Composites Communications 56 (2025) 102363

Contents lists available at ScienceDirect

Composites Communications

journal homepage: www.elsevier.com/locate/coco

Albumin fouling-free electrochemical sensors based on polyaniline single walled carbon nanotube composites for precise purine metabolomics

Thenmozhi Rajarathinam [a,b], Sivaguru Jayaraman [a], Devaraju Subramani [c], Suraj Aswale [d], Jaewon Lee [e], Hyun-jong Paik [d], Chang-Seok Kim [a,b], Jang-Hee Yoon [f], Seung-Cheol Chang [a,*]

[a] Department of Cogno-Mechatronics Engineering, College of Nanoscience and Nanotechnology, Pusan National University, Busan, 46241, Republic of Korea
[b] Engineering Research Center for Color-Modulated Extra-Sensory Perception Technology, Pusan National University, Busan, 46241, Republic of Korea
[c] Polymer Engineering Laboratory, Department of Chemistry, PSG Institute of Technology and Applied Research, Neelambur, Coimbatore, Tamil Nadu, 641062, India
[d] Department of Polymer Science and Engineering, Pusan National University, Busan, 46241, Republic of Korea
[e] Department of Pharmacy, College of Pharmacy, Pusan National University, Busan, 46241, Republic of Korea
[f] Busan Center, Korea Basic Science Institute, Busan, 46742, Republic of Korea

A R T I C L E I N F O

Keywords:
Electrochemical sensor
Polymeric dispersant
Single-walled carbon nanotubes
Purine metabolites
Human serum

A B S T R A C T

Electrochemical sensors enable rapid and accurate detection of targets. However, fouling is a burden that restricts sensor performance in complex biofluids and fouling resistant or fouling-free property is paramount to guarantee the reliable operation of sensors. Single-walled carbon nanotubes (SWCNTs) possess an exceptional catalytic capability owing to the weak molecular adsorption of sp3 carbon. Poly(aniline-N-propane sulfonic acid) (PAPS) polymer dispersed SWCNTs with a high conductivity (4.184 S/cm), and hydrophilicity were prepared to circumvent the fouling issues. The length of the PAPS dispersed SWCNTs were 3.1 $\pm$ 1.0 μm and the modified screen-printed carbon electrodes (PAPS-SWCNTs/SPCEs) demonstrated efficient electro-oxidation of purines, such as, uric acid (UA), xanthine (XA), and hypoxanthine (HX) after exposure to high concentrations of a common foulant, serum albumin. The peak-to-peak separations of UA–XA, XA–HX, and UA–HX were 0.396 V, 0.352 V, and 0.748 V, respectively. The detection limits of UA, XA, and HX were 0.047, 0.049, and 0.052 μM respectively. The practical applicability of the sensor was established using human serum and synthetic urine samples. The fabricated sensor is fouling-free and could serve as a potential diagnostic device for the early detection of renal diseases, such as renal calculi, chronic kidney diseases, and renal failure in resource-limited settings, since it does not require scrupulous sample pretreatment, frequent recalibration or prolonged waiting times. Moreover, the developed sensor adheres to ASSURED criteria, which is crucial for the diagnosis of renal diseases in resource-limited settings.

1. Introduction[1]

The frequent and existing challenge of electrochemical sensors is fouling or interference, leading to poor sensitivity and selectivity. In biological samples, the common foulant is serum albumin. To overcome this constraint, fouling resistant or fouling-free sensor materials are paramount to guarantee their reliable operation [1–4]. Hence, stable, and cost-effective fouling free materials are crucial in fouling free sensors fabrication. To date, different macromolecular materials such as zwitterionic materials, poly(ethylene glycol), poly(3-octylthiophene), proteins, and peptides have been explored to deal with fouling issues [5,6]. To completely circumvent fouling, well-dispersed single-walled carbon nanotubes (SWCNTs) are ideal electrode modifiers [7]. Hence, Pristine SWCNTs have captivated considerable practical interest owing to their unique quasi-one-dimensional structure, mechanical strength, electrical conductivity, and chemical stability. Nonetheless, pristine SWCNTs have high surface energy to form bundles or entangled ropes. The hydrophobicity and significant inter-tube van der Waals interaction

Abbreviations: (SPCE), screen-printed carbon electrode; (SWCNT), single-wall carbon nanotubes; (FE-SEM), field-emission scanning electron microscope; (EDX), energy-dispersive X-ray spectroscopy; (TEM), transmission electron microscopy; (XPS), X-ray photoelectron spectroscopy; (CV), cyclic voltammetry; (ASA), active surface area; (XA), xanthine; (HX), hypoxanthine; (UA), uric acid; (AA), ascorbic acid; (DA), dopamine; (Cr), creatinine; (I_{pa}), anodic peak current; (I_{pc}), cathodic peak current; (EIS), electrochemical impedance spectroscopy; (DPV), differential pulse voltammetry; (LOD), limit of detection.

* Corresponding author.
E-mail address: s.c.chang@pusan.ac.kr (S.-C. Chang).

https://doi.org/10.1016/j.coco.2025.102363
Received 2 January 2025; Received in revised form 13 March 2025; Accepted 20 March 2025
Available online 21 March 2025

SWCNTs [67]. Despite considerable advancements, conjugated polymers still face several challenges on their path towards biosensing applications. These challenges include their complex structure, synthesis, and tendency to phase separate, resulting in multiphase arrangement with limited morphological stability.

Recently, efficient and simple methods for dispersing SWCNTs in aqueous media have focused on hydrophilizing CNTs with molecules that non-covalently bind to the CNT surface. This non-covalent functionalization holds great promise, as it minimizes the modification-induced changes in the electronic and mechanical properties of CNTs. Previously, we have utilized poly(2-dimethylaminoethyl methacrylate-co-styrene) poly(sodium 4-styrene sulfonate-r-LAHEMA) to increase the aspect ratio of SWCNTs [68]. Considering all these aspects, in this study, a simple PANI polymer, PAPS was employed not only to disperse SWCNTs but also to achieve fouling-free sensing of the targets in varied biological matrices.

4. Conclusions

A highly conductive PAPS-SWCNTs-2 was prepared to establish an ultrasensitive electrochemical sensor that could be applied for the selective and simultaneous quantification of purine metabolites, UA, XA, and HX. The PAPS-SWCNTs-2 provided abundant electrochemically active sites, and extraordinary electrical conductivity, which permitted the ultrasensitive quantification of purines. The selectivity results verified that the tested interferents had no apparent influence on the synchronous estimation of purine metabolites. Furthermore, the repeatability and stability of the sensor are high. Moreover, the quantification of UA, XA, and HX in human serum and synthetic urine samples showed appreciable recoveries of approximately 100 %. This is a conceptual study for the fouling free, ultrasensitive and convenient sensor preparation technique. It takes less than 10 min because PAPS-SWCNTs-2 is drop-casted directly on the electrode surface. A further advantage of our approach is the simple and simultaneous purine detection in human serum and synthetic urine. This involves a simple sample dilution with no requirements for separation or purification steps. The results indicate the favorable properties of the PAPS-SWCNTs-2/SPCE sensor for determining small purine metabolites in the presence of large albumin biomolecules, which do not influence the analysis.

CRediT authorship contribution statement

Thenmozhi Rajarathinam: Writing – original draft, Software, Methodology, Investigation, Data curation, Conceptualization. **Sivaguru Jayaraman:** Validation, Methodology, Investigation, Conceptualization. **Devaraju Subramani:** Validation, Methodology, Investigation, Data curation. **Suraj Aswale:** Validation, Methodology, Investigation, Data curation. **Jaewon Lee:** Writing – original draft, Validation, Supervision. **Hyun-jong Paik:** Validation, Supervision, Methodology. **Chang-Seok Kim:** Validation, Supervision, Methodology, Funding acquisition. **Jang-Hee Yoon:** Validation, Methodology, Investigation. **Seung-Cheol Chang:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (2022R1I1A3072535). This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2021R1A5A1032937).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.coco.2025.102363.

Data availability

Data will be made available on request.

References

[1] A.C. Power, B. Gorey, S. Chandra, J. Chapman, Carbon nanomaterials and their application to electrochemical sensors: a review, Nanotechnol. Rev. 7 (1) (2018) 19–41.
[2] H. Fang, X. Wei, Z. Cui, S. He, W. Shao, Ultrafast self-healing zwitterionic hydrogels reinforced by carboxymethyl chitosan-oxidized hyaluronic acid and graphene oxide toward high-performance strain sensors, Int. J. Biol. Macromol. 286 (2) (2025) 138330.
[3] D.K. Patel, S.Y. Won, T.V. Patel, S.D. Dutta, K.T. Lim, S.S. Han, Unzipped carbon nanotubes assisted 3D printable functionalized chitosan hydrogels for strain sensing applications, Int. J. Biol. Macromol. 265 (2) (2024) 131025.
[4] L. Snarski, I. Biran, T. Bendikov, I. Pinkas, M.A. Iron, I. Kaplan-Ashiri, H. Weissman, B. Rybtchinski, Highly conductive robust carbon nanotube networks for strong buckypapers and transparent electrodes, Adv. Funct. Mater. 34 (2024) 2309742.
[5] X. Feng, X. Wang, C. Zhang, C. Dang, Y. Chen, H. Qi, Highly conductive and multifunctional nanocomposites based on sulfated nanocellulose-assisted high dispersion limit of single-walled carbon nanotubes, Carbon 183 (2021) 187–195.
[6] M. Dolan, B.P. Watts, K. Tvrdy, Tailored synthesis of hydrogel media for chirality separation of single walled carbon nanotubes, Carbon 171 (2021) 597–609.
[7] T. Farrell, K. Wang, C.-W. Lin, R.B. Kaner, Organic dispersion of polyaniline and single-walled carbon nanotubes and polyblends with poly(methyl methacrylate), Polymer 129 (2017) 1–4.
[8] O.V. Sedelnikova, V.I. Sysoev, O.A. Gurova, Y.P. Ivanov, V.O. Koroteev, R. Arenal, A.A. Makarova, L.G. Bulusheva, A.V. Okotrub, Role of interface interactions in the sensitivity of sulfur-modified single-walled carbon nanotubes for nitrogen dioxide gas sensing, Carbon 186 (2022) 539–549.
[9] H. Zengin, W. Zhou, J. Jin, R. Czerw, D.W. Smith, L. Echegoyen, D.L. Carroll, S. H. Foulger, J. Ballato, Carbon nanotube doped polyaniline, Adv. Mater. 14 (20) (2002) 1480–1483.
[10] T. Farrell, K. Wang, C.-W. Lin, R.B. Kaner, Organic dispersion of polyaniline and single-walled carbon nanotubes and polyblends with poly(methyl methacrylate), Polymer 129 (2017) 1–4.
[11] O.V. Sedelnikova, V.I. Sysoev, O.A. Gurova, Y.P. Ivanov, V.O. Koroteev, R. Arenal, A.A. Makarova, L.G. Bulusheva, A.V. Okotrub, Role of interface interactions in the sensitivity of sulfur-modified single-walled carbon nanotubes for nitrogen dioxide gas sensing, Carbon 186 (2022) 539–549.
[12] K. Yokoyama, Y. Sato, M. Yamamoto, T. Nishida, T. Itoh, K. Motomiya, Y. Sato, Functionalization of primary amine groups to single-walled carbon nanotubes by reacting fluorinated SWCNTs with ammonia gas at a low temperature, Carbon 172 (2021) 360–371.
[13] X. Feng, X. Wang, C. Zhang, C. Dang, Y. Chen, H. Qi, Highly conductive and multifunctional nanocomposites based on sulfated nanocellulose-assisted high dispersion limit of single-walled carbon nanotubes, Carbon 183 (2021) 187–195.
[14] M. Boban, G. Kocic, S. Radenkovic, R. Pavlovic, T. Cvetkovic, M. Deljanin-Ilic, S. Ilic, M.D. Bobana, B. Djindjic, D. Stojanovic, D. Sokolovic, T. Jevtovic-Stoimenov, Circulating purine compounds, uric acid, and xanthine oxidase/dehydrogenase relationship in essential hypertension and end stage renal disease, Ren. Fail 36 (4) (2014) 613–618.
[15] Y. Wang, M. Deng, B. Deng, L. Ye, X. Fei, Z. Huang, Study on the diagnosis of gout with xanthine and hypoxanthine, J. Clin. Lab. Anal. 33 (5) (2019) e22868.
[16] Y. Li, X. Han, J. Tong, Y. Wang, X. Liu, Z. Liao, M. Jiang, H. Zhao, Analysis of metabolites in gout: a systematic review and meta-analysis, Nutrients 15 (14) (2023) 3143.
[17] S. Boroumand, M.A. Chamjangali, G. Bagherian, Double injection/single detection asymmetric flow injection manifold for spectrophotometric determination of ascorbic acid and uric acid: selection the optimal conditions by MCDM approach based on different criteria weighting methods, Spectrochim. Acta: Mol. Biomol. Spectrosc. 174 (2017) 203–213.
[18] L. Liu, H. Wang, X. Bo, L. Yang, L. Guo, Electrochemistry and simultaneous detection of metabolites of purine nucleotide based on large mesoporous carbon modified electrode, Electroanalysis 24 (6) (2012) 1401–1408.
[19] M.A. Raj, S.A. John, Simultaneous determination of uric acid, xanthine, hypoxanthine and caffeine in human blood serum and urine samples using electrochemically reduced graphene oxide modified electrode, Anal. Chim. Acta 771 (2013) 14–20.
[20] J. Yan, H. Lin, Y. Xu, L. Yu, S. Chen, Q. Zhang, L. Han, Y. Ou, M. Zhan, J. Wang, P. Ke, Y. Wang, X. Huang, Measurement of serum uric acid by isotope dilution liquid chromatography tandem mass spectrometry: modification of a candidate

reference measurement method and its clinical application, Int. J. Mass Spectrom. 482 (2022) 116911.
[21] T. Hallaj, N. Azizi, M. Amjadi, A dual-mode colorimetric and fluorometric nanosensor for detection of uric acid based on N, P co-doped carbon dots and in-situ formation of Au/Ag core-shell nanoparticles, Microchem. J. 162 (2021) 105865.
[22] M. Amjadi, T. Hallaj, E. Nasirloo, In situ formation of Ag/Au nanorods as a platform to design a non-aggregation colorimetric assay for uric acid detection in biological fluids, Microchem. J. 154 (2020) 104642.
[23] S. Zhao, J. Wang, F. Ye, Y.-M. Liu, Determination of uric acid in human urine and serum by capillary electrophoresis with chemiluminescence detection, Anal. Biochem. 378 (2) (2008) 127–131.
[24] T. Rajarathinam, D. Thirumalai, S. Jayaraman, S. Yang, A. Ishigami, J.-H. Yoon, H.-j. Paik, J. Lee, S.-C. Chang, Glutamate oxidase sheets-Prussian blue grafted amperometric biosensor for the real time monitoring of glutamate release from primary cortical neurons, Int. J. Biol. Macromol. 254(2) (2024) 127903 Km S. Kushwaha, B. Dey, M.S. Khan, M.W. Ahmad, A. S, H.A. AL-Shwaiman, L. S. Wong, P. Datta, A. Choudhury, Electrochemically enzyme-free detection of lactic acid in human sweat using magnesium organic framework@carbon nanofiber composite, Mater. Sci. Semicond. Process. 188 (2025) 109177.
[25] Km S. Kushwaha, A. Anand, B. Dey, M.W. Ahmad, A. Syed, H.A. AL-Shwaiman, M. Subramaniam, A. Choudhury, Novel electrochemical sensing platform based on zinc metal organic frameworks/carbon nanofiber nanocomposite for detection of creatinine in human urine, J. Electroanal. Chem. 971 (2024) 118574.
[26] B. Dey, M.W. Ahmad, R. Al-Shannaq, J.Y. Al-Humaidi, S.K.S. Hossain, C.N. Patra, R.H. Althomali, M.M. Rahman, A. Choudhury, Non-enzymatic electrochemical sensing of bisphenol A in drinking water and milk using bimetallic nickel-copper metal–organic framework, J. Anal. Test. 8 (2024) 451–465.
[27] B. Dey, G. Sarkhel, A. Choudhury, Facile synthesis of copper MOF/carbon nanofiber nanocomposite paper for electrochemical detection of toxic 4-nitrophenol, J. Macromol. Sci, Part. Accel. 60 (2) (2023) 150–160.
[28] M.W. Ahmad, S. Verma, D.-J. Yang, M.U. Islam, A. Choudhury, Synthesis of silver nanoparticles-decorated poly(m-aminophenol) nanofibers and their application in a non-enzymatic glucose biosensor, J. Macromol. Sci., Part A 58 (7) (2021) 461–471.
[29] J.-W. Cui, T.-J. Hou, Q. Wang, G.-G. Gao, S. Bi, K.-C. Zhou, J.-L. Li, D.-M. Wu, An enzyme assisted electrochemical detection system of purine intracellular utilizing MWCNTs-IL modified glassy carbon electrode, Electrochim. Acta 180 (2015) 360–365.
[30] X. Chen, G. Wu, Z. Cai, M. Oyama, X. Chen, Advances in enzyme-free electrochemical sensors for hydrogen peroxide, glucose, and uric acid, Mikrochim. Acta 181 (7–8) (2014) 689–705.
[31] Y. Wen, J. Chang, L. Xu, X. Liao, L. Bai, Y. Lan, M. Li, Simultaneous analysis of uric acid, xanthine and hypoxanthine using voltammetric sensor based on nanocomposite of palygorskite and nitrogen doped graphene, J. Electroanal. Chem. 805 (2017) 159–170.
[32] N.T.V. Hoan, N.N. Minh, N.T.H. Trang, L.T.T. Thuy, C. Van Hoang, T.X. Mau, H.X. A. Vu, P.T.K. Thu, N.H. Phong, D.Q. Khieu, Simultaneous voltammetric determination of uric acid, xanthine, and hypoxanthine using CoFe2O4/reduced graphene oxide-modified electrode, J. Nanomater. (2020) 1–15.
[33] F. Zhang, Z. Wang, Y. Zhang, Z. Zheng, C. Wang, Y. Du, W. Ye, Simultaneous electrochemical determination of uric acid, xanthine and hypoxanthine based on poly(L-arginine)/graphene composite film modified electrode, Talanta 93 (2012) 320–325.
[34] Y. Wang, L.-l. Tong, Electrochemical sensor for simultaneous determination of uric acid, xanthine and hypoxanthine based on poly (bromocresol purple) modified glassy carbon electrode, Sensor. Actuator. B Chem. 150 (1) (2010) 43–49.
[35] Y. Wang, Simultaneous determination of uric acid, xanthine and hypoxanthine at poly(pyrocatechol violet)/functionalized multi-walled carbon nanotubes composite film modified electrode, Colloids Surf., B 88 (2) (2011) 614–621.
[36] A. Luo, Q. Lian, Z. An, Z. Li, Y. Guo, D. Zhang, Z. Xue, X. Zhou, X. Lu, Simultaneous determination of uric acid, xanthine and hypoxanthine based on sulfonic groups functionalized nitrogen-doped graphene, J. Electroanal. Chem. 756 (2015) 22–29.
[37] Z. Wang, X. Dong, J. Li, An inlaying ultra-thin carbon paste electrode modified with functional single-wall carbon nanotubes for simultaneous determination of three purine derivatives, Sensor. Actuator. B Chem. 131 (2) (2008) 411–416.
[38] A.S. Kumar, P. Swetha, Ru(DMSO)4Cl2 nano-aggregated Nafion membrane modified electrode for simultaneous electrochemical detection of hypoxanthine, xanthine and uric acid, J. Electroanal. Chem. 642 (2) (2010) 135–142.
[39] S.G. Vaidya, S. Rastogi, A. Aguirre, Surfactant assisted processable organic nanocomposite dispersions of polyaniline–single wall carbon nanotubes, Synth. Met. 160 (1–2) (2010) 134–138.
[40] N. Gull, S.M. Khan, A. Islam, S. Zia, M. Shafiq, A. Sabir, M.A. Munawar, M.T. Z. Butt, T. Jamil, Effect of different oxidants on polyaniline/single walled carbon nanotubes composites synthesized via ultrasonically initiated in-situ chemical polymerization, Mater. Chem. Phys. 172 (2016) 39–46.
[41] N. Laube, B. Mohr, A. Hesse, Laser-probe-based investigation of the evolution of particle size distributions of calcium oxalate particles formed in artificial urines, J. Cryst. Growth 233 (1–2) (2001) 367–374.
[42] L. Liu, L. Shou, H. Yu, J. Yao, Mechanical properties and corrosion resistance of vulcanized silicone rubber after exposure to artificial urine, J. Macromol. Sci. Part B 54 (8) (2015) 962–974.
[43] M. Grigoras, A.M. Catargiu, F. Tudorache, M. Dobromir, Chemical synthesis and characterization of self-doped N-propanesulfonic acid polyaniline derivatives, Iran. Polym. J. (Engl. Ed.) 21 (2012) 131–141.
[44] X. Feng, X. Wang, M. Wang, S. Zhou, C. Dang, C. Zhang, Y. Chen, H. Qi, Novel PEDOT dispersion by in-situ polymerization based on sulfated nanocellulose, Chem. Eng. J. 418 (2021) 129533.
[45] D. Qu, Z. Sun, M. Zheng, J. Li, Y. Zhang, G. Zhang, H. Zhao, X. Liu, Z. Xie, Three colors emission from S,N co-doped graphene quantum dots for visible light H2 production and bioimaging, Adv. Opt. Mater. 3 (3) (2015) 360–367.
[46] Z. Zeng, D. Xu, M. Li, Z. Liu, R. Xu, D. Liu, Confined transformation of trifunctional Co(2)(OH)(2)CO(3) nanosheet assemblies into hollow porous Co@N-doped carbon spheres for efficient microwave absorption, J. Colloid Interface Sci. 622 (2022) 625–636.
[47] S.N. Faisal, E. Haque, N. Noorbehesht, W. Zhang, A.T. Harris, T.L. Church, A. I. Minett, Pyridinic and graphitic nitrogen-rich graphene for high-performance supercapacitors and metal-free bifunctional electrocatalysts for ORR and OER, RSC Adv. 7 (29) (2017) 17950–17958.
[48] S. Hong, D.-M. Lee, M. Park, J.-H. Wee, H.S. Jeong, B.-C. Ku, C.-M. Yang, D.S. Lee, M. Terrones, Y.A. Kim, J.Y. Hwang, Controlled synthesis of N-type single-walled carbon nanotubes with 100% of quaternary nitrogen, Carbon 167 (2020) 881–887.
[49] Z. Luo, S. Lim, Z. Tian, J. Shang, L. Lai, B. MacDonald, C. Fu, Z. Shen, T. Yu, J. Lin, Pyridinic N doped graphene: synthesis, electronic structure, and electrocatalytic property, J. Mater. Chem. 21 (22) (2011) 8038–8044.
[50] T. Rajarathinam, M. Kwon, D. Thirumalai, S. Kim, S. Lee, J.-H. Yoon, H.-j. Paik, S. Kim, J. Lee, H.K. Ha, S.-C. Chang, Polymer-dispersed reduced graphene oxide nanosheets and Prussian blue modified biosensor for amperometric detection of sarcosine, Anal. Chim. Acta 1175 (2021) 338749.
[51] H. Yin, Q. Zhang, Y. Zhou, Q. Ma, T. liu, L. Zhu, S. Ai, Electrochemical behavior of catechol, resorcinol and hydroquinone at graphene–chitosan composite film modified glassy carbon electrode and their simultaneous determination in water samples, Electrochim. Acta 56 (6) (2011) 2748–2753.
[52] M.-J. Wei, X.-Y. Lu, J. Li, F.-Y. Kong, J. Zhou, Z.-X. Wang, W. Wang, Coupling highly conductive covalent organic framework with nitrogen doped carbon nanotubes enables simultaneous and sensitive quantification of xanthine and hypoxanthine, Microchem. J. 194 (2023) 109205.
[53] B. Dey, Km S. Kushwaha, A. Choudhury, M.W. Ahmad, P. Datta, A. Syed, H.A. AL-Shwaiman, M. Subramaniam, Novel non-enzymatic electrochemical sensing platform based on copper metal organic frameworks for detection of glyphosate herbicide in vegetables extract, Microchem. J. 208 (2025) 112407.
[54] M.W. Ahmad, B. Dey, B.-H. Kim, G. Sarkhel, D.-J. Yang, S.K. Safdar Hossain, T. Kamal, A. Choudhury, Bimetallic copper-cobalt MOFs anchored carbon nanofibers hybrid mat based electrode for simultaneous determination of dopamine and tyramine, Microchem. J. 193 (2023) 109074.
[55] S. Saisree, J.S. Arya Nair, K.Y. Sandhya, A highly stable copper nano cluster on nitrogen-doped graphene quantum dots for the simultaneous electrochemical sensing of dopamine, serotonin, and nicotine: a possible addiction scrutinizing strategy, J. Mater. Chem. B 10 (21) (2022) 3974–3988.
[56] N. Lavanya, C. Sekar, R. Murugan, G. Ravi, An ultrasensitive electrochemical sensor for simultaneous determination of xanthine, hypoxanthine and uric acid based on Co doped CeO2 nanoparticles, Mater. Sci. Eng. C 65 (2016) 278–286.
[57] J.-M. Zen, Y.-Y. Lai, H.-H. Yang, A.S. Kumar, Multianalyte sensor for the simultaneous determination of hypoxanthine, xanthine and uric acid based on a preanodized nontronite-coated screen-printed electrode, Sensor. Actuator. B Chem. 84 (2–3) (2002) 237–244.
[58] X. Liu, X. Ou, Q. Lu, J. Zhang, S. Chen, S. Wei, Electrochemical sensor based on overoxidized dopamine polymer and 3,4,9,10-perylenetetracarboxylic acid for simultaneous determination of ascorbic acid, dopamine, uric acid, xanthine and hypoxanthine, RSC Adv. 4 (80) (2014) 42632–42637.
[59] D. Lan, L. Zhang, Electrochemical synthesis of a novel purine-based polymer and its use for the simultaneous determination of dopamine, uric acid, xanthine and hypoxanthine, J. Electroanal. Chem. 757 (2015) 107–115.
[60] B. Dey, M.W. Ahmad, G. Sarkhel, G. Ho Lee, A. Choudhury, Fabrication of niobium metal organic frameworks anchored carbon nanofiber hybrid film for simultaneous detection of xanthine, hypoxanthine and uric acid, Microchem. J. 186 (2023) 108295.
[61] H. Ibrahim, Y. Temerk, A novel electrochemical sensor based on B doped CeO2 nanocubes modified glassy carbon microspheres paste electrode for individual and simultaneous determination of xanthine and hypoxanthine, Sensor. Actuator. B Chem. 232 (2016) 125–137.
[62] D. Song, Q. Chen, C. Zhai, H. Tao, L. Zhang, T. Jia, Z. Lu, W. Sun, P. Yuan, B. Zhu, Label-free ZnIn2S4/UiO-66-NH2 modified glassy carbon electrode for electrochemically assessing fish freshness by monitoring xanthine and hypoxanthine, Chemosensors 10 (5) (2022) 158.
[63] K. Hayat, A. Munawar, A. Zulfiqar, M.H. Akhtar, H.B. Ahmad, Z. Shafiq, M. Akram, A.S. Saleemi, N. Akhtar, CuO hollow cubic caves wrapped with biogenic N-rich graphitic C for simultaneous monitoring of uric acid and xanthine, ACS Appl. Mater. Interfaces 12 (42) (2020) 47320–47329.
[64] G.D. Pierini, S.N. Robledo, M.A. Zon, M.S. Di Nezio, A.M. Granero, H. Fernández, Development of an electroanalytical method to control quality in fish samples based on an edge plane pyrolytic graphite electrode. Simultaneous determination of hypoxanthine, xanthine and uric acid, Microchem. J. 138 (2018) 58–64.
[65] R. Thangaraj, A.S. Kumar, Graphitized mesoporous carbon modified glassy carbon electrode for selective sensing of xanthine, hypoxanthine and uric acid, Anal. Methods 4 (7) (2012) 2162–2171.