**Supplemental materials of the manuscript:**

**Biochar derived from traditional Chinese medicine residues: An efficient adsorbent for heavy metal Pb(II)**

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Fig. S1 The point of zero charges diagrams for the TCMR biochars.



Fig. S2 Nitrogen isothermal adsorption and desorption curves of the TCMR biochars.



Fig. S3 (a) TGA pyrolysis curves and (b) DTG analysis of TCMR biochars.



Fig. S4 The SEM-EDS images of biochars (a) before and (b) after adsorption.

Table S1 Volume distribution of pore types of five types of biochar.

|  |  |  |  |
| --- | --- | --- | --- |
| Biochar | Pore-size range(nm) | Pore volume(cm3/g) | Percentage of pore volume (%) |
| BDNS | 2.00-10.00 | 0.00165 | 19.12 |
| 10.00-20.00 | 0.00082 | 9.47 |
| 20.00-50.00 | 0.00117 | 13.51 |
| >50.00 | 0.00500 | 57.90 |
| BCX | 2.00-10.00 | 0.00078 | 12.49 |
| 10.00-20.00 | 0.00054 | 8.67 |
| 20.00-50.00 | 0.0072 | 11.47 |
| >50.00 | 0.00423 | 67.37 |
| BDG | 2.00-10.00 | 0.00080 | 12.80 |
| 10.00-20.00 | 0.00059 | 9.41 |
| 20.00-50.00 | 0.00095 | 15.13 |
| >50.00 | 0.00392 | 62.66 |
| BDGS | 2.00-10.00 | 0.00151 | 22.92 |
| 10.00-20.00 | 0.00068 | 10.34 |
| 20.00-50.00 | 0.00063 | 9.53 |
| >50.00 | 0.00378 | 57.21 |
| BHQ | 2.00-10.00 | 0.00142 | 19.24 |
| 10.00-20.00 | 0.00061 | 8.27 |
| 20.00-50.00 | 0.00077 | 10.52 |
| >50.00 | 0.00457 | 61.97 |

Table S2 Concentrations of surface functional groups of five kinds of biochars determined by Boehm titration.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Biochar | Carboxylic(mmol/g) | Phenolic(mmol/g) | Lactonic(mmol/g) | Total acid functional group | Total alkaline functional group |
| BDNS | 0.15a | 0.05b | 0.14a | 0.33a | 0.45a |
| BCX | 0.06c | 0.04bc | 0.05c | 0.15d | 0.20d |
| BDG | 0.13b | 0.12a | 0.05c | 0.30b | 0.39b |
| BDGS | 0.12b | 0.02c | 0.11b | 0.25c | 0.30c |
| BHQ | 0.05c | 0.04bc | 0.04c | 0.14d | 0.21d |

The different letters in each column indicate significant differences between biochars from the various residues (p < 0.05).

Table S3 TGA Pyrolysis steps of TCMR biochars.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Biochar | Step 1(Midpoint) | Step 2(Midpoint) | Step 3(Midpoint) | Step 4(Midpoint) | Total weight loss rate |
| BDNS | 3.81%(92℃) | 9.50%(615℃) | 4.91%(902℃) | - | 18.22% |
| BCX | 5.69%(83℃) | 10.04%(591℃) | 8.23%(904℃) | - | 23.96% |
| BDG | 5.35%(111℃) | 11.27%(600℃) | 4.53%(916℃) | - | 21.15% |
| BDGS | 3.39%(96℃) | 2.69%(322℃) | 6.96%(619℃) | 6.24%(901℃) | 19.28% |
| BHQ | 3.89%(70℃) | 11.74%(583℃) | 6.32%(916℃) | - | 21.95% |

Table S4 The-D and G-band shifts, FWHMs, and ID/IG ratios.

|  |  |  |  |
| --- | --- | --- | --- |
| Biochar | D-Band | G-Band | ID/IG |
| Raman Shift (cm−1) | FWHMs | Raman Shift (cm−1) | FWHMs |
| BDNS | 1360 | 208 | 1584 | 94 | 1.27 |
| BCX | 1356 | 230 | 1588 | 99 | 1.47 |
| BDG | 1355 | 204 | 1584 | 105 | 0.97 |
| BDGS | 1360 | 202 | 1595 | 84 | 1.64 |
| BHQ | 1363 | 178 | 1592 | 93 | 0.99 |

Table S5 Adsorption characteristics of Pb(II) removal using different pristine biochars.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Biochar type | Pyrolysis temperature  | Residence time/min | Kinetic model | Isotherm model | Adsorption capacity(mg/g) | References |
| Peanut shell | 375℃ | 60 | Sec | Langmuir | 23.58 | ([Jiang et al., 2022](#_ENREF_4" \o "Jiang, 2022 #3085)) |
| Rice straw | 800℃ | 120 | Sec | Langmuir | 41.2 | ([Pham et al., 2022](#_ENREF_7" \o "Pham, 2022 #3401)) |
| Nut shells | 430℃ | 240 | Sec | Langmuir | 56.47 | ([Li et al., 2020](#_ENREF_5" \o "Li, 2020 #3400)) |
| Straw | 430℃ | 240 | Sec | Langmuir | 61.73 | ([Li et al., 2020](#_ENREF_5" \o "Li, 2020 #3400)) |
| Sheep manure | 500℃ | 90 | Sec | Freundlich | 36.2 | ([Wang et al., 2023](#_ENREF_8" \o "Wang, 2023 #3396)) |
| Robinia pseudoacacia | 500℃ | 90 | Sec | Freundlich | 7.4 | ([Wang et al., 2023](#_ENREF_8" \o "Wang, 2023 #3396)) |
| cherry kernel | 500℃ | - | Multiple | Freundlich | 44.92 | ([Pap et al., 2021](#_ENREF_6" \o "Pap, 2021 #3399)) |
| Orange peel | - | - | Sec | Langmuir | 27.86 | ([Abdelhafez & Li, 2016](#_ENREF_1" \o "Abdelhafez, 2016 #3390)) |
| Popinac | 550℃ | 240 | Sec | Freundlich | 22.9 | ([Huang et al., 2024](#_ENREF_3" \o "Huang, 2024 #3393)) |
| Avocado | 600℃ | 90 | Sec | Freundlich | 60.46 | ([Bassareh et al., 2023](#_ENREF_2" \o "Bassareh, 2023 #3395)) |
| Bitter orange | 600℃ | 90 | Sec | Freundlich | 59.42 | ([Bassareh et al., 2023](#_ENREF_2" \o "Bassareh, 2023 #3395)) |
| Walnut leaves | 600℃ | 90 | Sec | Freundlich | 58.48 | ([Bassareh et al., 2023](#_ENREF_2" \o "Bassareh, 2023 #3395)) |
| Danshen | 500℃ | 120 | Sec | Langmuir | 36.42 | This study |
| Chuanxiong | 500℃ | 120 | Sec | Langmuir | 7.84 |
| Danggui | 500℃ | 120 | Sec | Langmuir | 9.00 |
| Dangshen | 500℃ | 120 | Sec | Langmuir | 18.67 |
| Huangqi | 500℃ | 120 | Sec | Langmuir | 7.45 |

Sec: Pseudo-second-order model

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