

Original research

## **Electrochemical sensor based on a poly-murexide modified carbon paste electrode for determination of fluoroquinolone antibiotic ciprofloxacin**

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### **Abstract:**

Since the fluoroquinolone family of antibiotic drugs has recently been widely utilized to treat pneumonia during the COVID-19 pandemic spread, we shed light on them in our work. In the current investigation, a poly-murexide modified carbon paste electrode (PMUX/CPE) was utilized to detect second-generation fluoroquinolone antibiotic ciprofloxacin (CFLOX) in human serum samples and pharmaceutical formulations. PMUX/CPE showed high accuracy, good sensitivity, and selectivity toward CFLOX. For the morphological analysis of the fabricated sensor, scanning electron microscopy (SEM) was used. PMUX/CPE had an outstanding ability to enhance electron transfer compared to the unmodified electrode. The obtained differential pulse voltammograms (DPVs) exhibited that under ideal experimental conditions, the oxidation peak currents of CFLOX were linearly proportional to their concentration in the range of 0.05 to 3.00  $\mu\text{M}$ , with a detection limit (LOD) and quantification limit (LOQ) of 0.0057  $\mu\text{M}$ , and 0.0190  $\mu\text{M}$ , respectively. With a recovery of 93.25%–104%, this method was effectively applied to detect CFLOX concentrations in pharmaceutical tablets and spiked human serum.

**Keywords:** Ciprofloxacin, poly-murexide, electro-polymerization, carbon paste electrode, differential pulse voltammetry

### **1- Introduction**

Fluoroquinolones are an important class of antibacterial medications that have recently been developed and have a wide range of uses in both human and veterinary medicine (Fedorowicz et al., 2018). A second-generation fluoroquinolone antibiotic known as ciprofloxacin (CFLOX) is more effective against both Gram-positive and Gram-negative bacteria (Azriouil et al., 2022; Bagheri et al., 2016). CFLOX is therefore useful for treating pneumonia (Abbas et al., 2022) and various infectious disorders in people and livestock, including but not limited to infections of the urinary system, the digestive tract, and infections in the skin and soft tissues (Chauhan et al., 2020).

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For those who may have been exposed to anthrax bacteria through the air, CFLOX has been approved by the Food and Drug Administration as a treatment or preventative antibiotic (Deepak et al., 2015; Rahimpour et al., 2021). Due to its low toxicity and broad antibacterial efficacy, CFLOX has been extensively used in therapeutic practices. Developing a simple, sensitive, rapid, and dependable method for detecting CFLOX is therefore extremely essential and crucial. CFLOX has already been determined using various techniques, such as chromatographic (Sureshkumar et al., 2018; Tantawy et al., 2021; Vella et al., 2015; Zheng et al., 2019) and spectrophotometric techniques (Abd El-Aziz et al., 2021; An et al., 2022; Czyrski, 2022; Habib et al., 2019; Kadioglu et al., 2022; Turkey et al., 2013). However, despite their high sensitivity and precision, these methods take a long time to implement and require expensive and intricate equipment. Electroanalytical methods have recently been widely used for sensing electroactive pharmaceutical compounds due to many advantages, including low instrumental costs and simplicity and reliability of the methods, as well as their practical sensitivity with low detection limits and a wide dynamic range (Assaf et al., 2021; Rabie et al., 2019; Toghan et al., 2019; Toghan, Abou-Krishna, et al., 2021; Toghan, Gadow, et al., 2021). Chemical modification of the electrodes can improve the electrochemical detection of electroactive substances. Recent years have seen a rise in interest in modified CPEs because of their many advantages, including low background current, a wide variety of potential windows, low cost, fast manufacture, and quick surface renewal (Khodari et al., 1989; Nassar et al., 2022; Rabie et al., 2022; Švancara et al., 2009). Various modifiers have been employed on CPEs to promote the electron transfer process (Dehdashtian et al., 2016). Electro-polymerization is one of the most crucial processes for producing conducting polymers (Wang et al., 2022). The electro-polymerization process is also considered a particularly appealing process and alternative to chemical polymerization since the resulting film has high stability and reproducibility, and adheres well to the electrode's surface (Krishnan et al., 2020; Pinar et al., 2018). As a result of the superior conductivity of the conducting polymers, electrochemical sensors have become more sensitive. It has been proposed to use murexide in the electro-polymerization procedure because it facilitates the electron transfer kinetics (Krishnan et al., 2021; Kumar et al., 2019). The present work reported the preparation of a low-cost sensor based on the construction of conducting polymer film of murexide on the CPE surface through the electro-polymerization method for detecting CFLOX in real samples. The presence of the polymer film resulted in highly selective and sensitive CFLOX detection. To the best of our knowledge, there are no reports in the literature regarding using such a sensor for the voltammetric CFLOX determination.

## **2. Materials and Methods**

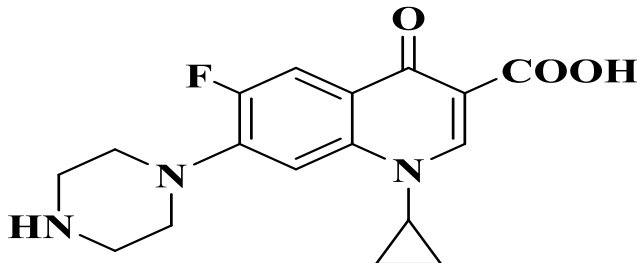
### **2.1. Apparatus**

A potentiostat (model versa STAT 4) and electroanalytical software (versa studio) were used to execute voltammetric techniques. Three electrodes were used in the electrochemical cell: Ag/AgCl, Pt wire, and unmodified or modified carbon paste electrodes as the reference, auxiliary, and working electrodes, respectively. Thermo/Orion model 420A pH/mV/Rel mV meter was used to adjust the pH value of buffer solutions. Scanning electron microscope (JEOL JSM-5500 LV, Japan) was used to perform the SEM measurements.

### **2.2. Materials**

All the chemicals in this work were used without any purification. The following chemicals were obtained from Sigma-Aldrich: Ciprofloxacin hydrochloride standard (Fig. 1), murexide dye

(ammonium purpurate), graphite powder, and paraffin wax. A stock solution of CFLOX ( $1 \times 10^{-3}$  M) was freshly prepared by dissolving 36.78 mg in 100 ml double-distilled water. Other standard CFLOX solutions were prepared by further diluting this stock solution. Various supporting electrolytes were used, such as Britton–Robinson (BR) buffer solution, acetate buffer solution (ABS) and phosphate buffer solution (PBS) have been used.



**Fig. 1.** Molecular structure of ciprofloxacin antibiotic (1-cyclopropyl-6-fluoro-1,4-dihydro-4-oxo-7-(1-piperazinyl)-3-quinoline carboxylic acid).

### 2.3. Fabrication of bare and modified CPE electrode

Bare CPE (BCPE) was fabricated by mixing graphite powder and paraffin wax in a 75:25 (w/w %) ratio with heating to get a homogeneous paste. Then, the paste was packed into an insulin syringe. Finally, copper wire was immersed in the paste to make contact with the cell. The CV technique was applied at the potential range of -1.8 V to +1.5 V in a BR buffer solution (pH= 5.5) until steady voltammograms were produced to activate the electrode surface. The electro-polymerization of 0.35 mM murexide on the activated surface of BCPE was employed to fabricate PMUX/CPE.

### 2.4. Preparation of real samples

The collected blood samples were centrifuged at 2500 rpm until the serum was completely separated. To get rid of protein from the serum sample, 3 mL of methanol was added to a tube containing a similar serum volume as a precipitating agent, and then the tube was vortexed for 10 min, followed by 20 min of centrifugation at 5000 rpm. The resulting supernatant was transferred into a volumetric flask and spiked with a specific CFLOX amount, followed by dilution with BR buffer (pH= 5.5) to get the required concentration. Cipromax™ tablets (750 mg) were used as the commercial pharmaceutical CFLOX sample. One tablet was weighed and ground. After that, an appropriate weight of the resulting powder was dissolved in double-distilled water until complete dissolution, except for active constituents. The resulting solution was filtered through filter paper and diluted with double-distilled water to 100 ml. From the produced solution, numerous quantities were taken and transferred to the electrochemical cell to prepare the desired concentrations. Quantifications were performed utilizing the standard addition method.

## 3. Results and discussion

### 3.1. Electrochemical formation of PMUX at BCPE surface and its characterization by SEM.

Electrochemical polymerization of murexide (0.35 mM) was done using repetitive CV at a scan rate of 100 mV/s for nine cycles in a pH equals 7.0. PBS solution in the potential range of -0.6 V to +2 V to prepare PMUX/CPE. As illustrated in Fig. 2, increasing the number of cycles enhanced the redox peak current of the murexide. This is due to the transformation of the

monomer murexide film that formed on the BCPE surface into an electroactive PMUX film which increased the electrode conductivity (Kumar et al., 2019). Once the polymerization process is completed, the physically adhered materials were eliminated from the PMUX/CPE surface by rinsing it with double-distilled water. SEM was used to characterize the surface morphology of BCPE and PMUX/CPE. Fig. 3A represents the SEM image for BCPE, depicting the flake-like structure of graphite (Krishnan et al., 2021a, 2021b). On the other hand, the surface morphology of BCPE changed by encapsulating the graphite flake structures with the PMUX film, as shown in Fig. 3B (Krishnan et al., 2021).

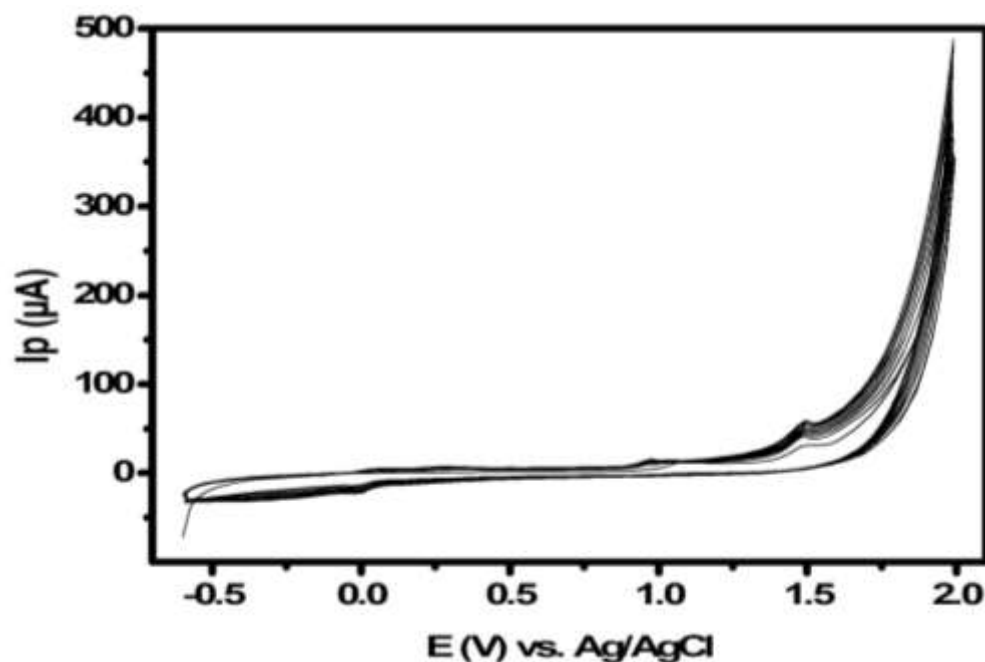


Fig. 2. CVs for the electro-polymerization of 0.35 mM murexide in the presence of PBS (pH = 7.0) at the surface of BCPE.

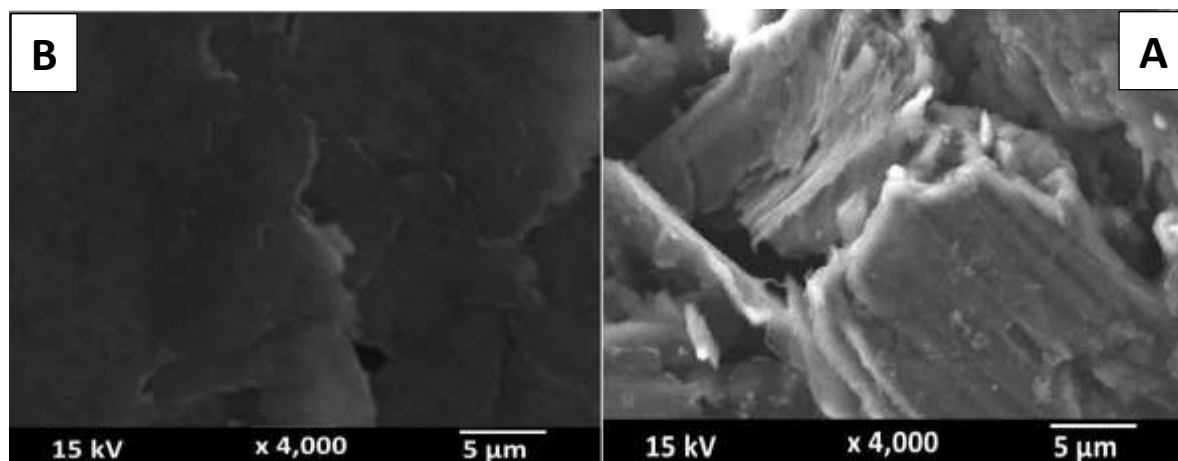


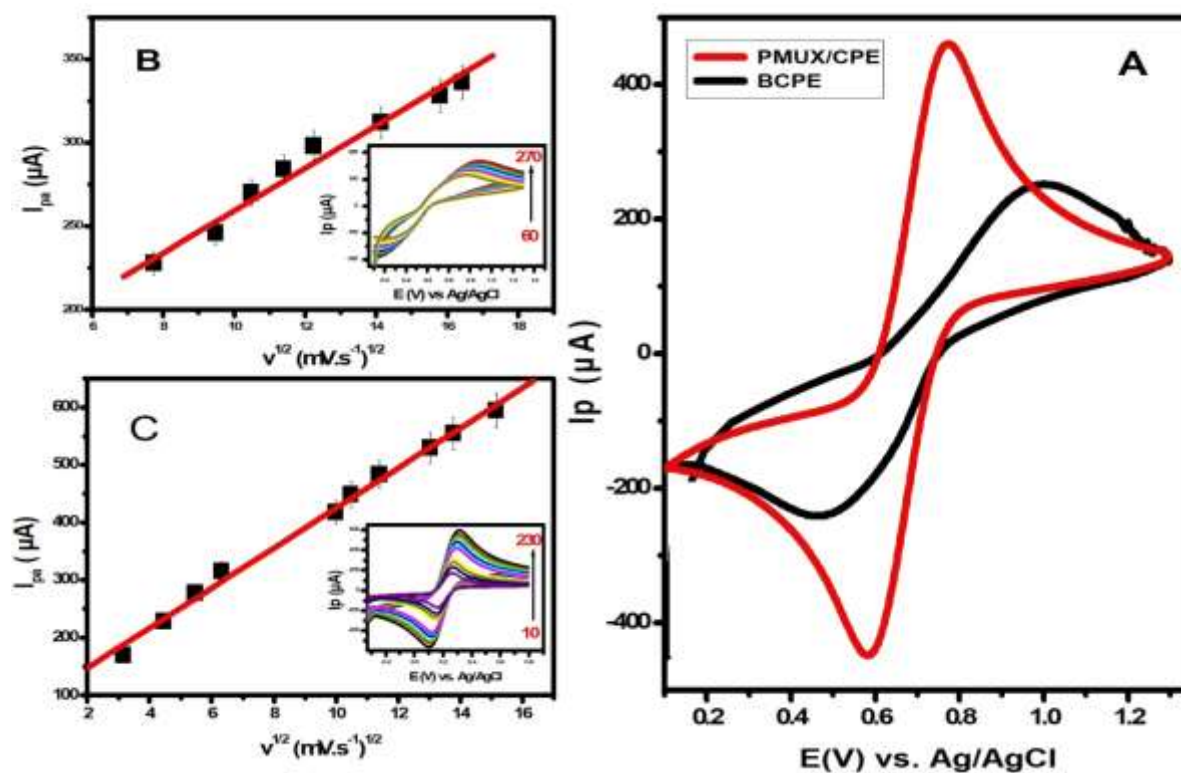
Fig. 3. SEM micrographs of (A) BCPE and (B) PMUX/CPE.

### 3.2. Electrochemical characterization of the modified and unmodified electrode

By employing the CV technique using 1.0 mM  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  in 0.1 M KCl, the electrochemical behaviors of BCPE and PMUX/CPE were characterized. As shown in Fig. 4A, the bare CPE had broad redox peaks with peak-to-peak potential separation value ( $\Delta E_p = 0.59$  V), which was considerable compared with PMUX/CPE whose  $\Delta E_p$  value was (0.19 V). Additionally, the current density at PMUX/CPE was noticeably increased compared with BCPE. This indicates that the polymer formed at the electrode surface facilitated the electron transfer process between  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  and the electrode, and thus enhanced the conductivity. The active surface area of the two former electrodes was estimated by applying CV to the same solution at various scan rates (the insets of Fig.4B,C) and using Randles-Sevcik's equation (Abd-ElSabour et al., 2022; Hernández et al., 2021).

$$I_{pa} = 2.69 \times 10^5 \text{ A } \sqrt{D} (\sqrt{n})^3 \sqrt{v} C_o \quad (1)$$

where  $I_{pa}$  refers to anodic peak current (A),  $A$  is the active surface area of the electrode in  $\text{cm}^2$ ,  $n$  is the number of electrons transferred ( $n=1$ ),  $D$  is the diffusion coefficient for  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  ( $7.60 \times 10^{-6} \text{ cm}^2/\text{s}$ ),  $v$  is the scan rate ( $\text{mV}/\text{s}$ ), and  $C_o$  represents the concentration of  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  in mM. The active surface area of both BCPE and PMUX/CPE was calculated to be  $0.0165 \text{ cm}^2$  and  $0.047 \text{ cm}^2$ , respectively, from the slope of the plot of  $I_{pa}$  vs.  $v^{1/2}$  (Fig 4B, C). According to these data, the surface area of PMUX/CPE was approximately 2.85-fold of the value of BCPE, indicating that the electro-polymerization enhanced the electrocatalytic activity of the modified electrode.



**Fig. 4.** (A) CVs for 1.0 mM  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  in the presence of 0.1 M KCl solution at BCPE and PMUX/CPE. (B) and (C) Linear plot of  $I_{pa}$  ( $\mu\text{A}$ ) vs.  $v^{1/2}$  ( $\text{mV}/\text{s}$ ) $^{1/2}$  (Inset- CVs at various scan rates) for 1.0 mM  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  at BCPE and PMUX/CPE, respectively.

### 3.3. Electrochemical oxidation of CFLOX at PMUX/CPE

CV was used to investigate the electrochemical behavior of 40  $\mu\text{M}$  CFLOX at the surface of both BCPE and PMUX/CPE, at a scan rate of  $50 \text{ mV}\cdot\text{s}^{-1}$  in the presence of BR buffer ( $\text{pH} = 5.5$ ). As illustrated in Fig. 5, PMUX/CPE showed a sharp peak with a high current value ( $I_{\text{pa}} = 37.5 \mu\text{A}$ ) at 1.08 V, in contrast to the BCPE, which displayed a broad oxidation peak with a low current ( $I_{\text{pa}} = 15.4 \mu\text{A}$ ). This is due to the increase in the CFLOX accumulation on the PMUX/CPE surface due to the attraction created between CFLOX and the active sites in the PUMX film, leading to an enhancement of the electro-oxidation process (Ishaq et al., 2012). The disappearance of the reduction peak further demonstrates the irreversibility of the electrochemical reaction involving CFLOX.

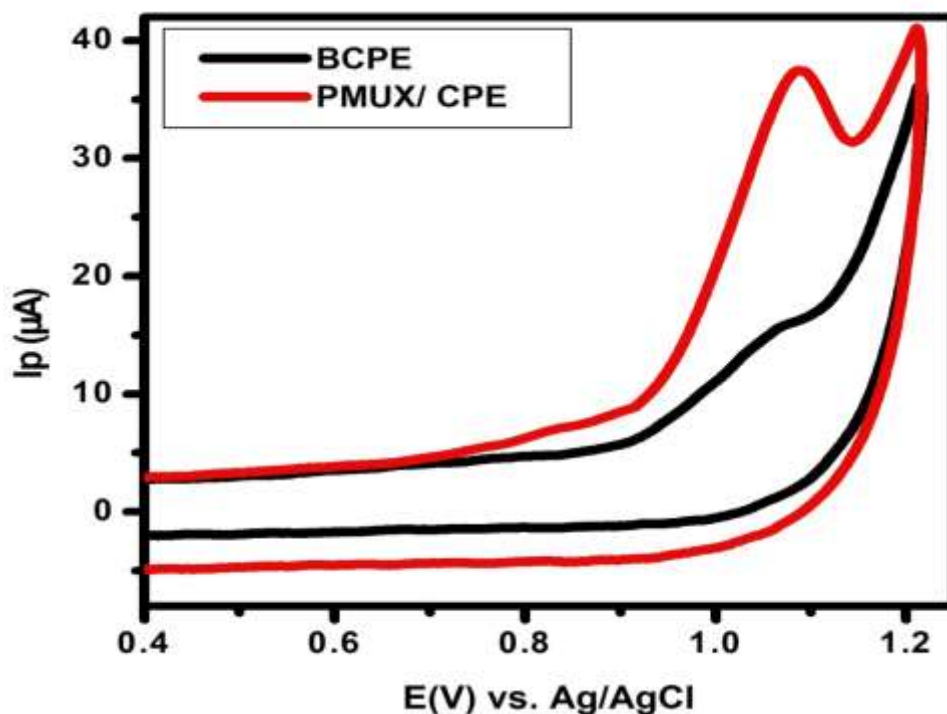
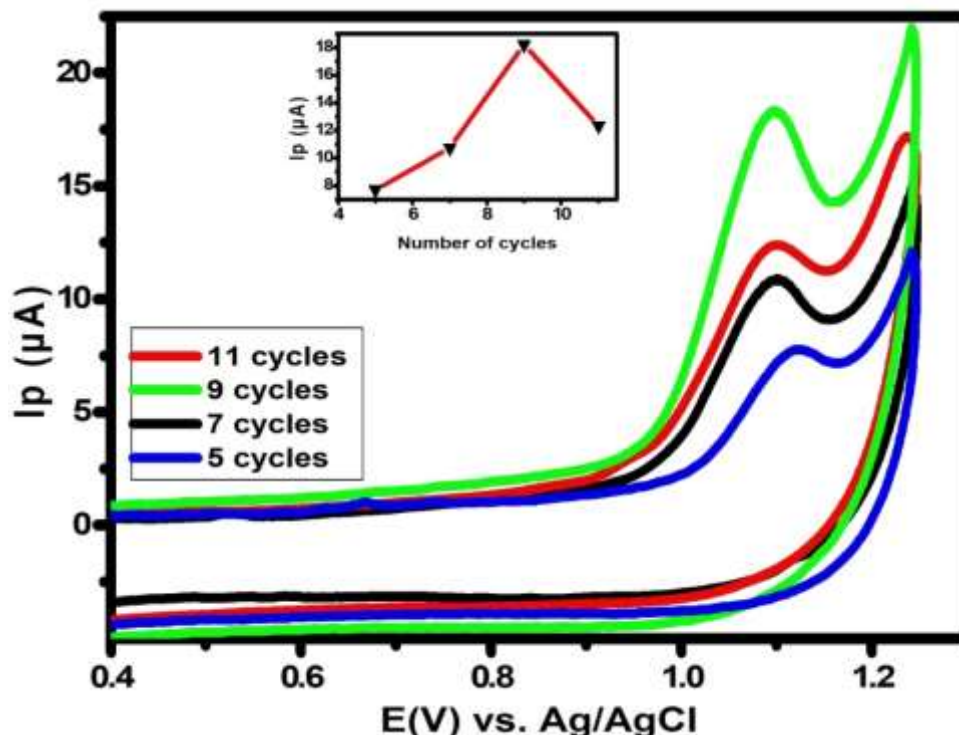


Fig 5. CV curves of 40  $\mu\text{M}$  CFLOX in BR buffer ( $\text{pH} = 5.5$ ) at scan rate  $0.05 \text{ V}\cdot\text{s}^{-1}$  at the surface of BCPE and PMUX/CPE.

### 3.4. Optimization of experimental conditions for CFLOX analysis

#### 3.4.1. Effect of number of electro-polymerization cycles

It is necessary to fix the number of electro-polymerization cycles on the CPE surface to determine the extent of the PMUX effect on the oxidation current of CFLOX. The oxidation current of CFLOX ( $10 \mu\text{M}$ ) increased gradually from 5.0 to 9.0 cycles, as shown in Fig. 6, and then decreased significantly when the number of cycles was greater than 9.0. This is because a thick PMUX film formed on the surface of CPE impeded the transfer of electrons and caused the surface to become electrically inactive; therefore, the oxidation current dropped considerably.



**Fig. 6.** CVs were obtained for the influence of various numbers of electro-polymerization cycles (5.0, 7.0, 9.0 and 11.0 cycles) on the anodic peak current of CFLOX (10  $\mu\text{M}$ ) at PMUX/CPE in the presence of BR buffer (pH = 5.5) at scan rate 50 mV/s (Inset shows the plot of the oxidation peak current of CFLOX against the number of electro-polymerization cycles).

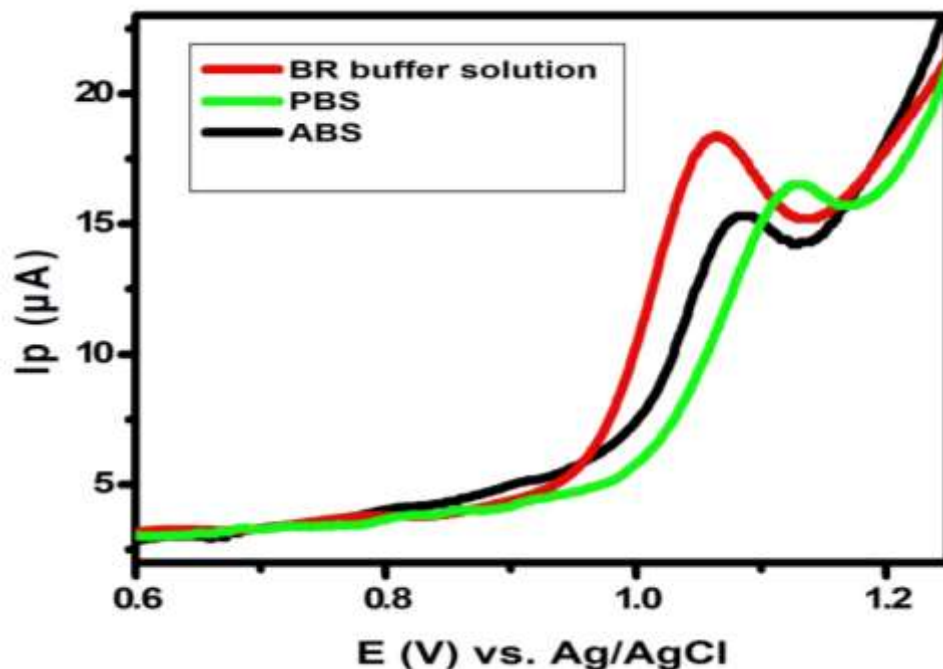
### 3.4.2. Influence of the supporting electrolyte

The supporting electrolyte has a noticeable effect on the electrochemical determination process, so it is necessary to select the convenient electrolyte to study the electrochemical response of CFLOX. The LSV technique was used to investigate the impact of different supporting electrolytes on the oxidation peak current of 10  $\mu\text{M}$  CFLOX at the same pH value (Fig. 7), such as the BR buffer solution, PBS, and ABS. The data revealed that the CFLOX oxidation in the presence of BR buffer solution produces  $I_p$  value of 18.4  $\mu\text{A}$  which is higher than that resulted in PBS and AC buffer solutions which equal 16.5 and 15.4  $\mu\text{A}$ , respectively. In addition, the  $E_p$  value shifted toward a less positive value in BR buffer, indicating that the oxidation process of CFLOX at PMUX/CPE in BR buffer as a supporting electrolyte was easier than in the presence of PBS or AC buffer. As a result, BR buffer was chosen in this investigation as the best supporting electrolyte for CFLOX estimation.

### 3.4.3. Influence of pH alteration on the oxidation of CFLOX

Selecting the optimum pH for BR buffer solution is critical, because the electrochemical response of CFLOX can be greatly influenced by this parameter. LSV technique had been used to demonstrate the influence of pH on the anodic peak of 10  $\mu\text{M}$  CFLOX, as shown in Fig. 8A. By increasing pH value from 3 to 5.5 the  $I_p$  intensity increased, while at higher pH values than 5.5  $I_p$  of intensity decreased. This behavior may be related to the acid dissociation values ( $pK_{a1}$  and  $pK_{a2}$ ) of the amine and carboxylic group in CFLOX, which are 8.7 and 6.1, respectively (Peng et al., 2016), where CFLOX would convert into the cationic form ( $\text{CFLOXH}^+$ ) at pH values lower

than 6.1 as a result of the protonation of the amine group, which would be electrostatically attracted to the anionic murexide (Ishaq et al., 2012).



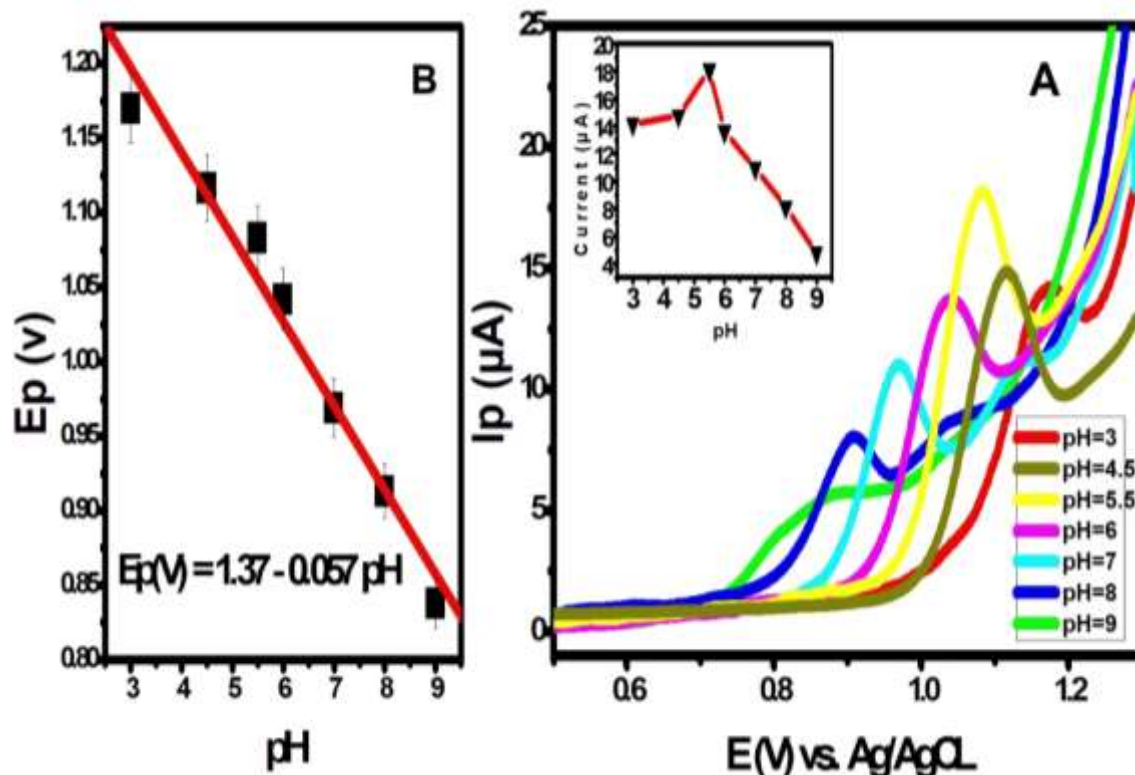
**Fig. 7.** LSVs of PMUX/CPE in different supporting electrolytes containing 10  $\mu\text{M}$  CFLOX at scan rate 50 mV/s.

However, in strongly acidic media, protons prefer to be adsorbed on PMUX more than  $\text{CFLOXH}^+$ , which may block the active sites of PMUX, resulting in a lower oxidation peak current of CFLOX (Ekinici et al., 2021). On the other hand, at  $6.1 < \text{pH} < 8.7$  CFLOX will be a zwitter ion ( $\text{CFLOX}^\pm$ ), therefore, lower amount of CFLOX can be attached to the polymer layer because of the repulsive forces between the negatively charged carboxylate of CFLOX and PMUX. The anodic peak current was noticeably reduced at pH greater than  $\text{pK}_{a2}$  of CFLOX because the amine group will be neutral, and the carboxylic group still be deprotonated which led to occurrence of severe electrostatic repulsion between it and the negatively charged murexide. As a result, the best pH value in our investigation was determined to be 5.5 which has already been selected in earlier study (Muungani et al., 2022). Fig. 8B shows a straight line derived from the relationship between the CFLOX peak potentials ( $E_p$ ) and the various values of pH which obeys the equation below:

$$E_p(\text{V}) = 1.37 - 0.057 \text{ pH} \quad (2)$$

By comparing with Nernst's theoretical value of  $-0.059 \text{ V/pH}$ , this slope ( $-0.057 \text{ V/pH}$ ) implies that the number of protons and electrons involved in CFLOX oxidation process is exactly equal to the same.





**Fig. 8.** (A) LSVs for 10 μM CFLOX at PMUX/CPE in BR buffer at different pH values (3.0, 4.5, 5.5, 6.0, 7.0, 8.0 and 9.0) at scan rate 50 mV.s<sup>-1</sup>. (B) Plot of the influence of pH values on the CFLOX peak potential (E<sub>p</sub>).

### 3.4.4. Impact of potential scan rate variation

The scan rate variation was applied using LSV in the presence of BR buffer at pH= 5.5 to calculate how many electrons were involved in 25 μM CFLOX oxidation process. The manner of mass transfer was accountable for the electrode reaction rate. As the scan rates rose from 20 to 300 mV/S (Fig. 9A), the E<sub>p</sub> shifted slightly to the right, increasing its positive value. This indicates that protons (H<sup>+</sup>) contributed to the electro-oxidation reaction of CFLOX. The intensity of I<sub>p</sub> also increased. The linear relationship and the high value of correlation coefficient (0.99) of the regression equation obtained from the plot of the anodic peak current (I<sub>p</sub>) against the square root of the scan rate (v<sup>1/2</sup>) denotes that the CFLOX oxidation process was diffusion-controlled on the PMUX/CPE surface (Fig. 9B) (Khodari et al., 2018 ; Moges et al., 2022):

$$I_p(\mu A) = -10.31 + 4.97 v^{1/2} (\text{mV} \cdot \text{s}^{-1}) \quad (R^2 = 0.99) \quad (3)$$

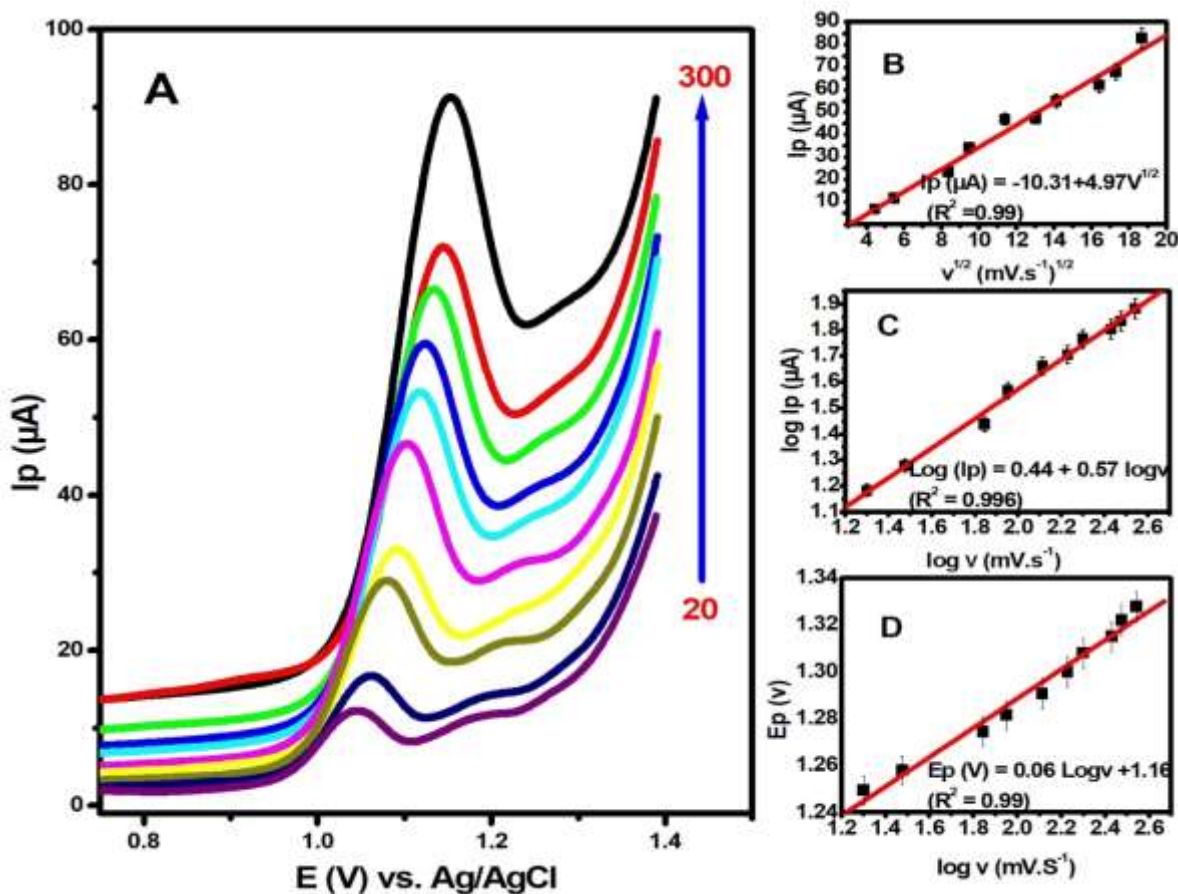
A direct relationship between the log v (mV/s) and log I<sub>p</sub> (μA) is shown in Fig. 9C, and the regression is given in Eq. (4). The slope value (α) of the straight line was determined to be 0.57, which was significantly close to the pre-calculated theoretical value of 0.50 for a diffusion-controlled process (Kumar et al., 2022).

$$\text{Log}(I_p) = 0.44 + 0.57 \text{ log } v \quad (R^2 = 0.996) \quad (4)$$

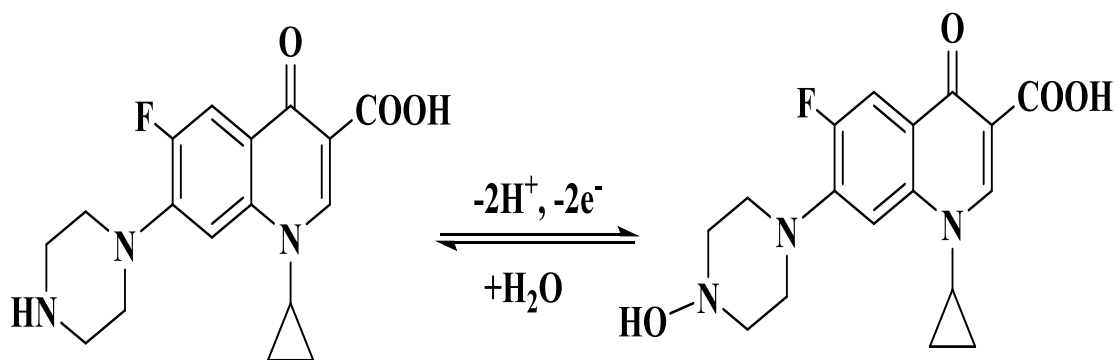
Likewise, a linear plot was obtained from the relationship between the peak voltage and the logarithm of the scan rate (Fig. 9D), obeying the following equation:

$$E_p(V) = 0.06 \log v + 1.16 \quad (R^2 = 0.99) \quad (5)$$

According to the Laviron's theory (Al-Qahtani et al., 2022), the value of (n) was estimated to be 1.6, implying that two electrons contribute to the electro-oxidation process of CFLOX at PMUX/CPE. This means that the predicted mechanism for the CFLOX oxidation process was in line with earlier studies (Sabeti et al., 2021) (Scheme 1).



**Fig. 9.** LSVs of 25  $\mu\text{M}$  CFLOX in the presence of BR buffer (pH= 5.5) at PMUX/CPE at various scan rates ranging from 20 to 300 mV (A). Linear relations of the oxidation peak current versus square root of scan rate (B), log (Ip) vs. log v (c) and the oxidation peak potential (Ep) versus log v (D).



**Scheme 1.** The suggested electro-oxidation mechanism of ciprofloxacin.

### 3.5. Analytical performance of PMUX/CPE

#### 3.5.1. Effect of concentration and calibration curve of CFLOX

Techniques like DPV are widely known for their capacity to enhance electrode sensitivity toward the drug of interest, which is why this study used this method. This enables the electrode to measure very low CFLOX concentrations at the predefined optimal conditions. Once the pulse height of 40 mV, the pulse width of 0.01 s, the step height of 5 mV, and the step width of 0.02 s were selected as optimal parameters for CFLOX analysis, an anodic peak emerged more clearly and sharply at a potential of 1.12 V. Fig. 10 exhibits that as the concentration of CFLOX raised from 0.05 to 3  $\mu\text{M}$ , the oxidation peak current increased, leading to the following regression equation in the linear calibration plot:

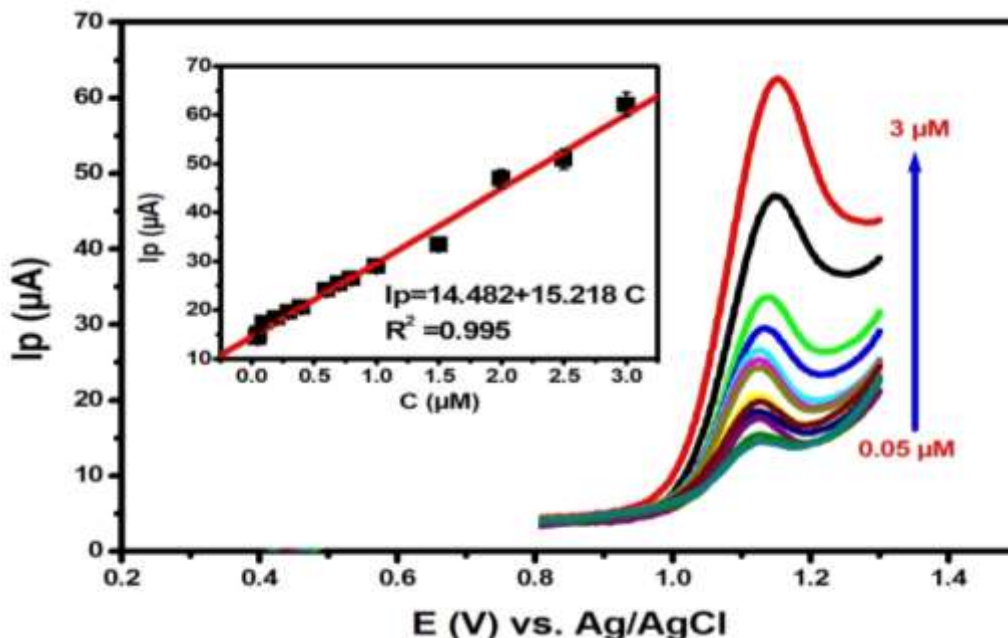
$$I_p (\mu\text{A}) = 14.482 + 15.218 C (\mu\text{M}) \quad (R^2 = 0.995, n = 13) \quad (6)$$

Based on the following relationships, the LOD and LOQ for PMUX/CPE were estimated to be 0.0057 and 0.0190  $\mu\text{M}$ , respectively:

$$\text{LOD} = 3 S/m \quad (7)$$

$$\text{LOQ} = 10 S/m \quad (8)$$

here, S is the standard deviation (SD) of three measurements of the oxidation peak current at the lowest CFLOX concentration in the dynamic linear range, and m refers to the calibration curve slope (Eq. 6). The low LOD indicates that PMUX/CPE was highly sensitive to CFLOX. Table 1 shows a comparison of the LOD values for determining CFLOX using different modified carbon paste electrodes.



**Fig. 10.** DP voltammograms for quantitative detection of different concentrations of CFLOX (0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 1.0, 1.5, 2 and 3  $\mu\text{M}$ ) in BR (pH=5.5) at PMUX/CPE surface (The inset shows the linear plot of the anodic peak current as a function of CFLOX concentration values).

**Table 1.** Comparison of the LOD values for the determination of CFLOX using different modified carbon paste electrodes.

Electrode	Technique	Linear dynamic range ( $\mu\text{M}$ )	Limit of detection (nM)	Reference
Clay/CPE	DPV	0.2 – 50	0.046	(Azriouil et al., 2022)
N-prGO <sup>a</sup> /CPE	DPV	0.1 – 10	0.039	(Rahimpour et al., 2021)
N-F <sup>b</sup> /CPE	DPV	1 – 18	1	(Hernández et al., 2021)
Sm <sub>2</sub> O <sub>3</sub> -9-3 <sup>c</sup> /GP	DPV	0.05 – 1– 170	0.005	(Biswas et al., 2020)
PEBSDSMCPE <sup>d</sup>	CV	2 - 45	0.183	(Pushpanjali et al., 2019)
SDSPXAMCNTGCPE <sup>e</sup>	CV	2 – 200	0.29	(Hareesha et al., 2020)
SDSPXAMCNTGCPE <sup>e</sup>	DPV	10 – 70	0.19	(Hareesha et al., 2020)
PMUX/CPE	DPV	0.05 – 3	0.0057	Present work

a = nitrogen doped porous reduce grapheme oxide, b = nafion and fullerene, c = Sm<sub>2</sub>O<sub>3</sub>- nanorod-modified graphite paste electrode, d = poly (Evans blue) sodium dodecylsulphate doubly modified carbon paste electrode, e = sodium dodecyl sulphate and polymerized xanthacridinum modified carbon nanotube and graphite composite paste electrode.

### 3.5.2. Repeatability and stability

Applying five successful runs ( $n = 5$ ) for 2.5  $\mu\text{M}$  CFLOX in the presence of BR buffer ( $\text{pH} = 5.5$ ) using DPV enabled us to assess the repeatability of PMUX/CPE. Because it was determined that the current values for the five anodic peaks did not change significantly, the RSD was only 2.31 %, demonstrating the proposed electrode's good repeatability. The proposed electrode's stability toward CFLOX was evaluated by simply polishing the bare CPE's surface before applying a polymerized film of murexide to it every day to determine 2.5  $\mu\text{M}$  CFLOX under optimal conditions. The oxidation peak current ( $I_{\text{pa}}$ ) decreased by only 7.8% after 21 days. This proved the high stability of the modified electrode.

### 3.5.3. Interferences

One of the main objectives of this study is to investigate how several species, including cations, anions, and organic compounds that are anticipated to be involved with the drug in commercial pharmaceuticals and serum samples, may affect the sensor's response to CFLOX. Under the optimal experimental circumstances, CFLOX was injected at a constant concentration of 10  $\mu\text{M}$  together with various concentrations of interference-causing agents. The results in Table 2 exhibit that the peak's shape remained sharp, and there was no discernible change in the current of the CFLOX's initial signal, which was reduced by 1.01-3.55 % with the addition of 0.003 M Na<sup>+</sup>, k<sup>+</sup>, Mg<sup>2+</sup>, Zn<sup>2+</sup>, Cl<sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and Fe<sup>3+</sup>, 0.0015 M urea, starch, and magnesium stearate and 0.001 M of L-cystine, alanine, Lactose and arginine in the presence of CFLOX at BR buffer ( $\text{pH} = 5.5$ ). This proves that PMUX/CPE had an acceptable selectivity toward CFLOX.

**Table 2.** Influence of some metal ions (A) and organic molecules (B and C) on the oxidation peak current of CFLOX (10  $\mu$ M).

Interfering agents (A) ( $\approx$ 300-fold)	$I_{pa}$ change %	Interfering agents (B) ( $\approx$ 150-fold)	$I_{pa}$ change %	Interfering agents (C) ( $\approx$ 100-fold)	$I_{pa}$ change %
Na <sup>+</sup>	-1.01	Urea	-3.04	L-cystine	-3.55
K <sup>+</sup>	-1.02	Starch	-2.20	Alanine	-3.25
Mg <sup>2+</sup>	-2.04	Magnesium stearate	-3.22	Lactose	-2.70
Zn <sup>2+</sup>	-2.10			Arginine	-2.09
Cl <sup>-</sup>	-1.02				
PO <sub>4</sub> <sup>3-</sup>	-1.05				
Fe <sup>3+</sup>	-2.43				

### 3.5.4. Analytical applications

The modified sensor's practical applicability was validated by detecting CFLOX in real samples such as pharmaceutical tablets and human serum samples using the standard addition method. Following the preparation of the real samples, as explained in Section 2.4, we spiked a quantity of CFLOX into the electrochemical cell and then used DPV to record the current value of the oxidation peaks. As indicated in Table 3, recovery values for CFLOX in both the human serum and the tablet samples ranged from 93.25 to 104 %, demonstrating the method's high efficiency.

**Table 3.** Analysis of CFLOX in commercial drugs in addition to serum samples.

Sample	CFLOX added ( $\mu$ M)	CFLOX founded ( $\mu$ M)	Recovery %
Cipromax™ (750 mg)	5.00	4.92	98.40
	10.00	9.48	94.80
	20.00	20.21	101.05
Human serum	5.00	4.84	96.80
	10.00	10.40	104
	20.00	18.52	93.25

## 4. Conclusion

This report outlines the efficacy of modifying CPE with PMUX in detecting trace amounts of CFLOX with a low LOD (0.0057  $\mu$ M) by employing DPV. PMUX/CPE electrocatalytic performance was superior to BCPE in terms of electron transfer. According to CV and analytical studies, the electrochemical response was diffusion-controlled and irreversible. Even with external interferences, the suggested sensor was able to detect CFLOX, a testament to the electrode's accuracy. It was also able to precisely measure the drug in human serum and commercial tablets. As a result, the electrode is an excellent choice for CFLOX detection.

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