JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2026, 27(3), 239–248
https://doi.org/10.12911/22998993/213525
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Received: 2025.10.08
Accepted: 2025.11.22
Published: 2026.02.01

Optimization of the extraction of dissolved organic carbon from macadamia husk biochar for agricultural applications

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ABSTRACT

Dissolved carbon (DOC) in biochar is of great significance in soil improvement. DOC extracted from biochar is considered a suitable solution for the trend of automated irrigation in Vietnamese agriculture. Macadamia husk is the precursor used in the study. This study aimed to determine the optimal parameters for extracting DOC from macadamia husk-derived biochar and to investigate the properties of the extracted DOC in the solution. The investigated parameters include biochar type (based on pyrolysis temperature 300, 450, and 600 °C), KOH content (0.5, 1.0, and 2.0 N), homogenization speed (4000, 6000, and 8000 rpm), extraction time (1, 2, and 3 h), and biochar dosage (50, 100, and 150 g/L). The survey results determined the optimal extraction parameters, including biochar prepared at 300 °C, KOH concentration of 1N, homogenization speed of 6000 rpm, extraction time of 2 hours, and biochar dosage: 100 g/L. The characteristics of DOC in the extract corresponding to the optimal extraction conditions were E2/E3 (0.6), indicating a high molecular weight; E4/E5 (2.8 < 3.5), suggesting that DOC was mainly composed of humic acid-like substances, and SUVA254 (0.78, the highest), indicating high stability. The research results provided a solution to use biochar to prepare DOC extract, a potential product made from agricultural by-products.

Keywords: biochar, characteristics of DOC, humic acid, Macca husk, SUVA254.

INTRODUCTION

Agriculture generates a large amount of agricultural by-products and wastes that can be reused for many purposes to increase their economic value (Tu Nguyen et al., 2022). Some are used to produce biochar for soil improvement (Liu et al., 2022; Varkolu et al., 2025) and activated carbon for environmental treatment (Dao et al., 2020). However, using biochar directly (in powder form) in soil improvement can be too much, reducing its positive effects and even being harmful (Cheng et al., 2019). Therefore, an alternative method to reduce the biochar application rate could be to use biochar extract in liquid form, such as dissolved organic carbon (DOC) (Sun et al., 2021), which aligns more closely with the trend of smart farming. Understanding the characteristics of DOC components in biochar extracts is necessary for using them in soil quality control as well as soil carbon sequestration strategies (Kujawska et al., 2024). DOC derived from biochar has a very diverse organic composition, mainly including aliphatic compounds, condensed aromatics, phenolics, and polyphenols, depending on the biochar feedstock (Sun et al., 2021). DOC fractions with larger molecular weights and higher aromaticity are generally less bioavailable than smaller, more biodegradable fractions (Kujawska et al., 2024; Zhang et al., 2022)

Many studies have demonstrated that the composition and characteristics of DOM released from biochar vary greatly, depending on extraction conditions such as the type of biochar used, temperature, pH, solid/liquid ratio, type of extraction solution, and extraction time (Kujawska et al., 2024; Liu et al., 2022; Wu et al., 2018). Therefore, it is not easy to make a quantitative and qualitative assessment of the diversity of DOC composition. A clear trend in the extraction process is that the content, aromaticity, and molecular weight of DOC derived from biochar generally show an increasing order in the extraction sequence with acid, water, and base (Kujawska et al., 2024). Extraction with NaOH or KOH promoted the dissociation of carboxyl and phenyl groups, as well as the breaking of ester bonds, increasing DOC content (Liu et al., 2022). In addition, Saito and Seckler reported that extraction with KOH obtained a larger amount of humic substances with higher purity than with NaOH (Saito and Seckler, 2014). Humic compounds derived from biochar, which are the most important components of biochar, directly improve soil fertility and play a role in soil improvement and restoration (Liu et al., 2022). On this basis, the choice of KOH as the extraction solution was proposed.

Macadamia nut production generates a large amount of by-product, known as macadamia nut husks. (Vu et al., 2023). In Dak Nong, Vietnam, with about 6500 ha, the yield is 1.5 tons of seeds/ha, and the waste hull accounts for 70–77% (Dao et al., 2020). This waste source has not yet been effectively exploited in studies other than biochar production, as a sub-layer that is at risk of causing environmental pollution. Therefore, the effective extraction of DOC from this biochar source and understanding the properties of the obtained DOC are essential in the orientation of agricultural applications. However, there is still a lack of information. Therefore, the current study of the extraction process with KOH was conducted with the objectives of (i) investigating the efficiency of DOC extraction and (ii) characterizing the components of DOC in the biochar extract.

MATERIALS AND METHODS

Preparation of biochar

Macadamia husks from Dak Nong (January 2024) were pre-dried, crushed (<5 mm), and dried at 60 °C for 24 hours. They were then pyrolyzed in a furnace (Nabertherm P330, Germany) at 300, 450, and 600 °C (named Bio 300; Bio 450, and Bio 600, respectively) at a heating rate of 10 °C/min and held for 2 hours. The resulting biochar was finely ground through a 1mm sieve, sealed in a PE bag at 4 °C, and used for the determination of volatile carbon (VOC), fixed carbon (FC), ash, and extraction assays (Van Phuong, 2025).

VOC determination is based on the decomposition of volatile organic compounds in biochar during high temperature (950 °C) combustion in an oxygen-deficient environment (covered crucible and air restriction). The mass loss after the combustion process is the amount of VOC. Ash determination is the complete combustion of organic components in biochar at high temperature (750 °C) and in an oxygen-deficient environment. After all organic substances have burned, the remaining unburned substances are inorganic minerals, called ash. FC content is calculated as the percentage remaining after subtracting VOC and Ash (Singh et al., 2017)

Experimental layout of extraction

The extraction process was simulated based from a previous study (Van Phuong, 2025), and was presented in Figure 1. Specifically, in a 500 mL glass beaker containing 400 mL of KOH solution at the determined concentrations. Weigh accurately 40 grams of biochar and slowly add it to the beaker containing KOH. The mixture is stirred and ground on an IKA T25 Digital Ultra–Turrax® (Germany) homogenizer at the speeds to be investigated. The homogenization time is between 1 and 3 hours (enough time for the reaction to reach equilibrium according to preliminary experiments). After the extraction process, the sample collection was centrifuged on a DLAB DM 0636 centrifuge at 4000 rpm for 5 minutes. The liquid fraction through a 0.45 μm filter (Azeem et al., 2023) is stored in glass tubes and sealed for later analysis.

Survey parameters: (i) biochar type (Bio 300, Bio 450, and Bio 600); (ii) KOH extraction concentration (0.5, 1.0, and 2.0 N); (iii) Homogenization speed (4000, 6000, and 8000 rpm); (iv) homogenization time (1, 2, and 3 h). Evaluation parameters: (i) DOC extraction efficiency; (ii) contribution ratio of humic acid-like substances (E4/E5), molecular weight (E2/E3), stable component (SUVA254) in the extraction solution.

Analysis and evaluation methods

Determination of total organic carbon (TOC) of biochar by the Walkley Black method (Tan, 2011) and DOC content (humic, fulvic acid) according to TCVN 8561:2010.

Determination of aromatic ring and molecular weight relationship (E2/E3): The absorbance of the extract solution was measured using a UV-VIS spectrophotometer (GENESY 10S UV-VIS, Thermo – USA). The spectral absorption ratio at

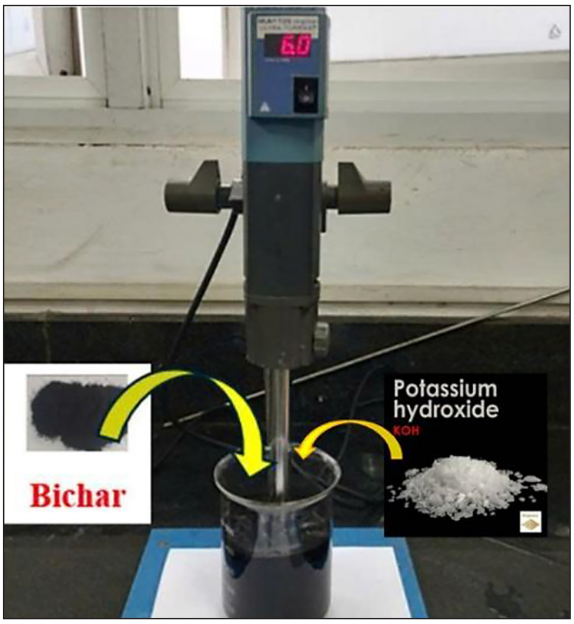

Figure 1. Experiment model

wavelengths of 254 and 365 nm (E2/E3) was calculated according to Formula 1:

$$E2/_{E3} = \frac{A_{254}}{A_{365}} \tag{1}$$

where: $A254$ and $A365$ are the absorbance at 254 and 365 nm. E2/E3 shows a correlation with both aromaticity and molecular weight (Mayhew et al., 2023). E2/E3 decreases with increasing molecular weight of organic matter (Zhang et al., 2022). This ratio can characterize the degree of humification of organic matter (Kujawska et al., 2024).

Determination of the correlation between organic components in the extract: E4/E5 is the ratio of the absorbance at 300 nm and 400 nm wavelengths, which characterizes the contribution of dissolved organic molecules. If E4/E5 < 3.5, the extract is mainly composed of humic acid-like substances. If E4/E5 > 3.5, the main component of the extract is mainly fulvic acid-like. (Zhang et al., 2022). The decrease in the E4/E5 absorption ratio is an indication of increasing aromaticity and molecular weight of humic substances.(Artinger et al., 2000).

$$E4/_{E5} = \frac{A_{300}}{A_{400}} \tag{2}$$

The absorbance was measured at 254 nm (SUVA254, L mg− 1 m− 1), representing the aromaticity or hydrophobicity of DOC. (Zhang et al., 2022), is calculated using Equation 3 (Sao et al., 2023).

$$SUVA_{254} = \frac{2.303 \times A_{254}}{L \times C} \tag{3}$$

where: C is the DOC concentration (mg/L) and L is the length of the quartz cuvette, which in this experiment was 1 cm. SUVA254 is the specific UV absorbance at 254 nm (L mg^{-1} m^{-1}).

DOC extraction efficiency was determined by formula 4:

$$H\% = \frac{V \times C}{m} 100 \tag{4}$$

where: C – DOC content in the extract, mg/L; H% – DOC extraction efficiency; m – is the mass of biochar used for extraction (dry conversion), g; V – is the volume of extracted solution obtained, g.

Experimental data processing

To ensure the reliability of the results and minimize errors, all experiments and analyses were repeated three times. Then, the collected data will be statistically analyzed using SPSS 23.0 software. Specifically, we first check the homogeneity of variances. Next, a one-way ANOVA test is used to determine the statistically significant difference between the mean values of the treatments. If the ANOVA test shows a significant difference ($p < 0.05$), we will conduct post-hoc tests to specifically identify pairs of different groups; in which, Tukey's HSD test is selected if the assumption of homogeneity of variance is satisfied (Sig > 0.05), but if this assumption is not satisfied (Sig < 0.05), the Tamhane test will be applied.

RESULTS AND DISCUSSION

Some properties of biochar

The results of determining some basic properties of biochar at pyrolysis temperatures (300, 450, and 600 °C) from macadamia husk based on approximate analysis, Table 1, show that the VOC trend decreased by 60.0, 28.1, and 25.5% respectively (statistically significant increase according to One-way ANOVA). The results of

Table 1. Basic properties of macadamia husk biochar

Parameters	Bio 300	Bio 450	Bio 600
Volatile carbon (VOC) content, %	60.0[a]	28.1[b]	25.5[b]
SD	0.0	0.8	1.8
Ash content, %	25.5[a]	54.1[b]	58.0[b]
SD	0.9	1.7	2.8
Fixed carbon (FC) content, %	14.4[a]	17.8[b]	22.4[c]
SD	1.0	1.0	1.0

Note: SD – standard deviation; Different letters a, b, c on the same row indicate significant differences according to One-way ANOVA analysis.

VOC fluctuations in the study were also similar to those of coffee husk biochar, ranging from 61.0 to 44.5%. (Van Phuong, 2025).

Ash content increased by 25.5%, 54.1%, and 58.0%, respectively (the increase in Bio 300 and Bio 450 was significant, while that between Bio 450 and Bio 600 °C was not significant). FC increased by 14.4%, 17.8%, and 22.4% respectively (the increase was similar to the change in ash content according to Oneway ANOVA analysis). The research results were consistent with the change trend of previous studies on biochar from coffee husks, rice straw, apple trees, and wood sawdust (Liu et al., 2022; Van Phuong, 2025). The increase in ash content with increasing pyrolysis temperature of biochar may be due to the loss of organic components during pyrolysis, and the content of inorganic components increases. A similar explanation is found in the report of Azeem et al. (2023).

Survey of DOC extraction efficiency

Biochar preparation temperature

The results of the DOC extraction process from biochar at pyrolysis temperatures derived from macadamia husks under conditions such as 1M KOH content, 6000 rpm grinding speed, two hours of extraction time, and 100 g/L biochar dosage are presented in Figure 2. The results show that the DOC extraction efficiency decreases with increasing pyrolysis temperature. Specifically, the DOC extracted from Bio 300, Bio 450, and Bio 600 samples had efficiencies of 12.7%, 11.0%, and 10.3%, respectively. The DOC extraction efficiency decreased significantly between Bio 300 and Bio 450, as shown in Figure 2. This decrease may be attributed to the significantly lower VOC content observed between Bio 300 and Bio 450, as detailed in Table 1 (Azeem et al., 2023). While the DOC extraction efficiency between Bio 450 and Bio 600 was not statistically different according to One-Way ANOVA analysis, it was similar to the change in VOC level of biochar. The results obtained were much higher than the research results of Liu et al., on rice straw, ranging from 0.47 to 4.9%. (Liu et al., 2022). However, this is lower than Van Phuong's study on coffee husks, which ranged from 16.7 to 33.7% (Van Phuong, 2025). This can be explained by the different materials used to prepare biochar and the pyrolysis conditions. On the other hand, the DOC extraction efficiency decreased when the pyrolysis temperature was high, possibly because at this temperature range, C in the crystalline form was not or was difficult to dissolve, affecting the DOC extraction efficiency (Azeem et al., 2023). Similar results were found in previous studies, a decreasing trend in DOC extraction efficiency with increasing pyrolysis temperature. (Kujawska et al., 2024; Van

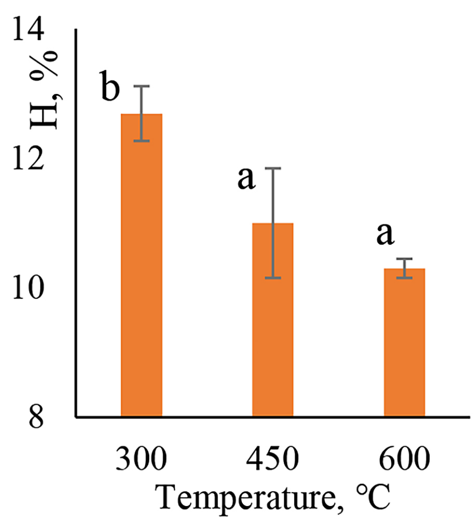

Figure 2. Demonstration of H% versus pyrolysis temperature. H%: DOC Extraction efficiency; Different letters a, b, c indicate statistically significant differences

Phuong, 2025). Based on the obtained DOC extraction efficiency, Bio 300 was selected for further investigations.

Extracted KOH content

The results of the survey on the influence of KOH content when extracting Bio 300 100 g/L under conditions such as speed 6000 rpm, and time 2 h are presented in Figure 3. The results show that H% increases when increasing KOH concentration. Specifically, H is 10.4%, 12.7%, and 13.3% corresponding to KOH 0.5, 1.0, and 2.0 N, respectively. The level of fluctuation increases significantly between KOH 0.5 and KOH 1.0 N. It can be explained that increasing KOH content breaks the bonds between organic acids and cations on the surface of biochar. The result is increased dissociation of carboxyl and phenyl groups, while causing hydrolysis of weak covalent bonds (such as ether, ester bonds) or breaking internal chain bonds (such as aromatic rings, fat bonds) (Kujawska et al., 2024; Van Phuong, 2025). On the other hand, KOH is a strong alkali, it can break down the hemicellulose structure contained in biochar with low pyrolysis temperature and release it into the extraction solution (Alwi et al., 2023). H% with KOH 1.0 and 2.0 N is not statistically significant. The difference between H% with KOH 1.0 and 2.0 N is not statistically significant. Increasing the KOH content leads to deep hydrolysis, producing CO_2, causing an insignificant change in H% (Wiranti et al., 2023). In addition, it is also possible that the organic matter dissolution process was saturated. With the results obtained, Bio 300 and 1N KOH content were selected for the following experiments.

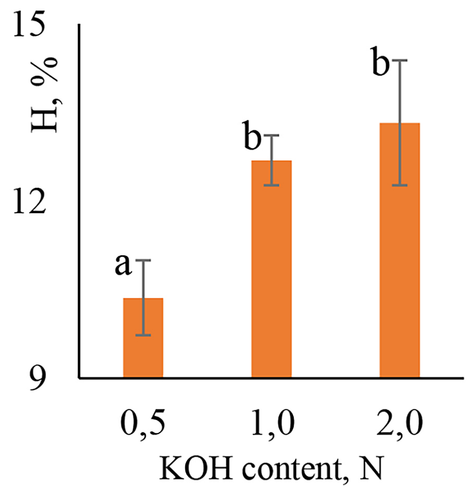

Figure 3. Demonstration of H% versus extracted KOH content. H%: DOC extraction efficiency; different letters a, b, c indicate statistically significant differences

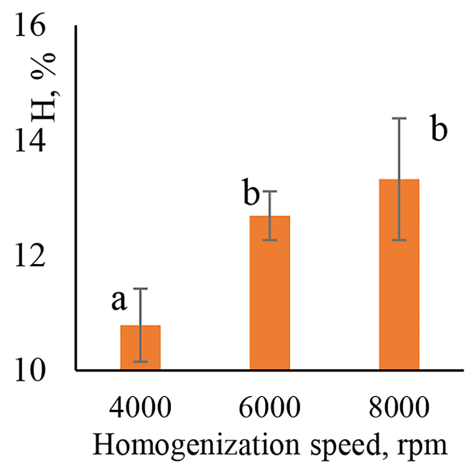

Figure 4. Representation of H% versus sample homogenization rate. H%: DOC extraction efficiency; different letters a, b, c indicate statistically significant differences

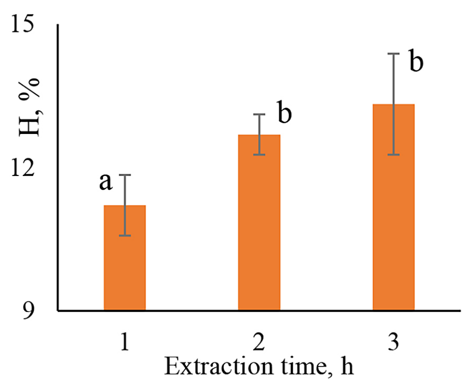

Figure 5. Representation of H% in homogeneous time. H%: DOC extraction efficiency; different letters a, b, c indicate statistically significant differences

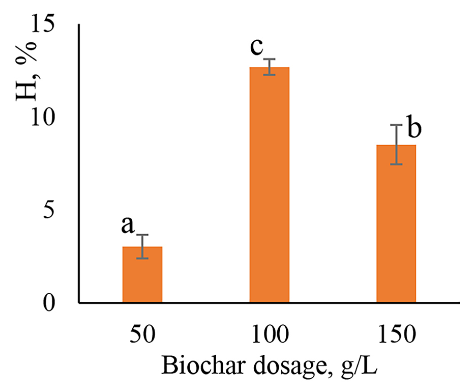

Figure 6. Representation of H% versus biochar dosage. H%: DOC extraction efficiency; different letters a, b, c indicate statistically significant differences

Homogenization speed

Figure 4 shows the H% from Bio 300 100 g/L when changing the homogenization speed (4000, 6000, and 8000 rpm) with 1N KOH, extraction time 2h. The results show that the DOC extraction efficiency increased by 10.8%, 12.7%, and 13.3% respectively. One-way ANOVA analysis shows that this change is statistically significant between the speeds of 4000 and 6000 rpm, while between 6000 and 8000 rpm, the difference is not statistically significant. This can be explained by the fact that increasing the homogenization speed increases the chance of releasing organic compounds from the biochar surface. Moreover, the impacts also rapidly reduce the biochar particle size, increasing the contact area of biochar with the KOH extract (Van Phuong, 2025). The selection of optimal conditions in this case will have to consider energy consumption, as well as equipment operation. Therefore, Bio 300, KOH 1N, and a homogenization speed of 6000 rpm were selected for further investigations.

Extraction time

The results of the investigation of the influence of extraction time with Bio 300 100 g/L, KOH 1N, speed 6000 rpm on H% are presented in Figure 5. H increased by 11.2%, 12.7%, and 13.3% respectively, for extraction times of 1, 2, and 3 hours. One-way ANOVA analysis revealed a significant increase in H% when the extraction time was extended from 1 hour to 2 hours. However, this increase was not significant when the time was further esxtended to 3 hours. A short time (1 hour) is not enough to reach the extraction equilibrium. Optimal efficiency at 2 hours and saturation after 3 hours (insignificant increase), similar to the previous study with coffee husk biochar (Van Phuong, 2025). Therefore, with Bio 300 100 g/L, KOH 1N, and speed 6000 rpm, extraction time of 2 hours was selected.

Biochar dosage

Figure 6 presents the results of the DOC extraction efficiency survey at Bio 300 doses of 50, 100, and 150 g/L. Specifically, H was 3.0%, 12.9% and 8.5% respectively for the biochar doses surveyed. Analyzing the differences in One-way ANOVA, H increased significantly when increasing the biochar dose from 50 to 100 g/L. Increasing the biochar dose will increase the chance of contact between biochar and the extract. However, when continuing to increase the biochar dose to 150 g/L, the efficiency decreased significantly. This can be explained by the fact that the DOC content in the extract has reached a state of dissolution equilibrium. In addition, there may be adhesion of organic colloidal particles to the biochar surface, hindering the dissolution of organic substances. (Van Phuong, 2025).

Survey on the composition characteristics of the DOC extraction solution

Biochar preparation temperature

The results of the survey on the influence of biochar type at pyrolysis temperatures with extraction conditions such as KOH 1N, speed 6000 rpm, extraction time 2 h, biochar dosage 100 g/L, Figure 7 shows that the E2/E3 value tends to increase from 0.6 to 0.8 and 3.6, respectively, with Bio 300, Bio 450, and Bio 600. The change is insignificant between Bio 300 and Bio 450, while there is a significant difference between Bio 450 and Bio 600. The research results show that the size of organic molecules in DOC decreases when the pyrolysis temperature of biochar is higher (E2/E3 increases) (Mayhew et al., 2023; Van Phuong, 2025). This may be due to the change in DOC composition from large molecular weight substances to medium and low molecular weight substances due to dissolution or chain cleavage reactions when the pyrolysis temperature increases (Liu et al., 2022; Van Phuong, 2025). The E2/E3 ratio value in the study was lower than that of the extract from biochar derived from coffee husk at pyrolysis temperatures of 300 and 450 °C (1.0 and 2.1) (Van Phuong, 2025), indicating that the organic chain cleavage process in macadamia husk was more difficult than coffee husk, or in other words, the amount of organic matter with considerable molecular weight in macadamia husk biochar was greater.

When considering the E4/E5 value, Figure 7 shows an increasing trend with biochar at higher pyrolysis temperatures. Specifically, E4/E5 increased from 2.8 to 5.2 and 11.0 for the biochar types, respectively. The increase was statistically significant at each pyrolysis temperature level. When E4/E5 <3.5, the DOC component was mainly composed of humic acid, whereas fulvic acid was the opposite (Van Phuong, 2025; Zhang et al., 2022). The results showed that only the extract from Bio 300 had an E4/E5 ratio <3.5 (2.8).

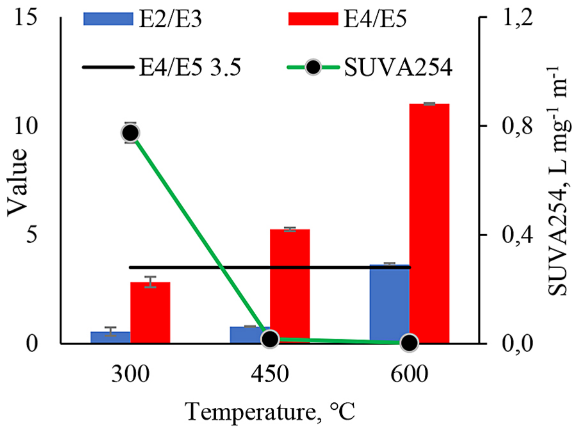

Figure 7. Characteristics of DOC extract according to biochar pyrolysis temperature

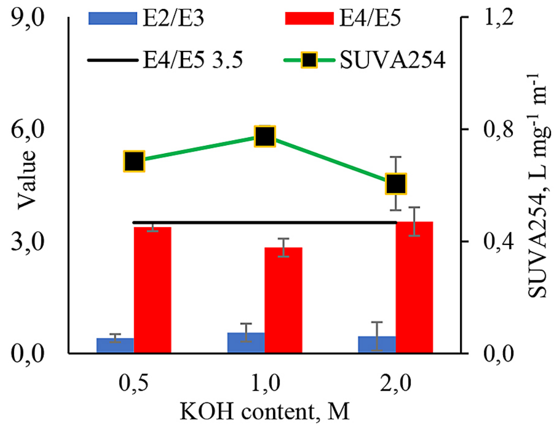

Figure 8. Representation of some characteristics of the extract according to KOH content

It can be concluded that the organic component with a humic acid-like structure accounted for the majority of the extract. Similar results were also found in Van Phuong's study in the case of coffee husk biochar. (Van Phuong, 2025). This can be explained: As the pyrolysis temperature increases, the properties of humic substances in biochar will change, namely the moisture content, aromaticity and molecular weight decrease. This phenomenon is mainly due to the secondary pyrolysis reactions occurring at high temperatures. Specifically, it leads to an increase in lower molecular weight compounds in the biochar product, including protic organic acids (low molecular weight acids) and neutral substances (such as alcohols, aldehydes, ketones, sugars, etc.). A similar explanation was found in the study by Liu and Van Phuong. (Liu et al., 2022; Van Phuong, 2025)

When looking at the SUVA254 value, it was found that it ranged from 0.003 to 0.78 L mg-1 m-1, Figure 7. The SUVA254 of Bio 300 extract was significantly higher (39 and 260 times higher than Bio 450 and Bio 600). SUVA254 showed that the aromaticity and hydrophobicity of DOC decreased gradually with increasing pyrolysis temperature, while the hydrophilicity increased. This may be related to the decomposition of aliphatic compounds at high temperatures. Similar trends were also found in previous studies (Liu et al., 2022; Van Phuong, 2025). Similar observations were also found in the study of Lehmann and Joseph that biochar with pyrolysis temperature >350 °C tended to lose more aromatic compounds and long-chain hydrocarbons (Lehmann and Joseph, 2024). Based on the values of E4/E5, E2/E3, SUVA254, Bio 300 was selected. The results were also consistent with the selection results when examining the DOC extraction efficiency, Figure 2.

Extracted KOH content

The results of the analysis of the DOC extract of the Bio 300 sample (100 g/L, speed 6000 rpm, extraction for 2 hours) at different KOH contents, at shown in Figure 8, indicate that the E2/E3 ratio does not fluctuate according to a clear trend. However, this difference is not significant, the values are 0.5, 0.4 and 0.6, respectively. The research results show that the molecular size of the organic components in the extract does not fluctuate significantly when changing the KOH extract content. When considering the value of the E4/E5 ratio, this ratio fluctuates from 2.8 to 3.5 (all <3.5) and the difference is also not significant according to Oneway ANOVA analysis. The results showed that the organic components with humic acid-like structure accounted for the majority of the extract at KOH contents in the range of 0.5 to 2.0 N. The SUVA254 values were 0.7, 0.8, and 0.6 L mg-1 m-1 corresponding to KOH contents of 0.5, 1.0 and 2.0N, respectively. SUVA254 had the highest value at 1N KOH content, showing higher aromatic and hydrophobic properties, Figure 8. When increasing KOH to 2.0N, the SUVA254 value decreased significantly. This indicates that high alkalinity triggers hydrolysis, chain cleavage, and decomposition processes occurred, which converted into insoluble substances (Liu et al., 2022). Based on the results obtained, Bio 300, KOH 1N was selected for the following experiments and this choice was also suitable for the case of considering the extraction efficiency.

Homogenization speed

The characteristics of the extract when changing the speed are shown in Figure 9. With the E2/E3 ratio, the value fluctuated from 0.39 to 0.56, an insignificant change. The results showed that the aromaticity and molecular weight of organic matter did not fluctuate much. With the E4/E5 index fluctuating from 2.5 to 3.1 (all <3.5), the change was not significant between the speed of 4000 and 6000 rpm, indicating that the organic components in the extract were mainly humic acid-like substances. The results were similar to the study of coffee husk biochar extraction at 300 °C with E4/E5 values all <3.5 (Van Phuong, 2025).

With the SUVA254 value, when increasing the homogenization speed, the homogenization efficiency was 0.8, 0.8, and 0.9 L mg-1 m-1 respectively. The SUVA254 values were not statistically different at the homogenization speeds, as shown in Figure 9. Based on the obtained results, a homogenization speed of 6000 rpm was selected, using Bio 300 100 g/L, KOH 1N, and an extraction time 2 h. The selected results were similar to those in the extraction efficiency survey.

Extraction time

The results of determining some characteristics of the extract with Bio 300 100 g/L, KOH 1N, speed 6000 rpm when changing the extraction time are shown in Figure 10. The E2/E3 values were 0.57, 0.56, and 0.64, respectively; the difference was not statistically significant. The results showed that the aromaticity and molecular weight of the organic components in the extract had reached a balance in the proportion of components soluble in KOH. The E4/E5 ratios were 2.7, 2.8, and 2.1 (all <3.5), respectively, corresponding to the extraction times of 1, 2 and 3 hours. The results showed that the main organic components in the extract were humic acid-like substances (Van Phuong, 2025). The E4/E5 values between the extraction times of 1 and 2 hours were not significantly different according to One-way ANOVA analysis. Meanwhile, between 2 and 3 hours, E4/E5 decreased statistically significantly. The SUVA254 values were 1.0, 0.8 and 0.9 L mg^{-1} m^{-1} respectively, for the three extraction times. The results showed that SUVA254 increased and decreased without a clear trend. In particular, SUVA254 with an extraction time of 2 hours showed a significant decrease compared to 1 and 3 hours. This indicates that the time was long enough to dissolve additional organic compounds characterized by aromaticity and hydrophobicity (Van Phuong, 2025). The survey results showed that based on the E2/E3 and E4/E5 values, the time of 2 hours was chosen, but according to SUVA254, the choice of 3 hours was preferred. Based on the extraction efficiency review results, the choice of 2 hours was more suitable.

Biochar dosage

Characteristics of the extract from Bio 300, KOH 1N, speed 6000 rpm, extraction time 2 hours when changing the dosage used, Figure 11, with E2/E3 values of 0.92, 0.56 and 0.73, respectively, for the biochar dosages used of 50, 100 and 150 g/L, Figure 10.

The increasing and decreasing trend is unclear, as the value decreases from 50 g/L to 100 g/L (significant decrease) then increases to 150

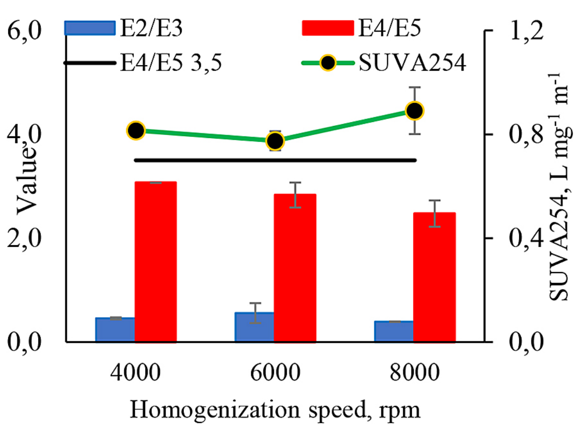

Figure 9. Representation of some extraction characteristics at homogenization speed

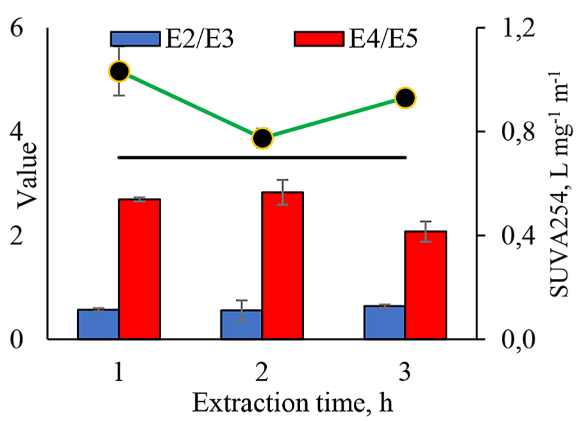

Figure 10. Representation of some extract characteristics according to extraction time

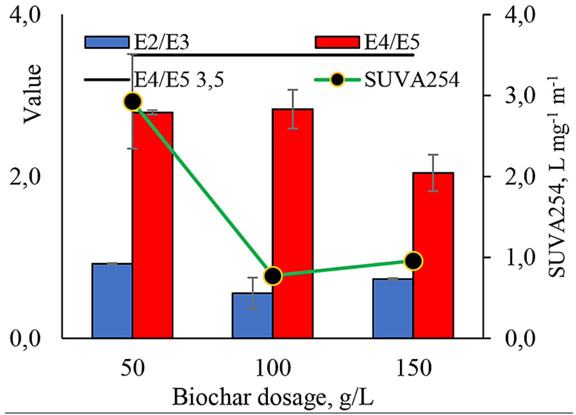

Figure 11. Extraction characteristics based on extraction time

g/L (significant increase). This can be explained based on the alkali ratio and the amount of biochar. When the alkali ratio is high, the extracted organic components have a smaller molecular weight under the condition that the extracted DOC is not saturated (larger E2/E3). When the biochar dose is too large compared to the organic matter with molecular weight re-adsorbed or adhered to the biochar particles, the low molecular weight organic component decreased sharply, Figure 10. With E4/E5 values of 2.8, 2.8 and 2.0 respectively <3.5, showing that the organic component in the extract is mainly humic acid-like components. The E4/E5 value between the doses of 50 and 100 g/L shows no significant difference, whereas between 100 and 150 g/L, a significant decrease is observed. With SUVA254 values of 2.9, 0.8 and 1.0 L/(mg m), respectively. The decrease is significant at the doses of 50 and 100 g/L and not significant between 100 and 150 g/L. This may be due to the fact that when the dose of biochar increased, aromatic compounds and double-bonded compounds or hydroxyl conjugates of organic compounds increased and then the absorption capacity at 254 nm increased strongly (Zhang et al., 2022).

Based on the research results, the Bio 300 dosage was prioritized in the order of 50, 100 and 150 g/L, respectively. Combined with the selection based on DOC extraction efficiency, it was shown that the extraction efficiency of 100 g/L was 4.2 times higher than that of 50 g/L, Figure 6. Therefore, the selected extraction parameters were Bio 300, KOH 1N, extraction time 2 h, extraction speed 6000 rpm, and the Bio 300 dosage used was 100 g/L.

CONCLUSION

This study has determined the important parameters for DOC extraction from macadamia husk biochar for agricultural purposes and with consideration of environmental protection. Firstly, the optimal extraction parameters under the laboratory survey conditions include biochar with a pyrolysis temperature of 300 °C (Bio 300), KOH extraction content of 1N, homogenization speed of 6000 rpm, extraction time of 2 hours, and biochar dosage of 100 g/L. Secondly, under these conditions, the highest DOC extraction efficiency was demonstrated at 12.7% and a DOC composition suitable for agricultural use with humic acid-like components mainly based on E4/E5 value (2.8), high molecular weight based on E2/E3 ratio (0.6), and stable components based on SUVA254 value (0.78). The results determined that pyrolysis temperature, extract content, homogenization speed, extraction time, and biochar dosage are important parameters determining the extraction efficiency and organic composition in the extract. Furthermore, the study provided a solution to improve the efficiency of agricultural by-products through liquid extracts is easily applicable through the prevalent automatic irrigation systems in Vietnamese agriculture.

Acknowledgements

The Authors are very grateful to the students of course 16, majoring in environmental technology. We are also very grateful to the Institute Of Science, Technology And Environmental Management for supporting the equipments. The reviewer's feedback is invaluable for improving the quality of our manuscript.

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