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Electrochemical Determination of Paracetamol Using Gold Nanoparticles – Application in Tablets and Human Fluids

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A highly sensitive and simple method was investigated for the determination of acetaminophen (ACOP) using gold nanoparticles modified carbon paste electrode (GNMCPE). GNMCPE displayed excellent electrochemical catalytic activities towards the oxidation of ACOP. Under optimized experimental conditions in differential pulse voltammetry (DPV) technique, the sensitivity of ACOP was improved greatly and gave a linear response over the ranges 5.0×10^{-8} to 2.7×10^{-4} mol L^{-1} with a detection limit of 1.46 x 10^{-8} mol L^{-1}. More over, the present method was also applied for the determination of ACOP in the presence of common interferents, namely ascorbic acid (AA) and uric acid (UA) and in binary mixture with dopamine (DA). This method could readily discriminate ACOP from DA. And an electrochemical detection of ACOP in spiked urine sample was succeeded with satisfactory results. This procedure was also successfully applied for the assay of paracetamol in pharmaceutical formulations.

Keywords: Electrochemical sensor; Paracetamol; Dopamine; Gold nanoparticles; Carbon paste electrode

1. INTRODUCTION

Paracetamol or acetaminophen (ACOP) is a widely used analgesic anti-pyretic drug. It is a suitable alternative when the patients are sensitive to aspirin [1]. it is used to reduce fever cough and cold, and reduce mild to moderate pain, including instances of tension headache, migraine headache, muscular aches, chronic pain, neuralgia, backache, joint pain, general pain and toothache [2–4]. It is also useful in osteoarthritis therapy [5] and it is sometimes used for management of cancer pain. Recent research suggests that paracetamol may help to protect from changes leading to hardening of arteries that cause cardiovascular disease [6]. It also remains the analgesic of choice for people with asthma [7]. There is also some evidence to suggest that paracetamol may offer some protection against ovarian cancer [8]. ACOP rapidly gets absorbed and distributed after oral administration and is easily

excreted in urine [9]. Generally, paracetamol (PC) does not exhibit any harmful side effects but hypersensitivity or overdoses in few cases leads to the formation of some liver and nephrotoxic metabolites [10]. Because PC is being increasingly used for therapeutic purposes, its determination and quality control are of vital importance [11].

Therefore, it is essential to develop simple and rapid methods for their determination in routine analysis without cross-interferences. Of these, electrochemical methods have received much interest because they are more selective, less expensive, and less time-consuming and can potentially be applied to a real-time determination in vivo [12]. There are reports of using conducting poly (3-methylthiophene) sensor electrode [13,14], Poly(3,4-ethylenedioxythiophene) [PEDOT] in presence of surface active agents [15], multiwall carbon nanotubes modified glassy carbon electrode [16], a carbon paste electrode prepared with 2,2′-[1,2 butanediylbis(nitriloethylidyne)]-bis-hydroquinone and TiO_2 nanoparticles [17], nano-TiO_2/polymer coated electrode [34], a hematoxylin biosensor [18], Palladium nanoclusters-coated polyfuran [19] and a glassy carbon paste electrodes modified with polyphenol oxidase [20].

Carbon paste (CP) electrode, which was made up of carbon particles and organic liquid, has been widely applied in the electroanalytical community due to its low cost, ease of fabrication, high sensitivity for detection and renewable surface [21–25]. However, the simultaneous determination at conventional solid electrodes (carbon and metal) usually struggles because they undergo an overlapping oxidation potential and electrode fouling takes place due to the adsorption of oxidation products [26].

Electrodeposition of gold nanoparticles onto the surface of the CP-electrode was another strategy to enhance the sensitivity of the immunosensor. Several research work had been conducted to construct CP-electrode modified with gold nanoparticles to be used as an immunosensor [27,28], or in streptavidinr-biotine interaction [29], or as an enzyme biosensors [30], sulphur containing compounds [31] and homocysteiene [32]. Electrodeposition of gold nanoparticles onto other surfaces such as glassy carbon in sensing of allergen-antibody interaction [33] and acetylcholine esterase-choline oxidase [34] were examined.

Since body fluids contain high concentrations of uric acid UA and ascorbic acid AA, the determination of ACOP in body fluids based on the electrochemical oxidation of ACOP is difficult. So the aim of this study is to construct a stable, sensitive and simple electrochemical sensor based on gold nanoparticles and graphite, to be used for the selective determination of ACOP in the presence of interferences.

The electrochemical behaviors of these species at our modified electrode will be investigated using CV and differential pulse voltammetry (DPV) techniques. The detection of ACOP in tablet sample and in human urine will be demonstrated as real sample applications.

2. EXPERIMENTAL

2.1. Materials and reagents

Paracetamol (ACOP) was purchased from Aldrich and was used as received. Britton–Robinson (B–R) (4.0×10^{-2} mol L^{-1}) buffer solution of pH 2–11 ($CH_3COOH+H_3BO_3+H_3PO_4$), and Phosphate

buffer saline (PBS, pH 7.4) (137 mmol L^{-1} NaCl, 2.7 mmol L^{-1} KCl, 87 mmol L^{-1} Na_2HPO_4 and 14 mmol L^{-1} KH_2PO_4) were used as the supporting electrolytes. The pH was adjusted using 0.2 mol L^{-1} NaOH. All solutions were prepared from analytical grade chemicals and sterilized Milli-Q deionized water.

2.1.1. Construction of gold nanoparticles modified CP-electrode (GNMCPE)

CP-electrode was fabricated as described elsewhere [35] then was immersed into 6 mM hydrogen-tetrachloroaurate $HAuCl_4$ solution containing 0.1 mol L^{-1} KNO_3 (prepared in doubly distilled water, and deaerated by bubbling with nitrogen).

A constant potential of -0.4 V versus Ag/AgCl was applied for 400 s. The surface coverage of gold nanoparticles was found to be 2.05×10^{-6} mol cm^{-2}.

Then, the modified electrode (GNMCPE) was washed with doubly distilled water and dried carefully.

2.2. Instrumental and experimental set-up

2.2.1. Electrochemical measurements

All voltammetric measurements were performed using a pc-controlled AEW2 electrochemistry work station and data were analyzed with EC_{prog3} electrochemistry software, manufactured by SYCOPEL SCIENTIFIC LIMITED (Tyne & Wear, UK).

The one compartment cell with the three electrodes was connected to the electrochemical workstation through a C_3-stand from BAS (USA). A platinum wire from BAS (USA) was employed as auxiliary electrode. All the cell potentials were measured with respect to Ag/AgCl (3 mol L^{-1} NaCl) reference electrode from BAS (USA). One compartment glass cell (15 ml) fitted with gas bubbler was used for electrochemical measurements. Solutions were degassed using pure nitrogen prior and throughout the electrochemical measurements. A JENWAY 3510 pH meter (England) with glass combination electrode was used for pH measurements.

Scanning electron microscopy (SEM) measurements were carried out using a JSM-6700F scanning electron microscope (Japan Electro Company). All the electrochemical experiments were performed at an ambient temperature of 25±2°C.

2.2. Analysis of urine

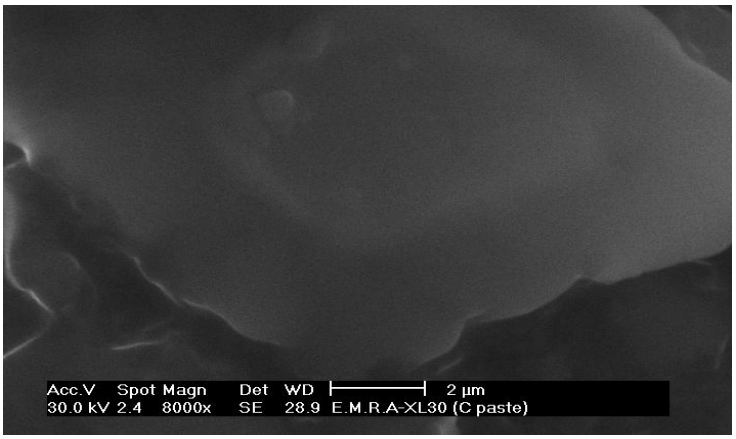
Standard ACOP provided by the National Organization for Drug Control and Research of Egypt was dissolved in urine to make a stock solution with 1.0×10^{-3} mol L^{-1} concentration.

Successive additions of ACOP 1.0×10^{-3} mol L^{-1} in urine were added to 5 ml B-R buffer pH (7.4).

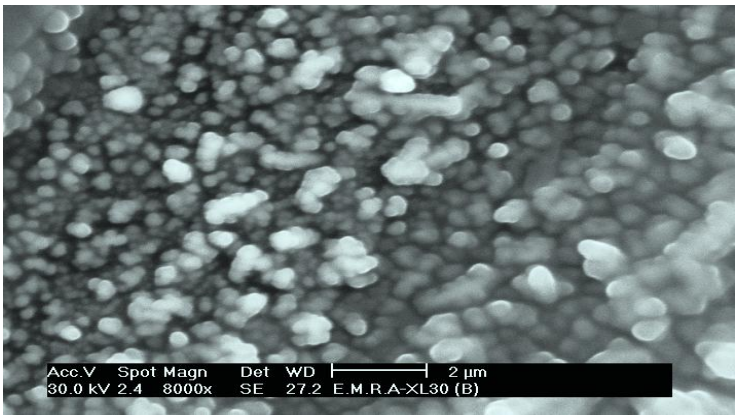
3. RESULTS AND DISCUSSION

3.1. Morphologies of the different electrodes

The response of an electrochemical sensor was related to its physical morphology. The SEM of CP-electrode and GNMCPE were shown [35] in Fig 1. Significant differences in the surface structure of CP-electrode and GNMCPE were observed. The surface of the CP-electrode was predominated by isolated and irregularly shaped graphite flakes and separated layers were noticed (Fig 1A). The SEM image of GNMCPE (Fig 1B) shows that metallic nanoparticles are located at different elevations over the substrate. Moreover, a random distribution and interstices among the nanoparticles were observed in SEM image of the GNMCPE exhibiting large surface area.



A



B

Figure 1. A)The Scanning electron microscope of bare CP-electrode. B) The Scanning electron microscope of GNMCPE

3.2. Electrochemistry of ACOP at GNMCPE

The voltammetric behavior of ACOP was examined using cyclic voltammetry. Fig 2 shows typical cyclic voltammograms of 1.0 x 10^{-3} mol L^{-1} of ACOP, in B-R buffer pH 7.4 at scan rate 100

mVs^{-1} recorded at two different working electrodes (i.e. a bare CP (solid line) and GNMCPE (dashed lines)). As can be seen, at bare CP-electrode the oxidation peak current was observed to be 49.5 μA which is nearly half the current value in case of GNMCPE that has a value of 85.7μA, whereas at GNMCPE the potential shifted to less positive potential (0.685 V) compared to 0.734 V at bare CP-electrode, due to the improvement in the reversibility of the electron transfer process and a larger real surface area of the modified electrode. The electrodeposition of Au particles on CP-electrode resulted in an observable increase in the peak current, which indicated an improvement in the electrode kinetics and a decrease in the potential of oxidation substantially.

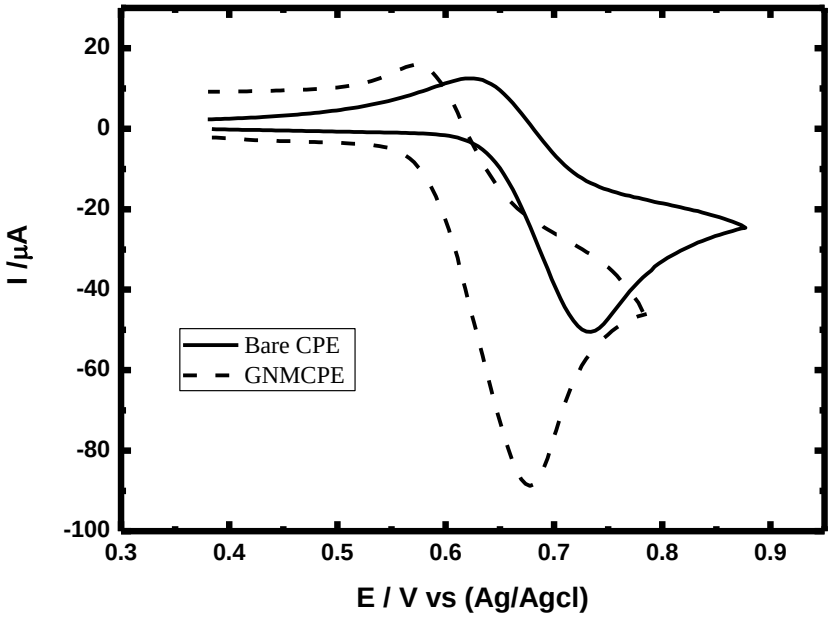


Figure 2. Cyclic voltammograms of 1.0 x 10^{-3} mol L^{-1} ACOP in B-R buffer pH 7.4 at scan rate 100 mVs^{-1} recorded at bare CP-electrode (—) and GNMCPE (----).

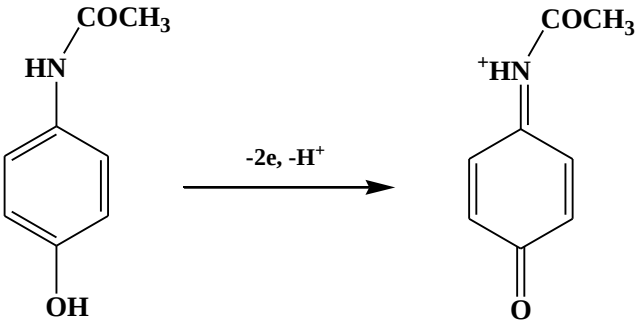
3.3. Effect of operational parameters

3.3.1. Effect of solution pH

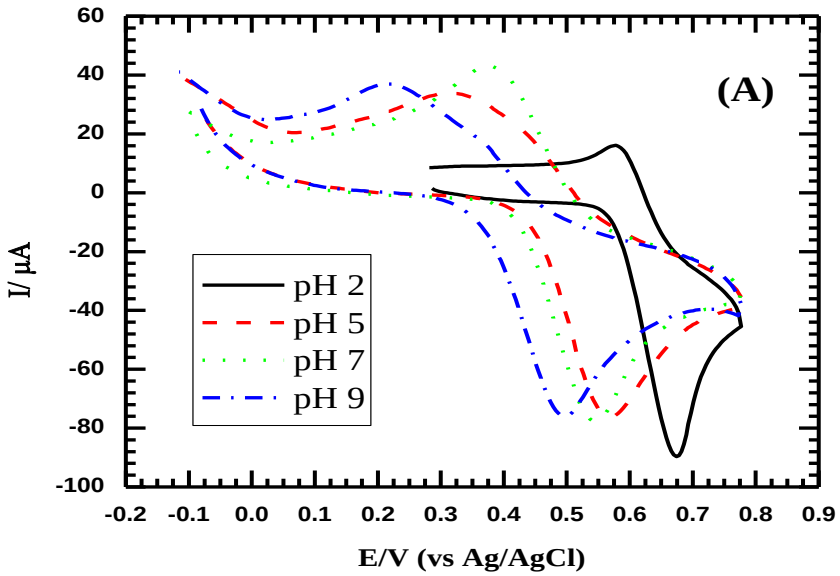
The effect of solution pH on the electrocatalytic oxidation of ACOP at the GNMCPE was studied by cyclic voltammogram technique using Britton–Robinson buffers within the pH range of 2–9 (fig 3A). It was found that ACOP gave their highest anodic current responses at low pH values, while at higher pH values the response was lower (fig 3B). Because the pKa values are 9.5 for ACOP [36], therefore, it carries a positive charge at pH values lower than their pKa's values (schematic 1), so there are attraction force between the positive charge of ACOP and the negative charge of gold nanoparticles, which indicates the effect of gold nanoparticles on the catalytic oxidation processes.

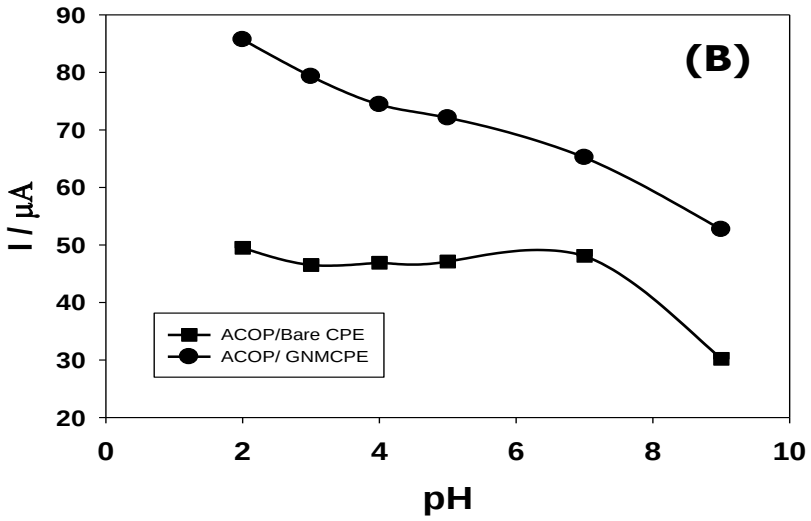
Also the pH of the solution has a significant influence on the peak potential of the catalytic oxidation of ACOP, i.e. the anodic peak potentials (E_{pa}) shifted negatively with the increase of the solution pH (fig 3C), which indicates that the electrocatalytic oxidation at the GNMCPE is a pH-

dependent reaction and that protons have taken part in their electrode reaction processes. Also, the peak potential for ACOP oxidation varies linearly with pH (over the pH range from 2 to 9).



(Schematic 1)





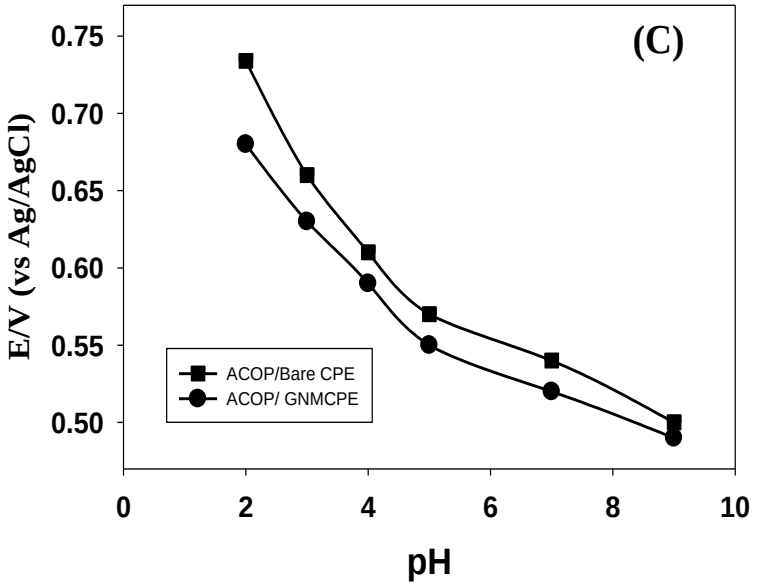


Figure 3. A)Cyclic voltammogram of 1.0 x 10^{-3} mol L^{-1} ACOP in B-R buffer pH 7.4 at scan rate 100 mVs^{-1} recorded at different pH values using GNMCPE. B) Relation between anodic peak current of 1.0 x 10^{-3} mol L^{-1} ACOP and pH at GNMCPE.C) Relation between anodic peak potential of 1.0 x 10^{-3} mol L^{-1} ACOP and pH at GNMCPE.

3.3.2. The effect of using different buffers

Although using pH 2 gave the highest current response, pH 7.4 which is the physiological pH of the human bodies will be used in the rest of the work, so the effect of changing the buffer type was studied on ACOP oxidation in the presence of B-R buffer pH 7.4 and PBS pH 7.4. It was clear that GNMCPE shows relatively better response in B-R buffer i.e. ACOP gave an oxidation peak current values of 65.6 µA and 49.1 µA, in case of B-R buffer and PBS, respectively (Fig 4).

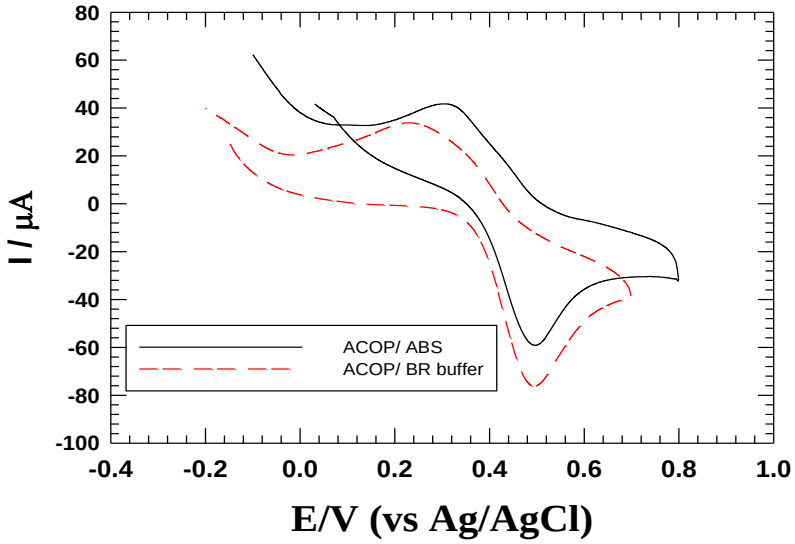


Figure 4. Cyclic voltammograms (CV) of 1.0 x 10^{-3} mol L^{-1} ACOP in the presence of B-R buffer pH 7.4 and PBS pH (7.4).

3.3.3 Diffusion coefficients of ACOP in different buffer electrolytes

The relation between anodic peak current, i_{pa} (μA), and the diffusion coefficient of the electroactive species, D_0 (cm^2s^{-1}), is given by randles- Sevcik equation [37]:

$$i_{pa} = (2.69x10^5)\, n^{3/2}\, A\, C_0{*}D_0^{1/2}\, \nu^{1/2} \qquad (1)$$

Where n is the number of electrons exchanged in oxidation at T=298K, A is the geometrical electrode area (0.0706 cm^2), C_0 is the analyte concentration (1×10^{-6} mol cm^{-3}) and ν is the scan rate (V s^{-1}).

The apparent diffusion coefficients, D_{app}, of ACOP in different electrolytes were calculated from cyclic voltammetry (CV) experiments and the results were compared. In this study, the dependence of the anodic peak current density on the scan rate has been used for the estimation of the D_{app}, of ACOP in different electrolytes according to Randles Sevcik equation. The calculated D_{app} values are 8.02 x 10^{-6} cm^2 s^{-1} and 5.96 x 10^{-6} cm^2 s^{-1} for bare CP-electrode and 1.49 x 10^{-5} cm^2 s^{-1} and 8.35 x 10^{-6} cm^2 s^{-1} for GNMCPE in B-R and PBS buffers, respectively. This indicated the quick mass transfer of the analyte molecules towards electrode surface from bulk solutions and/or fast electron transfer process of electrochemical oxidation of the analyte molecule at the electrode-solution interface [38,39] in case of ACOP using GNMCPE in B-R buffer. Furthermore, it also showed that the redox reaction of the analyte species took place at the surface of the electrode under the control of the diffusion of the molecules from solution to the electrode surface. The calculated D_{app} values for ACOP at bare CP-electrode and GNMCPE showed that Au particles improves the electron transfer kinetics at the electrode/solution interface, also changing the buffer type only caused changes in the current response and diffusion coefficient values.

3.4. Effect of interferences on the behavior of ACOP

An important parameter for a sensor is its ability to discriminate between the interfering species commonly present in similar physiological environment and the target analyte. In biological samples, AA and UA are the common important interferences coexisting in our body fluids. Therefore determination of ACOP in the presence of AA and UA is very important for the clinical point of view. So the voltammetric current responses of successive additions of ACOP were recorded in figure 5, using GNMCPE in B-R buffer (pH 7.4), containing 1.0 mmol L^{-1} AA and 1.0 mmol L^{-1} UA to check the sensitivity of the sensor in the presence of these interferences. Figure 5 inset shows the calibration plot of ACOP in the presence of the interfering substances, it was observed that there was no change in the peak currents or limit of detection for ACOP under the potential range used. So AA and UA did not interfere with ACOP at the GNMCPE. This behavior could be explained on the basis of the negatively charged surface of the GNMCPE in its anionic form at the working pH of 7.4, ACOP with pKa of 9.5 was mainly in its cationic form which can be attracted to the electrode surface, while AA with pKa of 4.2 [40] and UA with pKa of 5.4 [40] were in their anionic forms and were repelled by the negatively charged gold particles [41]. Also AA and UA remain negatively charged (which are highly

resonance stable due to their special chemical structure) as they could easily donate proton in the medium of pH 7.4, consequently they could not interfere with ACOP. From the above discussion we can conclude that GNMCPE can be applied for the determination of ACOP in the presence of AA and UA.

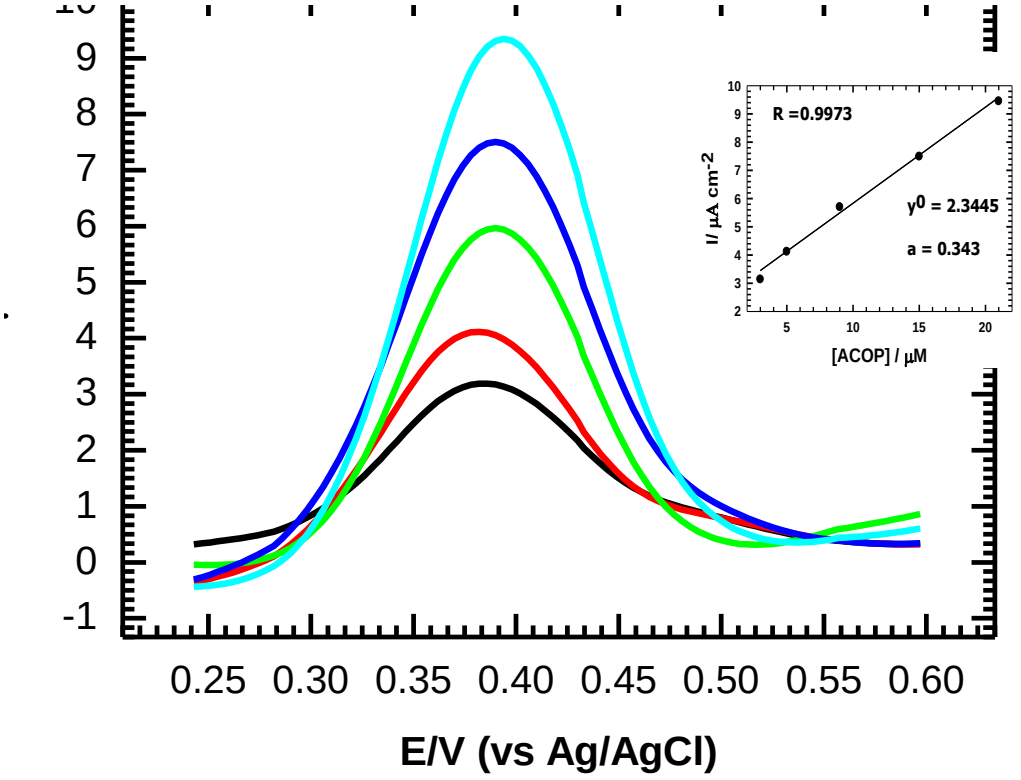


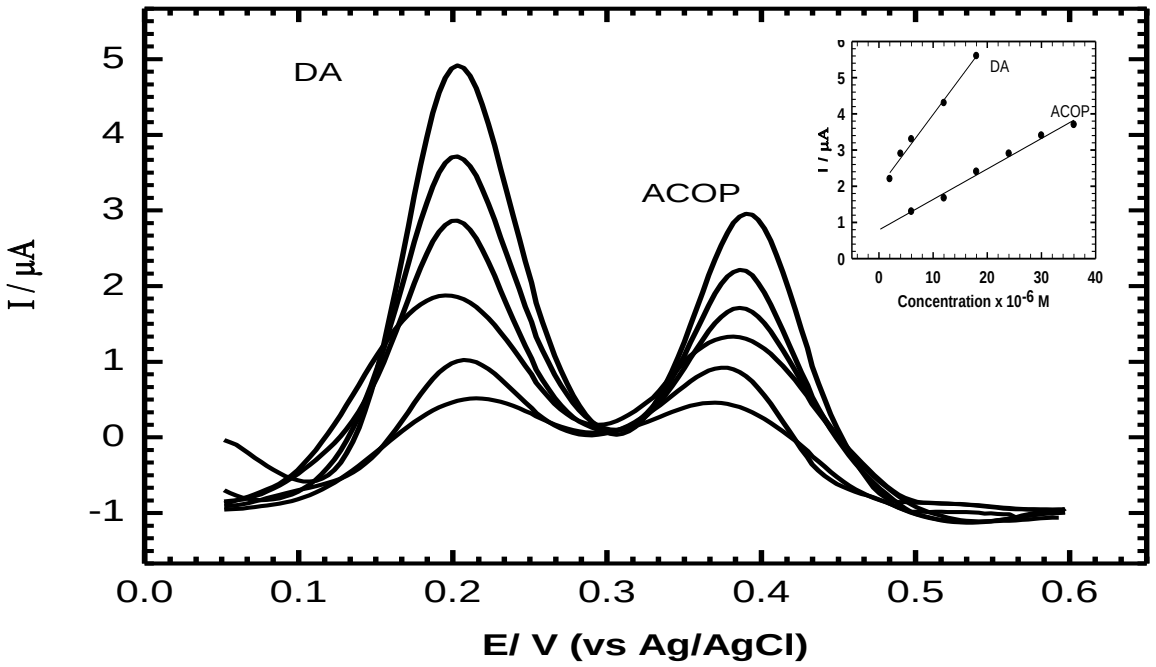
Figure 5. Voltammetric current responses of successive additions of ACOP using GNMCPE in B-R buffer (pH 7.4), containing 1.0 mmol L^{-1} AA and 1.0 mmol L^{-1} UA. The inset: plot of the calibration plot of ACOP in the presence of the interfering substances.

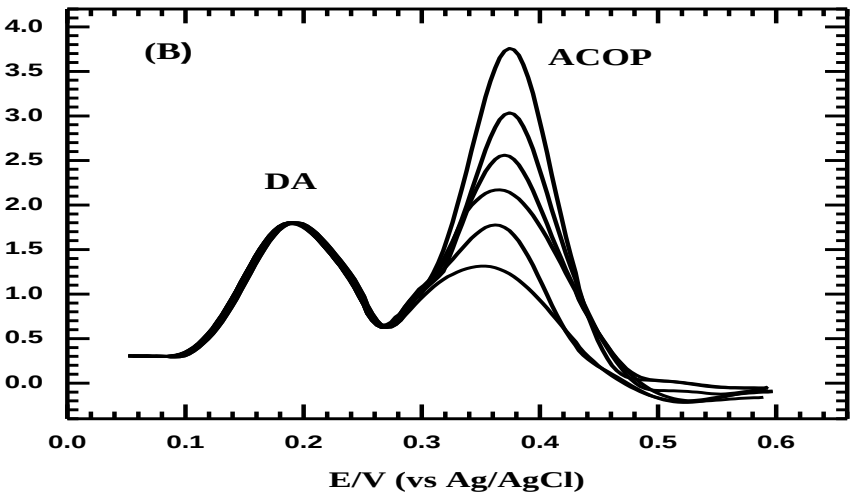
3.5. Simultaneous determination of ACOP and Dopamine

In biological samples, paracetamol generally suffers also from the interferences of dopamine (DA). Thus, experiment with interferences including DA was performed to test the selectivity of the GNMCPE sensing platform. As shown in Fig. 6A, ACOP exhibits well-defined differential pulse voltammograms DPV with good separations from DA in B-R buffer (pH 7.4) by changing the concentration of both ACOP (6→36 µmol L^{-1}) and DA (0.25→18 µmol L^{-1}).

The current responses due to the oxidation of DA (at 199 mV) and ACOP (at 393 ~~293~~ mV) with a peak separation of 194 mV were observed. With increasing their concentrations, the current responses of both ACOP and DA were increased linearly with a correlation coefficient of 0.9938 and 0.9952, respectively, also the regression equation for ACOP was found to be: Ip(µA) = 0.084 c(µmol L^{-1}) – 0.0842, while the regression equation for DA was : Ip(µA) = 0.201 c(µmol L^{-1}) + 0.15.

Simultaneous determination of ACOP and DA in the mixture was also investigated when the concentration of one species changed, whereas the other was kept constant. Fig 6B shows that the peak current of ACOP increased with an increase in the ACOP concentration (5→35 μmol L^{-1}) while the concentration of DA was kept constant (5.0 μmol L^{-1}). Also keeping the concentration of ACOP constant (6.0 μmol L^{-1}), the oxidation peak current of DA was positively proportional to its concentration (0.25→18 μmol L^{-1}) (fig 6C).





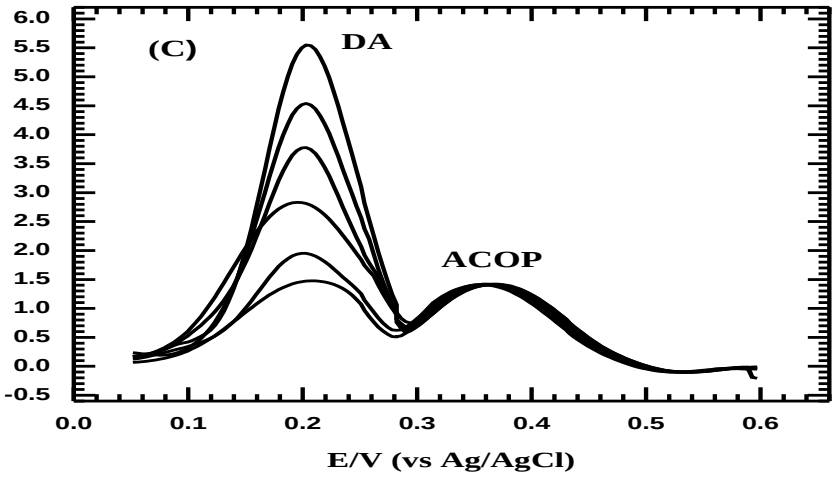


Figure 6. A) Differential pulse voltammograms DPV of simultaneous determination of DA (0.25→18 μM) and ACOP (6→36 μM) in B-R buffer (pH 7.4). B) Differential pulse voltammograms DPV of successive additions ACOP (5→35 μM) while the concentration of DA was kept constant (5.0μM) in B-R buffer (pH 7.4).C) Differential pulse voltammograms DPV of successive additions of DA (0.25→18 μM) and the concentration of ACOP was kept constant (6.0 μM) in B-R buffer (pH 7.4).

It should be noted that, the change of concentration of one compound did not have significant influence on the peak current and peak potential of the other compound.

3.6. Analytical characterization of ACOP and its reproducibility

Pulse voltammetric techniques such as DPV method was used to determine the concentration of ACOP. The plot of anodic peak current vs. ACOP concentration in B-R buffer pH 7.4 (fig 7) shows a linear range of 5.0×10^{-8} to 2.7×10^{-4} mol L^{-1} with the regression equation of Ip(μA) = 0.0349 c(μM) + 1.752 and correlation coefficient 0.9947. The corresponding calibration plot is given in the inset. The limit of detection (LOD) and the limits of quantitation (LOQ) were calculated using the following equations:

$$LOD = 3s/m$$

$$LOQ = 10s/m$$

Where *s* is the standard deviation of the oxidation peak current (three runs) and *m* is the slope of the related calibration curves, and they were found to be 1.46×10^{-8} mol L^{-1} and 4.8×10^{-8} mol L^{-1} respectively. Both LOD and LOQ values confirmed the sensitivity of GNMCPE.

Table 1 shows a comparison of the GNMCPE with the reported methods for the determination of paracetamol.

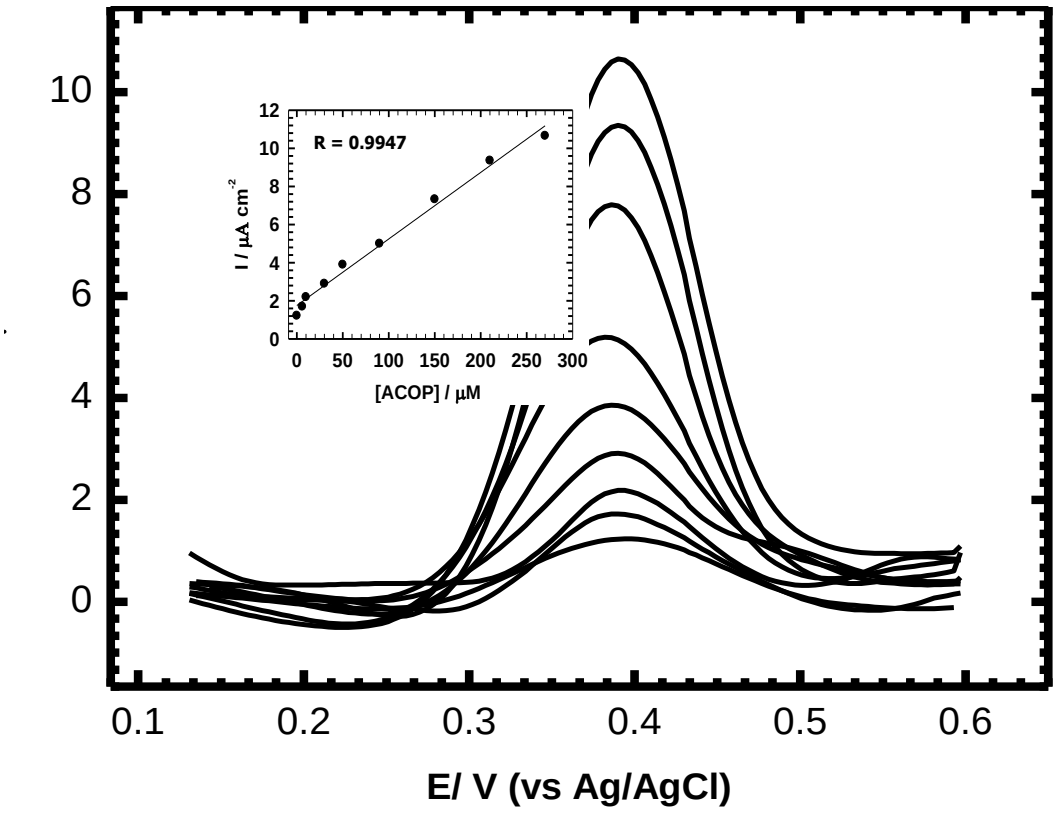


Figure 7. The effect of changing the concentration of ACOP, using differential pulse mode at GNMCPE in 0.04 M B-R buffer pH 7.4 and scan rate 10 mV/s. The inset (1): represents the calibration curve.

Table 1. Comparison of the GNMCPE with the reported methods for the determination of (ACOP).

Electrode used	Linear range µM	Detection limit µM	References
C_{60}/GCE[(a)]	50-1500	50	[42]
PIP/PGE [(b)]	5-500	0.79	[43]
SPE/PEDOT [(c)]	4-400	1.39	[44]
Graphene/GCE	0.1-20	0.032	[45]
GC/Cu(II)-complex	20-5000	5	[46]
GC/nano-TiO_2/PAY	12-120	2	[47]
GNMCPE	0.05-270	0.014	This work

(a) C60-modified glassy carbon electrode
(b) Electropolymerized-molecularly imprinted polypyrrole modified pencil graphite electrode
(c) Poly(3,4-ethylenedioxythiophene)-modified screen-printed electrodes

3.7. Analytical application

3.7.1. Detection of acetaminophen in tablets

In order to testify the performance of this sensor in real sample analysis, it was used to determine the content of ACOP in tablets. So commercial pharmaceutical samples (tablets) containing

ACOP was analyzed to evaluate the validity of the proposed method. The concentration of ACOP was measured by the standard addition method

Table 2. Recovery data obtained by standard addition method for (ACOP) in drug formulation.

Formulation	[tablet] taken x 10^{-6} M	[standard] added x 10^{-6} M	Found(M) x 10^{-6} M	Recovery %	RSD %
Paracetamol	5.00	2.0	7.012	100.1	0.61
	20.0		21.70	98.60	1.26
	50.0		52.68	101.3	0.67
	150.0		151.98	99.90	0.03
	250.0		252.15	100.0	0.07

Paracetamol tablets containing 500 mg ACOP were applied from SEDICO Company (Egypt). The tablets were weighed and finely pulverized. The appropriate amount of this powder was dissolved in double distilled water. The content of the tablet was diluted to get the concentration of ACOP in the working range and then DPV were recorded using GNMCPE. The concentration of ACOP in the pharmaceutical formulations was determined from the calibration curve. Average concentrations were calculated from five replicate measurements of two independent solutions of the same pharmaceutical preparations. Table-2 shows the data generated by standard addition method for the analysis of ACOP in buffered solution of pH 7.4. The data shows that the content values determined by the proposed method for the commercial samples are very close to the claimed amount. The analysis of the obtained responses allowed concluding that the drug excipients do not significantly interfere with the proposed method. The recovery is in the range from 98.6 % to 101.3 %, and the RSD is below 1.3 %, revealing that the results obtained by GNMCPE sensor are reliable and feasible. Thus, the practical application was demonstrated with the determination of ACOP in pharmaceutical formulation with high reproducibility and that there were no important matrix interferences for the samples analyzed by DPV mode and it would be a useful electrode for quantitative analysis of ACOP in pharmaceutical formulations.

3.7.2. Validation method in urine

In order to verify the reliability of the proposed method, it was applied for the determination of ACOP in human urine using B-R buffer pH 7.4, at scan rate 10 mV/s. The calibration curve gave a straight line in the linear dynamic range 6 x 10^{-7} mol L^{-1} – 2 x 10^{-4} mol L^{-1} with correlation coefficient, r = 0.9913, the LOD is 1.13 $\times 10^{-7}$ mol L^{-1}. Four different concentrations on the calibration curve are chosen to be repeated five times to evaluate the accuracy and precision of the proposed method which is represented in (table 3).

Table 3. Evaluation of the accuracy and precision of the proposed method for the determination of (ACOP) in urine sample

[ACOP] added (M) x 10^{-6}	[ACOP] Found[a] (M) x 10^{-6}	Recovery (%)	SD x 10^{-7}	S.E[b] x 10^{-7}	C.L.[c] x 10^{-7}
1.0	1.02	102.0	0.20	0.94	0.26
20.0	19.93	99.65	0.87	0.39	1.09
50.0	50.21	100.4	4.30	1.96	5.46
150.0	149.78	99.85	2.28	1.02	2.83

4. CONCLUSION

In the present work, a biosensor based on CP-electrode modified with gold nanoparticles was used for electrochemical determination of ACOP. The advantages of the gold nanoparticles enhanced the sensitivity of the CP-electrode significantly. The results showed that the method was simple and sensitive enough for determination of ACOP in human urine and in commercial tablet with good precision and accuracy.

In the present work, simultaneous determinations of ACOP with DA in a binary mixture and the selective determination of ACOP in presence of AA and UA in 0.04 M B-R buffer (pH 7.4) using GNMCPE were studied. Compared with other modified electrodes for the assay of ACOP, the GNMCPE sensor has good current response and stability with low detection limit. The results are fairy satisfactory beside the background causes no significant effects.

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