

Supplementary Material

Biochar for the Adsorption of Endocrine- disrupting Chemicals: Performance, Mechanisms, and Strategies

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Text S1. Factors Influencing Biochar Adsorption of EDCs

The removal of EDCs is influenced by various factors, including the amount of biochar added, the initial concentration of EDCs, temperature, pH, and the presence of coexisting ions and organic compounds in the environment. Among these, pH, coexisting ions, and coexisting organic compounds have a more complex effect on the removal of EDCs compared to other influencing factors.

1.1 pH

The pH value in the environment is a key factor affecting the adsorption effectiveness of biochar for EDCs. The pH primarily influences adsorption performance by altering the solubility and form of adsorbates in the solution and the surface charge characteristics of the adsorbent, thereby changing the interactions between the adsorbent and the adsorbates ¹. When the pH value is lower than the point of zero charge (pHpzc), the surface of the biochar is positively charged due to protonation, whereas when the pH value is higher than pHpzc, the surface is negatively charged due to deprotonation ². pH affects the interaction mechanism between biochar and EDCs, where electrostatic interactions are significantly influenced by pH, mainly due to changes in the surface charge of biochar ³. As the environmental pH increases, the negative electric charge on the surface of biochar increases, which may lead to electrostatic repulsion between the biochar and the anions of EDCs, thereby hindering the adsorption of EDCs and reducing its adsorption capacity ⁴. The pH value at the zero charge point (pHpzc) under different pH levels, the ionization state of different emerging contaminants (EDCs), changes in the chemical structure of biochar, whether the adsorption mechanism changes, and variations in the dispersion of biochar particles should be considered ⁵. Further research to clarify the influence of pH on the adsorption of EDCs by biochar.

1.2 Coexisting ions

The impact of coexisting ions in environmental factors on the removal of EDCs by biochar largely depends on the characteristics of the studied system, biochar and EDCs ⁶.

Generally, the presence of salt ions (such as Na^+ , NO_3^- , and Cl^-) in wastewater may have an adverse effect on the removal of organic EDCs due to competitive adsorption ⁷. Certainly, the presence of salt ions in the environment may also augment the adsorption of certain EDCs by biochar. Research has indicated that the presence of Mg^{2+} and Ca^{2+} enhances the adsorption capacity of per- and polyfluoroalkyl substances (PFAS), potentially due to the formation of cation bridges between deprotonated PFAS molecules and biochar ⁸. Research has found that when Cr(VI) and BPA coexist in a solution, the presence of Cr(VI) can enhance the removal efficiency of BPA, possibly due to increased hydrogen bonding interactions between BPA and biochar through bridge bonds of CrO_4^{2-} oxygen-containing groups ⁷.

In summary, the potential reasons for the influence of coexisting ions on the adsorption of EDCs by biochar may encompass competition for adsorption sites, direct or indirect modifications to the surface charge and other properties of the biochar, as well as changes in the solubility, hydrophobicity, and forms of existence of EDCs.

At the same time, both salt ions and heavy metal ions have a significant impact on the adsorption of EDCs by biochar due to their ionic strength. For example, when the concentration of NaCl reaches a certain level, the adsorption of E2 by biochar decreases as the concentration of NaCl increases ⁹. Research shows that ionic strength mainly affects the adsorption of EDCs in two ways: (1) coexisting ions may alter the static and conformational properties of EDCs, thereby reducing their solubility and hydrophobicity (the "salting-out" effect); (2) when the concentration of coexisting ions is high, the adsorption amount of EDCs decreases (the "squeeze-out" effect) ¹⁰⁻¹².

1.3 Coexisting organic compounds

Humic acid (HA) and fulvic acid (FA), which are dissolved organic matter (DOM), are commonly found in almost all aquatic ecosystems ¹⁰. These DOM can be adsorbed through π - π interactions, thereby occupying adsorption sites and reducing

adsorption capacity ¹³. In addition, HA may also reduce adsorption capacity by blocking the pores on the surface of biochar ¹⁴. At the same time, studies have found that timely removal of DOM can enhance the pore structure of biochar, thus improving its adsorption capacity ¹⁵. It is worth noting that when the concentrations of HA and FA are low, the functional groups of the adsorbed HA and FA can enhance the π - π EDA interactions and hydrogen bonding interactions, thereby increasing the adsorption capacity of the adsorbed pollutants ¹⁶.

Consequently, the influence of coexisting organic matter in the environment on the adsorption of EDCs by biochar can either be facilitative or detrimental. This effect is primarily determined by the concentrations of the coexisting organic matter and EDCs, the characteristics of the biochar (including charge, pore structure, surface area, etc.), and the interactions among these three factors. The early detection of organic matter content in the environment and the simulation of its impact on biochar's adsorption of EDCs can assist in optimizing the design of biochar, thereby mitigating the inhibitory effects of coexisting organic matter on adsorption or harnessing the facilitative effects of coexisting organic matter on adsorption.

Tab. S1 Regulation of Adsorption Mechanisms for Major EDCs Categories by Environmental Factors

| EDCs Category | Predominant Adsorption Mechanisms | pH Influence | Influence of Coexisting Ions | Influence of DOM |
|-----------------|--|--|---|---|
| Estrogenic EDCs | π - π EDA interaction, Hydrogen bonding, Hydrophobic interaction | Low pH (< pKa): Protonation reduces electrostatic repulsion, favoring adsorption; High pH (> pKa): Deprotonation increases electrostatic repulsion, inhibiting adsorption. | Ca ²⁺ /Mg ²⁺ : May enhance adsorption via cation bridging; Na ⁺ /K ⁺ : Compete for adsorption sites, causing mild inhibition. | Low DOM: May promote hydrophobic interaction; High DOM: Competitively inhibits via pore/site blocking; Specific DOM: May promote co-adsorption via hydrophobic or π - π interactions. |
| | | Low pH: PFAS protonation enhances electrostatic attraction; High pH: Deprotonated PFAS (negatively charged) repelled by negatively charged | Ca ²⁺ /Mg ²⁺ : May enhance adsorption via ion bridging; Cl ⁻ /SO ₄ ²⁻ : Compete for adsorption sites, inhibiting adsorption. | DOM-PFAS Interaction: Hydrophobic binding via fluorocarbon chains; competitive site occupation inhibits pore filling at high DOM. |
| PFAS | Hydrophobic interaction, Electrostatic attraction | | | |

biochar.

| | | | | |
|------|--|--|--|---|
| PAEs | Hydrophobic interaction, Pore filling | Minimal direct effect (primarily neutral molecules); Extreme pH may alter biochar surface charge and functional group protonation. | Na ⁺ : Alters ionic strength, mildly affecting hydrophobic interactions. | Hydrophobic DOM: May compete for hydrophobic sites, inhibiting adsorption; Hydrophilic DOM: Minimal effect. |
| PAHs | π - π EDA interaction, Hydrophobic interaction, Pore filling | Minimal direct effect (neutral molecules); Extreme pH may alter biochar surface functional groups and π -electron density. | Ionic strength has minor effect; Transition metal ions : May promote π - π interaction via surface complexation. | Aromatic DOM: May compete for adsorption sites via π - π interaction, inhibiting adsorption; Aliphatic DOM: Minimal effect. |
| OCPs | Hydrophobic interaction, Pore filling, Hydrogen bonding | Minimal direct effect; Indirectly influences adsorption by altering biochar surface charge. | Increased ionic strength may enhance hydrophobic adsorption via "salting-out" effect; Ca ²⁺ : May indirectly influence adsorption by bridging with DOM. | Hydrophobic DOM: Strongly competes for hydrophobic sites, significantly inhibiting adsorption; High DOM concentration: Generally inhibits adsorption. |

DOM: Dissolved Organic Matter, PFAS: Perfluoroalkyl substances, PAEs: Phthalate esters , PAHs: Polycyclic aromatic hydrocarbons, OCPs: organochlorine compounds

Tab. S2 Comparison between relevant reviews and this review

| Adsorption mechanisms | Preparation of biochar | Modification | | | Adsorption performance of biochar for different structural EDCs | Adsorption strategy | Factors affecting adsorption performance | | | Economic feasibility of biochar | Ref |
|---|------------------------|-----------------------|-----------------------|--------------------------|---|---------------------|--|----------------|--------------------------|---------------------------------|--------------------|
| | | physical modification | chemical modification | Biochar-based composites | | | pH | Ionic strength | dissolved organic matter | | |
| Yes | No | No | No | No | No | No | No | No | No | No | 17 |
| The review focuses on the value of lignocellulosic biomass as biochar for EDCs adsorption, as well as the characteristics and benefits of biochar | | | | | | | | | | | |
| No | Yes | Yes | Yes | Part | No | No | Yes | Yes | Yes | No | 18 |
| This review focuses on the removal of different types of EDCs by modified biochar and the impact of modification on the properties of biochar | | | | | | | | | | | |
| Yes | Yes | No | No | No | No | No | No | No | No | No | 19 |
| This review focuses on the most environmentally sustainable materials that can efficiently remove EDCs | | | | | | | | | | | |
| Yes | No | Yes | Yes | No | No | No | No | No | No | Yes | 20 |

This review aims to provide a systematic summary of current advancements in the adsorption of ECs by modified biochar

Yes No Yes Yes Part No No No No No Yes

This review focuses on biochar modification methods and adsorption mechanisms for ECs removal.

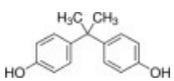
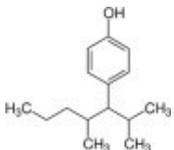
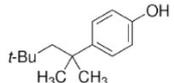
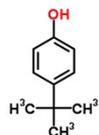
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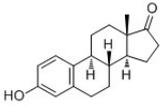
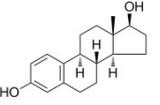
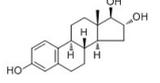
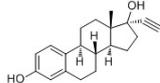
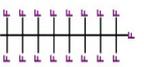
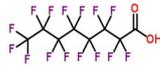
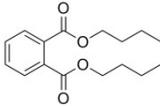
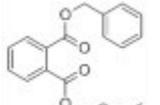
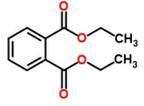
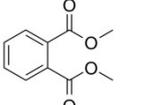
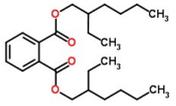
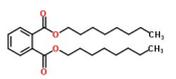
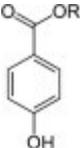
This review comprehensively analyzes the adsorption of EDCs by biochar, aiming to provide meaningful guidance for the design strategy and application of biochar for adsorbing EDCs

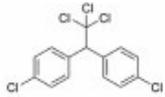
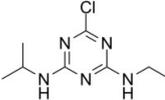
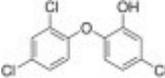
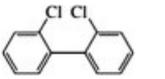
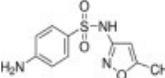
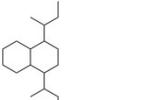
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This review

Tab. S3 The characteristics of some EDCs mentioned in the article.

| EDCs | Structure | Molecular formula | Molar mass (g/mol) | Water solubility (mg/L) | pKa | LogKow | Ref. |
|--------------------|---|--|--------------------|-------------------------|------------|-----------|-------|
| Bisphenol A |  | C ₁₅ H ₁₆ O ₂ | 228.29 | 120-130 | 9.60–10.02 | 2.20-3.40 | 22-24 |
| Nonylphenol |  | C ₁₅ H ₂₄ O | 220.35 | – | – | 4.00–5.00 | 24 |
| 4-tert-Octylphenol |  | C ₁₄ H ₂₂ O | 206.32 | – | 5.50 | – | 25 |
| 4-tert-Butylphenol |  | C ₁₀ H ₁₄ O | 150.22 | 610 | 10.16 | 3.31 | 22 |

| | | | | | | | |
|--------------------------------|---|-------------------|--------|--------------|------------------|-----------|------------|
| Estrone |  | $C_{18}H_{22}O_2$ | 270.37 | 30 | 10.34 ± 0.05 | 3.13–3.43 | 22 |
| 17 β -estradiol |  | $C_{18}H_{24}O_2$ | 272.38 | 13 | 10.46 ± 0.03 | 2.81 | 22 |
| Estriol |  | $C_{18}H_{24}O_3$ | 288.38 | 13 | 10.38 ± 0.02 | 2.81 | 22 |
| 17 α -ethinyl estradiol |  | $C_{20}H_{24}O_2$ | 296.40 | 4.7–19 | 10.40 | 3.67–4.20 | 11, 22, 24 |
| Perfluorooctane sulfonic acid |  | $C_8HF_{17}O_3S$ | 500.13 | – | -3.27 | 4.49 | 26 |
| Perfluorooctanoic acid |  | $C_8HF_{15}O_2$ | 414.07 | 3300 (25°C) | -0.5 0- 4.20 | – | 26 |
| Di-n-butyl phthalate |  | $C_{16}H_{22}O_4$ | 278.34 | 15 (25°C) | – | 4.83 | 5, 17, 24 |
| Butylbenzyl phthalate |  | $C_{19}H_{20}O_4$ | 312.36 | <2 (25°C) | – | 4.73 | 5, 17, 24 |
| Diethyl phthalate |  | $C_{12}H_{14}O_4$ | 222.24 | <1000 (25°C) | – | 2.70 | 5, 24 |
| Dimethyl phthalate (DMP) |  | $C_{10}H_{10}O_4$ | 194.18 | <100 (25°C) | – | 1.64 | 5, 24 |
| Di (2-ethylhexyl)-phthalate |  | $C_{24}H_{38}O_4$ | 390.56 | <1 (25°C) | – | 8.71 | 5, 24 |
| Di-n-octyl phthalate |  | $C_{24}H_{38}O_4$ | 390.56 | <1 (25°C) | – | 9.08 | 5, 24 |
| Paraben |  | – | – | – | – | 1.96–3.56 | 24 |

| | | | | | | | |
|-----------------------------------|---|---|--------|-----------------|------------|-----------|--------|
| Dichloro diphenyl trichloroethane |  | C ₁₄ H ₉ Cl ₅ | 354.49 | 5.5e-03 (25 °C) | – | 4.89–6.91 | 24 |
| Atrazine |  | C ₈ H ₁₄ ClN ₅ | 215.68 | 33 (25°C) | 1.60 | 2.61 | 24, 27 |
| Triclosan |  | C ₁₂ H ₇ Cl ₃ O ₂ | 289.54 | 10 (20°C) | 8.14 | – | 24 |
| 2,2'-dichlorobiphenyl |  | C ₁₂ H ₈ Cl ₂ | 223.00 | – | – | 4.65 | 28 |
| Sulfamethoxazole |  | C ₁₀ H ₁₁ N ₃ O ₃ S | 253.28 | 610 (37°C) | 1.80, 5.70 | 0.89 | 23 |
| Naphthalene |  | C ₁₈ H ₁₄ | 252.27 | – | – | – | 29 |

a. The partial pKa , LogKow and water solubility of EDCs are sourced from <https://pubchem.ncbi.nlm.nih.gov>

b. The structure, molecular formula, density, and molar mass of EDCs are derived from <https://www.chemsrc.com/>

c. Part of the table content has been mentioned in the references listed in the table

Tab. S4 Abbreviation of the full text

| Abbreviation | Full English Name |
|--------------|-------------------------------------|
| EDCs | Endocrine-disrupting chemicals |
| PFAS | Per- and polyfluoroalkyl substances |
| PAEs | Phthalate esters |
| AOP | Advanced oxidation processes |
| MBR | Membrane bioreactor |
| LBM | Lignocellulosic biomass |
| NLBM | Non-lignocellulosic biomass |
| BPA | Bisphenol A |
| SSA | Specific surface area |
| PCBs | Polychlorinated biphenyls |
| PAHs | Polycyclic aromatic hydrocarbons |
| ATR | Atrazine |
| TC | Tetracycline hydrochloride |
| GO | Graphene oxide |
| CNTs | Carbon nanotubes |
| EDA | Donor-acceptor |
| DOM | Dissolved organic matter |
| HA | Humic acid |
| OCPs | Organochlorine pesticides |
| E1 | Estrone |

| | |
|-------|-----------------------------------|
| E2 | 17 β -estradiol |
| E3 | Estriol |
| EE2 | 17 α -ethinylestradiol |
| BPA | Bisphenol A |
| BPS | Bisphenol S |
| NAP | Naphthalene |
| PHE | Phenanthrene |
| PFCA | Perfluoroalkyl carboxylic acids |
| PFSA | Perfluoroalkyl sulfonic acids |
| PFOA | Perfluorooctanoic acid |
| PFPeA | Perfluoropentanoic acid |
| PFOS | Perfluorooctanesulfonic acid |
| DBP | Dibutyl phthalate |
| DMP | Dimethyl phthalate |
| DEP | Diethyl phthalate |
| BBP | Butyl benzyl phthalate |
| DnOP | n-octyl phthalate |
| DEHP | Di (2-ethylhexyl) phthalate |
| MeP | Methylparaben |
| TCS | Triclosan |
| PHE | Phenanthrene |
| NP | Nonylphenol |
| SMZ | Sulfamethazine |
| SMX | Sulfamethoxazole |
| CIP | Ciprofloxacin |
| PCDDs | Polychlorinated dibenzo-p-dioxins |
| PCDFs | Polychlorinated dibenzofurans |
| LMW | Low molecular weight |
| HMW | High molecular weight |

Fig. S1

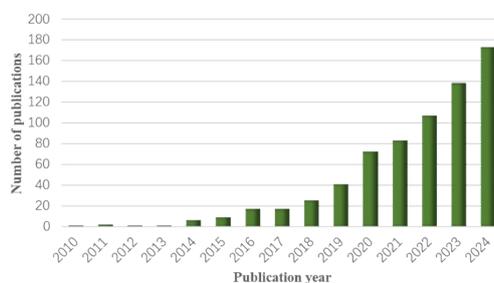


Fig. S1 Literature statistics on the topic of 'biochar' and 'emerging contaminants' in the Web of Science database from 2010 to 2024.

Fig. S2

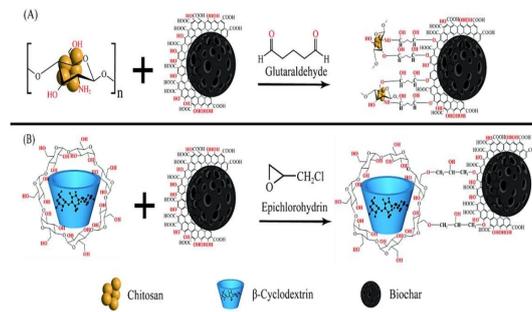


Fig. S2 Biochar modified with chitosan and β -cyclodextrin with Glutaraldehyde (A) and Epichlorohydrin (B) as the cross-linking agents, respectively ³⁰.

Fig. S3

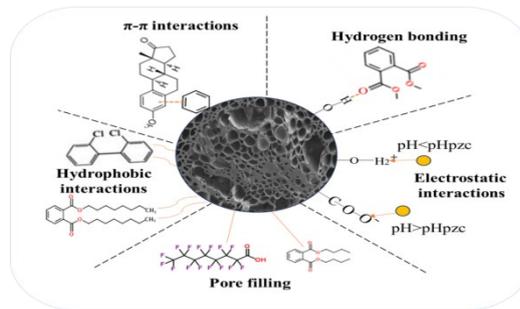


Fig. S3 The mechanisms underlying the adsorption of EDCs by biochar.

References

1. Dai, J., Meng, X., Zhang, Y., Huang, Y., Effects of modification and magnetization of rice straw derived biochar on adsorption of tetracycline from water, *Bioresour. Technol.*, **2020**, *311*, 123455, DOI: 10.1016/j.biortech.2020.123455.
2. Ma, S., Jing, F., Sohi, S. P., Chen, J., New insights into contrasting mechanisms for PAE adsorption on millimeter, micron- and nano-scale biochar, *Environ. Sci. Pollut Res.*, **2019**, *26* (18), 18636-18650, DOI: 10.1007/s11356-019-05181-3. Sangeeta Patel, J. H., Wei Gao,, Sorption of 17 β -estradiol from aqueous solutions on to bone char derived from waste cattle bones: Kinetics and isotherms,, *J. Environ. Chem. Eng.*, **2015**,, *3* (3), 1562-1569, DOI: 10.1016/j.jece.2015.04.027.
3. Luo, Z., Yao, B., Yang, X., Wang, L., Xu, Z., Yan, X., Tian, L., Zhou, H., Zhou, Y., Novel insights into the adsorption of organic contaminants by biochar: A review, *Chemosphere*, **2022**, *287*, 132113, DOI: 10.1016/j.chemosphere.2021.132113.
4. Tong, X., Jiang, L., Li, Y., Chen, X., Zhao, Y., Hu, B., Zhang, F., Function of agricultural waste montmorillonite-biochars for sorptive removal of 17 β -estradiol, *Bioresour. Technol.*, **2020**, *296*,

122368, DOI: 10.1016/j.biortech.2019.122368. Guo, W., Lu, S., Shi, J., Zhao, X., Effect of corn straw biochar application to sediments on the adsorption of 17 α -ethinyl estradiol and perfluorooctane sulfonate at sediment-water interface, *Ecotoxicology and Environmental Safety*, **2019**, *174*, 363-369, DOI: 10.1016/j.ecoenv.2019.01.128.

5. Ye, H., Zhao, B., Zhou, Y., Du, J., Huang, M., Recent advances in adsorbents for the removal of phthalate esters from water: Material, modification, and application, *Chem. Eng. J.*, **2021**, *409*, 128127, DOI: 10.1016/j.cej.2020.128127.

6. Mrozik, W., Minofar, B., Thongsamer, T., Wiriyaiphong, N., Khawkomol, S., Plaimart, J., Vakros, J., Karapanagioti, H., Vinitnantharat, S., Werner, D., Valorisation of agricultural waste derived biochars in aquaculture to remove organic micropollutants from water-experimental study and molecular dynamics simulations, *J. Environ. Manag.*, **2021**, *300*, 113717, DOI: 10.1016/j.jenvman.2021.113717.

Zeidabadi, F. A., Esfahani, E. B., Mohseni, M., Effects of water matrix on per- and poly-fluoroalkyl substances (PFAS) treatment: Physical-separation and degradation processes-A review, *Journal of Hazardous Materials Advances*, **2023**, *10*, 100322, DOI: 10.1016/j.hazadv.2023.100322.

7. Zhao, N., Zhao, C., Lv, Y., Zhang, W., Du, Y., Hao, Z., Zhang, J., Adsorption and coadsorption mechanisms of Cr(VI) and organic contaminants on H₃PO₄ treated biochar, *Chemosphere*, **2017**, *186*, 422-429, DOI: 10.1016/j.chemosphere.2017.08.016.

8. Liu, Z.-Z., Pan, C.-G., Peng, F.-J., Hu, J.-J., Tan, H.-M., Zhu, R.-G., Zhou, C.-Y., Liang, H., Yu, K., Rapid adsorptive removal of emerging and legacy per- and polyfluoroalkyl substances (PFASs) from water using zinc chloride-modified litchi seed-derived biochar, *Bioresour. Technol.*, **2024**, *408*, 131157, DOI: 10.1016/j.biortech.2024.131157.

9. Liu, N., Liu, Y., Zeng, G., Gong, J., Tan, X., Wen, J., Liu, S., Jiang, L., Li, M., Yin, Z., Adsorption of 17 β -estradiol from aqueous solution by raw and direct/pre/post-KOH treated lotus seedpod biochar, *J. Environ. Sci.*, **2020**, *87*, 10-23, DOI: 10.1016/j.jes.2019.05.026.

10. Shi, W., Wang, H., Yan, J., Shan, L., Quan, G., Pan, X., Cui, L., Wheat straw derived biochar with hierarchically porous structure for bisphenol A removal: Preparation, characterization, and adsorption properties, *Sep. Purif. Technol.*, **2022**, *289*, 120796, DOI: 10.1016/j.seppur.2022.120796.

11. Liu, Q., Li, D., Cheng, H., Cheng, J., Du, K., Hu, Y., Chen, Y., High mesoporosity phosphorus-containing biochar fabricated from *Camellia oleifera* shells: Impressive tetracycline adsorption performance and promotion of pyrophosphate-like surface functional groups (C-O-P bond), *Bioresour. Technol.*, **2021**, *329*, 124922, DOI: 10.1016/j.biortech.2021.124922.

12. Wang, X., Liu, N., Liu, Y., Jiang, L., Zeng, G., Tan, X., Liu, S., Yin, Z., Tian, S., Li, J., Adsorption Removal of 17 β -Estradiol from Water by Rice Straw-Derived Biochar with Special Attention to Pyrolysis Temperature and Background Chemistry, *Int. J. Environ. Res. Public Health*, **2017**, *14* (10), 1213, DOI: 10.3390/ijerph14101213.

13. Nebbioso, A., Piccolo, A., Molecular characterization of dissolved organic matter (DOM): a critical review, *Anal. Bioanal. Chem.*, **2013**, *405* (1), 109-124, DOI: 10.1007/s00216-012-6363-2.

14. Zhang, J., Lu, M., Wan, J., Sun, Y., Lan, H., Deng, X., Effects of pH, dissolved humic acid and Cu²⁺ on the adsorption of norfloxacin on montmorillonite-biochar composite derived from wheat straw, *Biochem. Eng. J.*, **2018**, *130*, 104-112, DOI: 10.1016/j.bej.2017.11.018.

15. Zhou, X., Lai, C., Almatra, E., Liu, S., Yan, H., Qian, S., Li, H., Qin, L., Yi, H., Fu, Y., Li, L., Zhang, M., Xu, F., Zeng, Z., Zeng, G., Unveiling the roles of dissolved organic matters derived from different biochar in biochar/persulfate system: Mechanism and toxicity, *Sci. Total Environ.*, **2023**, *864*, 161062, DOI: 10.1016/j.scitotenv.2022.161062.

16. Wu, Y., Yang, M., Long, D., Yang, F., Luo, S., Tetracycline Adsorption on Magnetic Sludge Biochar: Effects of pH, Humic Acid (HA), and Fulvic Acid (FA), *Micromachines*, **2022**, *13* (7), 1057, DOI: 10.3390/mi13071057.
17. Mahesh, N., Shyamalagowri, S., Pavithra, M. K. S., Alodhayb, A., Alarifi, N., Aravind, J., Kamaraj, M., Balakumar, S., Viable remediation techniques to cleansing wastewaters comprising endocrine-disrupting compounds, *Environ. Res.*, **2023**, *231*, 116245, DOI: 10.1016/j.envres.2023.116245.
18. Dixit, A., Ahammed, M. M., Use of modified biochar for removal of endocrine disrupting compounds from water and wastewater: A review, *Bioresour. Technol Rep.*, **2023**, *23*, 101519, DOI: 10.1016/j.biteb.2023.101519.
19. Nasir, H. M., Wee, S. Y., Aris, A. Z., Abdullah, L. C., Ismail, I., Processing of natural fibre and method improvement for removal of endocrine-disrupting compounds, *Chemosphere*, **2022**, *291*, 132726, DOI: 10.1016/j.chemosphere.2021.132726.
20. Zhang, J., Chen, Z., Liu, Y., Wei, W., Ni, B.-J., Removal of emerging contaminants (ECs) from aqueous solutions by modified biochar: A review, *Chem. Eng. J.*, **2024**, *479*, 147615, DOI: 10.1016/j.cej.2023.147615.
21. Cheng, N., Wang, B., Wu, P., Lee, X., Xing, Y., Chen, M., Gao, B., Adsorption of emerging contaminants from water and wastewater by modified biochar: A review, *Environ. Pollut.*, **2021**, *273*, 116448, DOI: 10.1016/j.envpol.2021.116448.
22. Ahmed, M. B., Zhou, J. L., Huo Hao, N., Johir, M. A. H., Sornalingam, K., Sorptive removal of phenolic endocrine disruptors by functionalized biochar: Competitive interaction mechanism, removal efficacy and application in wastewater, *Chem. Eng. J.*, **2018**, *335*, 801-811, DOI: 10.1016/j.cej.2017.11.041.
23. Ahsan, M. A., Islam, M. T., Imam, M. A., Hyder, A. H. M. G., Jabbari, V., Dominguez, N., Noveron, J. C., Biosorption of bisphenol A and sulfamethoxazole from water using sulfonated coffee waste: Isotherm, kinetic and thermodynamic studies, *J. Environ. Chem. Eng.*, **2018**, *6* (5), 6602-6611, DOI: 10.1016/j.jece.2018.10.004.
24. Surana, D., Gupta, J., Sharma, S., Kumar, S., Ghosh, P., A review on advances in removal of endocrine disrupting compounds from aquatic matrices: Future perspectives on utilization of agri-waste based adsorbents, *Sci. Total Environ.*, **2022**, *826*, 154129, DOI: 10.1016/j.scitotenv.2022.154129.
25. Lockington, C., Favetta, L. A., How Per- and Poly-Fluoroalkyl Substances Affect Gamete Viability and Fertilization Capability: Insights from the Literature, *J. Xenobiot.*, **2024**, *14* (2), 651-678, DOI: 10.3390/jox14020038.
26. Liu, Y., Ptacek, C. J., Baldwin, R. J., Cooper, J. M., Blowes, D. W., Application of zero-valent iron coupled with biochar for removal of perfluoroalkyl carboxylic and sulfonic acids from water under ambient environmental conditions, *Sci. Total Environ.*, **2020**, *719*, 137372, DOI: 10.1016/j.scitotenv.2020.137372. Hassan, M., Du, J., Liu, Y., Naidu, R., Zhang, J., Ahsan, M. A., Qi, F., Magnetic biochar for removal of perfluorooctane sulphonate (PFOS): Interfacial interaction and adsorption mechanism, *Environ. Technol. Innov.*, **2022**, *28*, 102593, DOI: 10.1016/j.eti.2022.102593.
27. Yaashikaa, P. R., Kumar, P. S., Varjani, S. J., Saravanan, A., Advances in production and application of biochar from lignocellulosic feedstocks for remediation of environmental pollutants, *Bioresour. Technol.*, **2019**, *292*, 122030, DOI: 10.1016/j.biortech.2019.122030.
28. Wang, F., Ren, X., Sun, H., Ma, L., Zhu, H., Xu, J., Sorption of polychlorinated biphenyls onto biochars derived from corn straw and the effect of propranolol, *Bioresour. Technol.*, **2016**, *219*, 458-465, DOI: 10.1016/j.biortech.2016.08.006.

29. Lamichhane, S., Krishna, K. C. B., Sarukkalige, R., Polycyclic aromatic hydrocarbons (PAHs) removal by sorption: A review, *Chemosphere*, **2016**, *148*, 336-353, DOI: 10.1016/j.chemosphere.2016.01.036.
30. Wang, Q., Tang, S.-F., Zhang, Y., Lai, C.-J.-S., Recent development of natural polysaccharide-modified biochar on adsorption of pollutants from wastewater: Preparation, characterization, mechanisms and applications, *Sep. Purif. Technol.*, **2024**, *343*, 127142, DOI: 10.1016/j.seppur.2024.127142.