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Full Paper

Biosurfactant-Facilitated Electrochemical Biosensor for Dopamine, Uric Acid, and Ascorbic Acid Detection: A Voltammetric Study

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Abstract- This study discusses an electrochemical biosensor developed for detecting dopamine (DA), utilizing a biosurfactant as its transducer element. Biosurfactants are amphiphilic molecules derived from microorganisms such as fungi, bacteria, and yeast, playing a crucial role in this biosensor. Their hydrophilic and hydrophobic moieties enhance analyte sensitivity, making them ideal for this application. In this work, we precisely fabricated a novel electrochemical biosensor for DA detection by modifying a carbon paste electrode with a biosurfactant (BSB/poly AB25/CPE). We examined the electrochemical behavior of DA across potentials ranging from 0.0 V to 0.8 V, anticipating a possible electrochemical redox mechanism. Additionally, the influence of electrolyte pH on redox behavior was investigated, with pH 7.0 identified as the optimal pH. Key kinetic parameters were determined through scan rate experiments, specifically a charge transfer coefficient of 0.386 and a heterogeneous rate constant of 4.92×10^{-5} s^{-1}. The biosensor also demonstrated favorable analytical parameters, including a limit of detection (LOD) of 3.2×10^{-7} M and a limit of quantification (LOQ) of 1.06×10^{-6} M. The biosensor exhibited excellent repeatability, reproducibility, and stability, confirming its practical utility. Finally, the developed biosensor was successfully applied to quantify DA concentration in pharmaceutical formulations, validating its potential for real-world applications.

Keywords- Biosurfactant; Dopamine; Heterogeneous rate constant; Acid blue 25; Adsorption-controlled process; Formulation studies

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1. INTRODUCTION

Electroanalytical methods have gained substantial traction as a promising approach for qualitative and quantitative analysis in recent decades [1]. Among various analytical techniques, voltammetry has become essential across almost all scientific fields due to its low cost, straightforward instrumentation, simple sample preparation, and portability. Voltammetric techniques rely on a three-electrode configuration, where the working electrode is crucial for conducting qualitative and quantitative determinations [2-5]. Traditional working electrode materials, including carbon paste, glassy carbon, platinum, and gold, often struggle to provide sensitive measurements because they are susceptible to surface fouling and lack strong selectivity. To address the inherent sensitivity limitations of conventional electrodes, researchers frequently enhance their surfaces with functional materials designed for improved analyte interaction. Currently, many types of materials are used as modifiers; among them, conducting polymers that incorporate various dyes [6] and amino acids [7], biomaterials like catalytic and inhibitory enzymes, proteins, peptides, and nucleic acids [8,9], as well as catalytic materials, nanomaterials, and ionic liquids [10,11], represent a critical class of modifiers for electrode surface modification.

However, simple, straightforward, and cost-effective materials are essential for developing electrochemical sensors and biosensors to achieve lower detection and quantification limits. Therefore, a significant focus remains on new materials and methods for modification [12]. Our current investigation reports on the use of biosurfactants as transducers for fabricating electrochemical biosensors. Biosurfactants are naturally occurring surface-active molecules produced by microorganisms and play a significant role in various fields, such as pharmaceuticals, agriculture, and environmental management [13]. Recently, surface-active biomolecules, particularly biosurfactants, have attracted considerable attention due to their unique properties, including high specificity, low toxicity, and ease of synthesis. Due to their amphipathic nature, which includes both hydrophilic and hydrophobic components, they effectively reduce surface and interfacial tensions by accumulating at phase boundaries. These molecules find wide applications in petrochemicals, mining, agriculture, food, cosmetics, and pharmaceuticals. Typically, biosurfactants are anionic or neutral; their hydrophilic portions consist of carbohydrates, amino acids, or phosphate groups, while the hydrophobic part is usually made of long-chain fatty acids. Their ability to lower interfacial tension in water-based and hydrocarbon systems makes them highly versatile. Given these advantageous properties, this study focuses on using biosurfactants to design and develop an electrochemical biosensor.

Following its discovery in 1959, dopamine (DA) has become widely recognized for its crucial role in modulating essential functions of the central nervous system [14-16]. The primary function of DA in the human brain is to transmit signals between neurons [17]. It also significantly impacts movement, memory, behavior, and learning [18,19]. However, dysregulated dopamine (DA) release has been linked to various neurological and psychological disorders, including sleep disturbances, mood instability, depressive symptoms, cognitive decline, and impaired concentration [20,21]. Impaired dopamine levels are closely associated with neurodegenerative and psychiatric disorders like Parkinson's disease, schizophrenia, and depression, as well as addiction. Therefore, detecting and quantifying dopamine in physiological fluids is crucial for clinical and research applications [22,23]. Several techniques have been developed to measure dopamine levels; however, an ongoing challenge is that uric acid and ascorbic acid have similar oxidation properties, making it difficult to differentiate them electrochemically [24]. Thus, developing methods capable of simultaneously determining DA in the presence of UA and AA is essential. Uric acid, a metabolic byproduct of purine nucleotides, can accumulate to harmful levels, leading to gout and renal dysfunction. Ascorbic acid (AA), a vital antioxidant, plays a significant role in metabolic and neurological functions and is also used to treat conditions such as the common cold, psychiatric disorders, and cancer. Given their physiological importance and frequent coexistence with DA, both UA and AA must be considered during DA analysis [25,26].

In this study, we present an electrochemical biosensor developed by modifying a carbon paste electrode with a biosurfactant and utilizing poly acid blue 25 as a mediator for the sensitive and simultaneous detection of dopamine in the presence of uric acid and ascorbic acid. We investigated the electrochemical behavior of dopamine, including the effects of supporting electrolyte pH and scan rate on the sensor's performance. Additionally, we calculated the surface coverage concentration of dopamine, the charge transfer coefficient, and the heterogeneous electron transfer rate constant. The sensor's practical applicability was demonstrated by analyzing dopamine in pharmaceutical formulations.

2. EXPERIMENTAL SECTION

2.1. Materials

All chemicals and reagents were obtained from commercial suppliers and used without further purification. Dopamine (DA) and Acid Blue 25 (AB25) were sourced from Sigma-Aldrich. Uric acid (UA), ascorbic acid (AA), potassium ferrocyanide ($K_4[Fe(CN)_6]$), and disodium hydrogen phosphate (Na_2HPO_4) were supplied by Merck Specialties Pvt. Ltd., Mumbai. Potassium ferricyanide ($K_3[Fe(CN)_6]$) and sodium dihydrogen phosphate (NaH_2PO_4) were obtained from Fisher Scientific India Pvt. Ltd. The biosurfactant-b, isolated from Bacillus licheniformis, was generously provided by the Applied Microbiology Laboratory, Department of Virology, Sri Venkateswara University, Tirupati, India, and its characteristics have been previously described by A. P. Kumar et al. [27].

2.2. Methods

Electrochemical analyses, including cyclic voltammetry (CV), chronoamperometry (CA), differential pulse voltammetry (DPV), and electrochemical impedance spectroscopy (EIS), were carried out using a CHI 660D electrochemical workstation (CH Instruments, USA). A standard three-electrode configuration was employed, consisting of a saturated calomel electrode (CHI150) as the reference, a glassy carbon rod as the counter electrode, and the BSB/polyAB25/CPE as the working electrode. Phosphate buffer solutions were prepared and adjusted to the desired pH using an ELICO pH meter with a standard glass electrode. All measurements were taken in the Department of Chemistry at Sri Venkateswara University, Tirupati, Andhra Pradesh, India.

2.3. Preparation of homemade CPE

To create the carbon paste electrode, 85% graphite powder and 15% silicone oil were manually ground in an agate mortar for approximately 40 to 45 minutes, resulting in a uniform paste. This paste was then filled into a Teflon tube with a 2 mm diameter, and a copper wire was added to guarantee electrical contact. Finally, the exposed surface was delicately polished on soft filter paper to obtain a smooth finish.

2.4. Biosensor fabrication

The fabricated CPE was polished on the surface of smooth filter paper to achieve a mirror-like sheen, and the resulting electrode was deemed bare CPE. Subsequently, the surface of the CPE was modified through the polymerization of acid blue 25 using the CV technique within the potential window of –0.4 V to 1.4 V, and the resulting electrode is now referred to as polyAB25/CPE. Finally, the polyAB25/CPE was modified with 5 µL of biosurfactant on the electrode surface through physical adsorption. The resulting electrode, henceforth referred to as BSB/polyAB25/CPE, was used as a working electrode.

3. RESULTS AND DISCUSSION

3.1. Electrochemical polymerization of Acid Blue 25

Generally, the biomolecules adsorbed onto the electrode surface are unstable; therefore, a conducting mediator is necessary to bridge the solid electrode surface and the biomolecule. In this investigation, we attempted to polymerize AB25 onto the CPE surface as a conducting mediator. Electrochemical polymerization of 0.1 mM AB25 in PBS (pH 7.0) was conducted by cycling the potential between –0.4 V and 1.4 V at a scan rate of 100 mV/s for 10 cycles. As seen in Figure 1, the increase in current response with each successive cycle indicates the successful deposition of a polymer film on the CPE surface, acting as a conductive medium to enhance electron transfer.

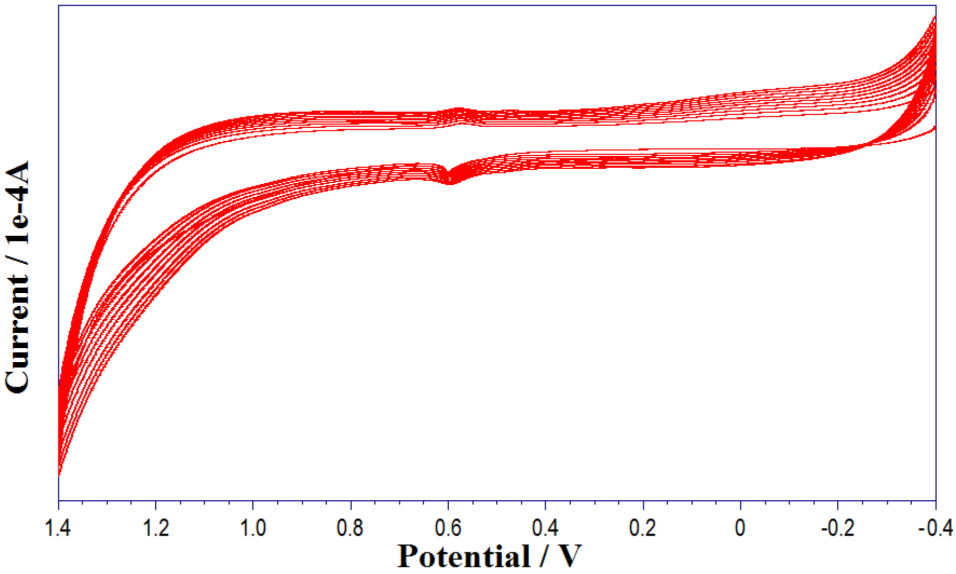

Figure 1. CV of 0.1 mM AB25 in PBS having pH 7.0 with 10 continuous cycles between the potentials of – 0.4 V to 1.4 V with the scan rate of 0.1 V/s

3.2. Electrochemical behavior of DA

The electrochemical behavior of 1 mM dopamine (DA) in phosphate-buffered saline (PBS, pH 7.0) was investigated using cyclic voltammetry (CV). Figure 2 shows the oxidation peak of DA at the bare CPE with a peak current of -1.129×10^{-5} A and a peak potential of 0.19 V in the forward scan, along with a reduction peak having a peak current of 1.065×10^{-5} A and a peak potential of 0.13 V. This resulted in a peak to peak current ratio of 1.06 and a peak separation of 60 mV, indicating good reversibility of DA at the bare CPE. The oxidation peak at potential (ΔE_p) of 0.19 V is due to the conversion of the catechol functional group into the corresponding ortho-quinone group. The reduction peak at potential 0.13 V in the reverse scan, i.e., from 0.8 V to 0.0 V, is due to converting the formed ortho-quinone group back into the catechol group. Following the polymerization of AB 25 on the bare CPE, the electrode exhibited anodic and cathodic peak currents of -3.599×10^{-5} A and 3.764×10^{-5} A, respectively, corresponding to peak potentials of 0.192 V and 0.134 V. The current ratio remained close to unity (0.96), and the peak separation (ΔE_p) was 58 mV, suggesting quasi-reversible electron transfer behavior. The enhancement in current response is attributed to the improved conductivity provided by the polyAB25 film coated on the CPE surface. Additionally, the modification of polyAB25/CPE with the biosurfactant-b molecule has further increased the current response of DA to -7.772×10^{-5} A and 8.351×10^{-5} A, with peak potentials of 0.212 V and 0.131 V for anodic and cathodic peaks, respectively. The increase in current response with the modification of polyAB25/CPE using biosurfactant-b is due to the presence of lyophilic and lyophobic moieties in the biosurfactant-b. We also studied the current response of DA at the bare CPE modified with biosurfactant-b, which showed a current response of 5.232×10^{-5}

A and 4.449×10^{-5} A, with peak potentials of 0.198 V and 0.134 V for anodic and cathodic peaks, respectively. The voltammetric profile in the figure reveals that the BSB/polyAB25/CPE displayed the highest current response, underscoring the role of polyAB25 in facilitating enhanced charge transfer due to its conductive polymeric matrix. Moreover, the film appears to provide a suitable scaffold for the stable immobilization of biosurfactant-B. For reference, the electrochemical behavior at the unmodified CPE showed a peak current ratio of 1.06 and a ΔE_P of 60 mV, indicative of relatively limited electron transfer kinetics. Modifying the bare CPE with AB 25 changes the peak current ratio to 0.956, with a peak separation of 58 mV. Furthermore, at BSB/polyAB25/CPE, the peak current ratio was 0.931 with a peak separation of ΔE_P 81 mV, suggesting that at the developed sensor, the electrochemical behavior of DA exhibits good reversibility [28-31].

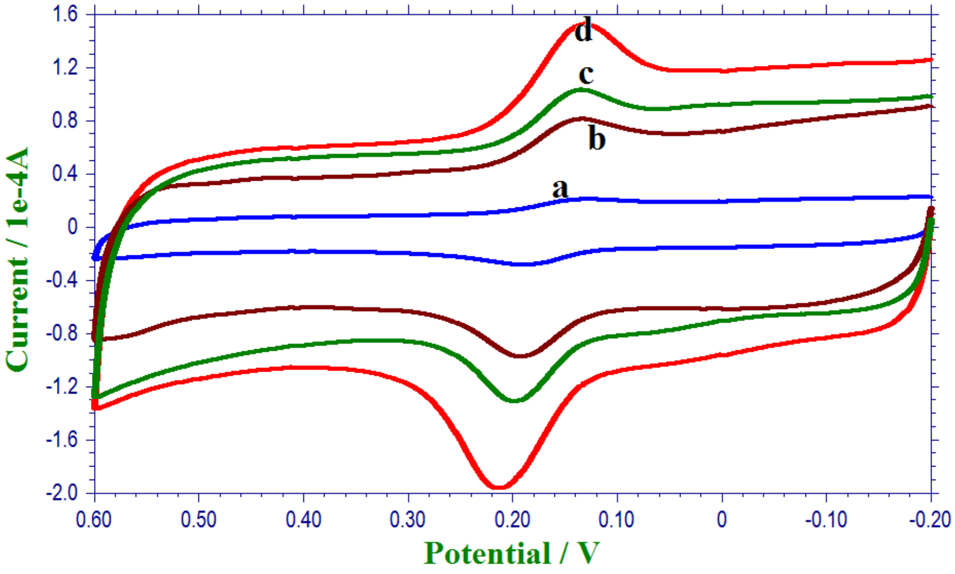

Figure 2. CVs of 1 mM DA in PBS having pH 7.0 at bare CPE (a), polyAB25/CPE (b), BSB/CPE (c), BSB/polyAB25/CPE (d) with the scan rate of 0.1 V

3.3. Chronoamperometry of DA

Chronoamperometry is one of the most critical and sensitive techniques, providing current information about an analyte at a specific potential. Initially, we studied the chronoamperometry of DA at bare CPE. From Figure 3, we can observe a peak with slope values of -2.936 ×10^{-5} and 3.496×10^{-5} for anodic and cathodic peaks, respectively. After polymerizing the bare CPE with acid blue 25, the peak slopes increased to -8.399×10^{-5} and 8.882×10^{-5}. The slope increase occurred because the polymerized AB 25 is an excellent conductor for the electron transfer rate, enhancing the current response. Additionally, after modifying polyAB25/CPE with biosurfactant-b, we observed a significant enhancement in the current response, with slope values of -9.923×10^{-5} and 10.304×10^{-5}, suggesting that the lyophilic and lyophobic moieties of the biosurfactants attract DA and the biosurfactant, resulting in increased current and slope values. We also observed the current response at (BSB/CPE) with slope values of -8.81×10^{-5} and 7.269×10^{-5}. Among all the selections, the maximum current response was noted at BSB/polyAB25/CPE, which showed greater slope values. This indicates that the polymerization of CPE with AB25 increases conductivity, and further sensitivity was enhanced by modifying AB25/CPE with biosurfactant-b [32].

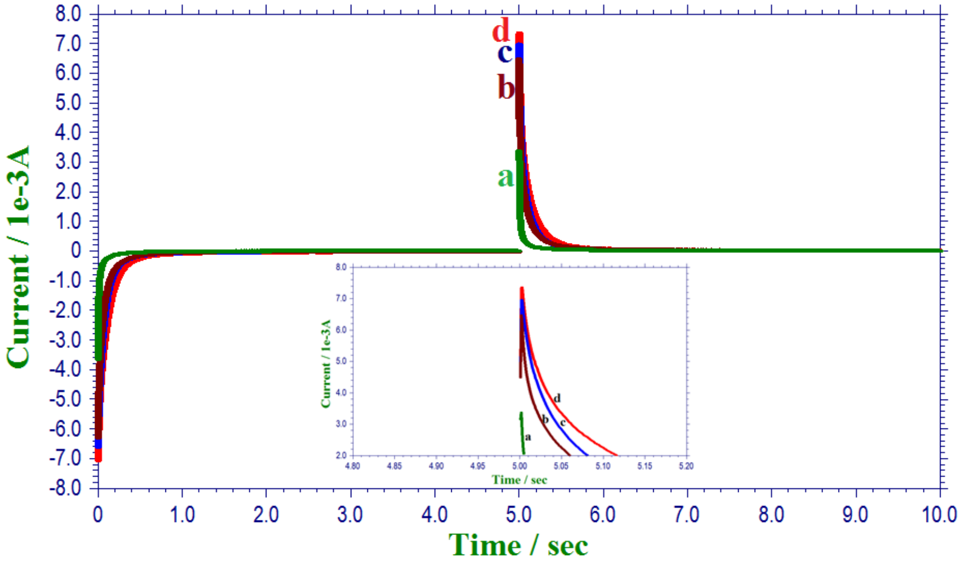

Figure 3. Chronoamperometry of 1 mM DA in PBS having pH 7.0 at bare CPE (a), polyAB25/CPE (b), BSB/CPE (c), BSB/polyAB25/CPE (d)

3.4. Effect of pH

The redox activity of analytes strongly depends on electron and proton transfer processes. Since biological environments typically exhibit a slightly basic pH, it is essential to assess how variations in pH of the supporting electrolyte affect the electrochemical behavior of dopamine. We have investigated the impact of PBS ranging from pH 5.0 to pH 9.0 on the redox behavior of DA using the DPV technique. As shown in Figure 4, an increase in the pH of the supporting electrolyte resulted in a shift of the peak potentials toward less positive values, indicating the involvement of protons in the redox process of dopamine (DA). A linear relationship was established between the peak potentials of DA and the pH, yielding the regression equation: $E_p(V)= 0.782–0.081\times pH$. The slope of –0.081 V/pH closely aligns with the theoretical Nernstian value of 0.059 V/pH, implying a redox process involving an equal number of protons and electrons. Additionally, peak currents increased with pH up to 7.0, after which a decline was observed in more basic conditions. This decrease in current response at higher pH levels suggests reduced electron transfer efficiency beyond physiological pH. Therefore, pH 7.0 was selected as the optimum condition for subsequent electrochemical investigations.

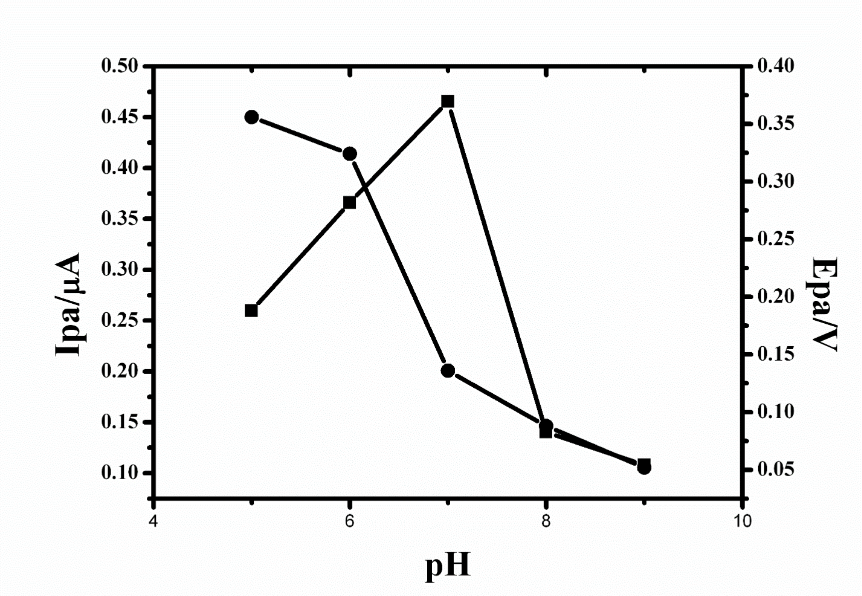

Figure 4. The plot between pH and potential and peak currents is drawn

3.5. Effect of scan rate

To investigate the kinetic parameters governing dopamine (DA) oxidation at the modified sensor, the effect of scan rate on the electrochemical response of 1 mM DA was evaluated using cyclic voltammetry over a potential range of 0.0 to 0.8 V in phosphate buffer solution (PBS, pH 7.0), with scan rates varying from 10 to 300 mV/s. As shown in Figure 5a, both anodic and cathodic peak currents increased proportionally with the scan rate, indicating enhanced electron transfer kinetics. A log–log plot of peak current (i_{pa} and i_{pc}) versus scan rate (ν) displayed strong linear correlations (Figure 5b), yielding the equations, $\log i_{pa} = 1.598 + 0.926 \log \nu$ ($R^2 = 0.9994$) and $\log i_{pc} = 1.926 + 1.201 \log \nu$ ($R^2 = 0.9993$). The obtained slope values of 0.926 (anodic) and 1.201 (cathodic) are close to unity, suggesting that an adsorption-controlled process predominantly governs the electrochemical behavior of DA. Further analysis of peak current versus scan rate revealed linear relationships expressed as $i_{pa} = -0.252 +(-0.0441)\nu$ and $i_{pc}= -0.549+0.0589\nu$. Using these relationships and equation (1), DA's surface coverage concentration (Γ) at the BSB/polyAB25/CPE interface was calculated to be 5.64×10^{-9} mol cm^{-2}, indicating efficient immobilization and interaction at the modified electrode surface. A shift in peak potentials toward more positive (anodic) and negative (cathodic) values with increasing scan rate was observed, reflecting kinetic limitations in charge transfer. From the plot of peak potential versus scan rate (Figure 5c), and by applying equation (2), the charge transfer coefficient (α) and heterogeneous electron transfer rate constant (k^0) were determined to be 0.386 and 4.92×10^{-5} s^{-1}, respectively [33,34].

$$i_p = n^2F^2\upsilon A\Gamma/4RT \quad (1)$$

$$\log k_s = \alpha \log (1 - \alpha) + (1 - \alpha) \log \alpha - \log (RT/nF\upsilon) - (1 - \alpha)\, \alpha F\Delta E_p/2.3RT \quad (2)$$

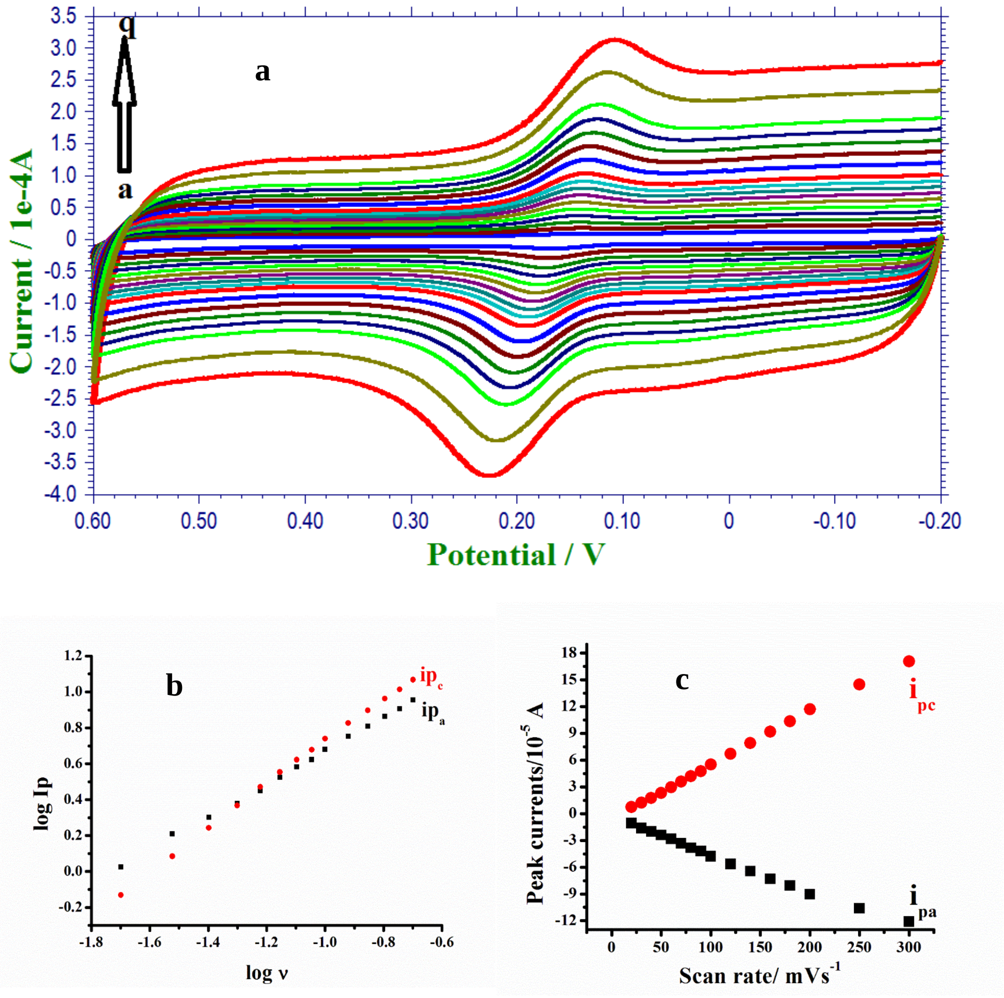

Figure 5. a: CVs of 1 mM DA in PBS having pH – 7.0 with the scan rates of 10 mV (a), 20 mV (b), 30 mV (c), 40 mV (d), 50 mV (e), 60 mV (f), 70 mV (g), 80 mV (h), 90 mV (i), 100 mV (j), 120 mV (k), 140 mV (l), 160 mV (m), 180 mV (n), 200 mV (o), 250 mV (p), 300 mV (q); b: Plot located between the logarithm of peak currents and the logarithm of scan rate; c: plot of scan rate and corresponding peak current response of DA

3.6. Effect of concentration

To evaluate the sensitivity of the developed electrochemical sensor, the limit of detection (LOD) and limit of quantification (LOQ) for dopamine (DA) were determined using differential pulse voltammetry (DPV). DPV measurements were performed at different concentrations of DA (Figure 6a), which showed a progressive increase in the anodic peak current with rising analyte concentration. As illustrated in Figure 6b (plot A), a strong linear correlation was obtained between DA concentration and peak current, described by the regression equation $i_{pa}(\mu A) = -1.0919 + 0.8475 \times [DA]\ (\mu M)$, with a correlation coefficient of $R^2 = 0.996$, indicating excellent linearity. Based on the slope (m) and standard deviation (S) of the blank signal and using standard analytical expressions (Equations 3 and 4), the LOD and LOQ were calculated at 3.2×10^{-7} M and 1.06×10^{-6} M, respectively. These values reflect the sensor's high sensitivity and its suitability for trace-level detection of dopamine. Furthermore, to investigate the reaction kinetics, a plot of the logarithm of peak current (log i_{pa}) versus the logarithm of DA concentration (log [DA]) was constructed (Figure 6b, plot B). The resulting linear equation log $i_{pa} = -0.2949+1.1411\times\log$ [DA], with $R^2 = 0.993$, yielded a slope of 1.141, close to unity, suggesting that the electrochemical oxidation of dopamine at the modified electrode follows a first-order kinetic process for dopamine concentration [35-40].

$$\text{LOD} = 3S/m \tag{3}$$

$$\text{LOQ} = 10S/m \tag{4}$$

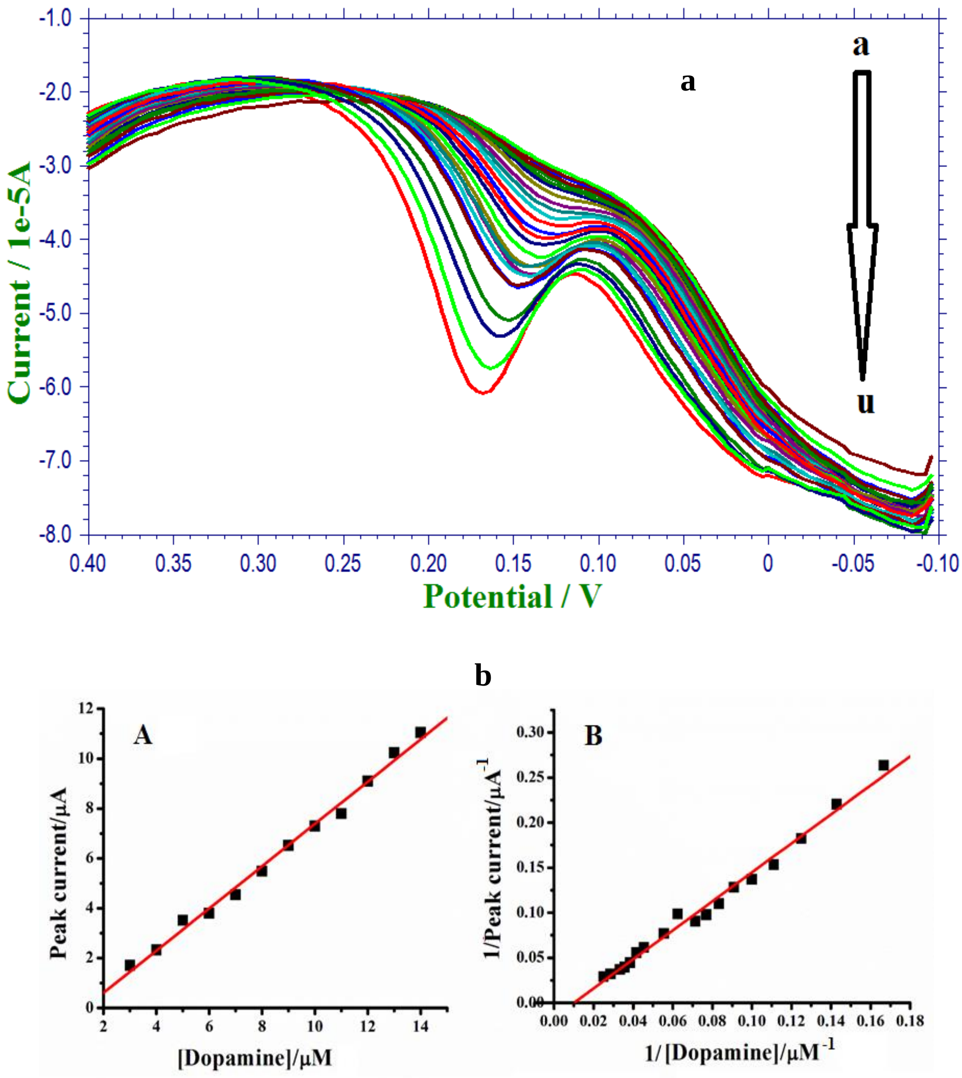

Figure 6. DPVs of DA with different concentrations at the BSB/polyAB25/CPE; b: A' is the plot originating between different concentrations of DA versus peak current response, and 'B' represents the plot drawn between the reciprocal of concentration and the reciprocal of peak currents

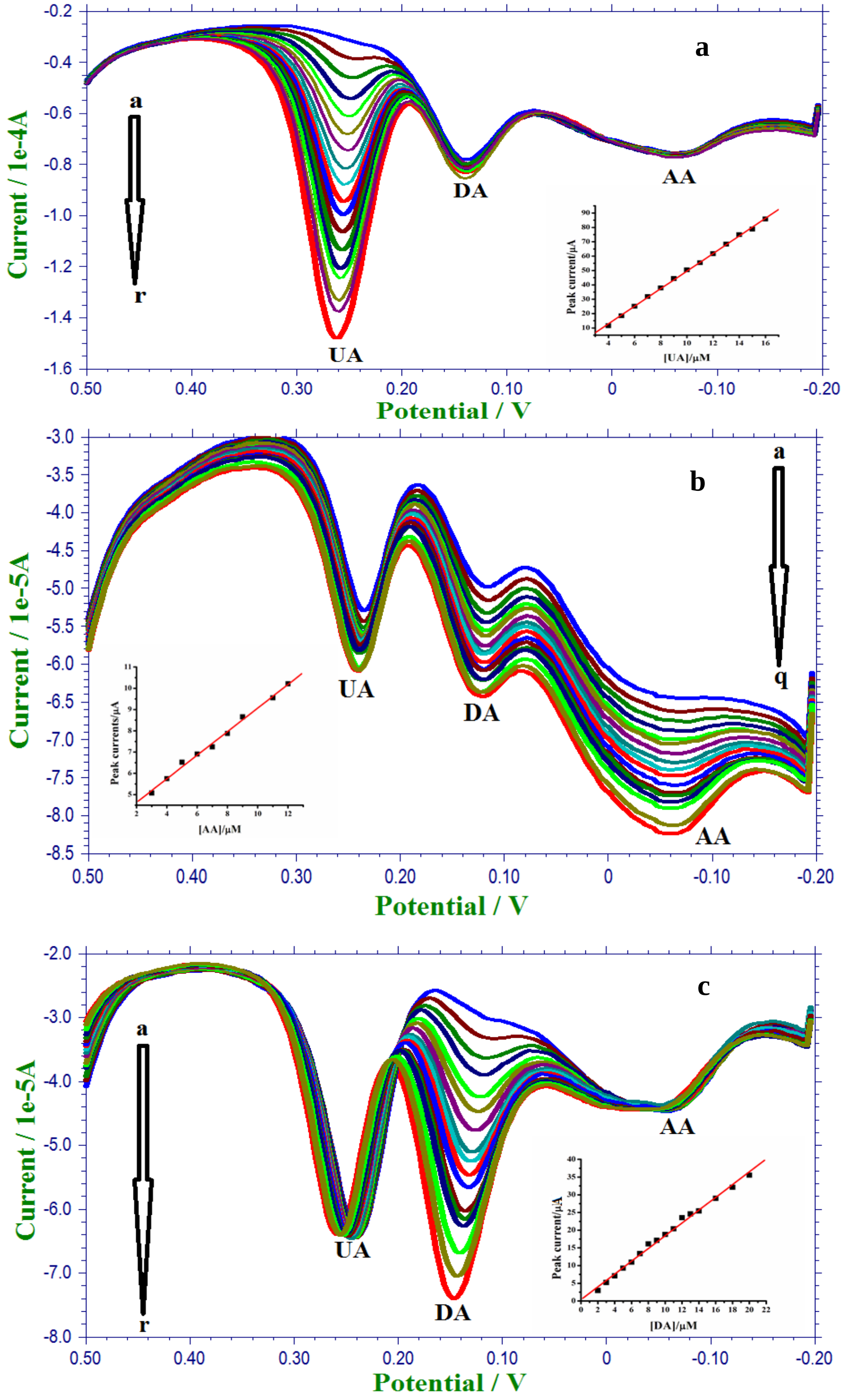

Figure 7. DPVs representing the monitoring of UA in the presence of AA and DA, and the insert is a plot between the concentration of UA and the corresponding current response; b: DPVs representing the monitoring of AA in the presence of UA and DA, and the insert is a plot between the concentration of AA and the corresponding peak current response; c: DPVs representing the monitoring of DA in the presence of AA and UA, and the insert is a plot between the concentration of DA and the corresponding current response

3.7. Simultaneous determination of DA in the presence of UA and AA

Uric acid (UA) and ascorbic acid (AA) are physiologically significant biomolecules typically found in higher concentrations in human biological fluids such as blood and serum. However, their oxidation potentials closely overlap with that of dopamine (DA), making the selective detection of DA challenging due to potential electrochemical interference. Therefore, the simultaneous and selective determination of DA in the presence of UA and AA is analytically important. To evaluate the selectivity of the developed sensor, the electrochemical responses of DA were assessed in the presence of varying concentrations of UA and AA. As illustrated in Figure 7a, the oxidation peak potential of DA remained unaffected despite the increasing UA concentration, indicating minimal interference from UA. From the inset of Figure 7a, the calculated limit of detection (LOD) and limit of quantification (LOQ) for UA in the presence of DA and AA were found to be 0.406×10^{-6} M and 1.357×10^{-6} M, respectively.

Likewise, the effect of ascorbic acid (AA) concentration on dopamine (DA) oxidation was investigated, as shown in Figure 7b. Despite an increase in AA concentration, no significant shift in the oxidation peak potential of DA was observed. However, minor variations in peak current were noted, likely due to AA's intrinsic electrochemical activity. The inset of Figure 7b illustrates a linear relationship between AA concentration and peak current, represented by the regression equation ipa (μA) = 3.5275+0.5545×[AA] (μM). The corresponding detection limits (LOD) and quantification (LOQ) were determined to be 0.721×10^{-6} M and 2.400×10^{-6} M, respectively. Furthermore, to ensure the reliability of DA detection in the simultaneous presence of uric acid (UA) and AA, the influence of DA concentration on its peak potential was also examined (Figure 7c). A linear increase in anodic peak current with increasing DA concentration was observed, characterized by the regression equation ipa (μA) = 0.39175 + 1.8056×[DA] (μM), with associated LOD and LOQ values calculated as 0.428×10^{-6} M and 1.427×10^{-6} M, respectively. These results demonstrate the high selectivity and sensitivity of the developed electrochemical sensor for dopamine, even in the presence of common interfering species such as uric acid and ascorbic acid, highlighting its potential applicability for clinical and biological sample analysis [41-43].

3.8. Analytical applications

The developed BSB/ployAB25/GCE sensor was used to quantify DA levels in pharmaceutical formulations available in medical stores. Initially, the biosensor measured the current response in a 20 μL injection sample, with a corresponding concentration of the DA standard sample prepared as specified on the DA injection label. A small aliquot of the standard DA was added, and the corresponding current response was recorded. Using the standard addition method, the concentration of DA in the injection samples was monitored, and the same process was repeated for measuring 40, 60, and 80 μL of DA injection samples. The results indicate that the developed electrochemical sensor can successfully quantify DA with low RSD values [44,45].

Table 1. Recovery of DA in pharmaceutical formulations at a buffer pH 7.0

Medium	Added	Found	Recovery	Bias
Buffer pH 7.0	20	19.6	98	-2
	40	41.2	103	+ 3
	60	60.9	101.5	+ 1.5
	80	81.6	102	+2

3.9. Repeatability, reproducibility, and stability

The developed method's repeatability, reproducibility, and stability significantly influenced its practical utility. Therefore, we examined the developed sensor's repeatable, reproducible, and stable nature for 1 mM DA in PBS at pH 7.0. Initially, we observed the CV response of 1 mM DA in PBS, serving as an electrolyte with pH 7.0. From Figure 8, the CV curves of all successive measurements exhibited nearly the same current response, indicating the excellent repeatability of the developed electrochemical sensor.

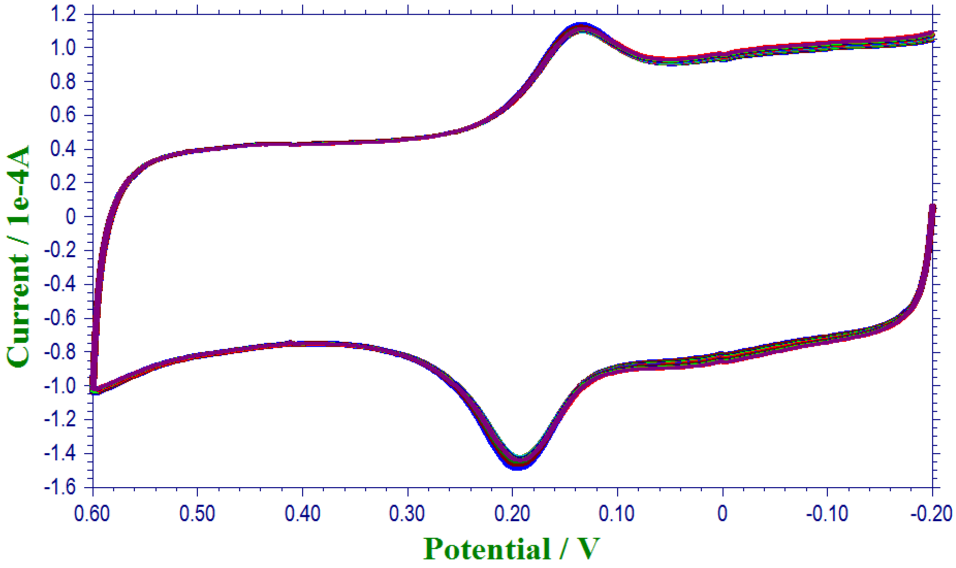

Figure 8. CVs representing the 1 mM DA with the different scans having a scan rate of 0.1 V/s at BSB/polyAB25/CPE

Furthermore, the developed sensor was examined for its reproducibility. For this study, we fabricated different BSB/polyAB25/CPE sensors by following the procedure outlined in the experimental section, and the corresponding CV responses were recorded. The CV results reveal that the current response at the different fabricated sensors exhibited similar responses, suggesting a fully reproducible nature of the developed method. Finally, the stability of the developed BSB/polyAB25/CPE was investigated; for this purpose, the CV technique was employed to recover the current response at various intervals for 1 mM DA in PBS with a pH of 7.0. The peak current of DA showed a nearly identical response, indicating the strong stability of the developed electrochemical sensor. In summary, the developed sensor demonstrated good repeatability, reproducibility, and stability with low RSD values of 2.67, 3.711, and 5.229%, respectively [46].

4. CONCLUSION

In this study, we aimed to use a biosurfactant as a transducer element for fabricating an electrochemical biosensor. The sensor was created by polymerizing a carbon paste electrode with acid blue 25, followed by the immobilization of biosurfactant-b. This investigation primarily focused on monitoring dopamine (DA) in the presence of uric acid and ascorbic acid and resolving them simultaneously. We also examined the effect of supporting electrolyte pH on the electrochemical redox behavior of DA. Additionally, we analyzed the impact of scan rate on the evolution of the charge transfer coefficient and the heterogeneous rate constant. The analytical parameters, including the limit of detection and quantification, were established, and the practical utility of the developed sensor was assessed by evaluating its repeatability, reproducibility, and stability. Ultimately, the BSB/polyAB25/CPE biosensor was successfully used to estimate DA concentration in pharmaceutical formulations quantitatively.

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Declarations of interest

The authors declare no conflict of interest in this reported work.

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