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Cyclic Voltammetry Study of the Influence of Concentration of $K_3[Fe(CN)_6]$ and Glucose on Glassy Carbon Electrode

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ABSTRACT. Biosensors are cost-effective, user-friendly devices with rapid response, sensitivity, selectivity, and stability. This study investigated the impact of $K_3[Fe(CN)_6]$ concentration and glucose on glassy carbon electrode (GCE) performance. The cyclic voltammetry method determined the effects of varying $K_3[Fe(CN)_6]$ and glucose concentrations on GCE. GCE characterization utilized $K_3[Fe(CN)_6]$ solutions (1 – 5 mM) in 0.2 M KCl and achieved an optimum scan rate of 75 mV/s within -1.5 to 1 V vs. Ag/AgCl. Reversible Fe^{2+}/Fe^{3+} redox occurred at 1mM (i_{pa}/i_{pc}= 0.99), with the highest reduction peak at 5mM. Glucose tests (1mM to 5mM) in 0.1 M NaOH exhibited an optimal scan rate of 200 mV/s within a potential range of -10 – 10 V at 1 mM (i_{pa}/i_{pc}= 1.01), with the highest oxidation peak at 5 mM. GCE effectively measured concentration effects, with i_{pa}/i_{pc} values close to 1, indicating reversible redox processes at low concentrations. Higher concentrations yielded stronger peak currents due to increased electroactive species.

INTRODUCTION

A biosensor is a chemical sensing device that converts signals generated by biochemical reactions. The advantages of biosensors include affordability, ease of use, speed in measurement, high sensitivity, selectivity, and high stability (Dorledo de Faria *et al*., 2019). The main components of biosensors are bioreceptors and transducers. The bioreceptor is a biomolecule that specifically recognizes the target analyte, while the transducer converts the binding event into a measurable signal (Jaiswal and Tiwari, 2017).

Electrochemical sensors in glucose biosensors show great potential because they have outstanding characteristics, including ease of use, simplicity, sensitivity, selectivity, and time-saving capabilities. These sensors also play an important role in the redox process of atomic non-enzymatic sensors capable of direct surface detection (Zhang *et al.*, 2019). The chemical processes in sugars involve oxidation, reduction, and glycosylation, which are essential for synthesizing sugar nucleotides and other organic compounds (Mikkola, 2020).

Although non-enzymatic glucose sensors offer better long-term stability than enzymatic glucose biosensors, they have a lower level of selectivity due to challenges in the ability of electrocatalytic materials to catalyze glucose oxidation specifically (Hassan *et al*., 2021). Using non-enzymatic analysis methods overcomes the limitations of enzymatic methods, which require several conditions for the enzyme to function. Fourth-generation non-enzymatic glucose biosensors can facilitate glucose oxidation without the need for enzymes by utilizing the electrocatalytic activity of various materials such as metals, metal oxides, alloys, complexes, and carbon (Taha *et al.*, 2020).

In electrochemical biosensors, electrodes play an essential role in signal transmission. Carbon electrodes are often chosen because of their wide potential range, inert, low background current, and affordable price (Gaffar *et al*., 2022). Although Au, Ag, and Pt electrodes are used in some electrochemical sensor experiments, they are relatively expensive (Mahajan *et al*., 2018). Glassy Carbon Electrode (GCE) has outstanding characteristics that

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are suitable for electrochemical applications. It has high electrical conductivity, wide potential range, high hardness, chemical stability, inert properties, and affordability. Additionally, it has high purity, dense pore volume, and a large surface area (Abdel-Aziz *et al*., 2022; EL-Deeb *et al*., 2018).

Cyclic voltammetry is an electrochemical method to study redox characteristics. This method applies a voltage to the electrodes, and the resulting current is measured (Venton and Cao, 2020). A voltammogram is a graph that shows the relationship between the measured current and the potential generated during cyclic voltammetry, which starts from the initial potential and returns to the initial potential (Wahyuni *et al*., 2018). This method is often used to study the reversible electron transfer capability in the redox reactions monitored through cyclic voltammograms, depicting the current and potential (Herbei *et al*., 2023). Cyclic voltammetry can be used to measure parameters such as half-wave potential, electron transfer coefficient, and concentration of redox species in solution, as well as to provide information on redox reaction kinetics, electrochemical properties of compounds, and identification of redox species in solution (Wang *et al*., 2021).

Understanding the effect of $K_3[Fe(CN)_6]$ and glucose concentrations on GCE is crucial for developing biosensors. This is because the $K_3[Fe(CN)_6]$ standard solution is commonly used in electrochemical studies due to its accessibility, low cost, stability in electron transfer, good diffusion capabilities, and its ability to be used at various concentrations (Koç *et al*., 2021). Therefore, understanding the effect of concentration variation can contribute to ensuring the optimal performance of GCE in real-world applications. Additionally, glucose is a highly important analyte for biomedical and industrial applications, especially for non-enzymatic glucose sensors. Understanding how glucose concentration affects electrode performance facilitates improved sensor calibration, leading to more sensitive and accurate glucose detection. This is essential for developing reliable glucose biosensors, which are widely used in healthcare for monitoring blood glucose levels in diabetic patients (Mousavi *et al*., 2021).

Most of the working electrodes used were modified, as conducted by Abdel-Aziz *et al*. (2022) and Chen *et al*. (2023). Using a commercial GCE, this study investigated how variations in the concentrations of $K_3[Fe(CN)_6]$ and glucose affect the performance of GCE using cyclic voltammetry. This study focused on how concentration variations influence the redox process. The results confidently will significantly contribute to the optimization of non-enzymatic biosensors for glucose detection. In addition, this study aims to enhance the sensitivity and accuracy of biosensors, especially for applications in the medical and industrial fields.

RESEARCH METHODS

Materials

The chemicals used in this research were pro-analysis (p.a.) from Merc*k*: potassium chloride (KCl), potassium ferricyanide $K_3[Fe(CN)_6]$, sodium hydroxide (NaOH), glucose, and distilled water. The equipment used included standard glassware in the chemistry laboratory. The cyclic voltammetry setup involved a mini electrolysis cell (25 mL) equipped with three electrodes (each diameter= 0.5 mm), a platinum (Pt) auxiliary electrode, a glassy carbon (GC) working electrode, and an Ag/AgCl reference electrode. For instrumentation, an INGSENS^{TM} Electrochemical Workstation potentiostat type 1030 was used, equipped with a connecting cable to connect to a computer to respond to real-time cyclic voltammogram results. Data was processed using Microsoft Excel and Origin Pro-lab software program version 2019.

Electrode Preparation

The GCE surface was rinsed with acetone and distilled water and then dried. The Pt electrode was also rinsed with distilled water thoroughly on its surface and dried. Next, each electrode was cleaned using ultrasonic cleaner in distilled water for 15 minutes to ensure complete removal of surface contaminants. The Ag/AgCl electrodes were rinsed with distilled water and dried. The electrodes used in this study are shown in Figure 1.

(a) (b) (c)

Figure 1. (a) Glassy carbon working electrode (GCE), (b) Platinum (Pt) auxiliary electrode, dan (c) Ag/AgCl reference electrode.

Characterization of Glassy Carbon Electrode with $K_3[Fe(CN)_6]$ Solution

A series of electrochemical instrumentation consisting of a potentiostat connected to software was used to perform cyclic voltammetry measurements. This system utilized three electrode systems: GCE as the working electrode, Pt electrode as the auxiliary electrode, and Ag/AgCl electrode as the reference electrode. The research analyzed $K_3[Fe(CN)_6]$ solution with five concentration variations, 1 to 5 mM in 0.2 M KCl solution. Cyclic voltammograms were recorded at different scanning speeds of 25, 50, 75, and 100 mV/s within a potential range of -1.5 – 1 V.

Performance of Glassy Carbon Electrode in Glucose Solution

Using the same electrochemical system, the analyte solution was glucose solution with concentration variations of 1 – 5 mM in 0.1 M NaOH solution. The scanning speeds used were 50, 100, 150, 200, 250, and 300 mV/s in the potential range between -10 and 10 V. In addition, 10 scanning cycles were performed at a concentration of 5 mM to verify the electrodes' stability and determine the amount of error in the measurements.

RESULTS AND DISCUSSION

Characterization of Glassy Carbon Electrode With $K_3[Fe(CN)_6]$ Solution

The characteristics of the cyclic voltammogram have been studied based on a three-electrode system of cyclic voltammetry measurement, including a working electrode for the redox reaction site, a reference electrode that regulates the potential range, and an auxiliary electrode to conduct the current flowing during the redox chemical process on the surface (Cakici *et al*., 2017). Before use, the electrode was initially cleaned using a cloth to clean the electrode (Puthongkham and Venton, 2020). Furthermore, the electrode was cleaned again using an ultrasonic cleaner to clean and remove dirt or disturbing substances. In this study, the measurement process of one unit of cyclic voltammetry is illustrated in (Figure 2).

(a) (b) (c)

Figure 2. (a) The electrochemical cell, (b) INGSENS^{TM} potentiostat apparatus, and (c) A computer unit with data processor.

In cyclic voltammetry measurements for electrode characterization, $K_3[Fe(CN)_6]$ solution was used because it has a fast electron transfer reaction, making it suitable as a standard solution for electrode calibration and produces electrochemical processes that are reversible and have stable redox properties (Pastor *et al*., 2020). The measurements were initiated with a 1mM $K_3[Fe(CN)_6]$ solution in 0.2 M KCl with scan rates of 25, 50, 75, and 100 mV/s and the potential given between -1.5 to 1 V (Figure 3). Based on the measurement results, several key parameters were identified, namely peak potential (E_{pc}, E_{pa}) and peak current (i_{pa}, i_{pc}) in the cyclic voltammogram (Elgrishi *et al*., 2018).

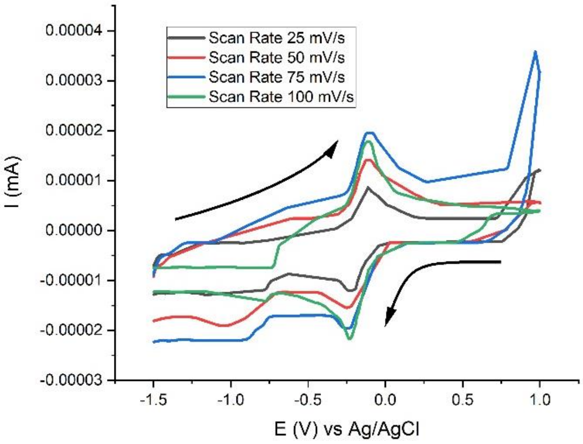


Figure 3. Cyclic voltammogram profile of $K_3[Fe(CN)_6]$ 1mM solution in 0.2M KCl solution, at 25, 50, 75, 100 mV/s scan rates.

During the measurement process, a redox chemical reaction occurred, producing anodic peak current (i_{pa} and cathodic peak current (Ipc) values observed at the optimal scan rate of 75 mV/s with a ratio of i_{pa}/i_{pc} = 0.99 (Table 1). The i_{pa}/i_{pc} ratio value close to 1 indicated that the redox process is reversible from Fe^{2+} to Fe^{3+}. Therefore, a scan rate of 75 mV/s was chosen for the subsequent measurement.

The fast scan rate formed a thin diffusion layer, making electron transfer around the electrode surface more efficient. A scan rate of 100 mV/s was previously attained for the Fe^{2+}/Fe^{3+} system using a polypyrrole/polyphenol oxidase-modified Pt electrode (Murniati *et al*., 2012a) and a polypyrrole/polyphenol oxidase-modified steel gauze electrode (Murniati *et al*., 2012b). Based on the research by Chen *et al*. (2023), the electrochemical sensor constructed through the process of electropolymerization (EP) of β-cyclodextrin on a glassy carbon electrode (β-CDP/GCE) attained a consistent scan rate of 100 mV/s.

Table 1. i_{pa}/i_{pc} measurement results of 1mM $K_3[Fe(CN)_6]$ solution in 0.2M KCl solution at scan rates of 25, 50, 75, 100mV/s.

Scan rate (Mv/s)	E_{pa} **(mV)**	E_{pc} **(mV)**	i_{pa} **(mA)**	i_{pc} **(mA)**	**ΔEP=** $E_{pa}-E_{pc}$	$E_0 = (E_{pa}+E_{pc})/2$ **(mV)**	i_{pa}/i_{pc}
25	-0.226	-0.112	-1.20×10^{-5}	8.62×10^{-6}	-0.114	-0.169	1.40
50	-0.234	-0.12	-1.54×10^{-5}	1.41×10^{-5}	-0.114	-0.177	1.09
75	-0.226	-0.102	-1.95×10^{-5}	1.96×10^{-5}	-0.124	-0.164	0.99
100	-0.232	-0.106	-2.17×10^{-5}	1.78×10^{-5}	-0.126	-116.053	1.18

In the previous study, tests on $K_3[Fe(CN)_6]$ were conducted at concentrations of 5 – 10 mM, showing relatively high sensitivity (Radhi and Al-Mulla, 2016). Another study also measured 5 mM $K_3[Fe(CN)_6]$ using a commercial Screen-Printed Carbon Electrode (SPCE), which resulted in an oxidation current of 19.92 μA (Wahyuni *et al*., 2019). However, neither study explained the effect of these concentration variations. Therefore, subsequent measurements were performed using $K_3[Fe(CN)_6]$ analyte solution with varying 1 – 5 mM concentrations, tested in a 0.2 M KCl solution. The measurements were carried out using an optimum scan rate of 75mV/s and a potential range of -1.5 to 1 V, as shown in Figure 4.

The results of the cyclic voltammograms profile in Figure 4 showed that the highest peak was observed at 5 mM $K_3[Fe(CN)_6]$. This is consistent with Faraday's law, which postulates that the current generated by an electrochemical cell is directly proportional to the concentration of the solution used. This study expects diffusion currents to occur during redox at the electrode surface in the anodic current from Fe^{2+} to Fe^{3+}.

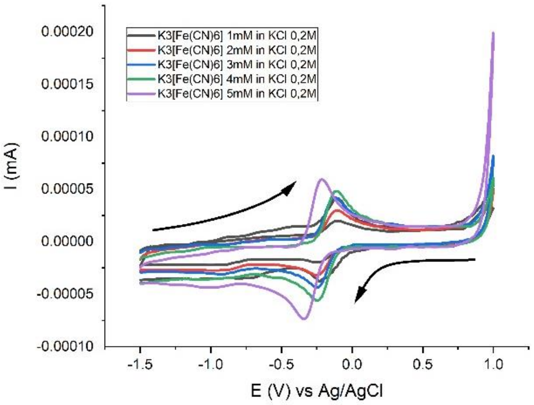


Figure 4. Cyclic voltammogram profiles of $K_3[Fe(CN)_6]$ 1 – 5 mM solutions in 0.2 M KCl solution at a scan rate of 75mV/s.

The diffusion process causes this phenomenon in an electrolyte phase solution where particles migrate from high to low concentrations (Joshi, P.S. and Sutrave, 2018). However, special attention was also paid to the i_{pa}/i_{pc} ratio value close to 1, which was observed at 1 mM concentration with $i_{pa}/i_{pc} = 0.99$, as noted in Table 2.To further quantify this trend, Table 2 presents a detailed comparison of peak potential (E_{pa}, E_{pc}), peak current (i_{pa} and i_{pc}), and the i_{pa}/i_{pc} ratio at different scan rates.

Table 2. The i_{pa}/i_{pc} measurement results of 1 – 5 mM $K_3[Fe(CN)_6]$ solution in 0.2 M KCl solution at scan rates of 25, 50, 75, 100 mV/s.

Concentration (mM)	E_{pa} (mV)	E_{pc} (mV)	i_{pa} (mA)	i_{pc} (mA)	ΔEP= E_{pa}-E_{pc}	E_0= (E_{pa}+E_{pc})/2 (mV)	i_{pa}/i_{pc}
1	-0.226	-0.102	-1.95×10^{-5}	1.96×10^{-5}	-0.124	-0.164	0.99
2	-0.256	-0.11	-3.17×10^{-5}	2.98×10^{-5}	-0.146	-0.183	1.06
3	-0.248	-0.124	-4.36×10^{-5}	3.01×10^{-5}	-0.124	-0.186	1.44
4	-0.254	-0.108	-5.59×10^{-5}	4.83×10^{-5}	-0.146	-0.181	1.16
5	-0.254	0.126	-7.24×10^{-5}	5.91×10^{-5}	-0.128	-0.19	1.22

The uses of different $K_3[Fe(CN)_6]$ concentration variations in 0.2 M KCl aim to ensure the stability of the commercial GC working electrode so that it can work optimally during the redox process. The redox reaction in the $K_3[Fe(CN)_6]$ system follows Equations 1 and 2.

Reduction: $Fe(CN)_6^{3-}{}_{(aq)} + e^-{}_{(aq)} \rightarrow Fe(CN)_6^{4-}{}_{(aq)}$ (1)

Oxidation: $Fe(CN)_6^{4-}{}_{(aq)} \rightarrow Fe(CN)_6^{3-}{}_{(aq)} + e^-{}_{(aq)}$ (2)

Figure 5 shows the results of variations in the concentration of $K_3[Fe(CN)_6]$ from 1 to 5 mM solution in 0.2 M KCl solution with a regression value close to 1. This indicates that the Fe^{2+} to Fe^{3+} redox reaction that occurs is stable.

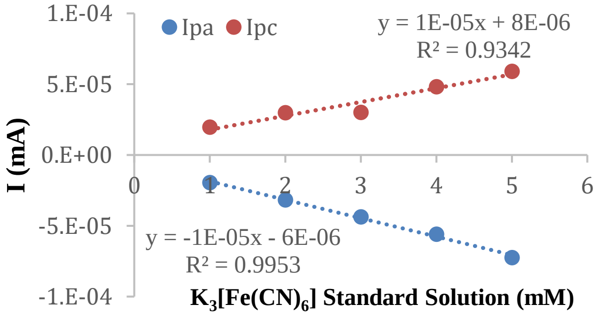
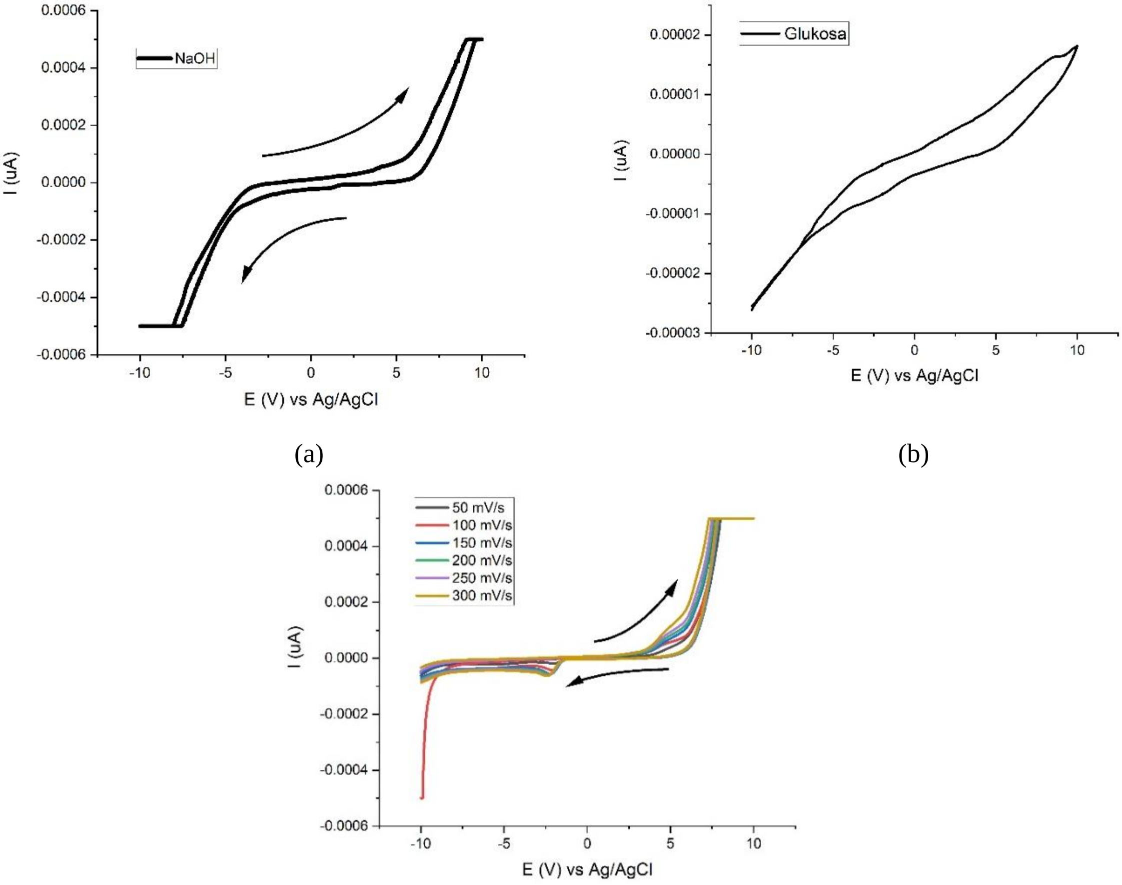


Figure 5. Linear i_{pa}-i_{pc} curves of varying concentrations of $K_3[Fe(CN)_6]$ standard.

Performance of Glassy Carbon Electrode In Glucose Solution

Previous non-enzymatic glucose testing was conducted with concentrations of 0 – 1.5 mM in 0.1 M NaOH using a scan rate of 100mV/s on a GC working electrode modified with copper sulfide using chitosan, nafion, and

PVP polymers, yielding the highest current peak at a concentration of 1.5 mM (Mazurków *et al*., 2021). The experiment used a 1 mM glucose in 0.1 M NaOH solution, with varying scan rates of 50, 100, 150, 200, 250, and 300 mV/s, and a potential range of -10 to 10 V. The measurement data are presented in Figure 6. Figure 6c, shows that the measurements commence with the highest scan rate and decrease to the lowest, while the potential increases from the lowest to the highest value. This methodology is intended to enhance the redox process, as indicated by the differences in oxidation and glucose reduction peak heights at various scan rates. The measurement data are presented in Table 3.



(a) (b)

(c)

Figure 6. (a) Cyclic voltammogram profile of NaOH solution, (b) Cyclic voltammogram profile of glucose solution, and (c) Cyclic voltammogram profile of 1mM glucose solution in 0.1 M NaOH solution, at scan rates of 50, 100, 150, 200, 250, 300 mV/s.

Table 3. i_{pa}/i_{pc} measurement results of 1mM glucose solution in 0.2 M NaOH solution at scan rates of 25, 50, 75, and 100 mV/s.

Scan rate (Mv/s)	**E_{pa} (mV)**	**E_{pc} (mV)**	**i_{pa} (mA)**	**i_{pc} (mA)**	**ΔEP= E_{pa}-E_{pc}**	**E0= (E_{pa}+E_{pc})/2 (mV)**	**i_{pa}/i_{pc}**
50	4.42	-1.94	2.38×10^{-5}	-1.84×10^{-5}	6.38	1.24	1.29
100	4.49	-2.11	4.65×10^{-5}	-4.19×10^{-5}	6.60	1.19	1.11
150	4.38	-2.2	4.68×10^{-5}	-5.61×10^{-5}	6.58	1.09	0.834
200	4.05	-1.9	3.69×10^{-5}	-3.66×10^{-5}	5.95	1.075	1.01
250	4.4	-2.36	6.71×10^{-5}	-6.15×10^{-5}	6.76	1.02	1.09
300	4.74	-2.45	9.99×10^{-5}	-6.27×10^{-5}	7.19	1.145	1.59

The data from Table 3 and the information illustrated in Figure 7 indicate that the optimal scan rate is 200 mV/s, with an i_{pa}/i_{pc} ratio of 1.01. At this scan rate, the reduction and oxidation processes are balanced. The peak current increases with the scan rate. However, an excessively high scan rate can result in an insufficiently thin diffusion layer, hindering electron transfer and preventing full oxidation of the analyte. Conversely, a scan rate that is too low leads to the formation of a diffusion layer that also inhibits electron transfer (Irdhawati *et al.*, 2017). Therefore, a scan rate of 200 mV/s is recommended.

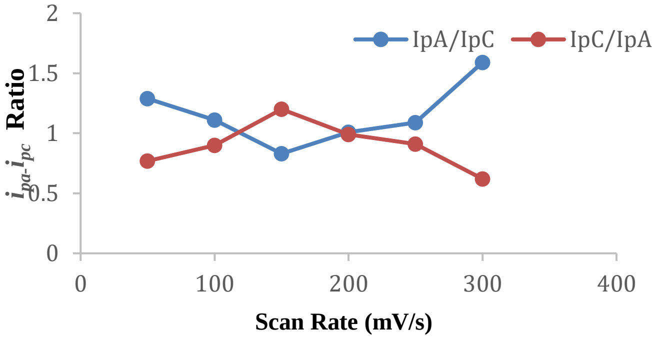
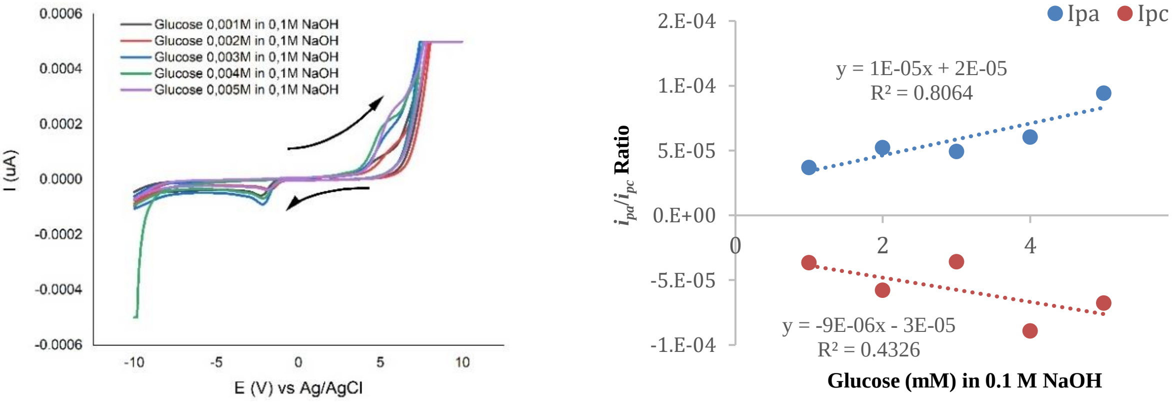


Figure 7. Comparison of i_{pa}-i_{pc} spots from various scan rates.

Subsequent measurements were performed using glucose analyte solutions with varying concentrations ranging from 1 to 5 mM tested in 0.1 M NaOH solution. Measurements were performed with an optimum scan rate of 200 mV/s and a potential range from -10 to 10 V. The measurement results are presented in (Figure 8a). In Figure 8a and Table 4, it can be seen that the oxidation peak reaches the highest value at 5 mM concentration. This is due to the involvement of more electroactive species at higher concentrations.



(a) (b)

Figure 8. (a) Cyclic voltammogram profiles of 1 to 5 mM in 0.1 M NaOH solution at a scan rate of 200 mV/s dan (b) Linear curve of i_{pa}/i_{pc} vs varying glucose concentration in 0.1 M NaOH.

Additionally, as shown in Figure 8b, linear regression calculations were performed for the anodic and cathodic peaks relative to the glucose solution. The linear correlation obtained for the anodic peak (i_{pa}) was R = 0.8064, indicating a more stable response than the cathodic peak (i_{pc}), which correlated with R = 0.4326. This suggests that the predominant reaction is anodic or oxidative. Furthermore, Table 4 demonstrates that the measurement results for i_{pa} exhibited a stable increase from the lowest to the highest glucose concentration, while i_{pc} displays an unstable trend.

Table 4. i_{pa} and i_{pc} data of analyte solutions of concentration variation 1 – 5 mM in 0.1 M NaOH solution.

Concentration (mM)	i_{pa} (µA)	i_{pc} (µA)	Ratio (i_{pa}/i_{pc})
1	3.69×10^{-5}	-3.66×10^{-5}	1.01
2	5.23×10^{-5}	-5.78×10^{-5}	0.90
3	4.92×10^{-5}	-3.58×10^{-5}	1.38
4	6.05×10^{-5}	-8.93×10^{-5}	0.67
5	9.42×10^{-5}	-6.76×10^{-5}	1.39

The following reaction equations characterize the oxidation and reduction processes in glucose solution, as described in Equations 3 and 4.

$$\text{Oxidation: } C_6H_{12}O_6 + 2OH^- \rightarrow C_6H_{10}O_6 + 2e^- + 2H_2O \qquad (3)$$

$$\text{Reduction: } 2OH^- \rightarrow H_2O + \frac{1}{2}O_2 + 2e^- \qquad (4)$$

The measurement of a 5 mM glucose solution using GCE was performed with 10 repetitions, with the cyclic voltammogram over 10 cycles shown in Figure 9.

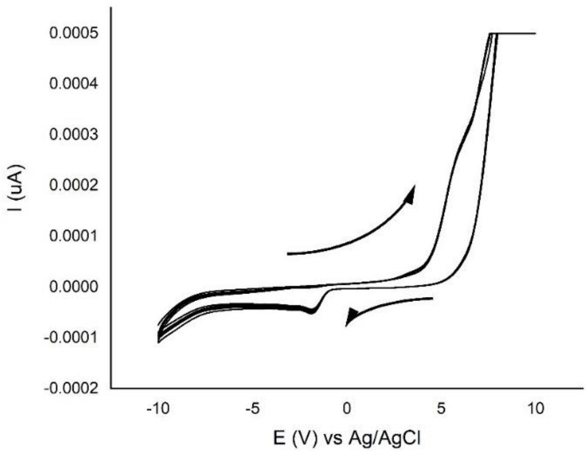


Figure 9. Repeatability cyclic voltammogram profile of 10 cycles of 5 mM glucose solution in 0.1 M NaOH solution with a scan rate of 300 mV/s.

According to Table 5, the average values were $i_{pa} = 4.86 \times 10^{-5} \pm 3.23 \times 10^{-6}$ and $i_{pc} = -4.83 \times 10^{-5} \pm 2.56 \times 10^{-6}$, with $i_{pa}/\ i_{pc} = (-1.007) \pm 0.062$. These results indicate relatively stable and precise standard deviations for measuring 5 mM glucose in 0.1M NaOH over 10 cycles on the GCE.

Table 5. Repeatability measurement data.

Repetition	i_{pa}	i_{pc}	**Ratio (i_{pa}/i_{pc})**
1	4.42×10^{-5}	-4.33×10^{-5}	-1.021
2	5.14×10^{-5}	-5.07×10^{-5}	-1.014
3	4.77×10^{-5}	-5.20×10^{-5}	-0.917
4	5.19×10^{-5}	-5.02×10^{-5}	-1.034
5	4.86×10^{-5}	-4.93×10^{-5}	-0.986
6	5.08×10^{-5}	-4.95×10^{-5}	-1.026
7	4.50×10^{-5}	-4.78×10^{-5}	-0.941
8	4.68×10^{-5}	-4.71×10^{-5}	-0.994
9	4.56×10^{-5}	-4.68×10^{-5}	-0.974
10	5.36×10^{-5}	-4.62×10^{-5}	-1.160
Mean	4.85×10^{-5}	-4.82×10^{-5}	-1.007
Standard deviation	3.23×10^{-5}	2.55×10^{-5}	0.062

CONCLUSION

This study found that a concentration of 1mM $K_3[Fe(CN)_6]$ and glucose provided an i_{pa}/i_{pc} ratio close to 1, indicating a stable and reversible redox process. On the other hand, a concentration of 5 mM produced the highest peak current, indicating higher sensitivity. Therefore, a concentration of 1 mM is optimal for redox stability, while a concentration of 5 mM is best for increasing sensitivity.

CONFLICT OF INTEREST

There is no conflict of interest in this article.

AUTHOR CONTRIBUTION

AM: Conceptualization, Methodology, Supervision, Manuscript Review, and Editing; AFG: Data Analysis, Manuscript Drafting; AH: Supervision, Manuscript Review, and Editing.

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REFERENCES

Abdel-Aziz, A.M., Hassan, H.H., and Badr, I.H.A., 2022. Activated Glassy Carbon Electrode as an Electrochemical Sensing Platform for the Determination of 4-Nitrophenol and Dopamine in Real Samples. *ACS Omega*, 7, 34127–34135. https://doi.org/10.1021/acsomega.2c03427.

Cakici, M., Reddy, K.R., and Alonso-Marroquin, F., 2017. Advanced Electrochemical Energy Storage Supercapacitors Based on the Flexible Carbon Fiber Fabric-Coated with Uniform Coral-like MnO_2 Structured Electrodes. *Chemical Engineering Journal*, 309, 151–158. https://doi.org/10.1016/j.cej.2016.10.012.

Chen, Y., Xu, S., Liu, G., Li, W., Liu, L., Wang, Z., Dai, X., and Jiang, X., 2023. An Electrochemical Sensor Based on PEI/CS/GN Composite–Modified Glassy Carbon Electrode for Determination of Pb(II). *Ionics*, 29, 2031–2041. https://doi.org/10.1007/s11581-023-04954-8.

Dorledo de Faria, R.A., Messaddeq, Y., Heneine, G.D., and Matencio, T., 2019. Application of Screen-Printed Carbon Electrode as an Electrochemical Transducer in Biosensors. *International Journal of Biosensors & Bioelectronics*, 5, 9–10. https://doi.org/10.15406/ijbsbe.2019.05.00143.

EL-Deeb, M.M., El Rouby, W.M.A., Abdelwahab, A., and Farghali, A.A., 2018. Effect of Pore Geometry on the Electrocatalytic Performance of Nickel Cobaltite/ Carbon Xerogel Nanocomposite for Methanol Oxidation. *Electrochimica Acta*, 259, 77–85. https://doi.org/10.1016/j.electacta.2017.10.152.

Elgrishi, N., Rountree, K.J., McCarthy, B.D., Rountree, E.S., Eisenhart, T.T., and Dempsey, J.L., 2018. A Practical Beginner's Guide to Cyclic Voltammetry. *Journal of Chemical Education*, 95, 197–206. https://doi.org/10.1021/acs.jchemed.7b00361.

Gaffar, S., Naviardianti, A.I., Wyantuti, S., and Hartati, Y.W., 2022. Biosensor DNA Elektrokimia untuk Deteksi Makanan Mengandung Babi (*Sus scrofa*) Menggunakan *Screen Printed Carbon Electrode* Termodifikasi Emas. *ALCHEMY Jurnal Penelitian Kimia*, 18, 37. https://doi.org/10.20961/alchemy.18.1.50170.37-47.

Hassan, M.H., Vyas, C., Grieve, B., and Bartolo, P., 2021. Recent Advances in Enzymatic and Non-Enzymatic Electrochemical Glucose Sensing. *Sensors*, 21. https://doi.org/10.3390/s21144672.

Herbei, E.E., Alexandru, P., and Busila, M., 2023. Cyclic Voltammetry of Screen-Printed Carbon Electrode Coated with Ag-ZnO Nanoparticles in Chitosan Matrix. *Materials*, 16, 1–12. https://doi.org/10.3390/ma16083266.

Irdhawati, I., Suyanto, H., and Andani, P.Y., 2017. Zeolite-Modified Carbon Paste Electrode for Determination of Copper Using Anodic Stripping Voltammetry Method. *ALCHEMY Jurnal Penelitian Kimia*, 13, 1. https://doi.org/10.20961/alchemy.v13i1.1808.

Jaiswal, N., and Tiwari, I., 2017. Recent Build Outs in Electroanalytical Biosensors Based on Carbon-Nanomaterial Modified Screen Printed Electrode Platforms. *Analytical Methods*, 9, 3895–3907. https://doi.org/10.1039/c7ay01276d.

Joshi, P. S., and Sutrave, D.S., 2018. A Brief Study of Cyclic Voltammetry and Electrochemical Analysis. *International Journal of ChemTech Research*, 11, 77–88. https://doi.org/10.20902/ijctr.2018.110911.

Koç, Y., Morali, U., Erol, S., and Avci, H., 2021. Investigation of Electrochemical Behavior of Potassium Ferricyanide/Ferrocyanide Redox Probes on Screen Printed Carbon Electrode through Cyclic Voltammetry and Electrochemical Impedance Spectroscopy. *Turkish Journal of Chemistry*, 45, 1895–1915. https://doi.org/10.3906/kim-2105-55.

Mahajan, R., Krishna, H., Singh, A.K., and Ghadai, R.K., 2018. A Review on Copper and Its Alloys Used as Electrode in EDM. *IOP Conference Series: Materials Science and Engineering*, 377. https://doi.org/10.1088/1757-899X/377/1/012183.

Mazurków, J.M., Kusior, A., and Radecka, M., 2021. Electrochemical Characterization of Modified Glassy Carbon Electrodes for Non-enzymatic Glucose Sensors. *Sensors*, 21. https://doi.org/10.3390/s21237928.

Mikkola, S., 2020. Nucleotide Sugars in Chemistry and Biology. *Molecules*, 25. https://doi.org/10.3390/molecules25235755.

Mousavi, S.M., Hashemi, S.A., Gholami, A., Mazraedoost, S., Chiang, W.H., Arjmand, O., Omidifar, N., and Babapoor, A., 2021. Precise Blood Glucose Sensing by Nitrogen-Doped Graphene Quantum Dots for Tight Control of Diabetes. *Journal of Sensors*, 2021. https://doi.org/10.1155/2021/5580203.

Murniati, A., Buchari, B., Gandasasmita, S., and Nurachman, Z., 2012a. Synthesis and Characterization of Polypyrrole Polyphenol Oxidase (PPy/PPO) on Platinum Electrode. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 3, 855–864.

Murniati, A., Gandasasmita, S., Buchari, and Nurachman, Z., 2012b. Sintesis dan Karakterisasi Polipirol pada Elektroda Kerja Kasa Baja dengan Metode Voltametri Siklik. *Jurnal Sains Materi Indonesia*, 13, 210–215.

Pastor, F.T., Šegan, D.M., Gorjanović, S., Kalušević, A.M., and Sužnjević, D., 2020. Development of Voltammetric Methods for Antioxidant Activity Determination Based on Fe(III) Reduction. *Microchemical Journal*, 155. https://doi.org/10.1016/j.microc.2020.104721.

Puthongkham, P., and Venton, B.J., 2020. Recent Advances in Fast-Scan Cyclic Voltammetry. *Analyst*, 145, 1087–1102. https://doi.org/10.1039/c9an01925a.

Radhi, M.M., and Al-Mulla, E.A.J., 2016. Voltammetric Characterization of Grafted Polymer Electrode Self Modification with Carbon Nanotubes (GPESMCNT). *Portugaliae Electrochimica Acta*, 34, 97–103. https://doi.org/10.4152/pea.201602097.

Taha, M.H.F., Ashraf, H., and Caesarendra, W., 2020. A Brief Description of Cyclic Voltammetry Transducer-Based Non-Enzymatic Glucose Biosensor Using Synthesized Graphene Electrodes. *Applied System Innovation*, 3, 1–33. https://doi.org/10.3390/asi3030032.

Venton, B.J., and Cao, Q., 2020. Fundamentals of Fast-Scan Cyclic Voltammetry for Dopamine Detection. *Analyst*, 145, 1158–1168. https://doi.org/10.1039/c9an01586h.

Wahyuni, W.T., Darusman, L.K., and Diksy, Y., 2018. Deteksi Kurkumin dan Bisdemetoksikurkumin dengan Teknik Voltammetri Menggunakan Elektrode Boron-Doped Diamond. *ALCHEMY Jurnal Penelitian Kimia*, 14, 253. https://doi.org/10.20961/alchemy.14.2.19576.253-266.

Wahyuni, W.T., Zalvianita, R., and Heryanto, R., 2019. Fabrication of Recycle Screen Printed Carbon Electrode and Its Application for Voltammetric Detection of Gallic Acid. *Jurnal Kimia Sains dan Aplikasi*, 22, 164–172. https://doi.org/10.14710/jksa.22.5.164-172.

Wang, H.W., Bringans, C., Hickey, A.J.R., Windsor, J.A., Kilmartin, P.A., and Phillips, A.R.J., 2021. Cyclic Voltammetry in Biological Samples: A Systematic Review of Methods and Techniques Applicable to Clinical Settings. *Signals*, 2, 138–158. https://doi.org/10.3390/signals2010012.

Zhang, J., Chen, L., and Yang, K., 2019. In Situ Synthesis of CuO Nanoparticles Decorated Hierarchical Ce-Metal-Organic Framework Nanocomposite for an Ultrasensitive Non-Enzymatic Glucose Sensor. *Ionics*, 25, 4447–4457. https://doi.org/10.1007/s11581-019-02996-5.