ADMET & DMPK **14** (2026) 3504*; doi: https://doi.org/10.5599/admet.3504*

ADMET

Open Access : ISSN : 1848-7718

http://www.pub.iapchem.org/ojs/index.php/admet

Original scientific paper

$ZnFe_2O_4$ nanoparticle-modified screen-printed electrode for determination of serotonin in the presence of dopamine and tryptophan

Ahmed Hameed AlSaeedi[1,*], Emad Salaam Abood[2] and Rafah Mohammed Thyab[3]

[1]*University of Hilla, Faculty of Pharmacy, Department of Pharmaceutics, Babylon, Iraq*
[2] *Medical Physics Department, College of Science, University of Hilla, Babylon, Iraq*
[3]*Department of Chemistry, College of Science, University of Kufa, Nagaf, Iraq*

Corresponding Author: E-mail: *ahmed.alsaeedi@outlook.de*

Received: May 15, 2026; Revised: June 21, 2026; Published: August 18, 2026

Abstract

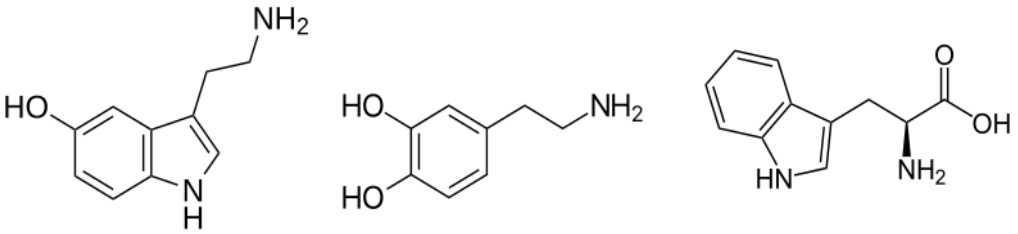
Background and purpose: An easy, accurate, faultless, meteoric and inexpensive methodology has to be created for determining important compounds serotonin (SRT), dopamine (DPE) and tryptophan (TPT). **Experimental approach:** This work explored the use of $ZnFe_2O_4$ nanoparticles to construct a $ZnFe_2O_4$ nanoparticle-modified screen-printed electrode (ZFO/SPE) sensor for analysing the biomolecule SRT in the presence of DPE and TPT. The results show that $ZnFe_2O_4$ nanoparticles can greatly enhance electron-transfer kinetics and exhibit high electrocatalytic activity, making them a useful tool for biomolecule analysis. For detection, differential pulse and cyclic voltammetry have been used to analyse the electrochemical treatment of the analytes. **Key results:** Under optimal conditions, the calibration curve of current versus SRT concentration in the range of 0.06 to 400.0 µM is linear. The obtained limit of detection is 0.02 µM. By employing this sensing system in detecting SRT, DPE and TPT in human urine and pharmaceutical samples to examine their feasibility for practical applications. The recovery percentage analysis for the real sample was found to be in the range of 96.9 to 103.5. **Conclusion:** It can be concluded that the ZFO/SPE possesses the features of good stability, reproducibility and repeatability for the regular detection of SRT, DPE and TPT.

Keywords

Neurotransmitters, amino acids, voltammetry, electrochemical sensors

Introduction

Serotonin (SRT) and dopamine (DPE) (Scheme 1) are neurotransmitters, and the former, as a catecholamine, is very important in the normal function of the central nervous system, endocrine and renal systems [1]. On the other hand, the second, a monoamine, plays an indispensable role in many physical, biological and psychological processes [1]. Also, it is worth noting that the neurotransmitter SRT affects sleep, emotion and mental state [1], whereas tryptophan (TPT), which is the main part of proteins and one type of amino acid, is not synthesized by the human body and so has to be taken from food or other supplements [1] for SRT's synthesis [6]. Measurement of these naturally occurring compounds to assess their significance in various clinical problems [2] is indispensable for diagnosis.



Serotonin **Dopamine** **Tryptophan**

Scheme 1. Chemical structures of serotonin, dopamine and tryptophan

Neurotransmitters are important biochemical messengers released by neurons that can transmit signals to other nerve cells [3]. Neurotransmitters are vital for normal body function and can be synthesized from chemical precursors, including essential or non-essential amino acids, or transformed from other starting points [3]. Their lack or abundance may be highly detrimental to the body [3]. Serotonin is a mood-regulating monoamine neurotransmitter found in the human body, and some reports indicate that normal serotonin levels in human blood range from 0.5 to 1.6 M [4]. Lack of serotonin can cause a variety of problems like migraine, depression, bipolar disorders and anxiety, while excessive levels of serotonin can result in carcinoid syndrome due to excessive release of SRT in the blood by endogenous tumours in the body, like on the small intestine, colon, appendix, and lungs [4]. DPE is a catecholamine neurotransmitter and its typical concentration within the normal blood of humans is in the range of 65 to 390 pM [5].

Tryptophan (TPT) (Scheme 1) is an indispensable amino acid, and the immediate precursor for niacin, melatonin and serotonin. The level of TPT is normal 25 to 73 M [6] in the human body, and the increase of TPT serum concentration is a disorder, hypertryptophanemia, which means that TPT increases excessively in the human serum, causing agitation, confusion and tryptophanuria [6]. Therefore, an easy, accurate, faultless, meteoric and inexpensive methodology must be created for determining SRT, DPE and TPT as an important precursor of SRT.

Screen-printed electrodes (SPEs) offer a highly effective and versatile platform for electrochemical sensing [7]. Therefore, they are highly useful for biosensing; modifications to their surfaces and integration into portable systems have increased their use in both research and commercialization [8,9].

It is evident that nano-sensors offer a lot of advantages, such as stability, excellent reproducibility, higher linear response range, a lower detection limit and better sensitivity than many other types of sensors. Now-adays, many analytical methods are being applied in clinical, pharmaceutical, and environmental laboratories, as well as in commercial point-of-care devices, to some extent utilizing nanosensors [10].

Nanoparticles are widely used as sensor modifiers; however, zinc ferrite nanoparticles have gained significant interest in the nanomedicine industry, primarily because of their low Zn^{2+} toxicity. It is particularly significant for magnetic resonance imaging (MRI) contrast agents, a medical diagnostic tool, because their toxicity is lower than that of common MRI contrast agents [11]. Considering the reference daily intake (RDI) of the permitted dosages of Fe and Zn (18 and 15 mg *per* day), $ZnFe_2O_4$ can be an excellent candidate for an MRI contrast agent because its RDI values are significantly higher than those of other biocompatible materials [12].

In the present study, the SPE was modified with $ZnFe_2O_4$ nanoparticles and utilized for the simultaneous determination of target biomolecules (SRT, DPE, TPT) in various real samples. The DPV and CV were adopted to investigate the electrochemical behaviour of the SRT on $ZnFe_2O_4$ nanoparticle-modified screen-printed electrode (ZFO/SPE). The results show that modifying bare SPE enhances electron transfer between the analytes and ZFO/SPE; the electrochemical surface area of modified SPE also improved greatly, further

enhancing the electrode performance for detecting SRT, DPE and TPT. Finally, to explore the practical applicability of ZFO/SPE in real samples, it was used to detect SRT, DPE and TPT in urine and pharmaceutical samples.

Experimental

Apparatus and chemicals

The electrochemical measurements were carried out on an Autolab potentiostat/galvanostat. SPEs (Dropsens, DRP 110) were used, containing a graphite working and auxiliary electrodes and a silver pseudo-reference electrode.

The pH was measured using a Metrohm 827 pH/ion meter. All solutions were freshly prepared. SRT, DPE, TPT and all other chemicals used were of analytical grade and purchased from Merck. Buffer solutions were prepared using orthophosphoric acid (PBS) and its salts within the pH range of 2.0 to 9.0.

Synthesis of $ZnFe_2O_4$ nanoparticles

$ZnFe_2O_4$ nanoparticles were prepared by the coprecipitation method. To synthesize $ZnFe_2O_4$ nanoparticles, 250.2 g of $ZnCl_2{\cdot}4H_2O$ salt and 570.5 g of $FeCl_3{\cdot}6H_2O$ salt were mixed in 200 mL of water in a 250 mL double-necked volumetric flask simultaneously. Both solutions were then heated at 80 °C for 6 hours in an oil bath in a nitrogen atmosphere. In that process, 50 mL of 6 M NaOH was added very slowly to the final solution. After a few minutes, nucleation of the first $ZnFe_2O_4$ nanoparticle precipitates began. As with $NiFe_2O_4$ nanoparticles, the solution was washed several times with distilled water at this stage to remove impurities. Then, the solution was centrifuged to separate the $ZnFe_2O_4$ nanoparticles. Finally, to remove residual impurities from the particle structure, the material was placed in an oven at 60 °C for 24 hours.

Preparation of screen-printed electrode modified with $ZnFe_2O_4$ nanoparticles

Modified electrode fabrication (ZFO/SPE): $ZnFe_2O_4$ nanoparticles (1.0 mg) were sonicated in deionized water (1.0 mL) at room temperature for 10 minutes to obtain a homogeneous suspension. 3.0 L of $ZnFe_2O_4$ nanoparticles suspension was then drop-cast onto the SPCE surface to prepare ZFO/SPE.

Procedure of real samples preparation

10 mL of the urine samples was centrifuged at 2000 rpm for 12 min. The precise volume of solution was transferred into a 10 mL volumetric flask and diluted with PBS. Amounts of SRT, DPE and TPT of various concentrations were added to the urine sample.

0.1 mL of DPE from a 200 mg *per* 5 mL DPE ampoule was added to 10.0 mL PBS. Then, various volumes of the above solution were added to a 25 mL volumetric flask. The SRT, DPE and TPT were determined by standard addition.

Results and discussion

Electrocatalytic oxidation of SRT at a $ZnFe_2O_4$ nanoparticle-modified screen-printed electrode

Figure 1 shows the CV response curves for 0.1 mM SRT on ZFO/SPE and unmodified SPE. From Figure 1, the potential at ZFO/SPE is about 385 mV and on the unmodified SPE is 460 mV. The I_{pa} on the ZFO/SPE is much larger than on the unmodified SPE, indicating that the ZnFe2O4 nanoparticles effectively improve the electrode performance for SRT oxidation.

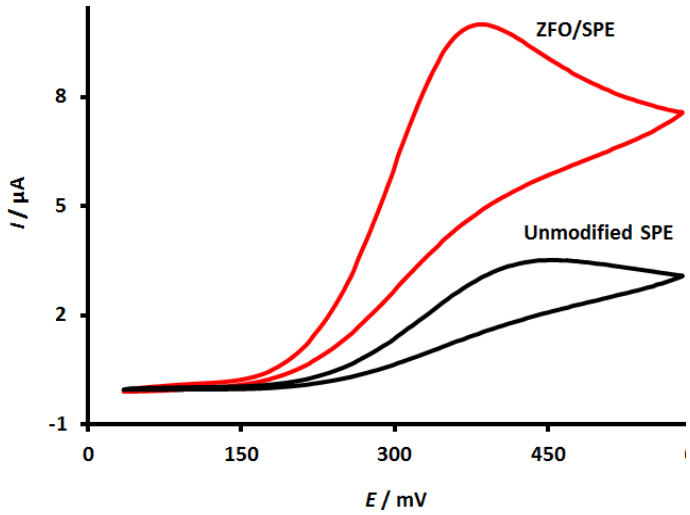


Figure 1. CVs of unmodified SPE and ZFO/SPE in 0.1 mM SRT at scan rate 50 mV s^{-1}

CV was used to study the effect of scan rate on oxidation of SRT on the ZFO/SPE (as shown in Figure 2A).

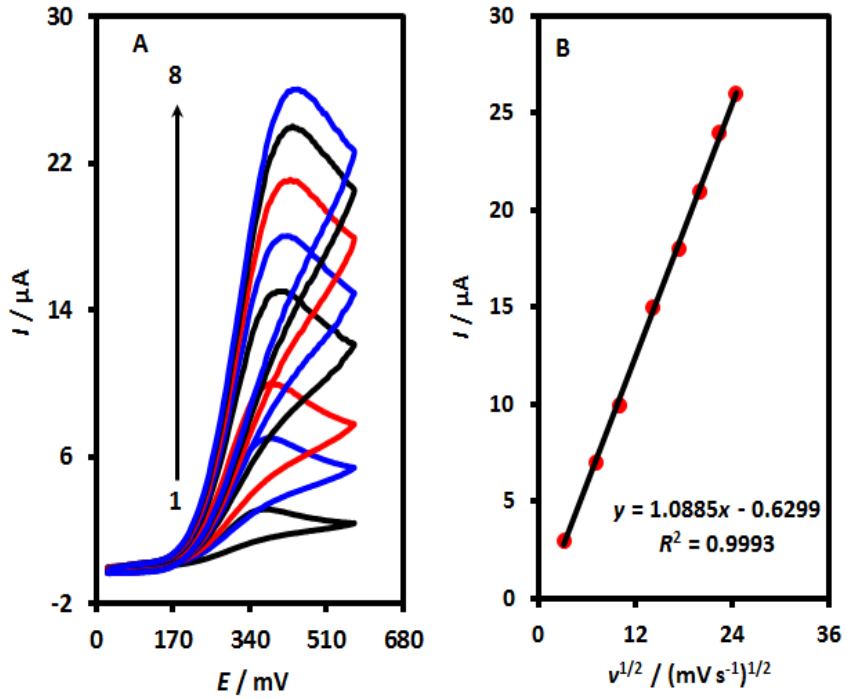


Figure 2. (A) CVs of ZFO/SPE in 70.0 µM SRT at different scan rates; from 1 to 8 scan rates of 10, 50, 100, 200, 300, 400, 500 and 600 mV s^{-1}, respectively. (B) Variation of anodic peak current *vs.* $v^{1/2}$

With increasing scan rate, E_{pa} shifts to more positive values, indicating that the electrode process is kinetically controlled at lower potentials. Furthermore, as the scan rate increases, I_p versus the square root of the scan rate ($v^{1/2}$) relationship shown in Figure 2B is linear, indicating that the electrochemical oxidation of SRT at the ZFO/SPE is diffusion-controlled at higher overpotentials.

Chronoamperometric measurements

The working electrode potential was adjusted to 0.35 V to perform chronoamperometric measurements of SRT at ZFO/SPE (Figure 3). The Cottrell equation was used to calculate the diffusion coefficient, *D*. The best fits for various I_P doses were obtained from experimental plots of *I vs.* $t^{-1/2}$ (Figure 3 inset). The *D* was determined to be 2.2×10^{-5} cm^2 s^{-1}.

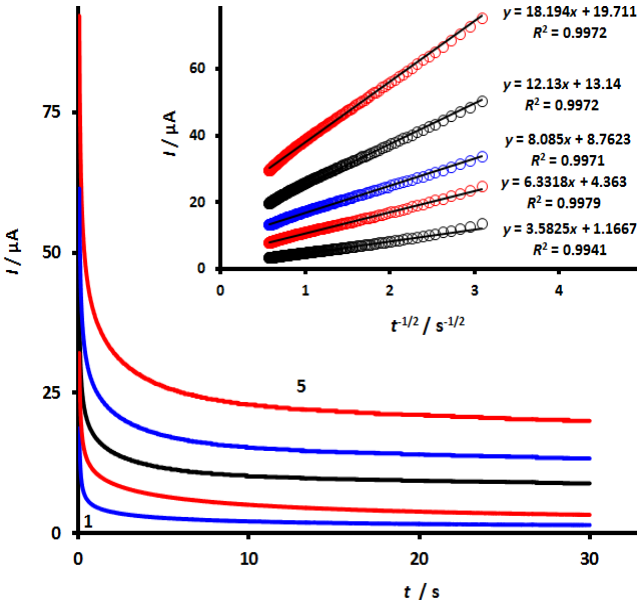


Figure 3. Chronoamperograms obtained at ZFO/SPE for different concentrations of SRT. The numbers 1 to 5 correspond to 0.1, 0.25, 0.4 and 1.0 mM of SRT. Inset: Plots of *I vs.* $t^{-1/2}$ obtained from chronoamperograms 1 to 5

Electroanalytical determination of serotonin

The current for SRT at the modified electrode surface can be used to determine SRT in solution, so DPV experiments were carried out (see Figure 4).

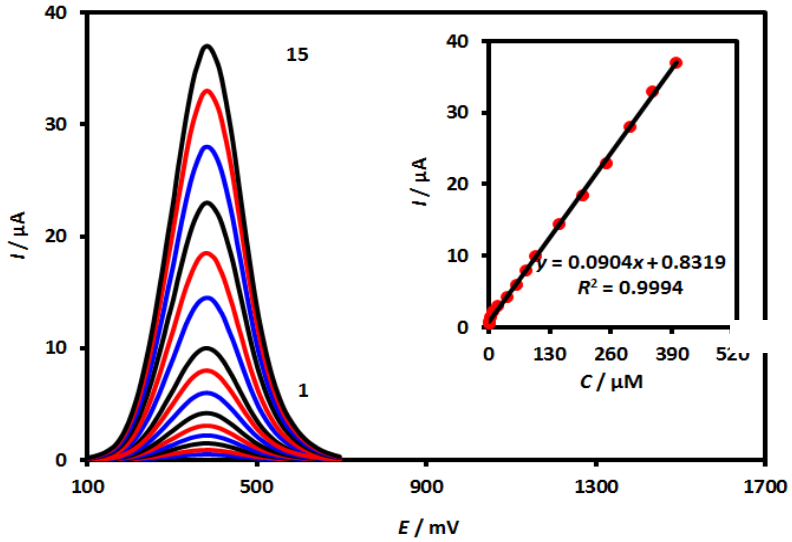


Figure 4. DPVs of ZFO/SPE for different concentrations of SRT. From 1 to 15 correspond to 0.06, 1.0, 5.0, 10.0, 20.0, 40.0, 60.0, 80.0, 100.0, 150.0, 200.0, 250.0, 300.0, 350.0 and 400.0 µM of SRT. Inset shows the calibration curve.

The linear dynamic range (LDR) was 60 nM to 0.4 mM in DPV measurements (Figure 4 inset). The detection limit was 20 nM.

Simultaneous determination of serotonin, dopamine and tryptophan

simultaneously detect SRT, DPE, and TPT was done by changing the concentrations of SRT, DPE and TPT together and then taking the DPVs. The voltammetric data gave pretty clear anodic peaks around 385, 240 and 655 mV; these should match the oxidation of SRT, DPE and TPT, respectively, meaning that a co-determination of these compounds is indeed doable at the ZFO/SPE, as it is illustrated in Figure 5.

Regarding the modified electrode response, the sensitivity for SRT oxidation was estimated as 0.0898 µA μM^{-1} (Figure 6).

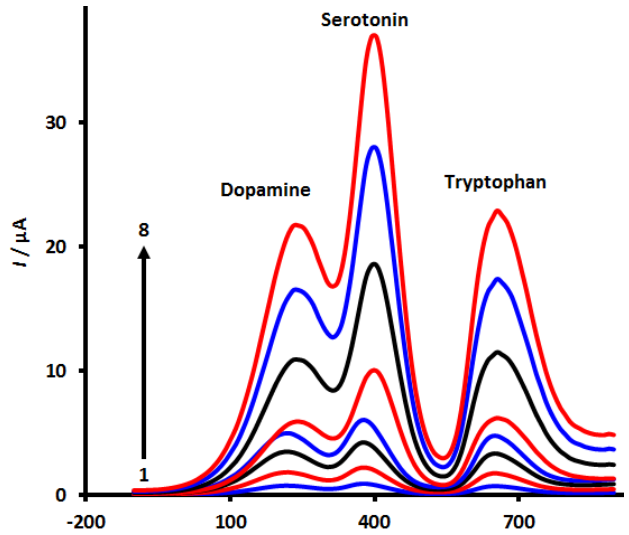


Figure 5. DPVs of ZFO/SPE for different concentrations of SRT+DPE+TPT, from 1 to 8: 1.0, 10.0, 40.0, 60.0, 100.0, 200.0, 300.0 and 400.0 µM, respectively.

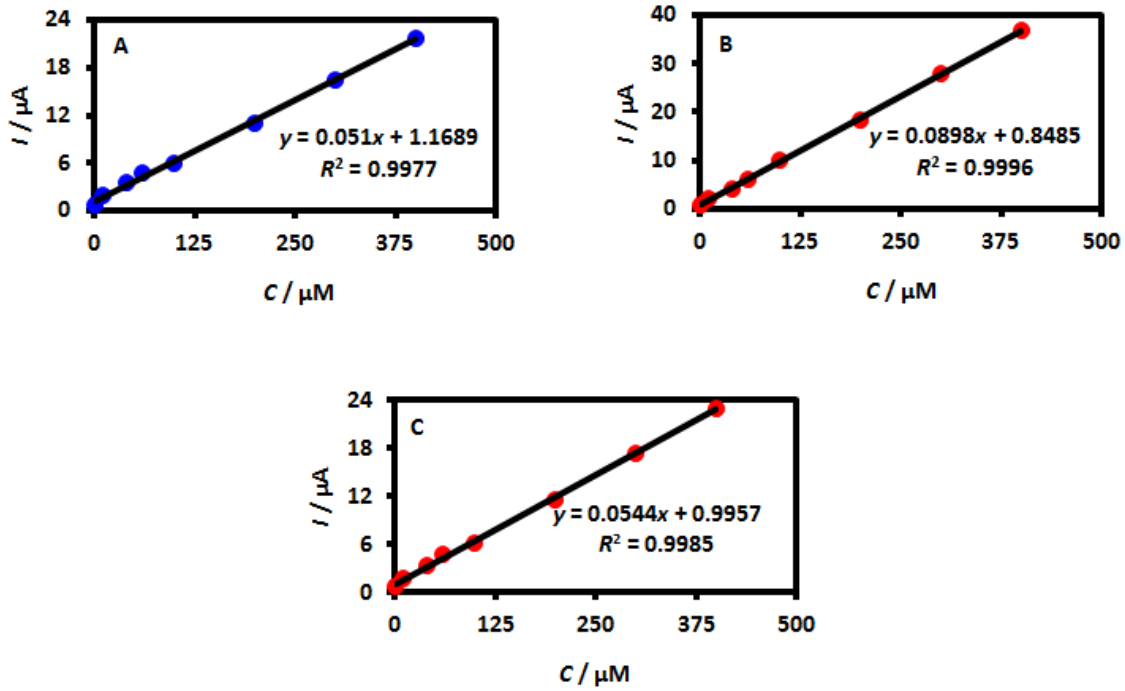


Figure 6., Plots of I_p *vs.* (A) DPE, (B) SRT and (C) TPT concentration

It is almost identical to the figure measured when DPE and TPT were not present (0.0904 µA μM^{-1}; see previous section), suggesting that oxidation of these compounds at the ZFO/SPE does not significantly interfere with each other. In other words, the mixture can be determined simultaneously without major interference.

The stability and repeatability of ZFO/SPE

Over three weeks, the long-term stability of the ZFO/SPE was tested. After the modified electrode was kept in room-temperature air, CVs were recorded again, and the peak potential associated with SRT oxidation remained unchanged. At the same time, the current signals showed less than a 2.3 % drop compared with the very first response.

Next, the antifouling behaviour of the ZFO/SPE was examined by comparing CVs before and after exposure to SRT. Even then, E_{pa} was unchanged, and I_{pa} decreased by under 2.5 %, so the fouling effect isn't just reduced a little.

Interference studies

The influence of several chemicals was examined under optimal conditions as potential interferents in SRT estimation. Histidine, glucose, glycine, L -lysine, NADH, tryptophan, glutathione, acetaminophen, methionine, uric acid, L-asparagine, L-cysteine, L-serine, LL-proline, -threonine, phenylalanine, dopamine, N-acetyl cysteine, lactose, fructose, saccharose, methanol, benzoic acid, Fe^{3+}, Fe^{2+}, SO_4^{2-} F^- and S^{2-} did not appear to affect the measurement of SRT.

Real sample analysis

To investigate the application of this method to analytical purposes, we also used it to measure SRT, DPE and TPT in samples like urine and DEP injection samples. Table 1 lists the measurements of three species in a practical sample. Recovery rate of SRT, DPE and TPT was found to be satisfactory with experimental values, and reproducibility is investigated with mean relative standard deviation (RSD, %).

Table 1. Determination of SRT, DPE and TPT in urine and DPE injection samples (n = 3)

Sample	Amount, μM						SRT		DPE		TPT	
	SRT		DPE		TPT							
	Added	Found	Added	Found	Added	Found	Recovery, %	RSD, %	Recovery, %	RSD, %	Recovery, %	RSD, %
Urine	0	-	0	-	0	-	-	-	-	-	-	-
	5.0	4.9	5.5	5.7	6.0	5.9	98.0	2.9	103.6	3.0	98.3	2.5
	7.0	7.1	7.5	7.4	8.0	8.3	101.4	4.0	98.7	2.2	103.7	2.4
	9.0	8.7	9.5	9.7	10.0	10.1	96.7	2.1	102.1	2.6	101.0	3.3
	11.0	11.3	11.5	11.4	12.0	11.7	102.7	2.7	99.1	1.9	97.5	2.0
DPE injection	0	-	0	3.1	0	-	-	-	-	2.4	-	-
	4.5	4.6	2.0	5.0	4.0	3.9	102.0	2.6	98.0	3.3	97.5	3.9
	6.5	6.3	4.0	7.4	6.0	6.1	96.9	1.8	104.2	2.5	101.7	2.9
	8.5	8.8	6.0	8.9	8.0	8.3	103.5	2.7	97.8	2.8	103.7	1.6
	10.5	10.4	8.0	11.2	10.0	10.2	99.0	3.1	100.9	2.2	102.0	2.5

Conclusions

The ZFO/SPE exhibited very good activity toward the oxidation of SRT. When compared with the plain or bare electrode, I_{pa} for SRT increased significantly, and E_{pa} shifted toward more negative values by about 75 mV. After that, the DPV currents associated with SRT at the ZFO/SPE increased in an almost ideal linear fashion with SRT concentration over the range 60 nM to 0.4 mM, and the detection limit was estimated at 20 nM. In addition, potential differences of 145, 270 and 415 mV between SRT-DPE, SRT-TPT and DPE-TPT were observed, respectively. These differences were large enough that SRT, DPE, and TPT could be identified individually and even simultaneously. At the end, the approach was

Funding: *Not applicable.*

Conflict of interest*: None.*

References

[1] M. Nikbakhtzadeh, S. Bordbar, S. Seyedi, M. Ranjbaran, G. Ashabi, A. Kheradmand. Significance of neurotransmitters in cerebral ischemia: understanding the role of serotonin, dopamine, glutamate, and GABA in stroke recovery and treatment. *Central Nervous System Agents in Medicinal Chemistry* **25** (2025) 211-229. https://doi.org/10.2174/0118715249302594240801171612

[2] [2] I.B. Carneiro, A.E. Toscano, D.C. Lacerda, M.D. da Cunha, R.M. De Castro, T.C. de Jesus, J.M. Medeiros. L-tryptophan administration and increase in cerebral serotonin levels: systematic review. *European Journal of Pharmacology* **836** (2018) 129-135. https://doi.org/10.1016/j.ejphar.2018.08.009

[3] L. Meng, W. Liu, Y. Niu, X. Lv, T. Jin, G. Wang, Z. Sun, Y.M. Wang, Y. Yang, Y. Wang. Advances in Real-Time Electrochemical Monitoring of Neurotransmitter Dynamics in Drosophila. *ACS Chemical Neuroscience* **17(11)** 2026 2037-2048. https://doi.org/10.1021/acschemneuro.5c00960

[4] T. Wang, M. Wöhr. Serotonin's fundamental role in early social development: Socio-affective communication through ultrasonic vocalizations, maternal affiliation, and the bidirectional nature of mother-infant interactions. N*euroscience & Biobehavioral Reviews* **187** (2026) 106747. https://doi.org/10.1016/j.neubiorev.2026.106747

[5] Z.N. Yurtsever, S. Capuani, M. Fratini, C. Nicaise, Y. Salman, B. Hanseeuw, G.A. Carlesimo, E.C. Latagliata, R. Coccurello. Norepinephrine and dopamine Imbalance in the medial frontal gyrus from patients with Alzheimer's disease. *IBRO Neuroscience Reports* **20** (2026) 94-100. https://doi.org/10.1016/j.ibneur.2026.01.001

[6] W.K. Chan, S.J. Shiadeh, C. Mallard, M. Ardalan. Tiny infections, big consequences: early-life bacteria, tryptophan–serotonin disruption, and autism-like traits. *Neuroscience Applied* **5** (2026) 106981. https://doi.org/10.1016/j.nsa.2026.106981

[7] N.A. Salman, I.A. Jassem, I.N. Taeb, A simple UiO-66-NH_2@ MWCNTs based electrochemical sensor for the sensitive detection of metronidazole. *ADMET and DMPK.* **13(6)** (2025) 2940. https://doi.org/10.5599/admet.2940

[8] L.F. Castro, F. d'Orlyé, A. Varenne. Screen-printed electrodes as active microreactors for electrochemical sample pretreatment and disease screening. *TrAC Trends in Analytical Chemistry* **202** (2026) 118953. https://doi.org/10.1016/j.trac.2026.118953

[9] R. Muslim Muhibes, F. Khazaal, Q.M. Salih, Ra R. di Karabat, Electrochemical determination of calcium folinate in the presence of methotrexate and 5-fluorouracil using UiO-66/CdS composite modified screen-printed carbon electrode. *ADMET and DMPK* **13(6)** (2025) 2897. https://doi.org/10.5599/admet.2897

[10] N. Ahmad, S. Al-Hasnaawei, S. Sahoo, V. Abbot, A.S. Chauhan, S. Uppal, M. Dehghanipour, Electrochemical nanosensors for early detection of childhood cancer. *Clinica Chimica Acta* **578** (2025) 120493. https://doi.org/10.1016/j.cca.2025.120493

[11] J. Leng, J. Li, J. Ren, L. Deng, Lin C. Star–block copolymer micellar nanocomposites with Mn, Zn-doped nano-ferrite as superparamagnetic MRI contrast agent for tumor imaging. *Materials Letters* **152** (2015) 185-188. https://doi.org/10.1016/j.matlet.2015.03.120

[12] A.F. Shojaei, K. Tabatabaeian, S. Shakeri, F. Karimi. A novel 5-fluorouracile anticancer drug sensor based on $ZnFe_2O_4$ magnetic nanoparticles ionic liquids carbon paste electrode. *Sensors and Actuators B* **230** (2016) 607-614. https://doi.org/10.1016/j.snb.2016.02.082