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REVIEW PAPER

Recent advances in electrochemical modified Electrodes for sensing phenol derivatives

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ABSTRACT

Enzymless electrode is a device combines a material component and electrochemical transducer, used for the detection of an analyte. Nanomaterials are widely used in sensing areas due to its high positive effect on the response of enzymeless based electrode, it could be used as transduction element or immobilized onto the surface of electrochemical transducers, their presence increases sensitivities and gives a lower detection limits and enhance the kinetic performance of sensors. In this work, we report the effect of the most recent nonmaterial used for electrochemical detection, catalytic effect of various nanoparticles such as, nanomaterials, gold nanoparticles, conducting polymer, carbon nanotubes, and metal oxide immobilized on the surface of electrochemical transducers (platinum electrode, Carbon electrode and Gold electrode) is intensively analyzed. A comparative study of the nanoparticles effect on the analytical performance of sensor for the detection of phenolic compounds is also presented and discussed.

Introduction

Electrochemical sensors are very powerful tools for monitoring analytes such as phenolic compounds. These tools are mainly constituted by transducers for real-time measurement of electrochemical reactions of analytes in aqueous medium. Therefore, the fast charge transfer factor are considered important during the construction of sensors. Hence, electroanalytical performance of sensors are mainly dependent on the presence of nanomaterials in sensing platforms. Moreover, optimization of experimental parameters is essential to give a very sensitive and stable response before the construction of sensors (Scheme 1). The aim of this work is to discuss the advantage of the presence of different nanomaterials and conducting polymers in sensing platforms and their effect on the electroanalytical performance for sensing phenolic compounds.

Electrochemical sensors for the detection of phenolic compounds

Glassy carbon electrode was extensively used as an electrochemical transducer for monitoring nitrophenol; it could be modified with zinc [1, 2] or graphene [3,4,5] oxide nanoparticles or with the use of multi wall carbon nanotubes [6, 7]. Various graphene materials (GR, Go, rGo) were assembled with molecular imprinting polymers (MIPs) [8], β-cyclodextrin [9, 10].

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It was showed by [11] that the modification of glassy carbon electrode surface with single-walled carbon nanotube enhances the sensitivity of p-cresol sensor (94.9 µA/µM) but the combination of reduced graphene oxide and multi walled carbon nanotube can extend the linear range of p-cresol detection (from 5 µM to 430 µM) [12]. Multiwall carbon nanotubes (MWCNTs) were also combined with silver nanoparticles (AgNPs) to form stable film for the simultaneous voltammetric determination of hydroquinone and catechol (stability 95.4% 4 weeks) deposited at the surface of glassy carbon electrode [13]. An electrochemical sensor based on titanium dioxide and multi-walled carbon nanotubes (MWCNTs) developed for the simultaneous determination of hydroquinone and catechol displays a detection limit of (LOD=0.8) [14]. A sensor for electrochemical detection of hydroquinone (HQ) and catechol (CC) was prepared using atomic layer deposition (ALD) to modify glassy carbon electrode with nanocompoiste film composed of nickel oxide (NiO) and carbon nanotube (CNT) (LOD=2.5 µM) [15]. A novel multielectrode array using multiwall carbon nanotubes (MWCNTs) was designed by[16]for the electrochemical sensing of catechol (LOD=0.2 µM). Graphene nanosheets were used for the modification of glassy carbon electrode surface combined with ionic liquid [17], titanium dioxide [18] or with poly(4-vinyl pyridine) [19], it was observed that the best analytical performance of modified glassy carbon electrode in terms of sensitivity (660 µA/µM) and stability (99 % 2 months) was obtained using graphen nanosheets combined with poly(4-vinyl pyridine).

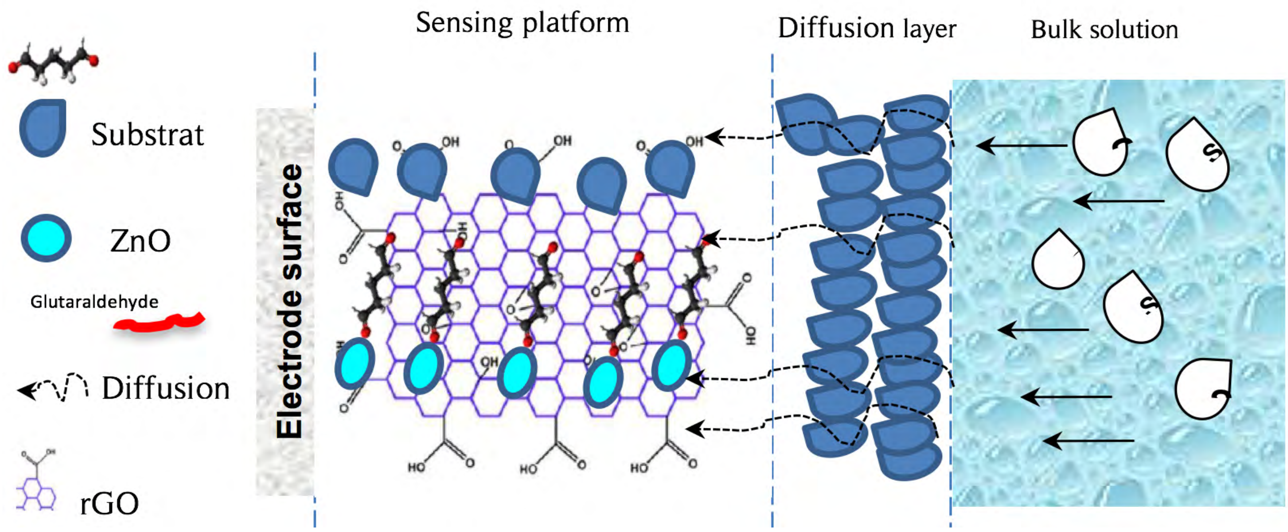
Table 1. Analytical performance of electrochemical sensors for the detection of phenolic compounds

Modified Electrode surface	Sensitivity	Linear Range	L.O.D.	pH	Stability (%)	Ref.
			Nitrophenol			
ZnO/GCE	0.40435 μA/μM.cm²	10 – 1000 μM	13 μM	7.0	60 % 1 month	[1]
Meso-$ZnCO_2O_4$/GCE	0.318 μA/μM.cm²	1 – 4000 μM	0.3 μM	7.0	N.R.	[2]
G-Cs/GCE	1.091 μA/μM	0.1 – 140 μM	0.09 μM	3.0	90 % 1 month	[3]
MWCNTs/GCE	6.202 μA/mM	2 – 4000 μM	0.4 μM	5.0	N.R.	[6]
AuNPs@MWCNTs/GCE	1.72 μA/μM.cm²	0.01 – 50 μM	N.R.	6.0	N.R.	[7]
			Chlorophenols			
MIPs/Go/GCE	1.295 μA/μM	0.004 – 10 μM	0.5 nM	6.0	98.6 % 10 days	[8]
β-CD/G/CPE	N.R.	0.4 – 77 μM	0.09 μM	5.5	N.R.	[9]
HP-β-CD-G NR/GCE	1.12 μA/μM	0.01–16 μM	4 nM	6.0	87.6 (6 weeks)	[10]
			Catechol			
SWCNTs/GCE	135.08 μA/μM	100 nM – 2 μM	2.3 nM	7.2	N.R.	[11]
AgNPs/MWCNTs/GCE	N.R.	20 – 260 μM	0.20 μM	3.0	95.4 % 4 weeks	[13]
rGo-MWCNTs/GCE	0.07 μA/μM	5.5 – 540 μM	1.8 μM	7.0	95.5 % 20 days	[12]
TiO_2/MWCNTs/ GCE	78.15 μA/mM	1.5 μM–0.3 mM	0.8 μM	7.0	96.3 % 10 days	[14]
NiO_2/CNTs/GCE	0.1964 μA/μM	10 – 400 μM	2.5 μM	7.0	97.2 % 3 weeks	[15]
MWCNTs/SPCE	0.04 μA/μM	1 – 100 μM	0.2 μM	5.4	N.R.	[16]
			Hydroquinone			
Gs/BMMPF6/GCE	N.R.	0.5 – 50 μM	0.01 μM	5.0	93 % 2 weeks	[17]
Gs-TiO_2/GCE	0.1341 μA/μM	0.5 – 100 μM	0.087 μM	7.0	95 % 2 weeks	[18]
Gs-P4VP/GCE	660 μA/μM	0.1 – 10 μM	8.1 nM	2.5	99 % 2 months	[19]

Recent advances in electrochemical sensing for phenolic compounds

A ternary nanocomposites electrode prepared by [20] for the detection of caffeic acid using chlorophyll as reductants and stabilizers (stability =93 % 30 days) with a very wide linear range (from 19 to 1869 μM) [21]. Constructed a novel electrochemical sensor for the determination of caffeic acid in wine samples using screen printed electrode modified with cobalt oxide microballs due to tis roughed surface and high crystallinity and large surface area. A low detection limit for the determination of caffeic acid in red wine samples (4 nM) was obtained using synthesized hierarchical mesoporous graphite oxide (HMGO) via carbonization method [22]. A novel electrochemical sensing platform for the detection of dopamine in urine sample was prepared by [23] based on the use of kiwi skin and zinc chloride nanoparticles, the biosensor exhibited a very stable response (99.06 % during 30 days) and wide linear concentration range (from 2 μM to 2000 μM). [24] Have reported the formulation of flexible plastic electrodes for electrochemical sensing of dopamine, the sensor displays a very long term stability response about 93.2 % during 6 months. An electrochemical sensor based on the synthesis of novel ZnO nanoclusters covered with reduced graphene oxide was constructed by [25], the sensor was applied for electrocatalytic detection of BPA tissue paper samples that displays a low detection limit (2.1 nM). A lowest detection limit for electrochemical sensing of Bisphenol A in milk powder and water samples (80 aM) was obtained by [26], the sensor was constructed using gold nanoparticles (AuNPs) electrodeposited on the surface of a glassy carbon electrode (GCE) combined with a mixture of a thiolated DNA sequence. Several efforts were devoted for the development of electrochemical sensors for monitoring hydroquinone [17,18], some of them successfully applied to obtain a very stable response for monitoring hydroquinone in tap and lake water samples [19] (99 % during 2 months) or in urine sample of a healthy man [27], the sensors provides a very stable response (98 % during 5 months).

Recently, electrochemical sensors applied for monitoring catechol display a wide linear range [26-28] but most of them provide a low stability response compared with other phenolic compound based sensors. [31] have prepared a novel electrochemical sensor for the determination of catechol based on the modification of glassy carbon electrode with zinc and aluminum oxide ceramic nanofibers deposited onto the mixture of graphene oxide and gold nanoparticle using chitosan as film forming agent (LOD = 3.1 μM).



Scheme 1. Material based platforms of an electrochemical sensor with diffusion of substrate.

Nitrophenol based sensors prepared using different materials such as conducting polymer of Poly(3,4-ethylenedioxythiophene) [32], silver nanodentrites [33] or with using CoMnO3 nanosheets [34] provide a good stability reponse (91.3 % during 30 days). An electrochemical sensor for the detection of nitrophenol using glassy carbon electrode modified with hydrogel matrix containing spherical shaped gold nanoparticles (AuNPs) was decorated with multi-walled carbon nanotubes (MWCNTs) [7].

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Conclusion

In this work, the use of different nanomaterials and conducting polymers in electrochemical sensing platforms that have been recently explored using a variety of transducers was briefly discussed. The advantage of the most important materials used in the modification of electrode surface in order to enhance its electrocatalytic activity for monitoring phenolic compounds were showed, and their effect on the analytical performance of sensor was mentioned. The combination of conductive nanomaterial and some conducting polymers ensure an excellent and fast response with longest stability.

Table 2. Recent advances in electrochemical sensing for phenolic compounds

Modified Electrode surface	Sensitivity	Linear Range	Limit Of Detection	pH	Stability (%)	Ref.
			Caffeic acid			
Au@α-Fe_2O_3@rGo/GCE	315 µA/µM.cm²	19 – 1869 µM	0.098 µM	7.0	93 % 30 days	[20]
Co_3O_4/SPCE	1.276 µA/µM.cm²	0.2 – 272 µM	48 nM	7.0	91.52 % 4 weeks	[21]
HMGO/GCE	0.429 µA/µM.cm²	0.01 – 608 µM	4 nM	7.0	96.45 % 1 month	[22]
			Dopamine			
$ZnCl_2$-CF/GCE	0.0511 µA/µM	2 – 2000 µM	0.16 µM	7.0	99.06 % 30 days	[23]
PE	0.0384 µA/µM	10 – 550 µM	3 µM	6.8	93.2 % 6 months	[24]
			Bisphenol A			
ZnO.NCs/rGo/SPCE	3.4266 µA/µM.cm²	0.05 – 1332 µM	2.1 nM	7.0	97.7 % 1 month	[25]
PPy/@p-63/AuNPs/GCE	N.R.	0.5 fM – 5 pM	80 aM	7.0	93 % 30 days	[26]
			Hydroquinone			
Gs/BMMPF6/GCE	N.R.	0.5 – 50 µM	0.01 µM	5.0	93 % 2 weeks	[17]
Gs-TiO_2/GCE	0,1341 µA/µM	0.5 – 100 µM	0.087 µM	7.0	95 % 2 weeks	[18]
Gs-P4VP/GCE	660 µA/µM	0.1 – 10 µM	8.1 nM	2.5	99 % 2 months	[19]
SnO_2/SnS/CPE (DPV)	1.8 µA/µM.cm²	1 – 85 µM	0.2 µM	4.0	98 % 5 months	[27]
			Nitrophenols			
PEDOT-PSS/ITO	0.1921 µA/µM 0.1902 µA/µM 0.1290 µA/µM	0 – 80 µM	4.55 µM 4.59 µM 4.51 µM	4.0	N.R.	[32]
Au@MWCNTs/GCE	1.72 µA/µM.cm²	10 nM – 50 µM	N.R.	6.0	N.R.	[7]
AgNDs/GCE	1.970 µA/µM.cm²	20 – 1380 µM	1.76 µM	5.0	95.3 % 30 days	[33]
$CoMnO_3$/GCE	2.458 µA/µM.cm²	0 – 249 µM	10 nM	7.0	91.3 % 30 days	[34]
			Catechol			
AuNPs/ZnO Al_2O_3/Go.Cs	0.17 µA/µM	0.5 – 40 µM	3.1 µM	3.0	93.1 % 1 week	[31]
PANI nanorods/CPE (CV)	49.68 µA/µM.cm²	5 µM – 100 mM	2.1 µM	7.0	N.R.	[28]
Pdnano@Cs/ITO	N.R.	25 – 600 µM	2.99 µM	7.0	N.R.	[29]
CD-CA-f-PEDOT:PSS	0.36327 µA/µM	0.05 – 200 µM	0.0275µM	7.4	N.R.	[30]

References

1. A. Sinhamahapatra, D. Bhattacharjya, J.-S. Yu, Green fabrication of 3-dimensional flower-shaped zinc glycerolate and ZnO microstructures for p-nitrophenol sensing, RSC Advances. 5, 37721–37728 (2015).
2. J. Zhang, S. Cui, Y. Ding, X. Yang, K. Guo, J.-T. Zhao, Two-dimensional mesoporous $ZnCo_2O_4$ nanosheets as a novel electrocatalyst for detection of o-nitrophenol and p-nitrophenol, Biosensors and Bioelectronics. 112, 177–185 (2018).
3. J. Tang, L. Zhang, G. Han, Y. Liu, W. Tang, Graphene-Chitosan Composite Modified Electrode for Simultaneous Detection of Nitrophenol Isomers, Journal of The Electrochemical Society. 162, B269–B274 (2015).
4. P. Wiench, B. Grzyb, Z. González, R. Menéndez, B. Handke, G. Gryglewicz, pH robust electrochemical detection of 4-nitrophenol on a reduced graphene oxide modified glassy carbon electrode, Journal of Electroanalytical Chemistry. 787, 80–87 (2017).
5. J. Li, D. Kuang, Y. Feng, F. Zhang, Z. Xu, M. Liu, A graphene oxide-based electrochemical sensor for sensitive determination of 4-nitrophenol, Journal of Hazardous Materials. 201–202, 250–259 (2012).
6. L. Luo, X. Zou, Y. Ding, Q. Wu, Derivative voltammetric direct simultaneous determination of nitrophenol isomers at a carbon nanotube modified electrode, Sensors and Actuators B: Chemical. 135, 61–65 (2008).
7. A.A. Al-Kahtani, T. Almuqati, N. Alhokbany, T. Ahamad, M. Naushad, S.M. Alshehri, A clean approach for the reduction of hazardous 4-nitrophenol using gold nanoparticles decorated multiwalled carbon nanotubes, Journal of Cleaner Production. 191, 429–435 (2018).

8. Y. Liang, L. Yu, R. Yang, X. Li, L. Qu, J. Li, High sensitive and selective graphene oxide/molecularly imprinted polymer electrochemical sensor for 2,4-dichlorophenol in water, Sensors and Actuators B: Chemical. 240, 1330–1335 (2017).
9. M. Wei, D. Tian, S. Liu, X. Zheng, S. Duan, C. Zhou, β-Cyclodextrin functionalized graphene material: A novel electrochemical sensor for simultaneous determination of 2-chlorophenol and 3-chlorophenol, Sensors and Actuators B: Chemical. 195, 452–458 (2014).
10. G. Zhu, J. Qian, H. Sun, X. Wu, K. Wang, Y. Yi, Voltammetric determination of o-chlorophenol using β-cyclodextrin/graphene nanoribbon hybrids modified electrode, Journal of Electroanalytical Chemistry. 794, 126–131 (2017).
11. M. Govindhan, T. Lafleur, B.-R. Adhikari, A. Chen, Electrochemical Sensor Based on Carbon Nanotubes for the Simultaneous Detection of Phenolic Pollutants, Electroanalysis. 27, 902–909 (2015).
12. F. Hu, S. Chen, C. Wang, R. Yuan, D. Yuan, C. Wang, Study on the application of reduced graphene oxide and multiwall carbon nanotubes hybrid materials for simultaneous determination of catechol, hydroquinone, p-cresol and nitrite, Analytica Chimica Acta. 724, 40–46 (2012).
13. L.A. Goulart, R. Gonçalves, A.A. Correa, E.C. Pereira, L.H. Mascaro, Synergic effect of silver nanoparticles and carbon nanotubes on the simultaneous voltammetric determination of hydroquinone, catechol, bisphenol A and phenol, Microchimica Acta. 185 (2018).
14. Z. Meng, H. Zhang, J. Zheng, An electrochemical sensor based on titanium oxide–carbon nanotubes nanocomposite for simultaneous determination of hydroquinone and catechol, Research on Chemical Intermediates. 41, 3135–3146 (2015).
15. L. Zhao, J. Yu, S. Yue, L. Zhang, Z. Wang, P. Guo, Q. Liu, Nickel oxide/carbon nanotube nanocomposites prepared by atomic layer deposition for electrochemical sensing of hydroquinone and catechol, Journal of Electroanalytical Chemistry. 808, 245–251 (2018).
16. D. Zhang, Y. Peng, H. Qi, Q. Gao, C. Zhang, Application of multielectrode array modified with carbon nanotubes to simultaneous amperometric determination of dihydroxybenzene isomers, Sensors and Actuators B: Chemical. 136, 113–121 (2009).
17. Z. Liu, Z. Wang, Y. Cao, Y. Jing, Y. Liu, High sensitive simultaneous determination of hydroquinone and catechol based on graphene/BMIMPF6 nanocomposite modified electrode, Sensors and Actuators B: Chemical. 157, 540–546 (2011).
18. Y. Zhang, S. Xiao, J. Xie, Z. Yang, P. Pang, Y. Gao, Simultaneous electrochemical determination of catechol and hydroquinone based on graphene–TiO_2 nanocomposite modified glassy carbon electrode, Sensors and Actuators B: Chemical. 204, 102–108 (2014). doi:10.1016/j.snb.2014.07.078.
19. R. M.A. Tehrani, H. Ghadimi, S. Ab Ghani, Electrochemical studies of two diphenols isomers at graphene nanosheet–poly(4-vinyl pyridine) composite modified electrode, Sensors and Actuators B: Chemical. 177, 612–619 (2013). .
20. G. Bharath, E. Alhseinat, R. Madhu, S.M. Mugo, S. Alwasel, A.H. Harrath, Facile synthesis of Au@α-Fe_2O_3@RGO ternary nanocomposites for enhanced electrochemical sensing of caffeic acid toward biomedical applications, Journal of Alloys and Compounds. 750, 819–827 (2018).
21. Department of Chemical Engineering and Biotechnology, National Taipei University of Technology, Taipei 106, Taiwan, ROC, S. Ramki, Voltammetric Determination of Caffeic Acid Using Co3O4 Microballs Modified Screen Printed Carbon Electrode, International Journal of Electrochemical Science. 1241–1249 (2018).
22. K. Sivasankar, R. Devasenathipathy, S.-F. Wang, K. Kohila rani, D.S. Raja, C.-H. Lin, Synthesis of hierarchical mesoporous graphite oxide/Al 2 O 3 from MIL-100(Al) for the electrochemical determination of caffeic acid in red wine samples, Journal of the Taiwan Institute of Chemical Engineers. 84, 188–195 (2018).
23. W. Zhang, L. Liu, Y. Li, D. Wang, H. Ma, H. Ren, Y. Shi, Y. Han, B.-C. Ye, Electrochemical sensing platform based on the biomass-derived microporous carbons for simultaneous determination of ascorbic acid, dopamine, and uric acid, Biosensors and Bioelectronics. 121, 96–103 (2018).
24. M. Marsilia, S. Susmel, Free-standing Plastic electrodes: Formulation, electrochemical characterization and application to dopamine detection, Sensors and Actuators B: Chemical. 255, 1087–1096 (2018).
25. M. Akilarasan, S. Kogularasu, S.-M. Chen, T.-W. Chen, S.-H. Lin, One-step synthesis of reduced graphene oxide sheathed zinc oxide nanoclusters for the trace level detection of bisphenol A in tissue papers, Ecotoxicology and Environmental Safety. 161, 699–705 (2018).
26. A.A. Ensafi, M. Amini, B. Rezaei, Molecularly imprinted electrochemical aptasensor for the attomolar detection of bisphenol A, Microchimica Acta. 185 (2018).
27. E. Naghian, M. Najafi, Carbon paste electrodes modified with SnO_2/CuS, SnO_2/SnS and Cu@SnO2/SnS nanocomposites as voltammetric sensors for paracetamol and hydroquinone, Microchimica Acta. 185 (2018).
28. V. Gautam, K.P. Singh, V.L. Yadav, Multicomponent Template Effects—Preparation of Highly Porous Polyaniline Nanorods Using Crude Lemon Juice and Its Application for Selective Detection of Catechol, ACS Sustainable Chemistry & Engineering. 6, 2256–2268 (2018).
29. S. Nellaiappan, A.S. Kumar, Selective amperometric and flow injection analysis of 1,2-dihydroxy benzene isomer in presence of 1,3- and 1,4-dihydroxy benzene isomers using palladium nanoparticles-chitosan modified ITO electrode, Sensors and Actuators B: Chemical. 254 (2018) 820–826.
30. Y. Qian, C. Ma, S. Zhang, J. Gao, M. Liu, K. Xie, S. Wang, K. Sun, H. Song, High performance electrochemical electrode based on polymeric composite film for sensing of dopamine and catechol, Sensors and Actuators B: Chemical. 255, 1655–1662 (2018).
31. M. Nazari, S. Kashanian, P. Moradipour, N. Maleki, A novel fabrication of sensor using ZnO-Al_2O_3 ceramic nanofibers to simultaneously detect catechol and hydroquinone, Journal of Electroanalytical Chemistry. 812, 122–131 (2018).
32. B.M. Hryniewicz, E.S. Orth, M. Vidotti, Enzymeless PEDOT-based electrochemical sensor for the detection of nitrophenols and organophosphates, Sensors and Actuators B: Chemical. 257, 570–578 (2018).
33. Department of Materials and Mineral Resources Engineering, National Taipei University of Technology, Taipei, Taiwan., N. Murthy Umesh, Phosphate-mediated Silver Nanodentrites Modified Glassy Carbon Electrode for the

Determination of Nitrophenol, International Journal of Electrochemical Science. 4946–4955 (2018).
34. P. Balasubramanian, T.S.T. Balamurugan, S.-M. Chen, T.-W. Chen, Simplistic synthesis of ultrafine CoMnO3 nanosheets: An excellent electrocatalyst for highly sensitive detection of toxic 4-nitrophenol in environmental water samples, Journal of Hazardous Materials. 361, 123–133 (2019).
35. A. Bensana, F. Achi , A. Bouguettoucha , A. Chebli. Theoretical analysis and experimental investigation of the physicochemical parameters of amperometric biosensor for phenols detection. Materials and Biomaterials Science 01, 016-018 (2018).

Conflicts of interest

Authors declare no conflict of interests.

Notes

The authors declare no competing financial interest.

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