Supplementary Material

Ginger straw waste derived porous carbons as effective adsorbents toward methylene blue

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Supplementary caption:
Figure S1. Effect of (A) c0 (2 h, 25°C, pH: 12) for MB adsorption on GSPC. (B) Pseudo-second-order kinetic model of MB adsorption on GSPC.

Figure S2. SEM image of GSPC after five cycles of adsorption-desorption.

Figure S3. EDS spectra of GSPC (A) before first cycle and (B) after fifth cycle.

Table S1. Specific surface area and pore characteristics of GSPC at various temperatures.

Table S2. Comparison of the specific surface area of other biomass carbons.

Table S3. Kinetic model parameters of MB adsorption on GSPC.

Table S4. Isotherm model parameters of MB adsorption on GSPC.

Table S5. Comparison of the max adsorption capacities of MB on various biomass carbons.

Materials and methods

Materials

Ginger straw was collected from the ginger field. Methylene blue (MB) were purchased from Sigma-Aldrich Co. LLC. (St Louis, USA) and other chemicals were all obtained from Chengdu Kelong Chemical Reagent Co. (Sichuan, China). Ultrapure water was used for all experiments.

Characterizations

The morphology of prepared samples was obtained on a Hitachi SU8220 field-emission scanning electron microscope (SEM, Japan) operated at 20 kV. X-ray diffraction (XRD) patterns were performed by a Bruker D8 diffractometer (Bruker, Germany) using the CuKa radiation. Fourier transform-infrared (FTIR) spectra were recorded using a Nicolet 6700 spectrophotometer (Thermo Fisher, USA). Nitrogen adsorption-desorption isotherm was measured using a Quadrasorb instrument (Quantachrome, USA) at 150°C, and data analysis was performed with Quantachrome software. The average pore sizes were calculated from the nitrogen adsorption isotherms according to the nonlocal density functional theory (NLDFT) model. UV-vis absorption spectra were performed on a Perkin Elmer Lambda 25 spectrophotometer.

Synthesis of ginger straw derived porous carbons (GSPC)

In a typical process, 5.0 g ginger straw powder was transferred in a tube furnace under nitrogen flow with a heating rate of 5°C min⁻¹ and then held at 300, 400, 500, 600, 700 °C for 1 h, respectively. Then, the as-prepared samples were washed with ultrapure water. Finally, the
product was dried at 60 ºC in an oven for 24 h.

**Batch adsorption experiments**

Batch adsorption experiments were performed in glass bottles containing 10 mg of GSPC and 10 mL of MB aqueous solutions with the initial concentrations ranging from 100 and 300 mg L⁻¹. Subsequently, the mixtures were shaken in a shaking incubator at different times with a shaking speed of 200 rpm. Then, the mixtures were centrifuged and the supernatant concentrations of MB were determined by a UV-Vis spectrophotometer at 664 nm. The effect of solution pH on MB adsorption on GSPC was investigated by varying pH value from 2 to 12. The effect of temperature on MB removal was also studied by keeping the temperature at 25-55 ºC. The adsorption capacity of MB by GSPC was calculated via the following equations:

\[ q_e = \frac{(c_0 - c_e)V}{m} \]  
(1)

\[ q_t = \frac{b q_m C_e}{1 + b C_e} \]  
(4)

\[ q_e = k C_e^{1/n} \]  
(5)

where \( q_e \) (mg g⁻¹) represents the equilibrium adsorption capacity of MB on GSPC, \( c_0 \) (mg L⁻¹) and \( c_e \) (mg L⁻¹) are the initial and equilibrium concentrations of MB, respectively, \( V \) (L) is the volume of solution, and \( m \) (g) is the mass of GSPC.

**Adsorption kinetic and isotherm models**

To understand the adsorption dynamics of MB-GSPC system in relation to time and depict the nature of solute-surface interaction between adsorbent and MB as well as to investigate the performance of adsorbent, three kinetic models (pseudo-first-order and pseudo-second-order) and two isotherm models (Langmuir and Freundlich) were studied. The equations can be listed as follows:

\[ \log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \]  
(2)

\[ \frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \]  
(3)

\[ q_e = \frac{b q_m C_e}{1 + b C_e} \]  
(4)

\[ q_e = k C_e^{1/n} \]  
(5)

where \( q_t \) (mg g⁻¹) represents adsorption capacity of MB on GSPC at any time \( t \) (min), \( k_1 \) (min⁻¹) and \( k_2 \) (g mg⁻¹ min⁻¹) are pseudo-first-order and pseudo-second-order adsorption rate constants, respectively, \( t \) is contact time (min). \( k_i \) (mg g⁻¹ h⁻¹) is intraparticle diffusion rate constant and \( c_i \) (mg g⁻¹) is a constant. \( q_m \) (mg g⁻¹) is maximum adsorption capacity of MB on GSPC, \( b \) (L mg⁻¹) is Langmuir adsorption constant, \( k \) is indicator of adsorption capacity, and \( 1/n \) represents heterogeneity factor.

**Regeneration experiments**

For the regeneration study, 10 mg GSPC were added to 10 mL MB solution (100 mg L⁻¹) at pH 12 and the mixture was shaken at 200 rpm for 60 min at 25 ºC. After adsorption and centrifugation, the supernatant MB solution was discarded leaving GSPC. Then, the MB-adsorbed GSPC were added to 10 mL of absolute ethanol and shaken at 200 rpm for 10 min. Subsequently, the GSPC were isolated from the solution by centrifugation and used for
next cycle. The final concentrations of MB were determined by UV-vis spectra. The adsorption-desorption processes as described were carried out successively for five times.

**Table S1.** Specific surface area and pore characteristics of GSPC at various temperatures.

| T(°C) | SSA (m²g⁻¹) | Pore Volume (cm³g⁻¹) | Average Pore Size (nm) |
|-------|-------------|----------------------|------------------------|
| 300   | 50.50       | 0.019                | 1.70                   |
| 400   | 80.60       | 0.037                | 4.68                   |
| 500   | 89.04       | 0.039                | 5.76                   |
| 600   | 134.45      | 0.230                | 2.18                   |
| 700   | 171.50      | 0.245                | 5.30                   |

**Table S2.** Comparison of the specific surface area of other biomass carbons.

| Biomass carbons                        | S_BET (m²g⁻¹) | References |
|----------------------------------------|---------------|------------|
| Wheat straw derived carbons            | 0.75          | [1]        |
| Rice straw derived carbons             | 36.7          | [2]        |
| Corn straw derived carbons             | 49.4          | [3]        |
| Rice husk derived carbons              | 5.24          | [1]        |
| Walnut shell derived carbons           | 1.56          | [1]        |
| Peach branch derived carbons           | 3.88          | [1]        |
| Sewage sludge derived carbons          | 25            | [4]        |
| Eucalyptus saw dust derived carbons    | 1.57          | [5]        |
| Ginger straw derived porous carbons    | 171.5         | *This work*|

**Figure S1.** Effect of (A) c₀ (2 h, 25°C, pH: 12) for MB adsorption on GSPC. (B) Pseudo-second-order kinetic model of MB adsorption on GSPC.

**Table S3.** Kinetic model parameters of MB adsorption on GSPC.

| c₀      | qₑ,exp | qₑ,cal | k₁     | R²     | qₑ,cal | k₂     | R²     |
|---------|---------|---------|--------|--------|---------|--------|--------|
| (mg L⁻¹) | (mg g⁻¹) | (mg g⁻¹) | (min⁻¹) |        | (mg g⁻¹) | (g mg⁻¹ min⁻¹) |        |
Table S4. Isotherm model parameters of MB adsorption on GSPC.

| Temperature (°C) | Langmuir | Freundlich |
|------------------|----------|------------|
|                  | $q_m$ (mg g$^{-1}$) | $b$ (L mg$^{-1}$) | $R^2$ | $k$ | $1/n$ | $R^2$ |
| 25               | 345.0    | 0.16       | 0.9078 | 70.81 | 2.30 | 0.8412 |

Table S5. Comparison of the max adsorption capacities of MB on various biomass carbons.

| Biomass carbons                  | $q_m$ (mg g$^{-1}$) | References |
|----------------------------------|---------------------|------------|
| wheat straw derived carbons      | 46.6                | [6]        |
| Rice straw derived carbons       | 62.5                | [7]        |
| Rice husk derived carbons        | 40.59               | [8]        |
| Weeds derived carbons            | 39.68               | [9]        |
| Bamboo derived carbons           | 4.78                | [10]       |
| Peanut hull derived carbons      | 68.03               | [11]       |
| Palm bark derived carbons        | 2.66                | [12]       |
| Hickory wood derived carbons     | 16.3                | [13]       |
| Anaerobic digestion residue derived carbons | 9.50               | [14]       |
| Ginger straw derived porous carbons | 345.0              | This work  |

Figure S2. SEM image of GSPC after five cycles of adsorption-desorption.

Figure S3. EDS spectra of GSPC (A) before first cycle and (B) after fifth cycle.
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