A fungus-derived biomass porous carbon–MnO$_2$ nanocomposite-modified electrode for the voltammetric determination of rutin

Hui Cheng,$^{a,b}$ Juan Liu,$^{b}$ Yunxiu Sun,$^{b}$ Ting Zhou,$^{a}$ Qiuyue Yang,$^{a}$ Shuyao Zhang,$^{a}$ Xiaoping Zhang,$^{a}$ Guanjiu Li$^b$ and Wei Sun$^a$

In this study, we designed a simple procedure for the synthesis of fungus-derived biomass porous carbon (FBPC), which was further used to prepare a MnO$_2$@FBPC composite by a hydrothermal method. The MnO$_2$@FBPC nanocomposite showed a porous structure, large specific surface area, and high conductivity, and was modified on the carbon ionic liquid electrode (CILE) to obtain a working electrode for the sensitive voltammetric determination of rutin. The electrochemical response of rutin was studied via cyclic voltammetry with electrochemical parameters calculated. Under the optimal conditions, the linear range for the rutin analysis was obtained by the differential pulse voltammetry from 0.008 to 700.0 nmol L$^{-1}$ with the detection limit of 2.67 nmol L$^{-1}$ ($3\sigma$). This MnO$_2$@FBPC/CILE was applied to directly detect the rutin concentration in drug and human urine samples with satisfactory results.

1 Introduction

Rutin is one of the most important flavonoid glycoside compounds that is widely present in legumes, vegetables, fruits, nuts, and seeds of plants.$^1$ Due to the physiological activities such as anti-inflammatory, anti-bacterial, and anti-tumor,$^{2,3}$ rutin has been used in pharmaceutical applications. Therefore, it is necessary to develop sensitive methods to detect the rutin content in various samples. Numerous analytical techniques have been established for the analysis of rutin, such as capillary electrophoresis,$^4$ adsorptive stripping voltammetry,$^5$ chemiluminescence,$^6$ high-performance liquid chromatography,$^7$ sequential injection analysis,$^8$ and spectrophotometry.$^9$ However, some of these methods exhibit shortcomings including time-consuming, high cost, and complicated operation processes. Among these methods, electrochemical procedures have been applied to rutin detection due to its high sensitivity, convenient and fast procedure, cheap instrumentation, and on-site monitoring.$^{10}$ For example, He et al. fabricated an electrochemical sensor for the rutin detection based on amine-functionalized Fe$_3$O$_4$ nanoparticles and electrochemically reduced graphene oxide nanocomposite-modified glassy carbon electrode.$^{11}$ Apostei et al. presented a graphene–gold nanoparticle-based screen-printed voltammetric sensor for the determination and quantification of rutin in pharmaceutical samples.$^{12}$ Xing et al. presented a gold nanoparticle-loaded ZnS nanocomposite-based voltammetric sensor for the sensitive determination of rutin.$^{13}$ Niu et al. constructed a graphene and gold nanoparticle-modified acupuncture needle electrode to detect the concentration of rutin.$^{14}$ Sun et al. synthesized a graphene–MnO$_2$ nanocomposite-modified electrode for the sensitive determination of rutin.$^{15}$ Among the modified electrodes reported for rutin detection, numerous types of nanocomposites have been synthesised and used as modifiers that can adsorb more rutin on the electrode surface, exhibit fast electron transfer rate for rutin electrochemistry, and show certain electrocatalytic activity towards rutin. However, the modifiers have disadvantages such as expensive raw materials or complicated synthesis procedures.

Biomass porous carbon (BPC) is defined as a carbon-rich, porous solid produced by the thermal decomposition of biomass in a reactor with little or no available air at moderate temperatures.$^{16}$ It has received considerable attention in the fields of environment, energy, and sensing due to its large active surface areas, pore volumes, cheap price, high chemical, and thermal stability.$^{17,18}$ Recently, numerous synthetic methods have been proposed to prepare porous carbon by the pyrolysis of biomass in the presence of chemical agents such as KOH, ZnCl$_2$, and H$_3$PO$_4$.$^{19}$ For example, Sevilla et al. prepared nitrogen-doped porous carbon with a surface area of up to 3480 m$^2$ g$^{-1}$ by the KOH activation of polypyrrole as a carbon source.$^{20}$ Chang et al. synthesised biomass-activated carbon via the ZnCl$_2$ chemical activation of a recycled filter paper with specific capacitance as high as 302.3 F g$^{-1}$.$^{21}$ Dai et al. prepared argy wormwood-based...
porous carbon electrode materials through H₃PO₄ pre-treatment, hydrothermal carbonization, and subsequent KOH activation for high-performance supercapacitors.²¹

The electrode material is a major factor that affects the performance of electrochemical sensors. Numerous types of metal oxides have been used as electrode materials.²⁴–²⁷ As an attractive inorganic semiconductive material with electrocatalytic ability, MnO₂ has aroused widespread concern in sensing electrodes owing to its low toxicity, inexpensive cost, wide potential range, natural abundance, and high specific capacitance.²⁸,²⁹ Also, MnO₂ can be combined with other conductive materials to get composites with improved conductivity.²⁸ Jafa et al. prepared an asymmetric electrochemical device with an MnO₂/graphene oxide composite by a hydrothermal reaction.³³ Yuan et al. prepared an excellent electrochemical supercapacitor with MnO₂ and rice husk-based carbon composite as the active material.³²

In this study, fungus was used as the raw material to prepare fungus-derived biomass porous carbon (FBPC) by alkali-treatment activation and carbonization. Then, the hydrothermal method was used to get an MnO₂ decorated FBPC composite MnO₂@FBPC, which was further applied on the top of a carbon ionic liquid electrode (CILE) to obtain the modified electrode. CILE is prepared by using a highly conductive ionic liquid (IL) as the modifier, which has been used as the basic electrode in electroanalysis due to its specific characteristics such as faster electron transfer, higher stability, and wider potential window. Our group fabricated numerous types of modified electrodes using CILE for electrochemical sensors and electrocatalysis.³⁴–³⁷ Therefore, CILE is used as the substrate electrode with the MnO₂@FBPC nanocomposite as the modifier. The electrochemical responses of rutin on MnO₂@FBPC/CILE were investigated via cyclic voltammetry (CV) and differential pulse voltammetry (DPV) with electrochemical parameters calculated. The modified electrode was further applied for the analysis of samples with satisfactory results.

2 Materials and methods

2.1 Reagents

1-Hexylpyridinium hexafluorophosphate (HPPF₆ > 99%, Lanzhou Yulu Fine Chemical Co., Ltd., China), graphite powder (average particle size 30 μm, Shanghai Colloid Chemical Co., China), KMnO₄ (Tianjin Zhiyuan Chemical Reagent Co., Ltd., China), MnSO₄·H₂O (Guangdong Xiqiao Chemical Co., Ltd., China), rutin (Sinopharm Chemical Reagent Co., Ltd., China) and rutin tablet sample (Shanxi Yunpeng Pharmaceutical Co., Ltd., China, and Shanghai Zhaohui Pharmaceutical Co., Ltd., China) were used as received. Fungus was purchased from a local agricultural market of Haikou. A 0.1 mol L⁻¹ phosphate buffer solution (PBS) with different pH values was used as a supporting electrolyte. All the other chemicals were of analytical reagent grade without further purification, and ultrapure water (Milli-Q, IQ-7000, USA) was used in all the experiments.

2.2 Instruments

The morphologies of the as-prepared materials were examined using a JSM-7100F scanning electron microscope (JEOL, Japan). X-ray diffraction (XRD) measurements were performed on a D2 phaser advance diffractometer (Bruker, Germany) with Cu Kα (λ = 1.5406 nm) radiation. X-ray photoelectron spectroscopy (XPS) and the surface elemental compositions were performed on an AXIS H165 spectrometer (Kratos Analytical, UK). Raman spectrum was obtained on a LabRAM HR system (Horiba, France) at an excitation wavelength of 532 nm. Electrochemical measurements were carried out on a CHI 660E electrochemical workstation (Shanghai CH Instruments, China) with a traditional three-electrode system, including MnO₂@FBPC/CILE as the working electrode, Ag/AgCl (saturated KCl) as the reference electrode, and a platinum wire electrode as the counter electrode. An Agilent 1200 (Agilent Technologies, USA) was used for HPLC with chromatographic separation performed on the Agilent Diamonsil C18 column (250 mm × 4.6 mm, 5 μm, USA). HPLC mobile phase consisted of a 0.4% phosphoric acid–methanol (48 : 52, v/v) mixture, which was filtered through a 0.45 μm filter, followed by degassing under vacuum and passed at a flow rate of 0.5 mL min⁻¹ at an injection volume of 10 μL. The measurement process was carried out in a chromatographic column at 30 °C with the detector wavelength set at 368 nm.

2.3 Synthesis of FBPC

The fungus was washed with water and dried at 100 °C for 12 h. Then, 2.0 g fungus was mixed with 50 mL of 0.1 mol L⁻¹ KOH, transferred into a Teflon lined stainless-steel autoclave (100 mL), and heated at 120 °C for 6 h. After the product was cooled to room temperature naturally and dried at 100 °C for 24 h, the sample was heated in a KMTF-100 tube furnace (Anhui Kemi Instruments, China) under an Ar flow at 800 °C (10 °C min⁻¹) for 1 h. Finally, the sample was washed three times with water and 1.0 mol L⁻¹ HCl, respectively, until the pH of the solution reached 7.0. Then, the product was dried at 100 °C in an oven for 12 h to obtain FBPC.

2.4 Synthesis of MnO₂@FBPC

The MnO₂@FBPC composite was synthesized by a hydrothermal method.³⁸ Briefly, 0.17 g KMnO₄, 0.28 g MnSO₄, and 0.24 g FBPC were dispersed in 10 mL water to form a homogeneous solution under constant magnetic stirring. Then, the mixture was transferred into a Teflon lined stainless-steel autoclave and heated at 140 °C for 12 h. The sample was filtered and washed three times with water and 1.0 mol L⁻¹ HCl, respectively, until the pH of the solution reached 7.0. Then, the product was dried at 100 °C in an oven for 12 h to obtain MnO₂@FBPC.

2.5 Preparation of the modified electrode

According to the previous literature,³⁹ CILE was prepared with HPPF₆ and graphite powder, which was smoothed to a mirror-like surface before use. 2.0 mg mL⁻¹ of the MnO₂@FBPC suspension was sonicated for 4 h to obtain a uniform dispersion. Then, 8.0 μL of the MnO₂@FBPC suspension was cast on the CILE surface and dried at room temperature in air to construct MnO₂@FBPC/CILE.
3 Results and discussion

3.1 Principles

Scheme 1 illustrates the fabrication process of the MnO$_2$@FBPC composite, which was modified on the surface of CILE and used for the rutin analysis. The fungus is activated in 0.1 mol L$^{-1}$ KOH and then carbonized at 800 °C to form a loose and porous structure. Subsequently, MnO$_2$ nanoneedles are formed on FBPC by the hydrothermal method. The as-prepared materials are used for electrode modification, and the electrochemical behavior of rutin is further investigated on the MnO$_2$@FBPC modified electrode.

3.2 Characterization of MnO$_2$@FBPC

SEM images of FBPC and MnO$_2$@FBPC were recorded and are exhibited in Fig. 1. As for FBPC (Fig. 1A), a tubular channel and three-dimensional porous structure could be observed, which was attributed to activation by KOH and further high-temperature carbonization. This porous structure can provide a good interface for the further attachment or growth of other nanomaterials on and inside its structure. As for MnO$_2$@FBPC, MnO$_2$ nanoneedles could be observed on the FBPC surface (Fig. 1B and C). The possible formation mechanism of MnO$_2$ can be described with the following chemical equation:

$$3\text{MnSO}_4 + 2\text{KMnO}_4 + 2\text{H}_2\text{O} \rightarrow 5\text{MnO}_2 + 2\text{H}_2\text{SO}_4 + \text{K}_2\text{SO}_4.$$ 

Raman spectroscopy is an effective approach to study the structure of carbon materials and the curves are shown in Fig. 1D. The characteristic peaks of the Raman spectrum are located at 1603 cm$^{-1}$ and 1337 cm$^{-1}$ (curve a and b), which are attributed to the G and D bands of the carbon material, respectively. Because the intensity ratio of $I_D/I_G$ represents the disorder/defect degree of the carbon material, the $I_D/I_G$ values of FBPC and MnO$_2$@FBPC were obtained as 1.2 and 0.7, respectively. Obviously, the $I_D/I_G$ value decreased in the presence of MnO$_2$ nanoneedles, indicating a relatively high degree of graphitization. Compared with that of FBPC, a new peak could be found at 631 cm$^{-1}$ (curve b), which belonged to the characteristic peak of MnO$_2$.

XRD patterns were recorded to determine the crystal structure of FBPC and MnO$_2$@FBPC, and the curves are shown in Fig. 1E. In the XRD pattern of FBPC (curve a), two typical diffraction peaks at 2θ values of 29.1° and 42.4° could be ascribed to reflections from the (002) and (110) crystal planes of the carbon material. For the MnO$_2$@FBPC nanocomposite, strong diffraction peaks appeared at 18.0°, 22.4°, 28.7°, 37.6°, 41.9°, 49.8°, 56.0°, 60.1°, and 65.5°, which were attributed to the (200), (220), (310), (211), (301), (411), (600), (521), and (002) crystal faces of MnO$_2$. Therefore, the MnO$_2$ crystal face is retained in MnO$_2$@FBPC.

XPS was performed to obtain the elemental composition of FBPC and MnO$_2$@FBPC, and the resulting curves are shown in Fig. 1F. The C 1s spectra were fitted with five component peaks, as shown in Fig. 1G. The peaks located at 284.78 eV, 286.38 eV, 288.38 eV, 292.02 eV and 294.78 eV are attributed to the structure of graphite carbon (C–C), carbon–oxygen (C–O), carboxyl group (C=O), K 2p$_{3/2}$ and K 2p$_{1/2}$, respectively. The characteristic peaks (529.80 eV, 531.28 eV, and 532.72 eV) of O 1s indicated that the structures of Mn–O, C–O, and C–O, respectively, as shown in Fig. 1H existed in the composite. Mn 2p was combined with the fitted peaks (642.00 eV and 643.90 eV) of Mn 2p$_{3/2}$ and the fitted peaks (653.40 eV and 654.70 eV) of Mn 2p$_{1/2}$. Therefore, it was concluded that MnO$_2$ was synthesized and coated on FBPC. Moreover, the atomic ratio of Mn in the MnO$_2$@FBPC composite was calculated as 9.95%.

3.3 Electrochemical investigations

Cyclic voltammetric responses of different electrodes were recorded using a 1.0 mmol L$^{-1}$ [Fe (CN)$_6$]$^{3-}$ solution as an

\[ \text{Scheme 1 Fabrication process of MnO}_2\text{@FBPC composites and the electrochemical detection of rutin.} \]
electrochemical probe, and the results are shown in Fig. 2A. A pair of symmetric redox peaks could be observed on bare CILE (curve a), and the redox peaks increased gradually on FBPC/CILE (curve b) and MnO2@FBPC/CILE (curve c), indicating that the highly conductive FBPC and MnO2@FBPC composite were beneficial for the electron transfer and further effectively improved the interfacial conductivity. The linear relationships between $I_p$ and the square-root of the scan rate ($v^{1/2}$) was obtained with the equations as $I_p (\mu A) = 46.408 v^{1/2} - 14.348$ ($n = 17, \gamma = 0.992$) and $I_p (\mu A) = -40.043 v^{1/2} + 11.628$ ($n = 17, \gamma = 0.990$). According to the Randles–Sevcik formula, $I_p (A) = (2.69 \times 10^5)n^{3/2}AD^{1/2}C_0v^{1/2}$, the effective surface area ($A$) of MnO2@FBPC/CILE was calculated to be 0.241 cm$^2$, which was 1.67 times larger than that of CILE (0.144 cm$^2$), indicating that the presence of the MnO2@FBPC composite on the electrode increased the effective area and provided more active sites on the electrochemical surface with improved electrode performance.

To get the impedance information, electrochemical impedance spectroscopy (EIS) was performed in a 10 mmol L$^{-1}$ [Fe(CN)$_6$]$_3^3^-$ and 0.5 mol L$^{-1}$ KCl solution with frequency ranging from $10^4$ to 0.1 Hz. The experimental data were fitted by the R(CR)(CR) model in Fig. 2B. The $R_{ct}$ of MnO2@FBPC/CILE (35.0 $\Omega$, curve a) was smallest among those of three electrodes, and the $R_{ct}$ of FBPC/CILE (182.3 $\Omega$, curve b) was lower than that of CILE (302.4 $\Omega$, curve c), indicating an improved electron transfer, which was attributed to the presence of porous FBPC and MnO2.

![Fig. 1 SEM images of (A) FBPC and (B and C) MnO2@FBPC at various magnification, (D) Raman spectra, (E) XRD survey and (F) XPS patterns of FBPC (a) and MnO2@FBPC (b); XPS spectra of the MnO2@FBPC (G) C 1s, (H) O 1s, (I) Mn 2p.](image1)

![Fig. 2 (A) Cyclic voltammograms of CILE (a), FBPC/CILE (b) and MnO2@FBPC/CILE (c) in 1.0 mmol L$^{-1}$ [Fe(CN)$_6$]$_3^3^-$ and 0.5 mol L$^{-1}$ KCl solution at a scan rate of 100 mV s$^{-1}$. (B) EIS of MnO2@FBPC/CILE (a), FBPC/CILE (b) and CILE (c) in 10.0 mmol L$^{-1}$ [Fe(CN)$_6$]$_3^3^-$ and 0.5 mol L$^{-1}$ KCl solution with frequency ranging from $10^4$ to 0.1 Hz. (C) Cyclic voltammograms of 1.0 $\times$ 10$^{-5}$ mol L$^{-1}$ rutin in PBS (pH 4.0) on CILE (a), FBPC/CILE (b) and MnO2@FBPC/CILE (c) at a scan rate of 100 mV s$^{-1}$.](image2)
The electrochemical behaviour of $1.0 \times 10^{-5}$ mol L$^{-1}$ rutin on different electrodes was studied via CV in PBS ($0.1$ mol L$^{-1}$, pH 4.0), and the curves are shown in Fig. 2C. A couple of well-defined redox peaks could be observed, which was the typical electrochemical reaction of rutin. On CILE, the peak currents were obtained as $3.206 \mu$A ($I_{pa}$) and $3.268 \mu$A ($I_{pc}$) with the peak-to-peak separation ($\Delta E_p$) of $35$ mV (curve a). On FBPC/CILE, the redox peak currents of rutin were increased to $4.100 \mu$A ($I_{pa}$) and $3.474 \mu$A ($I_{pc}$) with $\Delta E_p$ as $39$ mV (curve b), proving the positive effect of FBPC to the rutin electrochemistry. Also, the increase in the background currents was due to the porous structure and large surface area of FBPC, indicating that the presence of the porous structure increased the interfacial capacitance. Moreover, on MnO$_2$@FBPC/CILE (curve c), the electrochemical responses were further increased with the decrease of $\Delta E_p$ to $31$ mV, indicating that the redox reaction of rutin become more reversible. The corresponding redox peak currents were $5.338 \mu$A ($I_{pa}$) and $3.997 \mu$A ($I_{pc}$), and the currents were enlarged $1.7$ times for $I_{pa}$ and $1.2$ times for $I_{pc}$ as compared to that of CILE. The modification of MnO$_2$ nanoneedles on the surface of FBPC significantly increased the electrocatalytic activity towards the oxidation of rutin with the enhancement of the electrochemical responses. Therefore, the presence of the high conductivity of MnO$_2$@FBPC promoted the electron transfer ability towards rutin.

### 3.4 Effect of pH and scan rate

The effect of buffer pH on the electrochemical responses of $1.0 \times 10^{-5}$ mol L$^{-1}$ rutin on MnO$_2$@FBPC/CILE was investigated, and the results are shown in Fig. 3A. With the change in pH from 2.0 to 8.0, the redox peak potential shifted towards the negative direction and the peak current achieved a maximum value at pH 4.0, which was selected as the supporting electrolyte. The formal peak potential ($E^{\text{pa}}$) had a good linear relationship with the pH value and the regression equation was $E^{\text{pa}} (V) = -0.531pH + 0.65 (\gamma = 0.998)$. The slope of $54$ mV pH$^{-1}$ was close to $59$ mV pH$^{-1}$, which suggested that the number of electrons transferred was equal to the protons in the electrode reaction process.

The effect of the scan rate on the redox response of $1.0 \times 10^{-5}$ mol L$^{-1}$ rutin was recorded, and the results are shown in Fig. 3B. The redox peak currents increased gradually with the increase in the scan rate in the range from $20$ mV s$^{-1}$ to $1000$ mV s$^{-1}$, and the linear relationship of peak currents and scan rate were $I_{pa} (\mu$A) = $32.64v (V s^{-1}) + 1.13 (n = 13, \gamma = 0.997)$ and $I_{pc} (\mu$A) = $-28.81v (V s^{-1}) - 1.11 (n = 13, \gamma = 0.998)$, which indicated that the electrode reaction was an adsorption-controlled process due to the porous structure of FBPC. The redox peak potential and ln v also exhibited good linear relationships with the linear regression equations, as $E_{pa} (V) = 0.023 \ln v + 0.458 (n = 8, \gamma = 0.990)$ and $E_{pc} (V) = -0.025 \ln v + 0.358 (n = 8, \gamma = 0.994)$. According to the Laviron’s equation[41], the values of the electron transfer coefficient ($\alpha$), electron transfer number ($n$), and electrode reaction standard rate constant ($k_s$) were calculated as $0.48, 2.14$, and $4.65$ s$^{-1}$, respectively.

### 3.5 Effects of accumulation conditions

To improve the detection sensitivity, the effects of accumulation time and potential on the oxidation peak current were
Normal human urine

| Sample       | Labeled (µmol L⁻¹) | Found (µmol L⁻¹) | Added (µmol L⁻¹) | Measured (µmol L⁻¹) | RSD (%) | Recovery (%) |
|--------------|--------------------|------------------|------------------|--------------------|---------|--------------|
| B080302      | 60.20              | 59.18            | 20.00            | 80.67              | 2.18    | 107.46       |
| 090904        | 60.20              | 60.03            | 40.00            | 100.96             | 3.23    | 103.22       |
| Normal human urine | 60.00              | 0.00             | 60.00            | 59.05              | 1.69    | 98.42        |

Table 2 Detection of rutin in different samples with MnO₂@FBPC/CILE (n = 3)

investigated, as shown in Fig. 4. \( I_{pa} \) increased rapidly with the accumulation time from 0 s to 40 s and then decreased by more than 40 s, indicating the saturated adsorption of rutin (Fig. 4A). Simultaneously, \( I_{pa} \) increased with the increase in the accumulation potential from 0 V to 0.4 V and gradually decreased when the accumulation potential was more than 0.4 V (Fig. 4B). Therefore, 40 s and 0.4 V were chosen as the optimal accumulation conditions in the subsequent experiments.

3.6 Calibration curve

Differential pulse voltammetric (DPV) curves of different rutin concentrations on MnO₂@FBPC/CILE are shown in Fig. 5A. The oxidation peak currents increased with rutin in two concentration ranges, i.e., from 0.008 to 100.0 µmol L⁻¹ and 100.0 to 700.0 µmol L⁻¹. The linear regression equations were calculated as

\[
\frac{\Delta I_{pa}}{C} = 0.047C (\mu\text{mol L}^{-1}) + 61.095 \quad (n = 4, \gamma = 0.992)
\]

with the detection limit calculated as 2.67 nmol L⁻¹ (3σ). Two different slopes of the calibration curves could be attributed to the difference in the activity of the modified electrode surface at low and high rutin concentrations. At the low concentration range, a large slope was due to the relatively high ratio of active sites to the total number of rutin molecules. At the high concentration range, the active sites decreased in comparison to the total number of rutin molecules at the electrode surface, leading to a smaller slope value. The analytical parameters for the electrochemical detection of rutin on different modified electrodes are summarized in Table 1. The low detection limit was due to the presence of MnO₂ on the surface of FBPC with a porous structure, larger surface area, high conductivity, and excellent electrocatalytic activity.

3.7 Analytical applications

In order to verify the practicality and reliability of the proposed sensor, MnO₂@FBPC/CILE was applied for the determination of rutin content in compound rutin tablets (20 mg per tablet) and human urine by the calibration curve method and standard addition method. Drug tablets were purchased from Shanxi Yunpeng Pharmaceutical Ltd. Co. (B080302) and Shanghai Zhaohui Pharmaceutical Ltd. Co. (090904). A piece of drug tablet was ground and dissolved in 5.0 mL ethanol to obtain a 6.02 mmol L⁻¹ stock solution. Then, a 100 µL stock solution was diluted with pH 4.0 PBS in a 10.0 mL calibration tube for

![Fig. 5 DPV curves of rutin with various concentrations (A) a–q: 0.008, 0.01, 0.1, 0.6, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0, 30.0, 50.0, 70.0, 100.0, 300.0, 500.0, 700.0 µmol L⁻¹. (B) The linear relationship between \( I_{pa} \) and rutin concentration.](image)
3.7 Reproducibility, repeatability, and stability

The reproducibility of MnO₂@FBPC/CILE was performed by detecting the 1.0 \times 10^{-5} \text{ mol L}^{-1} rutin solution. The RSD value of six parallel measurements with a single electrode was calculated as 6.98\%, indicating the good reproducibility of this method. In a series of five electrodes prepared in the same way, an RSD of 2.40\% was obtained for the 1.0 \times 10^{-5} \text{ mol L}^{-1} rutin solution, indicating excellent repeatability. The long-term stability of MnO₂@FBPC/CILE was tested after being stored at room temperature for a week. The current responses were retained at 90\% of its original signal strength for the same rutin solution, which showed long-term stability.

4 Conclusions

The fungus-based biomass porous carbon (FBPC) was prepared by activation and high temperature carbonization, and the MnO₂@FBPC composite was directly synthesized by a hydro-thermal method. The morphology, structure, and composition of the materials were characterized by SEM, Raman, XRD, and XPS. The results showed that the MnO₂@FBPC composite had a porous structure, large surface area, good conductivity, and high electrocatalytic activity. The electrochemical response of rutin on MnO₂@FBPC/CILE was investigated with the electrochemical parameters calculated, which exhibited a wider linear range (0.008–700.0 \text{ µmol L}^{-1}) and lower detection limit for the rutin detection, and the method was successfully applied to the real sample detection. This work extended the usage of biomass porous carbon and the related composite in the field of electroanalysis.

Conflicts of interest

There are no conflicts to declare.

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