

RESEARCH PAPER

G5-PAMAM Platinum Nanoparticle Carbon Nanotube Nanocomposite for Hydrogen Peroxide Transduction and Enzymatic Glucose Sensing

Ameerah K. Asfoor *, Olfat A. Mahmood, Firas H. Ibrahim

Department of Physics, College of Science, University of Diyala, Diyala, Iraq

ARTICLE INFO

Article History:

Received 20 August 2026

Accepted 13 October 2026

Published 01 January 2027

Keywords:

Cyclic voltammetry

Glucose biosensor

Hydrogen peroxide

PAMAM dendrimer

Platinum nanoparticles

Screen-printed electrode

ABSTRACT

A ternary nanocomposite comprising a fifth-generation poly(amidoamine) dendrimer (G5-PAMAM), platinum nanoparticles (PtNPs), and acid-functionalized multi-walled carbon nanotubes (f-MWCNTs) was developed as an electrochemical interface on a screen-printed carbon electrode. X-ray diffraction confirmed graphitic MWCNT reflections and face-centered-cubic Pt, while FTIR, FESEM, and TEM supported surface functionalization and distribution of Pt-containing domains within the hybrid network. The mean apparent PtNP diameter decreased from 58.32 ± 18.67 nm for independently prepared PtNPs to 41.45 ± 19.66 nm in the ternary composite. Three sequential nanocomposite coatings produced the largest ferricyanide peak currents among the one to four tested layers. Peak current was linear with the square root of scan rate, with R^2 values of 0.9946 and 0.9993 for the anodic and cathodic responses, respectively. Hydrogen peroxide gave a linear cyclic-voltammetric response from 5 to 250 μM : $|I_p| = 1.2263C + 118.905$ ($R^2 = 0.9983$), with regression-based LOD and LOQ estimates of 14.16 and 42.91 μM . After glucose oxidase immobilization, glucose was linear from 10 to 100 μM : $|I_p| = 1.3715C - 1.3457$ ($R^2 = 0.9916$). Nine valid same-electrode measurements gave an RSD of 4.98%. The results establish a proof-of-concept G5-PAMAM/PtNPs/f-MWCNT interface for hydrogen peroxide transduction and enzymatic glucose sensing.

How to cite this article

Asfoor A., Mahmood O., Ibrahim F. G5-PAMAM Platinum Nanoparticle Carbon Nanotube Nanocomposite for Hydrogen Peroxide Transduction and Enzymatic Glucose Sensing. J Nanostruct, 2027; 17(1):179-189. DOI: 10.22052/JNS.2027.01.017

INTRODUCTION

Electrochemical glucose biosensors remain important analytical platforms because they combine rapid electrical readout, low sample-volume requirements, and compatibility with compact point-of-care devices [1,2]. Carbon nanomaterials are particularly attractive for screen-printed electrodes because their conductivity and high surface area can strengthen interfacial

electron transport while retaining the low cost and disposability of the printed platform [3,4]. Sensor performance nevertheless depends strongly on the interfacial material used to immobilize the enzyme and transduce the enzymatic reaction.

In first-generation glucose biosensors, glucose oxidase (GOx) catalyzes glucose oxidation using molecular oxygen as the electron

* Corresponding Author Email: amera@uodiyala.edu.iq



acceptor, producing hydrogen peroxide (H_2O_2) as an electroactive product [5]. H_2O_2 can then be detected electrochemically, linking enzymatic recognition to the measured current. Recent nanostructured GOx electrodes have demonstrated that carbon nanotubes and high-surface-area platinum architectures can improve enzyme loading, electron transport, and peroxide transduction [4,6,7]. PtNPs are effective electrocatalysts for H_2O_2 , while carbon nanotubes provide conductive pathways and a high-surface-area support [8,9]

PAMAM dendrimers provide a complementary interfacial function. Their highly branched architecture and numerous terminal groups can organize metal nanoparticles, interact with functionalized carbon nanomaterials, and support biomolecule immobilization [10,11]. The stepwise synthesis and characteristic generation structure of PAMAM were originally established by Tomalia and co-workers [12]. In the present study, G5-PAMAM, PtNPs, and acid-functionalized MWCNTs were integrated on a screen-printed carbon electrode. The composite was first evaluated for H_2O_2 transduction and was subsequently

coupled to immobilized GOx for enzymatic glucose sensing. The study examines structure-property relationships, coating-layer optimization, scan-rate behavior, calibration, and same-electrode repeatability.

MATERIALS AND METHODS

Materials and electrode platform

MWCNTs (outer diameter 13-18 nm, length 1-12 μm , purity >99%), ethylenediamine, methyl acrylate, chloroplatinic acid (H_2PtCl_6), sodium borohydride, polyvinylpyrrolidone, GOx, chitosan, glutaraldehyde, ethanol, methanol, nitric acid, sulfuric acid, potassium ferricyanide, potassium chloride, H_2O_2 , D-glucose, and phosphate-buffer constituents were used as received. Commercial HY-PC100 screen-printed carbon electrodes (ICHY, Shenzhen Haoyang Technology Co., Ltd., China) contained a 3-mm-diameter carbon working electrode (geometric area 0.0707 cm^2), a carbon counter electrode, and an integrated Ag/AgCl reference electrode.

Synthesis of G5-PAMAM

G5-PAMAM was synthesized by alternating

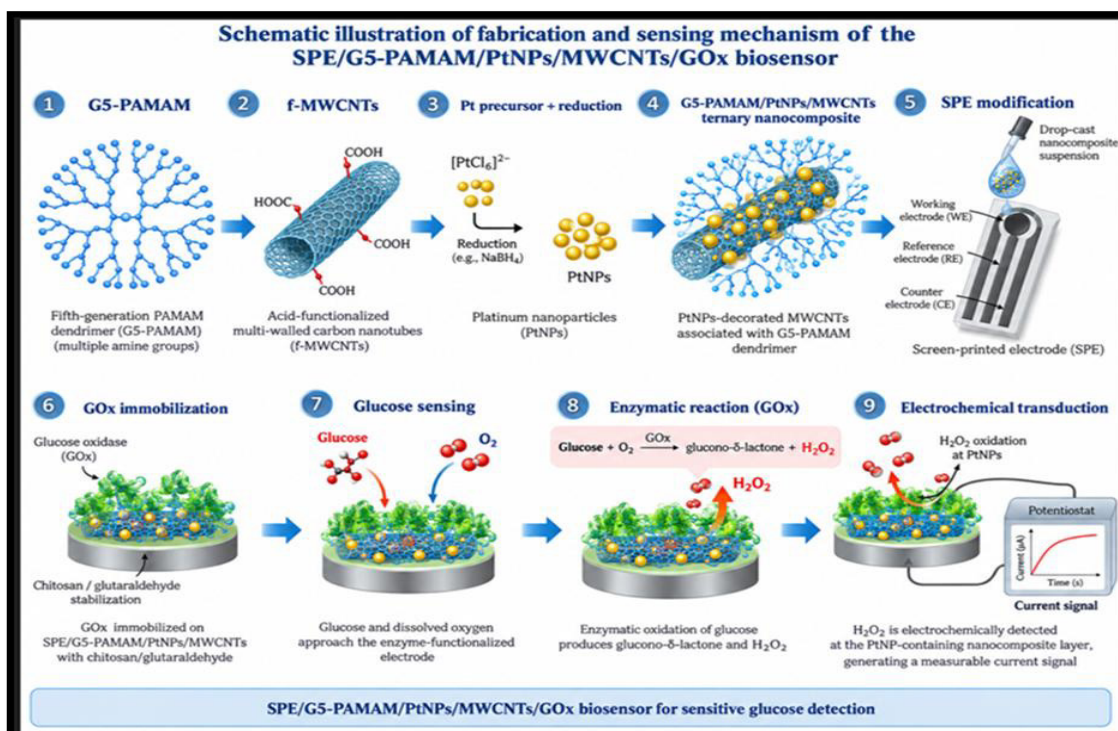


Fig. 1. Schematic illustration of ternary nanocomposite preparation, SPCE modification, GOx immobilization, and H_2O_2 -mediated glucose transduction.

Michael addition and amidation steps [12]. Ethylenediamine (10 mL) was diluted in ethanol (40 mL), cooled in an ice bath under nitrogen, and reacted with methyl acrylate (112 mL) for 1-2 h to form the ester-terminated G0.5 intermediate. Volatile components were removed by rotary evaporation at 65 °C. For G1 formation, 16 g of G0.5 was reacted with ethylenediamine (54 mL) in ethanol (40 mL). Alternating half- and full-generation reactions were continued to G5, with solvent removal and purification between steps. Reaction completion was monitored using the ninhydrin assay, and the final product was purified by dialysis.

Acid functionalization of MWCNTs

Pristine MWCNTs (100 mg) were dispersed in a mixed $\text{HNO}_3/\text{H}_2\text{SO}_4$ oxidizing solution and maintained at 90 °C for 4 h to introduce oxygen-containing surface groups [13]. After cooling, the material was filtered and repeatedly washed with deionized water until neutral, then dried to obtain f-MWCNTs.

Synthesis of PtNPs and ternary nanocomposite

For independent PtNP synthesis, 1.0 mL of 0.01 M H_2PtCl_6 was added to 9.0 mL of distilled water containing 1% polyvinylpyrrolidone. The mixture was cooled in an ice bath, and freshly prepared 0.01 M NaBH_4 was added dropwise under stirring at 500 rpm. Reduction was continued for 30 min. The product was collected by centrifugation at 10,000 rpm for 10 min, washed four times with distilled water, and dried at 60 °C.

For the ternary composite, G5-PAMAM (100 mg) was dissolved in 5.0 mL methanol containing 1% polyvinylpyrrolidone and cooled in an ice bath. H_2PtCl_6 solution (1.0 mL) was added and stirred for 10 min before dropwise addition of cold NaBH_4 . Separately, f-MWCNTs (50 mg) were ultrasonically dispersed in 10 mL deionized water. The nanotube dispersion was gradually added to the G5-PAMAM/PtNP dispersion and stirred for 6 h. The product was centrifuged at 10,000 rpm for 10 min, washed three to four times with deionized water, and vacuum-dried at room temperature for at least 24 h.

Electrode modification and GOx immobilization

The working electrode was rinsed with deionized water and pH 7.4 buffer, immersed in 30% HNO_3 for 1 h, washed three times with

deionized water and three times with buffer, and dried at room temperature. The ternary nanocomposite was dispersed in pH 7.4 buffer at 10 mg mL^{-1} . A 5 μL aliquot was drop-cast onto the working electrode, dried, and gently rinsed. This sequence was repeated twice to form three nanocomposite layers.

GOx was prepared at 10 mg mL^{-1} in pH 7.4 buffer. A 5 μL aliquot was applied to the nanocomposite-modified electrode and held at 8 °C for 24 h; deposition was repeated twice to form three GOx layers. After rinsing, 5 μL of 5% chitosan was applied and dried at 8 °C for 24 h. Finally, 5 μL of 25% glutaraldehyde was applied for 30 min, followed by rinsing with pH 7.4 buffer.

Structural and morphological characterization

X-ray diffraction patterns were collected using a Shimadzu XRD-6000 diffractometer with $\text{Cu K}\alpha$ radiation ($\lambda = 1.5406 \text{ \AA}$) at 40 kV and 30 mA over 5-80° (2θ) with a 0.05° step. FTIR spectra were recorded using a Shimadzu IRAffinity-1 spectrometer over 400-4000 cm^{-1} . FESEM images were obtained using a TESCAN MIRA3 LMU microscope at 20 kV. TEM was used to examine Pt-containing nanodomains after ultrasonication and deposition on carbon-coated copper grids. Particle diameters were measured using FIJI/ImageJ.

Electrochemical measurements and data analysis

Electrochemical measurements were performed with a computer-controlled potentiostat using the integrated three-electrode SPCE. Ferricyanide characterization used $\text{K}_3[\text{Fe}(\text{CN})_6]$ in 0.2 M KCl supporting electrolyte at pH 7.4. A 150 μL aliquot covered the three-electrode area. Layer-number optimization compared one to four sequential nanocomposite coatings. Scan-rate measurements were recorded at 10, 25, 50, 100, and 200 mV s^{-1} .

H_2O_2 CV responses were recorded in 0.1 M PBS (pH 7.4) at 100 mV s^{-1} using 5, 10, 25, 50, 100, 250, and 500 μM H_2O_2 . H_2O_2 amperometry was performed at -100 mV versus integrated Ag/AgCl using 25, 50, 100, 250, and 500 μM . Glucose CV measurements used 10, 20, 40, 60, 80, 100, and 200 μM glucose in pH 7.4 buffer, 150 μL per measurement, a scan rate of 100 mV s^{-1} , and a potential sweep from -0.40 to +0.70 V and back. The magnitude of the selected reverse-scan cathodic peak was used as the analytical signal.

Linear regression used the ranges that remained linear after inspection of the full concentration

series. The regression residual standard deviation was calculated as $\sigma = [\sum(y_i - \hat{y}_i)^2 / (n - 2)]^{1/2}$. LOD and LOQ were estimated as $3.3\sigma/S$ and $10\sigma/S$, respectively, where S is the slope, following the general ICH Q2(R2) framework [14]. Repeatability was summarized as the sample standard deviation

and relative standard deviation (RSD).

RESULTS AND DISCUSSION

Structural and morphological characterization

Pristine MWCNTs showed a major XRD reflection at 25.9° assigned to the graphitic (002)

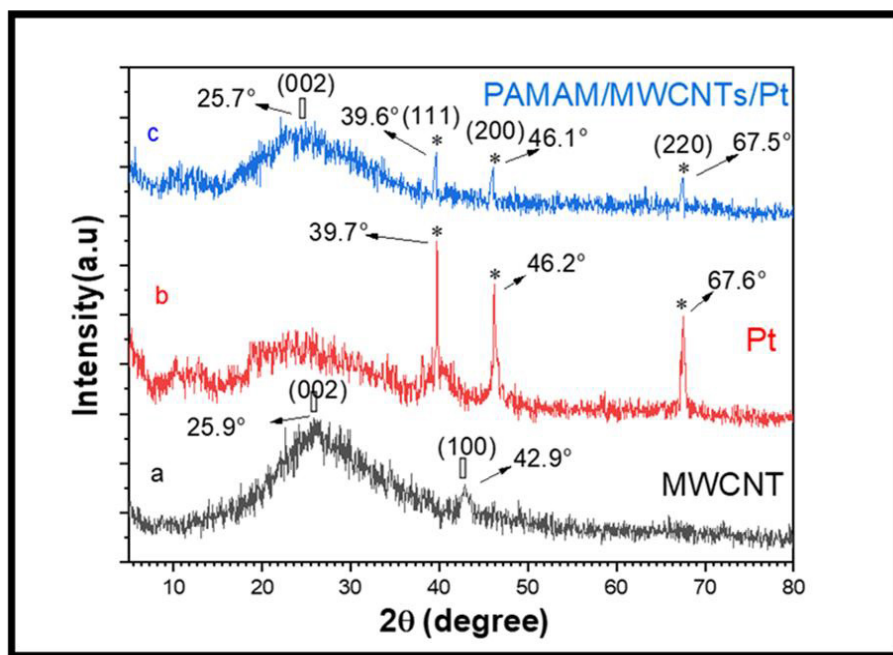


Fig. 2. XRD patterns of MWCNTs, PtNPs, and the G5-PAMAM/PtNPs/f-MWCNT ternary nanocomposite.

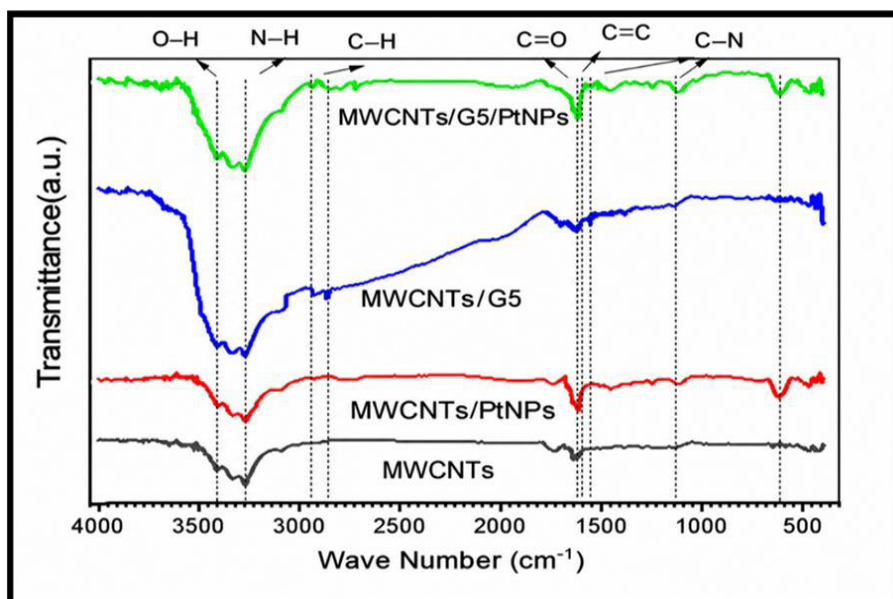


Fig. 3. FTIR spectra of f-MWCNTs and selected G5-PAMAM/PtNP-containing materials.

plane and a weaker reflection at 42.9° associated with the (100) plane. Independently prepared PtNPs exhibited reflections at 39.7° , 46.2° , and 67.6° , consistent with the (111), (200), and (220) planes of face-centered-cubic Pt. In the ternary material, the MWCNT-related reflection occurred at 25.7° and Pt-related reflections at 39.6° , 46.1° , and 67.5° . These results support the coexistence of the graphitic and metallic-Pt crystalline components and are consistent with reported crystalline Pt nanomaterials used in electrochemical sensing [8,15,16]. No crystalline Pt oxide peak was detected. G5-PAMAM is predominantly amorphous and therefore was not expected to produce a sharp diffraction peak.

FTIR provided complementary evidence of surface functionalization and retention of PAMAM-related groups [10,13].

Acid-functionalized MWCNTs showed a broad O-H feature near 3390 cm^{-1} and a carbonyl band

near 1729 cm^{-1} . PAMAM-containing materials retained N-H stretching at approximately $3280\text{--}3400\text{ cm}^{-1}$, Amide I absorption near $1630\text{--}1650\text{ cm}^{-1}$, and C-N features in the $1110\text{--}1200\text{ cm}^{-1}$ region. Changes in band position and intensity are consistent with interfacial association, but they do not independently establish a specific Pt-N or Pt-O covalent bond.

FESEM showed preservation of an interconnected tubular MWCNT network together with a rougher nanogranular morphology after composite formation. TEM gave more direct evidence of Pt-containing nanoscale domains distributed within the f-MWCNT framework. Independently prepared PtNPs had a mean apparent diameter of $58.32 \pm 18.67\text{ nm}$ ($n = 51$), whereas Pt-containing domains in the ternary composite had a mean apparent diameter of $41.45 \pm 19.66\text{ nm}$, median 38.52 nm , and range $15.83\text{--}108.30\text{ nm}$ ($n = 21$). The approximately 28.9%

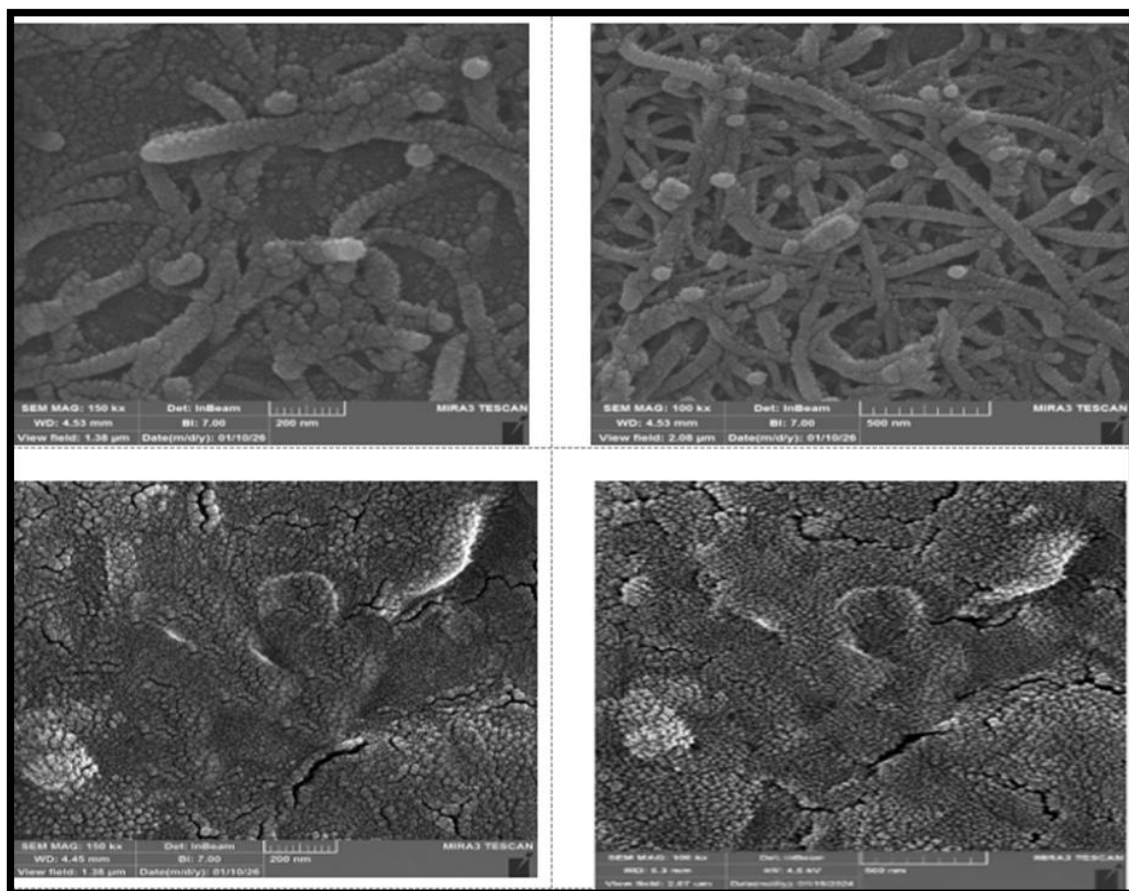


Fig. 4. Representative FESEM micrographs of the nanocomposite components and final hybrid. Scale bars and acquisition information are shown in the individual panels.

lower mean apparent diameter is consistent with interfacial stabilization by PAMAM and f-MWCNT functional groups [10,11,16], although localized aggregation remained visible.

Optimization of nanocomposite layer number

The three-layer coating produced the largest peak currents among the tested conditions: $I_{pa} = 377.02 \mu A$ and $|I_{pc}| = 327.43 \mu A$. The corresponding values were 221.53/154.99 μA for one layer, 254.47/178.45 μA for two layers, and 349.01/293.20 μA for four layers. Relative to one layer, three layers increased I_{pa} by 70.2% and $|I_{pc}|$ by 111.3%. A fourth layer reduced I_{pa} by 7.4% and $|I_{pc}|$ by 10.5% compared with the three-layer coating. The decline is consistent with increased

transport resistance in a thicker film, although the experiment does not independently identify the mechanism. Three layers were therefore used in subsequent measurements.

Scan-rate behavior

Both anodic and cathodic peak-current magnitudes increased as the scan rate rose from 10 to 200 $mV s^{-1}$. Linear regression against the square root of scan rate gave $I_{pa} (\mu A) = 78.05v^{1/2} + 0.32$ ($R^2 = 0.9946$) and $|I_{pc}| (\mu A) = 80.45v^{1/2} - 87.96$ ($R^2 = 0.9993$), where v is expressed in $mV s^{-1}$. These relationships support a major diffusion-related contribution. Peak-to-peak separation increased with scan rate, however, indicating non-ideal reversibility. The data were therefore

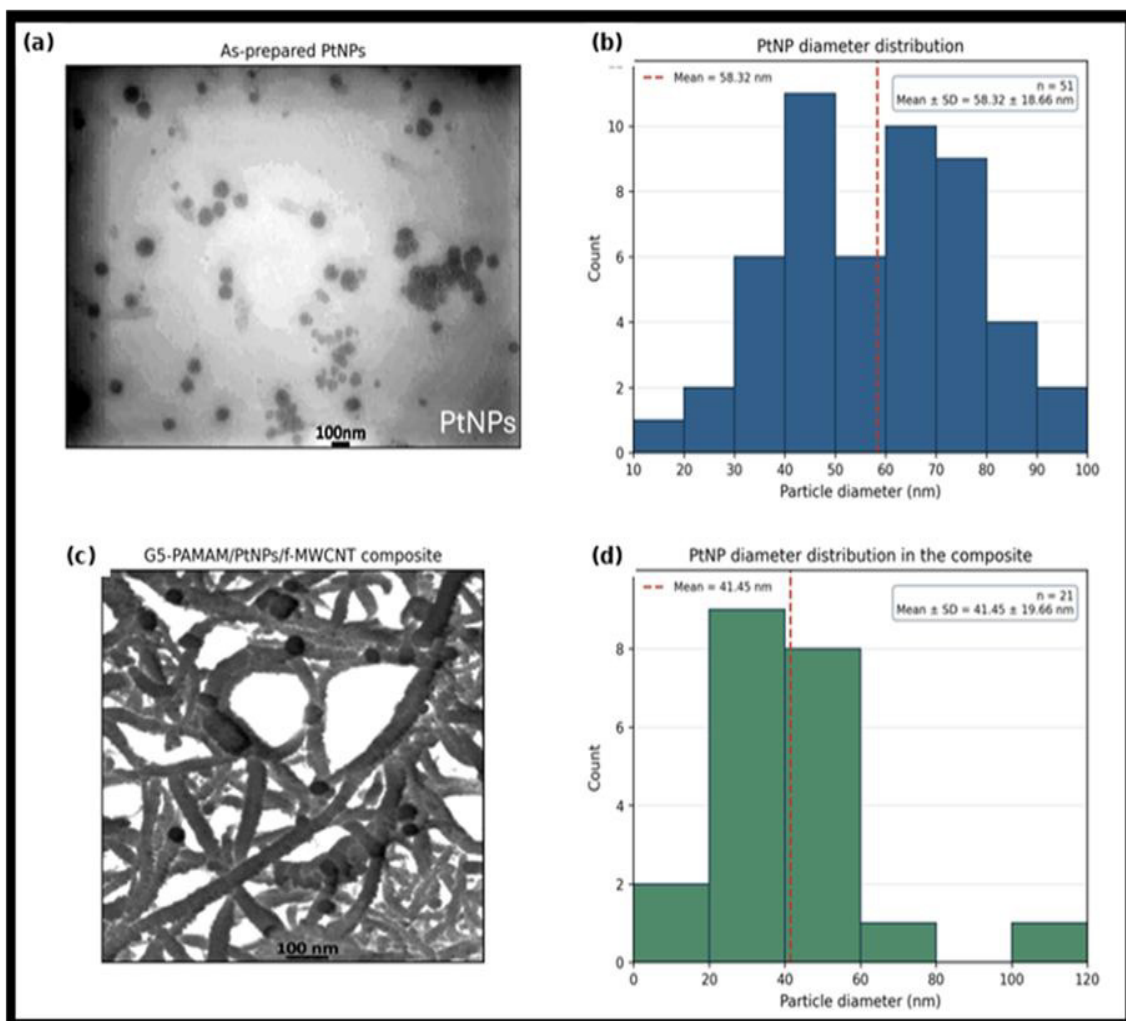


Fig. 5. TEM images and apparent PtNP diameter distributions for independently prepared PtNPs and the G5-PAMAM/PtNPs/f-MWCNT ternary nanocomposite.

not used to calculate an electroactive area with the classical reversible Randles-Sevcik equation.

H_2O_2 transduction

H_2O_2 was examined before enzyme immobilization because it is the electroactive product of GOx-catalyzed glucose oxidation. The

selected CV peak-current magnitude increased from 5 to 500 μM . The principal linear interval was 5–250 μM and followed $|I_p|$ (μA) = 1.2263C (μM) + 118.905 with $R^2 = 0.9983$. The residual-regression estimates were LOD = 14.16 μM and LOQ = 42.91 μM . The 500 μM point deviated from the fitted trend, consistent with the onset of a

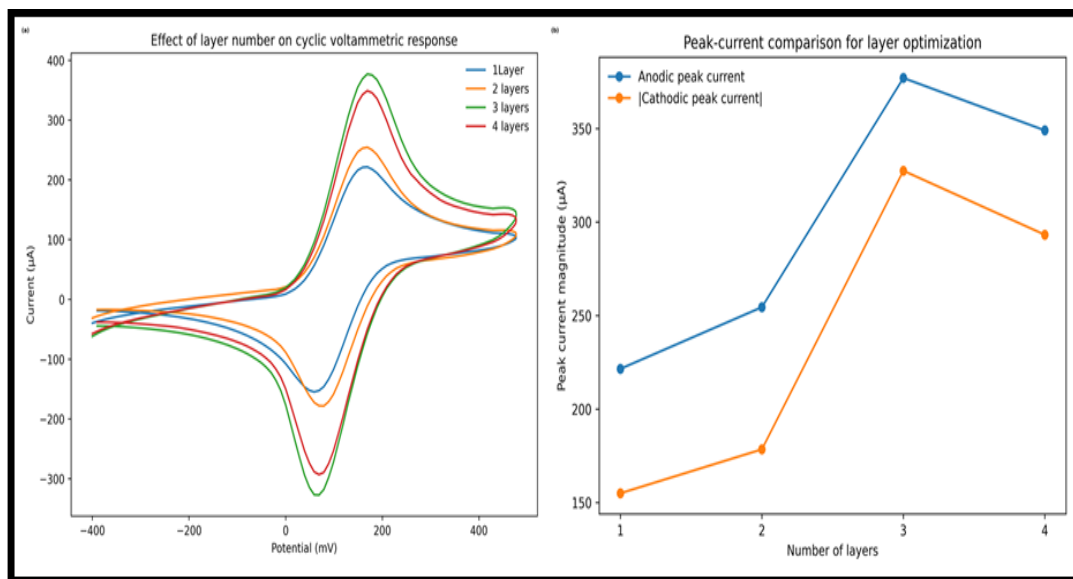


Fig. 6. (a) Cyclic voltammograms obtained with one to four nanocomposite layers. (b) Anodic and absolute cathodic peak-current magnitudes versus layer number.

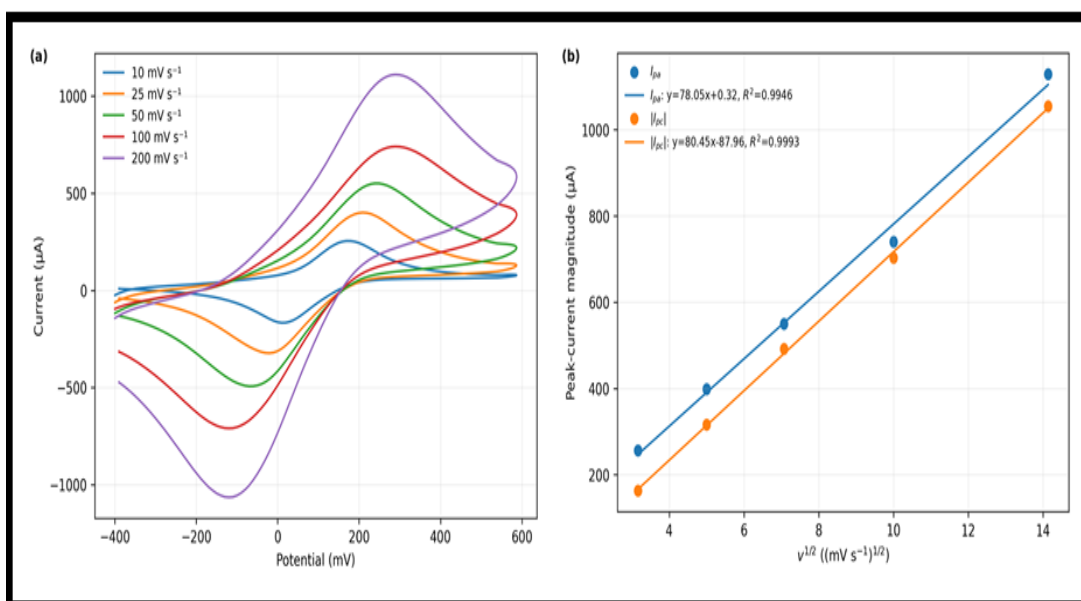


Fig. 7. (a) Ferricyanide cyclic voltammograms at 10, 25, 50, 100, and 200 $mV s^{-1}$. (b) Peak-current magnitude versus the square root of scan rate.

non-linear response region. Because the 5 μM calibration point lies below the regression-derived LOD, it supports the fitted trend but should not be interpreted as a separately validated quantitative detection limit.

At -100 mV versus integrated Ag/AgCl, the

steady-state current shifted systematically from -41.27 μA at 25 μM to -29.60 μA at 500 μM H_2O_2 . The regression was $I (\mu\text{A}) = 0.0240C - 41.364$ with $R^2 = 0.9875$. The monotonic concentration-dependent response establishes the ability of the Pt-containing interface to transduce H_2O_2 under

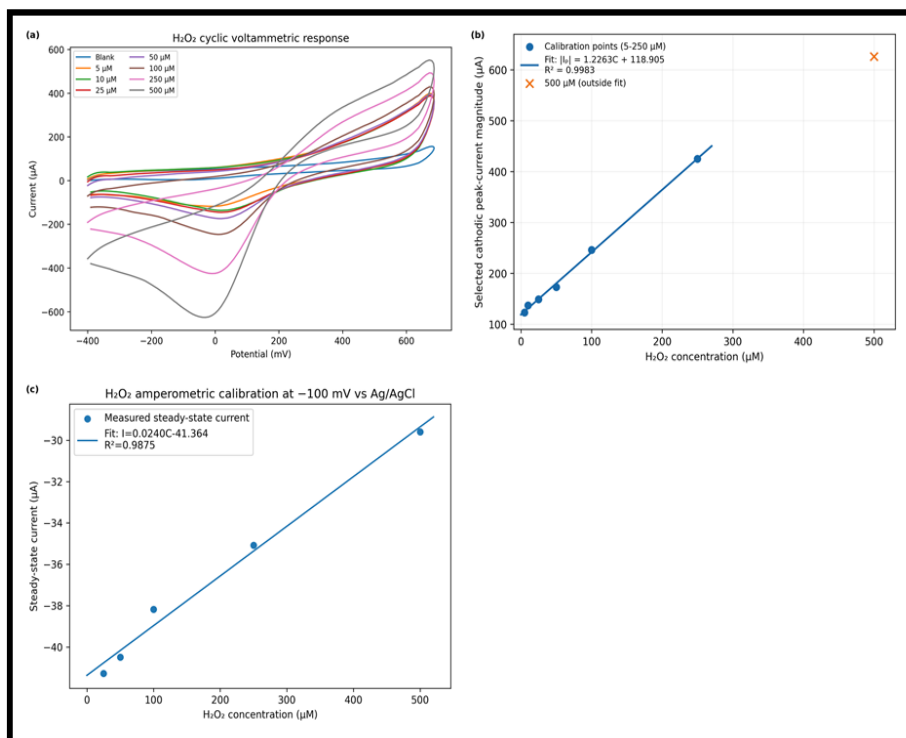


Fig. 8. (a) H_2O_2 cyclic voltammograms from blank through 500 μM at 100 mV s^{-1} . (b) CV calibration over 5-250 μM ; the 500 μM point is shown outside the fit. (c) Steady-state amperometric H_2O_2 response at -100 mV versus integrated Ag/AgCl.

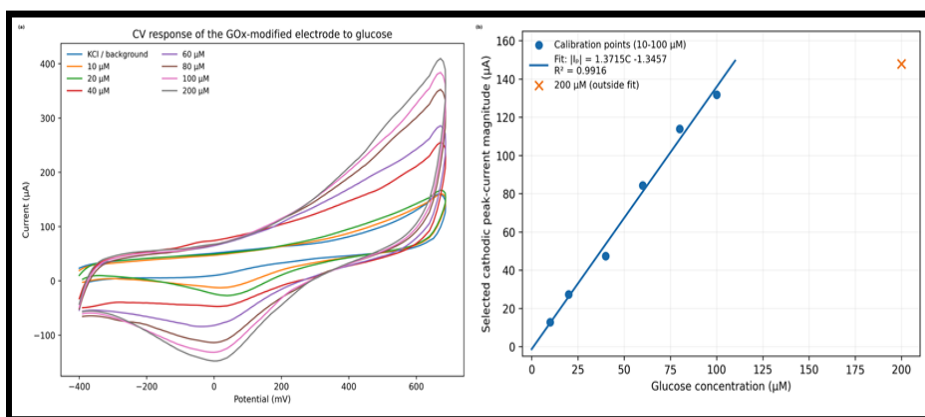


Fig. 9. (a) Cyclic voltammograms of the GOx-modified electrode at 10-200 μM glucose. (b) Calibration based on uniformly extracted reverse-scan cathodic peak-current magnitudes; the fit used 10-100 μM and the 200 μM point is shown outside the fit

the tested conditions. This behavior is consistent with reports describing PtNP electrocatalysis and Pt/carbon interfaces for peroxide detection [8,9,15,16].

Enzymatic glucose sensing

After GOx immobilization, reverse-scan cathodic peak-current magnitudes were 12.80, 27.28, 47.30, 84.20, 113.79, 131.71, and 147.83 μA at 10, 20, 40, 60, 80, 100, and 200 μM glucose, respectively. The 10-100 μM interval was linear, while the small additional response at 200 μM indicated the onset of saturation or another transport/transduction limitation. Regression over 10-100 μM gave $|I_p| (\mu\text{A}) = 1.3715C (\mu\text{M}) - 1.3457$ with $R^2 = 0.9916$ and a non-area-normalized slope of $1.3715 \mu\text{A } \mu\text{M}^{-1}$. Using $\sigma = 4.9222 \mu\text{A}$, the estimated LOD and LOQ were 11.84 and 35.89 μM , respectively. Blank-based limits from independent replicates would provide stronger validation of

low-concentration performance.

The response is consistent with GOx-mediated conversion of glucose to D-glucono- δ -lactone and H_2O_2 , followed by electrochemical transduction at the PtNP-containing interface. PAMAM supports nanoparticle organization and enzyme immobilization, f-MWCNTs provide conductive pathways, and PtNPs provide peroxide electrocatalysis. Recent GOx biosensors using Pt nanostructures, carbon nanotubes, screen-printed electrodes, and chitosan-based enzyme immobilization support this functional interpretation [4,6,7,17-19].

Earlier Pt/CNT and dendrimer-containing platforms established the usefulness of combining nanoscale platinum with conductive nanotube networks [20-23]. while other hybrid nanostructured GOx electrodes demonstrate the broader importance of high-area enzyme-supporting interfaces [23-25]. Direct numerical

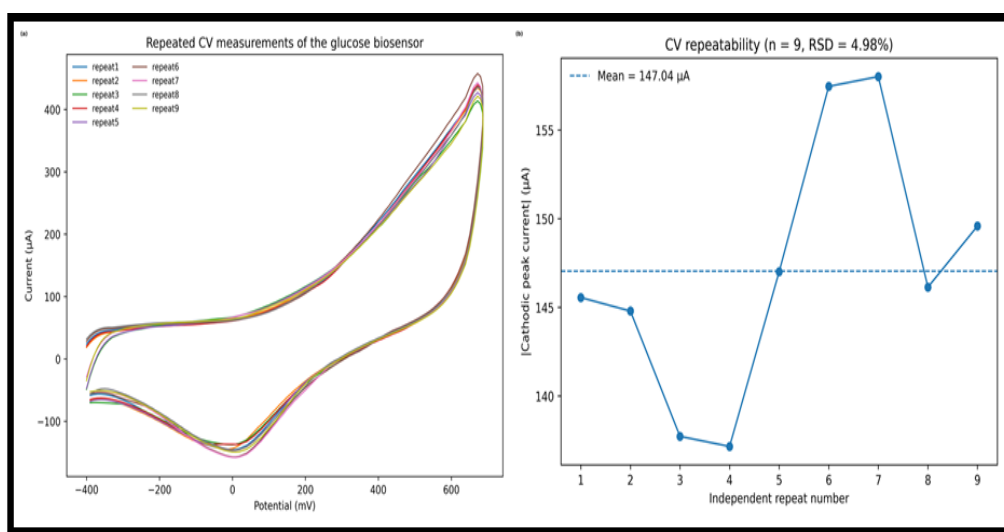


Fig. 10. (a) Nine valid consecutive cyclic voltammograms recorded with the same glucose biosensor. (b) Cathodic peak-current magnitude across the nine measurements; the dashed line denotes the mean.

Table 1. Summary of analytical performance.

Analyte	Technique	Linear range (μM)	Slope	R^2	LOD (μM)	LOQ (μM)
H_2O_2	CV	5-250	$1.2263 \mu\text{A } \mu\text{M}^{-1}$	0.9983	14.16	42.91
H_2O_2	Amperometry	25-500	$0.0240 \mu\text{A } \mu\text{M}^{-1}$	0.9875	Not estimated	Not estimated
Glucose	CV	10-100	$1.3715 \mu\text{A } \mu\text{M}^{-1}$	0.9916	11.84	35.89

ranking remains inappropriate because technique, electrode area, operating potential, matrix, and the calculation of sensitivity and detection limit differ among studies.

Same-electrode repeatability and analytical scope

Nine valid consecutive CV measurements were analyzed on the same glucose biosensor. A tenth stored trace was excluded because it was an exact point-by-point duplicate of the fifth trace and therefore was not an independent observation. The nine cathodic peak-current magnitudes had a mean of 147.04 μA , sample SD of 7.32 μA , and RSD of 4.98%. This experiment demonstrates intra-electrode repeatability; it does not establish reproducibility across independently fabricated electrodes.

The present dataset supports proof-of-concept H_2O_2 transduction and enzymatic glucose sensing. It does not yet provide complete analytical validation for practical or clinical use. Inter-electrode reproducibility, quantitative selectivity at documented interferent levels, storage stability, pH optimization, and recovery in a representative sample matrix remain to be established. Claims are therefore limited to the measured buffer-system performance.

CONCLUSION

A G5-PAMAM/PtNPs/f-MWCNT ternary nanocomposite was integrated with a screen-printed carbon electrode and coupled to GOx for H_2O_2 -mediated glucose sensing. Structural and morphological characterization supported coexistence of a graphitic nanotube framework, crystalline FCC Pt, and a chemically functional PAMAM-containing interface. Three nanocomposite layers produced the largest ferricyanide peak currents among the tested coatings. The modified electrode showed linear H_2O_2 CV behavior over 5–250 μM with $R^2 = 0.9983$. After GOx immobilization, the glucose response was linear over 10–100 μM with $R^2 = 0.9916$, and nine valid same-electrode measurements gave an RSD of 4.98%. These results establish the feasibility of the ternary material as a peroxide-transducing interface for enzymatic glucose detection.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Al-Zanganawee J, Mahmood OA, Hussein NK, Brincoveanu O, Stoian M, Gavrilă R. Impact of Addition of ZnO and CuO Colloidal Nanoparticles on the Physical Properties of the NiO Nanostructured Thin Film for Gas Sensing. *Journal of Nanotechnology*. 2025;2025(1).
2. Kim J, Jeong J, Ko SH. Electrochemical biosensors for point-of-care testing. *Bio-Design and Manufacturing*. 2024;7(4):548–565.
3. Gupta S, Tai N-H. Carbon nanomaterials and their composites for electrochemical glucose biosensors: A review on fabrication and sensing properties. *Journal of the Taiwan Institute of Chemical Engineers*. 2024;154:104957.
4. Khumngern S, Nontipichet N, Thavarungkul P, Kanatharana P, Numnuam A. Smartphone-enabled flow injection amperometric glucose monitoring based on a screen-printed carbon electrode modified with PEDOT@PB and a GOx@PPTNPs@MWCNTs nanocomposite. *Talanta*. 2024;277:126336.
5. Bollella P. Enzyme-based amperometric biosensors: 60 years later ... Quo Vadis? *Anal Chim Acta*. 2022;1234:340517.
6. Li Y-Y, Ma X-X, Song X-Y, Ma L-L, Li Y-Y, Meng X, et al. Glucose Biosensor Based on Glucose Oxidase Immobilized on BSA Cross-Linked Nanocomposite Modified Glassy Carbon Electrode. *Sensors*. 2023;23(6):3209.
7. Wu B, Xu H, Shi Y, Yao Z, Yu J, Zhou H, et al. Microelectrode glucose biosensor based on nanoporous platinum/graphene oxide nanostructure for rapid glucose detection of tomato and cucumber fruits. *Food Quality and Safety*. 2022;6.
8. Mazzotta E, Di Giulio T, Mastronardi V, Pompa PP, Moglianetti M, Malitesta C. Bare Platinum Nanoparticles Deposited on Glassy Carbon Electrodes for Electrocatalytic Detection of Hydrogen Peroxide. *ACS Applied Nano Materials*. 2021;4(8):7650–7662.
9. Ahmad T, Iqbal A, Halim SA, Uddin J, Khan A, El Deeb S, et al. Recent Advances in Electrochemical Sensing of Hydrogen Peroxide (H_2O_2) Released from Cancer Cells. *Nanomaterials*. 2022;12(9):1475.
10. Poellmann MJ, Rawding P, Kim D, Bu J, Kim Y, Hong S. Branched, dendritic, and hyperbranched polymers in liquid biopsy device design. *WIREs Nanomedicine and Nanobiotechnology*. 2022;14(3).
11. Soto D, Orozco J. Hybrid Nanobioengineered Nanomaterial-Based Electrochemical Biosensors. *Molecules*. 2022;27(12):3841.
12. Tomalia DA, Baker H, Dewald J, Hall M, Kallos G, Martin S, et al. A New Class of Polymers: Starburst-Dendritic Macromolecules. *Polym J*. 1985;17(1):117–132.
13. Datsyuk V, Kalyva M, Papagelis K, Parthenios J, Tasis D, Siokou A, et al. Chemical oxidation of multiwalled carbon nanotubes. *Carbon*. 2008;46(6):833–840.
14. The International Council for Harmonisation: Pharmaceutical Standard-Setting on the Global Level. The Interplay of Global Standards and EU Pharmaceutical Regulation: Hart Publishing; 2021. <http://dx.doi.org/10.5040/9781509943029.ch-003>
15. Chou T-C, Wu K-Y, Hsu F-X, Lee C-K. Pt-MWCNT modified carbon electrode strip for rapid and quantitative detection of H_2O_2 in food. *J Food Drug Anal*. 2018;26(2):662–669.
16. Yu H, Yu J, Li L, Zhang Y, Xin S, Ni X, et al. Recent Progress of the Practical Applications of the Platinum Nanoparticle-Based Electrochemistry Biosensors. *Frontiers in Chemistry*. 2021;9.

17. Liu C-T, Liu C-H, Lai Y-T, Lee C-Y, Gupta S, Tai N-H. A salivary glucose biosensor based on immobilization of glucose oxidase in Nafion-carbon nanotubes nanocomposites modified on screen printed electrode. *Microchem J.* 2023;191:108872.
18. Ting J-H, Lin P-C, Gupta S, Liu C-H, Yang T, Lee C-Y, et al. Dipole moment as the underlying mechanism for enhancing the immobilization of glucose oxidase by ferrocene-chitosan for superior specificity non-invasive glucose sensing. *Nanoscale Advances.* 2023;5(18):4881-4891.
19. Marchianò V, Pellegrini C, Tricase A, Macchia E, Brattelli A, Gentile L, et al. Mussel-Bioinspired Edible Ca^{2+} -Crosslinked Alginate Hydrogel Electrodes for Glucose Gastrointestinal Monitoring. *Advanced Science.* 2025;13(8).
20. Xu L, Zhu Y, Yang X, Li C. Amperometric biosensor based on carbon nanotubes coated with polyaniline/dendrimer-encapsulated Pt nanoparticles for glucose detection. *Materials Science and Engineering: C.* 2009;29(4):1306-1310.
21. Kang X, Mai Z, Zou X, Cai P, Mo J. Glucose biosensors based on platinum nanoparticles-deposited carbon nanotubes in sol-gel chitosan/silica hybrid. *Talanta.* 2008;74(4):879-886.
22. Chicea D, Nicolae-Maranciuc A. Metal Nanocomposites as Biosensors for Biological Fluids Analysis. *Materials.* 2025;18(8):1809.
23. Cabaj J, Sołoduch J. Nano-Sized Elements in Electrochemical Biosensors. *Materials Sciences and Applications.* 2014;05(10):752-766.
24. Zhang D, Chen X, Ma W, Yang T, Li D, Dai B, et al. Direct electrochemistry of glucose oxidase based on one step electrodeposition of reduced graphene oxide incorporating polymerized l-lysine and its application in glucose sensing. *Materials Science and Engineering: C.* 2019;104:109880.
25. Song Y, Xu M, Gong C, Shen Y, Wang L, Xie Y, et al. Ratiometric electrochemical glucose biosensor based on GOD/AuNPs/Cu-BTC MOFs/macroporous carbon integrated electrode. *Sensors Actuators B: Chem.* 2018;257:792-799.