temperatures of pyrolysis. *Open Science and Technology*, *2*(2), 198–202.

Rahmat, A., Ramadhani, W. S., Nur, M., Sutiharni, S., and Mutolib, A. (2022a). Chemical properties of salacca seed biochar under low temperature of pyrolysis. *Applied Research in Science and Technology*, *2*(1), 43–46.

Ramadhan, D. F., Fabian, A. M., and Saputra, H. M. (2022). Dental suction aerosol: Bibliometric analysis. *ASEAN Journal of Science and Engineering*, *2*(3), 295-302.

Ruzmetov, A., and Ibragimov, A. (2023). Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021. *ASEAN Journal for Science and Engineering in Materials*, *2*(1), 53-68.

Sahidin, I., Nohong, N., Manggau, M. A., Arfan, A., Wahyuni, W., Meylani, I., and Muktiarni, M. (2023). Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis. *Indonesian Journal of Science and Technology*, *8*(2), 217-242.

Sait, H.H., Hussain, A., *et al.,* 2012. Pyrolysis and combustion kinetics of date palm biomass using thermogravimetric analysis. *Bioresource Technology*, *118*, 382–389.

Santos, L. B., Striebeck, M. V., Crespi, M. S., Ribeiro, C. A., and De Julio, M. (2015). Characterization of biochar of pine pellet. *Journal of Thermal Analysis and Calorimetry*, *122*, 21-32.

Sarno, Iijima, M., Lumbanraja, J., Sunyoto, Yuliadi, E., Izumi, Y., and Watanabe, A. (2004). Soil chemical properties of an indonesian red acid soil as affected by land use and crop management. *Soil and Tillage Research*, *76*, 115-124.

Setiyo, M., Yuvenda, D., and Samuel, O. D. (2021). The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis. *Indonesian Journal of Science and Technology*, *6*(3), 469-490.

Shidiq, A. P. (2023). A bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSviewer. *ASEAN Journal of Science and Engineering*, *3*(1), 31-38.

Soegoto, H., Soeryanto Soegoto, E., Luckyardi, S., and Abhi Rafdhi, A. (2022). A bibliometric analysis of management bioenergy research using vosviewer application. *Indonesian Journal of Science and Technology*, *7*(1), 89-104.

Solehuddin, M., Muktiarni, M., Rahayu, N. I., and Maryanti, R. (2023). Counseling guidance in science education: Definition, literature review, and bibliometric analysis. *Journal of Engineering Science and Technology*, *18*, 1-13.

Strategies in language education to improve science student understanding during practicum in laboratory: Review and computational bibliometric analysis. *International Journal of Language Education*, *5*(4), 409-425.

Subagyono, R. D. J., Qi, Y., Chaffee, A. L., Amirta, R., and Marshall, M. (2021). Pyrolysis-GC/MS analysis of fast growing wood macaranga species. *Indonesian Journal of Science and Technology*, *6*(1), 141-158.

Sudarjat, H. (2023). Computing bibliometric analysis with mapping visualization using vosviewer on “pharmacy” and “special needs” research Data in 2017-2021. *ASEAN Journal of Community and Special Needs Education*, *2*(1), 1-8.

Suherman, I., Fauziah, S.P., Roestamy, M., Bilad, M.R., Abduh, A., Nandiyanto, A.B.D. (2023). How to improve student understanding in learning science by regulating strategy in language education? Definition, factors for enhancing students comprehension, and computational bibliometric review analysis. *International Journal of Language Education*, *7*(3), 527-562.

Sukamto, S., and Rahmat, A. (2022) Evaluation of FTIR, macro and micronutrients of compost from black soldier fly residual: in context of its use as fertilizer. *ASEAN Journal of Science and Engineering*, *3*(1), 21-30.

Sun, J., He, F., Pan, Y., and Zhang, Z. (2016). Effects of pyrolysis temperature and residence time on physicochemical properties of different biochar types. *Acta Agriculturae Scandinavica, Section B — Soil and Plant Science*, *67*(1), 12–22.

Sun, Y. N., Gao, B., Yao, Y., Fang, J. N., Zhang, M., Zhou, Y. M., Chen, H., Yang, L. Y. (2014). Effects of feedstock type, production method, and pyrolysis temperature on biochar and hydrochar properties. *Chemical Engineering Journal*, *240*, 574-578.

Tomczyk, A., Sokołowska, Z., and Boguta, P. (2020). Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects. *Reviews in Environmental Science and Biotechnology*, *19*, 191-215.

Traoré, M., Kaal, J., and Cortizas, A. M. (2016). Application of FTIR spectroscopy to the characterization of archeological wood. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *153*, 63-70.

Usman, A. R., Abduljabbar, A., Vithanage, M., Ok, Y. S., Ahmad, M., Ahmad, M., Elfaki, J., Abdulazeem, S. S., and Al-Wabel, M. I. (2015). Biochar production from date palm waste: Charring temperature induced changes in composition and surface chemistry. *Journal of Analytical and Applied Pyrolysis*, *115*, 392–400.

Wirzal, M. D. H., and Putra, Z. A. (2022). What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using vosviewer indexed by google scholar. *Indonesian Journal of Community and Special Needs Education*, *2*(2), 103-110.

Wu, J. G., Xu, Y. Z., Sun, C. W., Soloway, R. D., Xu, D. F., Wu, Q. G., and Xu, G. X. (2001). Distinguishing malignant from normal oral tissues using FTIR fiber-optic techniques. *Biopolymers: Original Research on Biomolecules*, *62*(4), 185-192.

Yolanda, Y. D., Widyaningsih, M., Ragadhita, R., and Nandiyanto, A. B. D. (2022). Literature review: Fabrication method, characterization, performance, and application of cassava peel as bio-coagulant for wastewater treatment. *Jurnal Kartika Kimia*, *5*(1), 1-23.

Yolanda, Y.D., and Nandiyanto, A.B.D. (2022). How to read and calculate diameter size from electron microscopy images. *ASEAN Journal of Science and Engineering Education*, *2*(1), 11-36.