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Development of Molecularly Imprinted Polymer (MIP) Modified Electrode for The Analysis of Fructose Content in Honey by Cyclic Voltammetry

Pengembangan Elektroda Termodifikasi *Molecularly Imprinted Polymer* (MIP) Sebagai Analisis Kadar Fruktosa Dalam Madu Secara Voltametri Siklik

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ABSTRACT

This study aims to develop a Molecularly Imprinted Polymer (MIP)-modified electrode using cyclic voltammetry for the analysis of fructose in honey. In this study, three types of polymers were synthesized: a Blank Polymer (PB) prepared without a fructose template, serving as a control; a Non-Imprinted Polymer (NIP) synthesized using a fructose template but without undergoing an extraction process; and a Molecularly Imprinted Polymer (MIP) synthesized using a fructose template and subjected to an extraction process to produce specific recognition sites. Characterization using Fourier Transform Infrared (FTIR) spectroscopy revealed an -OH group absorption peak at 3409.07 cm^{-1} in the NIP, which was not observed in the MIP or the Blank Polymer (PB). Characterization by Scanning Electron Microscopy (SEM) revealed the morphology of the MIP with heterogeneous particles and sharp pores, in contrast to the PB, which is non-porous, and the NIP, which has homogeneous particles. The optimal electrode was prepared with a composition of agar; MIP; KCl in a ratio of 1:1:2 (w/w). Voltammetric analysis at pH 5 provided the best operating conditions with a deposition time of 5 seconds and a scan rate of 0.5 V/s. This electrode yielded a Limit of Detection (LOD) of 2.642 ppm, a Limit of Quantitation (LOQ) of 8.808 ppm, and a % recovery of 101.112%. A comparison of fructose analysis results in honey using cyclic voltammetry and UV-Vis revealed no statistically significant differences, (p-value (2-tailed) = 0.694 > 0.05). These results indicate that the MIP-modified electrode has good accuracy and can be used as an alternative method for fructose analysis in honey.

Keywords: *cyclic voltammetry, fructose, honey, molecularly imprinted polymer*, *MIP-modified electrode*

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1. INTRODUCTION

Honey is a natural food product produced by bees from flower nectar (Se et al., 2019). The primary constituents of honey are simple carbohydrates, comprising fructose (38%), glucose (31%), maltose (7%), and sucrose (1.3%). Fructose is the largest component in honey and plays a crucial role in

its sweet taste and quality (Silva et al., 2016). Irresponsible producers have frequently exploited the high economic value of honey through adulteration practices, including the addition of artificial sweeteners or commercial sugars (Taskinen et al., 2019).

According to the Codex Alimentarius Commission, honey is a natural product that must not contain any additives (Codex Alimentarius, 2022). The presence of artificial sweeteners in honey not only causes economic harm to consumers but also poses significant health risks. Excessive fructose consumption has been reported to be associated with various metabolic disorders, including obesity, diabetes, hyperuricemia, and non-alcoholic fatty liver disease (Softic et al., 2016).

The analysis of fructose in honey presents considerable challenges due to the co-presence of other sugars, such as glucose, sucrose, and maltose, which naturally occur in the honey matrix (Se et al., 2019). Conventional analytical methods, such as high-performance liquid chromatography (HPLC), offer high accuracy but require lengthy analysis times, high operational costs, and complex sample preparation procedures (Rao et al., 2017). Infrared spectroscopy methods also suffer from limitations arising from signal overlap and interference from the complex honey matrix.

Cyclic voltammetry is a widely used electroanalytical method for detecting electroactive compounds due to its high sensitivity, simple procedure, minimal reagent use, and short analysis time (Shi et al., 2023). A voltammetric system consists of a working electrode, a reference electrode, and an auxiliary electrode, where the working electrode plays a crucial role as the site of oxidation and reduction reactions of the analyte (Inggriani & Setiarso, 2020). Fructose is an electroactive compound that can be oxidized on the electrode surface. However, conventional electrodes still exhibit low selectivity due to the similarity in the electrochemical properties of fructose with those of other sugars, leading to overlapping signals (Rao et al., 2017). Previous research on fructose sensors generally employed potentiometric methods, which have limitations in sensitivity and in the characterization of redox reaction kinetics. Therefore, electrode surface modification is necessary to enhance detection selectivity and sensitivity (Barry et al., 2023).

Electrode modification using Molecularly Imprinted Polymer (MIP) represents an innovative approach to enhancing the selectivity of electrochemical sensors. MIP is a synthetic polymer that possesses specific binding sites for target molecules through a molecular imprinting during polymerization (Zulfikar, 2022). After the template molecules are removed, cavities remain with shapes and functional groups complementary to the target molecules, allowing the MIP to selectively recognize those molecules (Jupri et al., 2022). The application of MIP as an electrode modification material has been reported to enhance sensor performance in complex matrices.

In this study, a simple analytical method was developed using a MIP modified electrode combined with the cyclic voltammetry technique. The MIP was synthesized from methyl methacrylate as the functional monomer, fructose as the template molecule, ethylene glycol dimethaclyrate as the crosslinker, and benzoyl peroxide as the initiator, with a template: monomer ratio of 1:3 with a crosslinker agent whose volume is six times that of the monomer (Oktaningtias & Sianita, 2025). It is hoped that this MIP

technique will yield electrodes that can be used to analyze fructose levels in honey, thereby providing a fast, selective, and sensitive analytical method.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this study were fructose (Merck), acetonitrile 99.9% v/v (Sigma-Aldrich), methyl methacrylate (MMA) 99% v/v (Merck), ethylene glycol dimethacrylate (EGDMA) 99% v/v (Sigma-Aldrich), benzoyl peroxide (Labotiq), methanol 99.9% v/v, acetic acid 99% v/v, ~~honey~~, three types of honey from different brands, potassium chloride, ~~agarose~~, agar, distilled water, and ultra-high purity (UHP) nitrogen gas (PT. Maestu Gotty Abadi, Indonesia). The tools used in this research are a hotplate, a magnetic stirrer, a LabNet vortex mixer, Whatman No. 42 filter paper, a vacuum pump, a digital analytical balance, an oven, an incubator, micropipettes, volumetric flasks, sandpaper, copper wire, and petri dishes. The instruments used in this study included a 797 VA Cyclic Voltammetry system, a pH meter, a PerkinElmer Two Spectrum FTIR spectrometer, a Hitachi FlexSEM 1000 Scanning Electron Microscope (SEM), and a Shimadzu UV-1800 UV-Vis spectrophotometer.

2.2. Synthesis of NIP and Blank Polymer (PB)

The NIP were synthesized by dissolving 0.5 mmol of fructose (template) (0.090 g) in 2 mL of methanol and 3 mL of acetonitrile. Subsequently, 1.5 mmol of methyl methacrylate (MMA) as the functional monomer (0.150 g) and 5 mL of acetonitrile as porogen were added, maintaining a template: MMA molar ratio of 1:3. The mixture was allowed to stand for 30 minutes, after which 9 mmol of ethylene glycol dimethacrylate (EGDMA) as the crosslinker (1.783 g), equivalent to six times the molar amount of MMA, was added (Fransiska & Sianita, 2021). The solution was vortexed until homogeneous and then purged with nitrogen gas for 5 minutes. Subsequently, 0.3 mmol of benzoyl peroxide (BPO) (0.072 g) was added as the initiator, followed by vortexing for an additional 5 minutes and further nitrogen purging for 5 minutes. The mixture was then placed on a hotplate at 70 °C for 4 hours until a white solid formed, designated as the Non-Imprinted Polymer (NIP). The resulting polymer is dried in an oven at 60 °C and then sieved through a 200-mesh sieve. Repeated the same procedure without adding of the template to produce the Blank Polymer (PB).

2.3. Template Extraction to Obtain MIP

Dried NIP (1–2 g) was extracted using a methanol: acetic acid mixture at a volume ratio of 8:2 for 4 hours via maceration at 70 °C on a magnetic stirrer at 270 rpm. The extracted polymer was subsequently washed with distilled water and dried in an oven at 60 °C until constant weight. The resulting polymer was designated as the MIP. FTIR then characterized the MIP to identify functional group absorptions, and SEM was used to examine its surface morphology.

2.4. Preparation of Standard Solutions

Prepared a 1000 ppm fructose stock solution by dissolving 0.1 g of fructose in a 100 mL volumetric flask and diluting to the mark with distilled water. Working standard solutions of 10, 20, 30, 40, and 50 ppm were prepared by pipetting 1, 2, 3, 4, and 5 mL of the stock solution, respectively, into 100 mL volumetric flasks and diluting to volume with distilled water

2.5. Determination of Optimum Electrode Composition

MIP-modified electrodes were prepared using various compositions of Agar: MIP: KCl, namely 1:1:1; 1:2:1; 1:1:2; 2:1:1 (w/w). These were alternately placed in a

voltammetric cell containing 10 mL of 50 ppm fructose standard solution, 5 mL of 2500 ppm KCl solution, and 5 mL of phosphate buffer at pH 5. Measurements were performed at a deposition time of 5 s, scan rate of 0.5 V/s, and potential range of −2.5 to +2.0 V. the results were compared to determine the optimum electrode composition.

2.6. Determination of Optimum Ph

The electrode with the optimum composition was placed in a voltammetric cell containing 10 mL of 50 ppm fructose standard solution and 5 mL of 2500 ppm KCl solution, with the addition of 5 mL of phosphate buffer at pH 4, 5, 6, 7, and 8, respectively. Measurements were conducted at the optimum deposition time and scan rate over a potential range of −2.5 to +2.0 V. The results were compared to identify the optimum pH.

2.7. Determination of Optimum Deposition Time and Scan Rate

The optimum electrode was placed in a voltammetric cell containing 10 mL of 50 ppm fructose standard solution, 5 mL of 2500 ppm KCl solution, and 5 mL of phosphate buffer at pH 5. Varied deposition time at 10, 20, 30, 40, and 50 s, and scan rate was varied at 0.1, 0.2, 0.3, 0.4, and 0.5 V/s, as well as within the potential range of −2.5 to +2.0 V. Then, compared the result to determine the optimal deposition time and scan rate (Rusnadi & Setiarso, 2020).

2.8. Determination of Fructose Content in Honey by Cyclic Voltammetry

For each of the 10–50 ppm fructose standard solutions and the three types of honey solutions (a, b, and c) which were diluted to 10 mL and placed in a voltammetric cell, 5 mL of 2500 ppm KCl solution and 5 mL of pH 5 buffer solution. Measurements were performed over a potential range of -2.5 V to 2.0 V. A fructose standard curve was plotted by plotting the concentration values of the fructose standard solutions on the X-axis and the IpC current on the Y-axis to obtain a linear equation from the calibration curve, which was used to calculate the fructose content in the honey.

2.9. Determination of Fructose Content in Honey by UV-Vis Spectrophotometry

Fructose standard solutions (10–50 ppm) and three types of honey solutions (a-c) were diluted and were each was taken in 0.5 mL portions and mixed with 2 mL of DNS reagent; the mixture was then heated to 100 °C for 5 minutes until a reddish-brown color change occurred (Ruswandi et al., 2018). The DNS reagent can be used for fructose analysis using a UV-Vis spectrophotometer because it forms colored complexes with reducing sugars, shifting the absorbance to the visible region. The solutions were then measured using a UV-Vis spectrophotometer at 497 nm. A fructose standard curve was created by plotting the concentration values of the fructose standard solutions on the X-axis and the absorbance values on the Y-axis yielding a linear equation used to calculate the fructose content in the honey.

3. RESULTS AND DISCUSSION

3.1. NIP and Blank Polymer (PB) Synthesis

The polymerization of NIP and PB was carried out by mixing methyl methacrylate, fructose, and EGDMA in a 3:1:18 ratio (Asni & Sianita, 2020). Fructose and the monomers are trapped within a three-dimensional polymer network, with EGDMA acting as a crosslinker to form crosslinks that enhance the stability and rigidity of the structure. Methyl methacrylate interacts noncovalently via

hydrogen bonding with the hydroxyl groups of fructose, thereby forming a selective molecular mold following the mold extraction process, as confirmed by FTIR analysis, which showed a shift in the -OH band from 3517.83 cm^{-1} in pure fructose to 3409.07 cm^{-1} in NIP due to hydrogen bonding, as well as the disappearance of this band in the MIP spectrum following template extraction. The synthesis was carried out using the bulk polymerization method because this method has been reported to produce polymers with relatively high purity and minimal solvent requirements. However, this method also requires grinding and sieving steps, which can result in the loss of some crosslinking sites; therefore, grinding must be performed gently and carefully, and the crosslinker ratio must be increased (Carballido et al., 2022). In this study, acetonitrile was selected as the porogen due to its polarity, which stabilizes hydrogen bonds in non-covalent interactions.. The process that takes place is addition polymerization, in which no small molecules are released. Benzoyl peroxide acts as an initiator, generating free radicals that trigger polymer chain formation. Nitrogen gas is introduced to remove oxygen and impurities that could inhibit radical formation. The presence of oxygen slows down polymer formation by allowing auto-polymerization reactions to occur through free radicals generated by benzoyl peroxide. Polymerization was carried out at 70 °C for 4 hours yielding a white solid.

3.2. MIP Extraction

MIP extraction was performed using the maceration method, which involves soaking the synthesized NIP polymer in a suitable solvent. The maceration method was chosen because it allows for longer direct contact time between the template and the solvent, which has the potential to increase extraction efficiency compared to techniques with shorter contact times, such as the soxhlet method (Sianita et al., 2019). However, a direct comparison of extraction efficiency between the two methods was not conducted in this study. The overall reaction mechanism for the formation and extraction of MIP is shown in **Fig. 1**.

At this stage, fructose and monomers are trapped within a three dimensional polymer network. Ethylene glycol dimethacrylate (EGDMA) is used as a crosslinker. EGDMA has two reactive groups methacrylate groups that can link two polymer chains, forming crosslinks between monomers, which enhance the stability and rigidity of the structure and act as the polymer backbone that forms crosslinks between monomers. EGDMA supports the stability of polymer chain growth, while methyl methacrylate functions as a hydrogen-bond acceptor (carbonyl (C=O) ester group) that interacts noncovalently with the hydroxyl (OH) groups of fructose, thereby supporting the formation of a molecular mold after template extraction. In the extraction process, acetic acid disrupted the hydrogen bonds between the template and the functional monomer, facilitating template removal. Distilled water was subsequently used to eliminate residual acetic acid, preventing interference in subsequent steps. Methanol was used to draw fructose out of the polymer matrix, as fructose is soluble in it. After the washing process, the resulting MIP has binding sites that are complementary to the fructose template molecule, as confirmed by FTIR and SEM characterization. Template removal is a critical step that directly determines MIP performance, as the generated cavities serve as selective binding sites for subsequent template rebinding. This process must therefore be carried out carefully, as the number of cavities formed governs the analytes binding capacity.

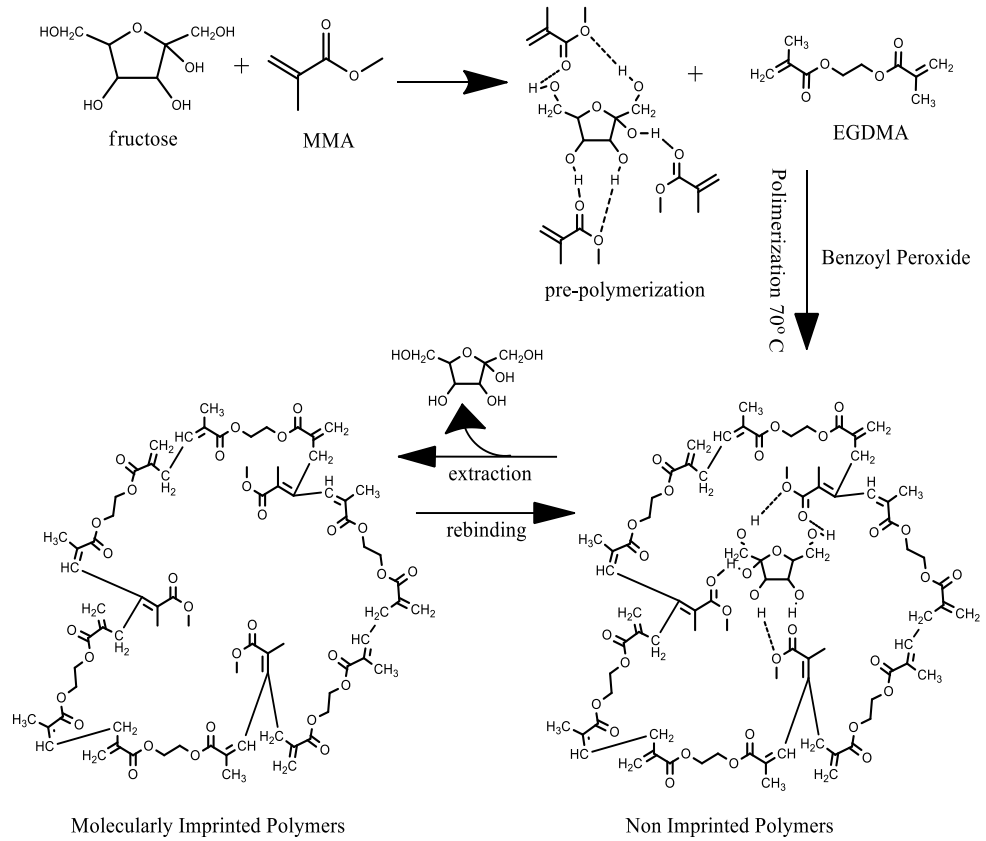


Figure 1. Synthesis and extraction mechanism of MIP

3.3. FTIR Functional Group Analysis

The purpose of FTIR characterization is to assess the success of the synthesis and template extraction processes by examining the functional groups involved in the formation of the blank polymer (PB), NIP, and MIP, as reflected in changes in absorption intensity and wavenumber shifts in the resulting FTIR spectra. The FTIR characterization results for fructose, PB, NIP, and MIP are shown in **Fig. 2.**

The fructose spectrum shows the characteristic bands of sugar molecules, namely the O-H stretching at 3517.83 and 3342.36, cm^{-1} aliphatic C–H stretching at 2935.07 cm^{-1}, as well as the C-O-C of the furanose ring at 1046.68 cm^{-1} and the pyranose/furanose ring vibrations at 922.26 and 868.06 cm^{-1} as characteristic markers of fructose presence. The blank polymer spectrum shows characteristic bands of the MMA–EGDMA backbone, namely the C=O ester at 1724.36 cm^{-1}, aliphatic C-H at 2946.35 cm^{-1}, and C-O-C ester at 1138.87 cm^{-1}, without any characteristic fructose bands, confirming that the blank polymer consists solely of a pure polymer backbone. The NIP spectrum shows a combination of polymer bands and fructose bands, still trapped within the matrix. A broad O-H band appears more clearly at 3409.07 cm^{-1}, indicating the contribution of the fructose -OH group as well as hydrogen bonding interactions with the C=O ester groups of MMA. Bands at 1637.73 cm^{-1} as well as the fructose fingerprint bands at 1043.29 and 868.95 cm^{-1} further confirm the presence of the

template within the polymer matrix at this stage (Sirumapea et al., 2021). After extraction, the MIP spectrum showed significant changes. The broad -OH band around 3400 cm^{-1} that previously appeared in the NIP was no longer observed; similarly, the band at 1637 cm^{-1} and the characteristic fructose bands in the 1043 cm^{-1} and 868 cm^{-1} regions either disappeared or experienced a drastic decrease in intensity. The MIP spectrum was once again dominated by characteristic polymer bands, namely the C=O ester band at 1727.41 cm^{-1}, the aliphatic C-H band at 2949.90 cm^{-1}, and the C-O-C ester bands at 1253.08 cm^{-1} and 1145.76 cm^{-1}. The significant decrease in the intensity of the -OH band in the MIP spectrum compared to the NIP spectrum indicates that most of the fructose molecules have been successfully removed from the polymer matrix through the extraction process. However, quantitative confirmation of the completeness of the template extraction requires additional analysis, such as monitoring the wash solutions or repeating the washing process until no fructose is detected, which may be recommended for future research (Herlina et al., 2025).

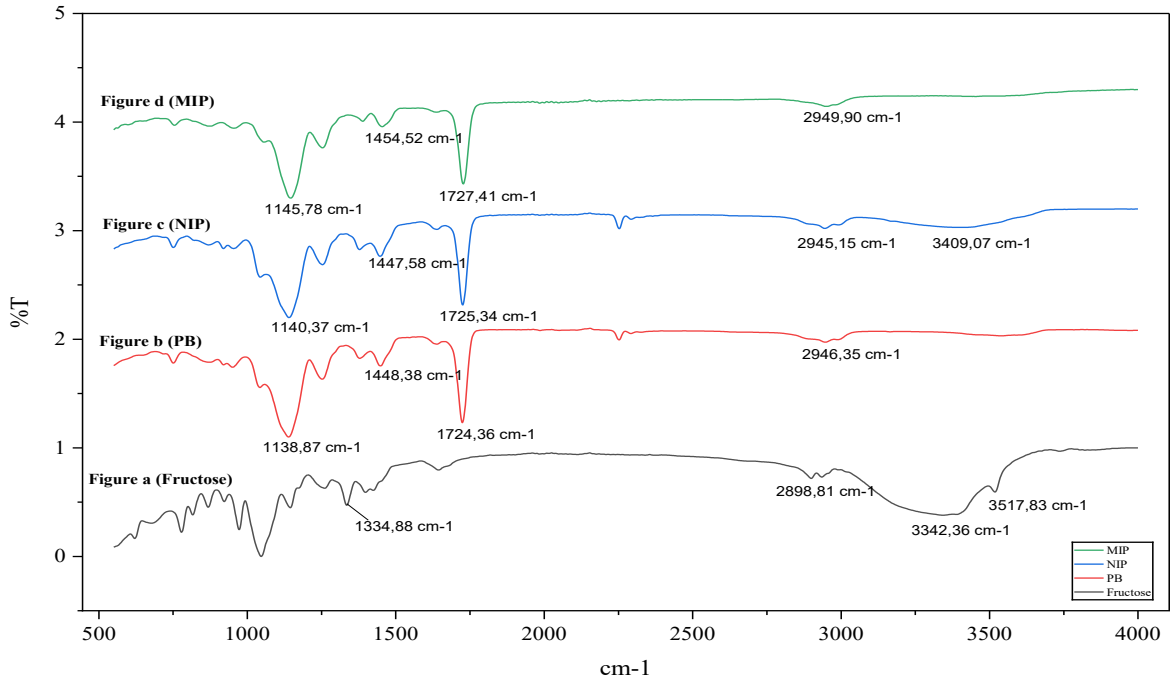
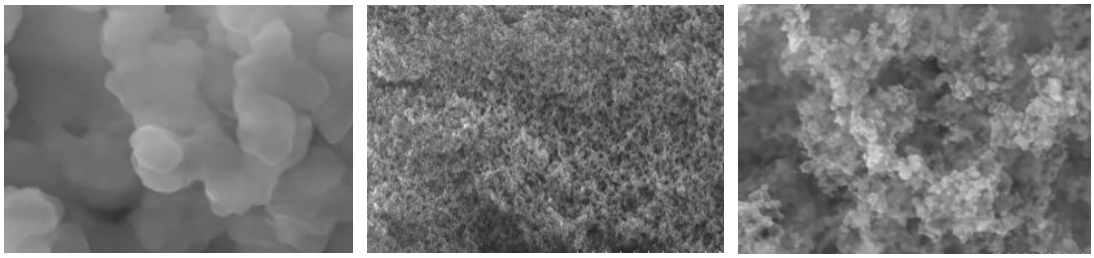


Figure 2. FTIR characterization results of (a) Fructose (b) PB (c) NIP (d) MIP

3.4. SEM Morphological Analysis

Conducted SEM morphological analysis at a magnification of 5000-20.000× to examine differences in surface morphology among PB, NIP, and MIP following the template extraction process (**Fig. 3**). The PB (**3a)** exhibited a dense, homogeneous structure with compact particle agglomeration and minimal porosity, indicating the absence of cavity formation due to the lack of template molecules that would otherwise serve as molecular molds within the MMA–EGDMA polymer matrix. The NIP (**3b**) displayed a relatively dense and compact morphology with a smooth surface, undeveloped pores, and no well-defined cavities, indicating that the template molecules remained entrapped within the polymer matrix, occupying the interstitial

spaces of the network and increasing structural density through hydrogen bonding interactions between the –OH groups of fructose and the ester C=O groups of MMA. The MIP (**3c**) exhibited the most significant morphological transformation, characterized by a rougher and more heterogeneous surface with clearly visible cavities and interparticle gaps. This increase in porosity provides evidence supporting the success of the molecular imprinting process, in which the removal of the template molecule results in the formation of specific recognition sites (Hasaneen et al., 2024).



(a) (b) (c)

Figure 3. SEM characterization results of (a) PB (b) NIP (c) MIP

3.5. Determination of Optimum Electrode Composition

The MIP modified electrode with the optimal composition was used as the working electrode. Each condition electrode composition variation was measured once per condition, so the reported IpC values represent single measurements, not averages of repeated measurements.

The cyclic voltammetric responses of electrodes with varying compositions are presented in **Fig. 4.** After obtaining the voltammogram results for the different electrode compositions, the IpC value was determined from the highest peak current for each composition, as shown in the **Table 1.**

The condition selected as the optimal condition was determined based on the highest cathodic peak current (IpC) value observed among the tested conditions. The composition of 1:1:2 (Agar: MIP: KCl) yielded the highest cathodic peak current (IpC) of -6.0583×10^{-3} A.

The dominance of KCl enhanced ionic conductivity and accelerated ion transport to the electrode surface, enabling more efficient fructose reduction at the MIP active sites. Compositions with a higher proportion of MIP (1:2:1) or agar (2:1:1) produced lower responses due to the insulating properties of both matrices, which hindered electron transfer. Based on these results, an Agar:MIP:KCl ratio of 1:1:2 was determined to be the optimal ratio for the detection of fructose using cyclic voltammetry.

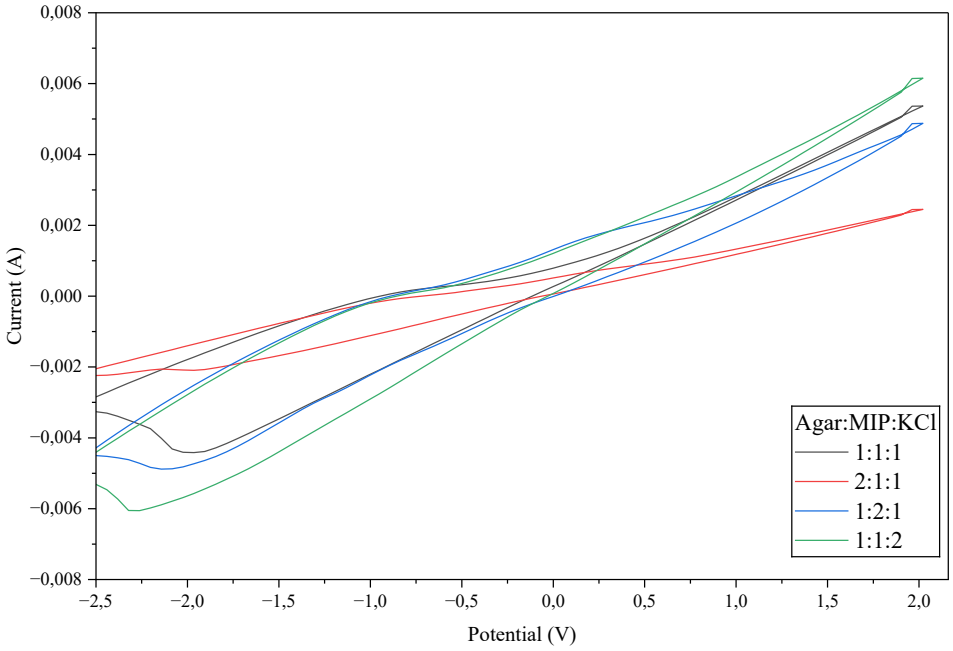


Figure 4. Cyclic voltammogram of electrode composition variations

Table 1. IpC values of electrode composition variations

Compositon Agar: MIP: KCl	**IpC (A)**
1:1:1	-4,4213 × 10^{-3}
1:1:2	-6,0583 × 10^{-3}
1:2:1	-4,8791 × 10^{-3}
2:1:1	-2,0726 × 10^{-3}

3.6. Determination of Optimum pH

The pH of the solution affects the stability and the electrodes performance during measurement (Sihombing & Hakim, 2020). Each condition pH variation was measured once per condition, so the reported IpC values represent single measurements, not averages of repeated measurements.

The cyclic voltammetric response at various pH levels is shown in **Fig. 5.** After obtaining the voltammogram results for the different pH, the IpC value was determined from the highest peak current for each composition, as shown in **Table 2.**

The condition selected as the optimal condition was determined based on the highest cathodic peak current (IpC) value observed among the tested conditions. The results showed that pH 5 yielded the highest IpC of -3.4224 × 10^{-3} A. This condition optimally supports fructose adsorption via hydrogen bonding between the fructose hydroxyl groups and the MIP active sites, while providing sufficient proton availability to facilitate the electrochemical redox mechanism. An increase in pH toward alkaline conditions reduced the IpC by decreasing H^+ ion availability. Meanwhile, a pH value that is too low (pH 4) causes overprotonation, which can lower the IpC value. Who also identified pH 5 as the optimal condition for a MIP modified electrode.

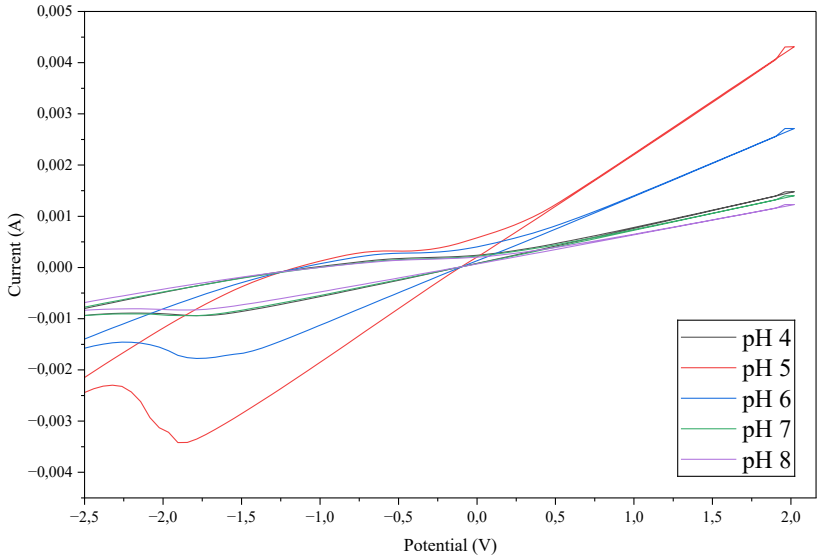


Figure 5. Cyclic voltammogram pH variations

Table 2. IpC values of pH variations

pH	IpC (A)
4	$-9{,}4163 \times 10^{-4}$
5	$-3{,}4224 \times 10^{-3}$
6	$-1{,}7790 \times 10^{-3}$
7	$-9{,}4224 \times 10^{-4}$
8	$-8{,}3543 \times 10^{-4}$

3.7. Determination of Optimum Deposition Time and Scan Rate

Deposition time determines the amount of analyte accumulated on the electrode surface before potential scanning (Rusnadi & Setiarso, 2020). Each condition deposition time and scan rate variation was measured once per condition, so the reported IpC values represent single measurements, not averages of repeated measurements. The cyclic voltammetric responses for variations in deposition time is shown in **Fig. 6.** After obtaining the voltammogram results for the different deposition time, the IpC value was determined from the highest peak current for each composition, as shown in the **Table 3.**

The condition selected as the optimal condition was determined based on the highest cathodic peak current (IpC) value observed among the tested conditions. The results showed that a deposition time of 5 seconds yielded the highest IpC of -4.9651×10^{-3} A. During longer deposition times, the accumulation of fructose on the electrode surface exceeds the binding capacity of the MIP cavities; this condition can inhibit electron transfer, leading to a decrease in cathodic current. Therefore, a deposition time of 5 seconds was established as the optimum condition, as it supported the most efficient electron transfer at the electrode surface.

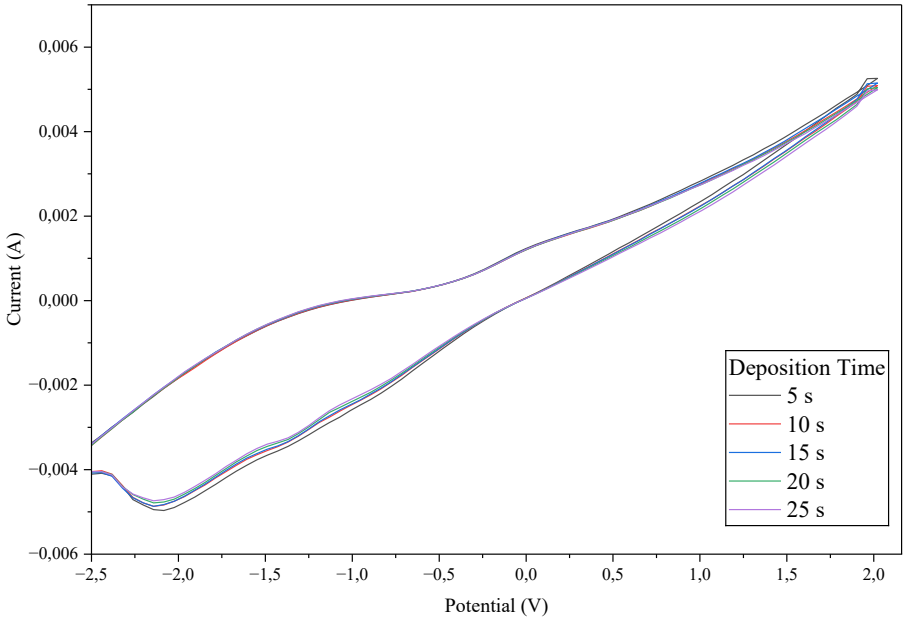


Figure 6. Cyclic voltammogram of deposition time variations

Table 3. IpC values of deposition time variations

Deposition time (s)	IpC (A)
5	-4,9651 x 10^{-3}
10	-4,8748 x 10^{-3}
15	-4,8678 x 10^{-3}
20	-4,7875 x 10^{-3}
25	-4,7359 x 10^{-3}

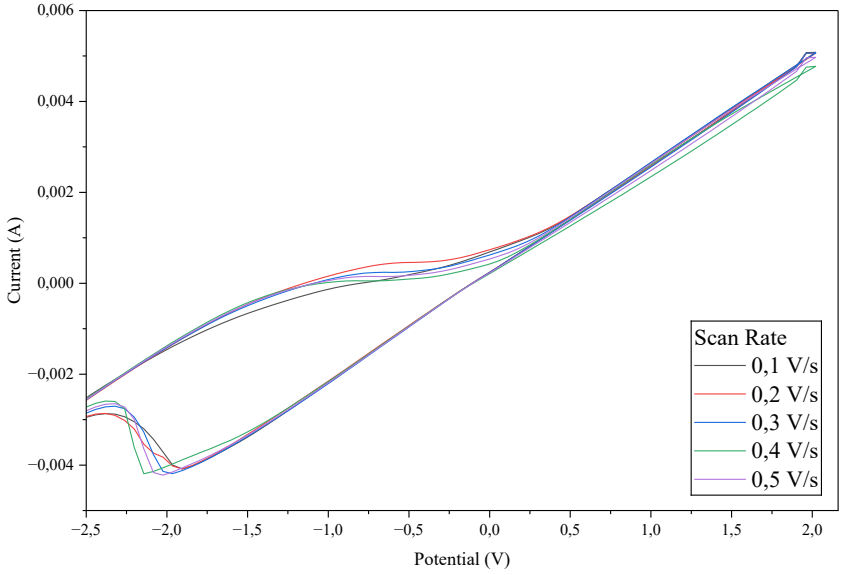


Figure 7. Cyclic voltammogram of scan rate variations

Table 4. IpC values of scan rate variations

Scan rate (V/s)	IpC (A)
0,1	-4,0860 × 10^{-3}
0,2	-4,0880 × 10^{-3}
0,3	-4,1210 × 10^{-3}
0,4	-4,1912 × 10^{-3}
0,5	-4,1924 × 10^{-3}

Scan rate influences the rate of diffusion layer formation and the magnitude of the peak current in the voltammogram. The cyclic voltammetric responses for variations in scan rate is shown in **Fig. 7**. After obtaining the voltammogram results for the different scan rate, the IpC value was determined from the highest peak current for each composition, as shown in the **Table 4**.

The condition selected as the optimal condition was determined based on the highest cathodic peak current (IpC) value observed among the tested conditions. The results demonstrated that IpC increased consistently with increasing scan rate, from -4.0860 × 10^{-3} A at 0.1 V/s to -4.1924 × 10^{-3} A at 0.5 V/s. This increase occurred because a higher scan rate accelerated the formation of the diffusion layer, thereby enhancing electron transfer at the electrode surface (Setiarso & Inggriani, 2021). Furthermore, the MIP and KCl modifiers accelerated the redox reaction rate at the electrode surface (Irdhawati et al., 2019). Based on these results, a scan rate of 0.5 V/s was established as the optimum condition for cyclic voltammetric measurement of fructose using the Agar: MIP: KCl modified electrode.

3.8. Comparison of MIP-modified electrodes in fructose and glucose

To ensure that the MIP-modified electrode used was selective for fructose, testing was conducted with another sugar glucosein three replicates. The testing was performed under various optimal conditions (electrode composition, pH, deposition time, and scan rate). The test results are shown in **Fig. 8**.

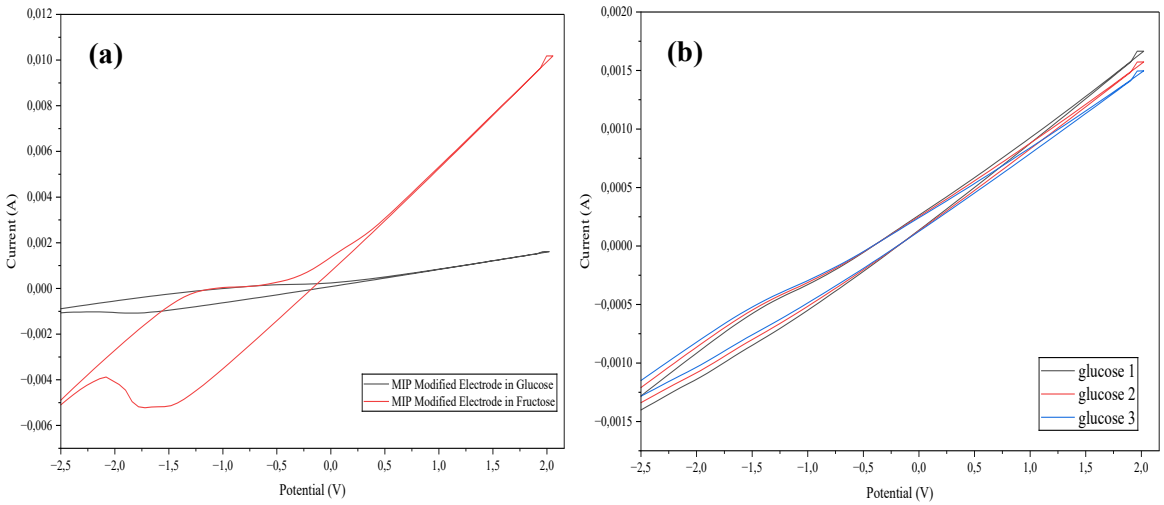


Figure 8. Comparison of MIP-modified electrodes in (a) fructose and (b) glucose

From the voltammogram data above, the IpC values were obtained from the highest current, as shown in **Table 5**. The measurement results show that the MIP (Molecularly Imprinted Polymer) electrode recorded the highest IpC value of -5.225 × 10^{-3} A. After the template extraction process, cavities of a specific size and shape corresponding to the fructose molecule were formed. These cavities allow fructose from the sample solution to enter and bind with optimal orientation, thereby significantly increasing the amount of fructose participating in the reduction reaction.

Supported by the ionic conductivity of KCl, electron transfer occurs more efficiently and produces the strongest electrochemical signal. When the electrode was tested on a glucose sample, the resulting peak current was very low, with an average IpC of (-1.276 × 10-3 A), and did not produce a broad electrochemical signal like that observed with the fructose sample. This data is crucial because it demonstrates that the cavities formed on the MIP are indeed specifically designed for fructose. Although glucose has a similar structure, it cannot fit perfectly into the MIP template. This proves that the developed MIP electrode exhibits high selectivity for fructose over glucose.

Table 5. IpC Values of MIP-modified electrodes in fructose and glucose

MIP-modified electrodes	IpC (Ampere)
In fructose	-5,225 × 10^{-3}
In glucose	-1,080 × 10^{-3}
In glucose 1	-1,402 × 10^{-3}
In glucose 2	-1,340 × 10^{-3}
In glucose 3	-1,285 × 10^{-3}

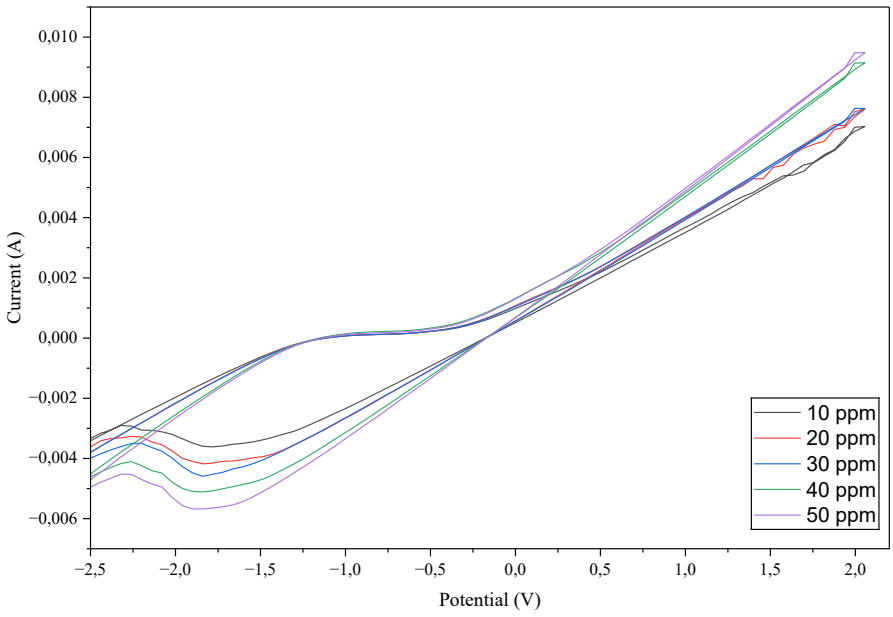


Figure 9. Cyclic voltammogram of fructose standard solutions

Table 6. IpC values of fructose standard solutions

Concentration (ppm)	IpC (A)
10	-3,6207 × 10^{-3}
20	-4,1810 × 10^{-3}
30	-4,5996 × 10^{-3}
40	-5,1199 × 10^{-3}
50	-5,6793 × 10^{-3}

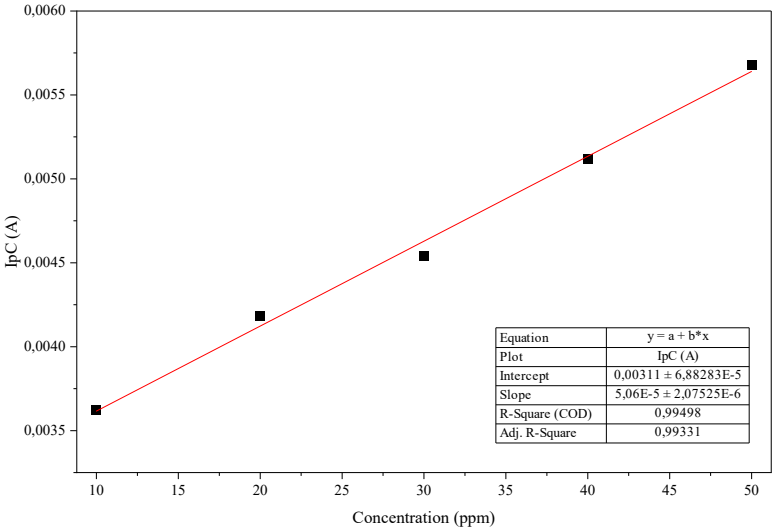


Figure 10. Calibration curve of IpC versus fructose standard solution concentration

Table 7. Absorbance values of fructose standard solutions

Concentration (ppm)	Absorbance
10	2,62 × 10^{-1}
20	2,73 × 10^{-1}
30	2,82 × 10^{-1}
40	2,93 × 10^{-1}
50	3,05 × 10^{-1}

3.9 Calibration Curves of Cyclic Voltammetry and UV-Vis Spectrophotometry

The cathodic peak current (IpC) values obtained from cyclic voltammetry at varying fructose concentrations were used to construct a calibration curve for fructose. The voltammogram results for the standard solution are shown in **Fig. 9.** Based on the results of the voltammogram, the IpC value was determined from the highest current value, as shown in **Table 6.** Next, a calibration curve was plotted showing the relationship between the standard solutions and the IpC values, as shown in the **Fig. 10.** Based on the IpC values, a standard fructose curve was plotted as

follows. From the cyclic voltammetry standard curve above, the equation of the line is $y = 0.0000506x + 0.00311$ with $R^2 = 0.99498$. Where these equations are used to calculate the recovery percentage, LOD, and LOQ as well as the honey content of each sample. Next, the standard solution was measured using UV-VIS spectrophotometry. The absorbance values are shown in the **Table 7.** Next, a calibration curve was plotted showing the relationship between the standard solutions and the absorbance values, as shown in the **Fig. 11.** From the UV-VIS spectrophotometer standard curve above, the equation is $y = 0.00105x + 0.2517$ with $R^2 = 0.9961$. Where these equations are used to calculate the recovery percentage, LOD, and LOQ as well as the honey content of each sample.

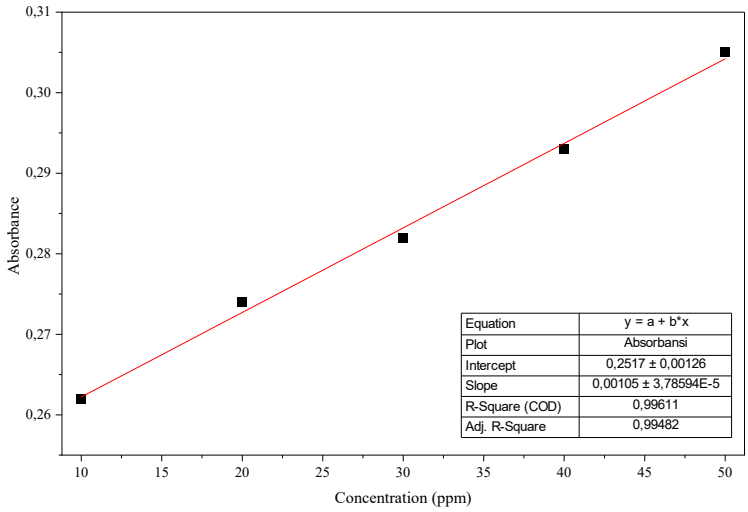


Figure 11. Calibration curve of Absorbance versus fructose standard solution concentration

3.9. Fructose Content Determination in Honey by Cyclic Voltammetry and UV-Vis Spectrophotometry

Subsequently, the honey samples were tested. The IpC values and sample absorbances were then substituted into the equations above to determine the honey's fructose content. The voltammogram results for the honey measurements are shown in **Fig. 12**. From the voltammogram results above, the IpC value is obtained from the highest current peak, as shown in **Table 8**.

Based on the IpC values above, the equation is $y = 0.0000506x + 0.00311$ with $R^2 = 0.99498$ was used to calculate the fructose content in honey. Thus, the cyclic voltammetric analysis yielded fructose contents of 27.667 ppm in honey A, 20.355 ppm in honey B, and 16.403 ppm in honey C. Next, the honey samples were analyzed using UV-Vis spectrophotometry, yielding the absorbance values shown in **Table 9**.

Based on the absorbance values above, the equation $y = 0.00105x + 0.2517$ with $R^2 = 0.9961$ was used to calculate the fructose content in honey. The UV-Vis spectrophotometry analysis yielded fructose contents of 25.047 ppm in honey A, 18.380 ppm in honey B, and 15.523 ppm in honey C.

The honey content results from both instruments were tested using an Independent Samples t-test in SPSS to determine whether there is a difference between measurements using UV-VIS and cyclic voltammetry, yielding a significance value (sig. 2-tailed) of $0.694 > 0.05$, indicating no significant difference between the cyclic voltammetry and UV-Vis spectrophotometry tests.

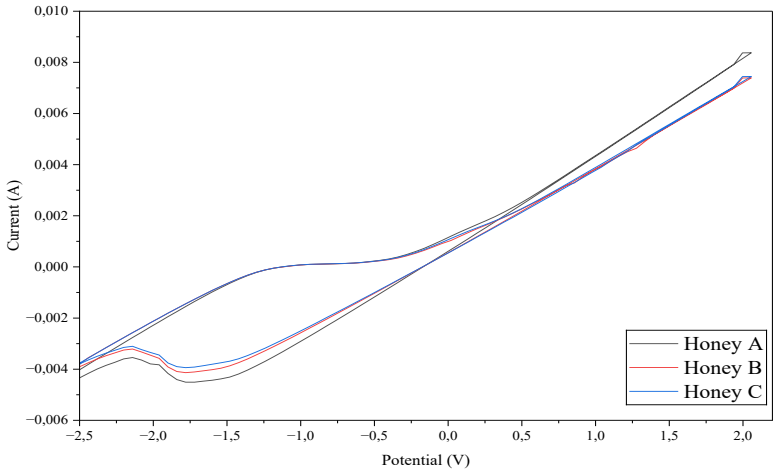


Figure 12. Cyclic voltammogram of fructose measurement in honey samples

Table 8. IpC values of honey sample measurements by cyclic voltammetry

Type of Honey	IpC (A)
Honey A	-4,5129 × 10^{-3}
Honey B	-4,1387 × 10^{-3}
Honey C	-3,9449 × 10^{-3}

Table 9. Absorbance values of honey sample measurements by UV-Vis spectrophotometry

Type of Honey	Absorbance
Honey A	2,780 × 10^{-1}
Honey B	2,710 × 10^{-1}
Honey C	2,680 × 10^{-1}

3.10. Limit of Detection (LOD), Limit of Quantitation (LOQ), and Percent Recovery

The Limit of Detection (LOD) is the lowest concentration of an analyte that an analytical instrument can detect. However, it cannot yet be accurately quantified. The Limit of Quantitation (LOQ) is the smallest concentration of an analyte that can be quantitatively determined with an acceptable level of accuracy and precision (Taleuzzaman, 2018). The calculations of the LOD and LOQ values using cyclic voltammetry can be found in **Table 10**.

$$\text{LOD} = \frac{3{,}3 \; x \; s(\frac{y}{x})}{slope} \quad \text{..... (1)}$$

$$\text{LOQ} = \frac{10 \; x \; s(\frac{y}{x})}{slope} \quad \text{..... (2)}$$

Based on the calculations, the cyclic voltammetry method yielded an LOD of 2.642 ppm, an LOQ of 8.808 ppm. Which demonstrates adequate detection capability for determining fructose levels in the sample matrix. The calculations of the LOD and LOQ values using UV-Vis spectrophotometry can be found in **Table 11.**

Table 10. LOD and LOQ Values Using Cyclic Voltammetry

Concentration (ppm)	IpC (Yi)	Ŷ	(Ŷ-Yi)²
10	3,620 × 10⁻³	3,616 × 10⁻³	1,600 × 10⁻¹¹
20	4,181 × 10⁻³	4,122 × 10⁻³	3,364 × 10⁻¹⁰
30	4,599 × 10⁻³	4,628 × 10⁻³	7,840 × 10⁻¹⁰
40	5,119 × 10⁻³	5,134 × 10⁻³	1,960 × 10⁻¹⁰
50	5,679 × 10⁻³	5,640 × 10⁻³	1,600 × 10⁻⁹
	∑(Ŷ − Yi)²		5,960 × 10⁻⁹
	s(y/x)		4,457 × 10⁻⁵
	slope		5,060 × 10⁻⁵
	LOD		2,642 ppm
	LOQ		8,808 ppm

Table 11. LOD and LOQ Values Using UV-Vis spectrophotometry

Concentration (ppm)	Absorbance (Yi)	Ŷ	(Ŷ-Yi)²
10	2,620 × 10⁻¹	2,620 × 10^{-1}	0
20	2,730 × 10⁻¹	2,730 × 10^{-1}	1 x 10^{-6}
30	2,820 × 10⁻¹	2,830 × 10^{-1}	1 x 10^{-6}
40	2,930 × 10⁻¹	2,930 × 10^{-1}	0
50	3,050 × 10⁻¹	3,040 × 10^{-1}	1 x 10^{-6}
	∑(Ŷ − Yi)²		3 x 10^{-6}
	s(y/x)		1 x 10^{-3}
	slope		1,050 x 10^{-3}
	LOD		2,857 ppm
	LOQ		9,524 ppm

Based on the calculations, the UV-Vis spectrophotometry yielded an LOD of 2.857 ppm, an LOQ of 9.524 ppm. Which demonstrates adequate detection capability for determining fructose levels in the sample matrix.

Percent recovery is a measure of how well an analytical method recovers a specific amount of a substance from a sample after testing. Percent recovery were calculated using the following equations.

$$\%\text{recovery} = \frac{Cmeasured}{Ctheoritical} \text{ x } 100\% \text{..... (3)}$$

The calculations of the recovery percentage using cyclic voltammetry are shown in **Table 12**. Based on the IpC values above, the equation $y = 0.0000506x + 0.00311$ with $R^2 = 0.99498$ was used to calculate the percentage recovery. The recovery percentage obtained using cyclic voltammetry was 101.112%. The calculations of the recovery percentage using UV-Vis spectrophotometry are shown in **Table 13**. Based on the absorbance values above, the equation $y = 0.00105x + 0.2517$ with $R^2 = 0.9961$ was used to calculate the percentage recovery. The recovery percentage obtained using UV-Vis spectrophotometry

was 98.500%. According to Harmita (2004), the acceptable range for the recovery percentage of an analyte is 90–110%. Both recovery values 101.112% for the cyclic voltammetric method and 98.50% for the UV-Vis spectrophotometric method fall within an acceptable range. This range is flexible depending on the analyte being tested, the sample concentration, and the laboratory conditions. Indicates that the voltammetry method using an MIP modified electrode good sensitivity and good accuracy for the analysis of fructose samples in honey.

Table 12. % Recovery in Cyclic Voltammetry

IpC (A)	C*theoritical* (ppm)	C*measured* (ppm)	%Recorvery
$3{,}620 \times 10^{-3}$	10	10,079	100,790%
$4{,}181 \times 10^{-3}$	20	21,146	105,730%
$4{,}599 \times 10^{-3}$	30	29,446	98,153%
$5{,}119 \times 10^{-3}$	40	39,723	99,307%
$5{,}679 \times 10^{-3}$	50	50,790	101,580%
	Mean		**101,112%**

Table 13. % Recovery in UV-Vis spectrophotometry

Absorbance	C*theoritical* (ppm)	C*measured* (ppm)	%Recorvery
$2{,}620 \times 10^{-1}$	10	9,809	98,090%
$2{,}730 \times 10^{-1}$	20	20,285	101,420%
$2{,}820 \times 10^{-1}$	30	28,857	96,190%
$2{,}930 \times 10^{-1}$	40	39,333	98,330%
$3{,}050 \times 10^{-1}$	50	50,761	101,430%
	Mean		**98,500%**

4. CONCLUSIONS

The optimal composition of the MIP-modified electrode was determined to be 1:1:2 (w/w) agar: MIP: KCl. The optimum measurement conditions for fructose determination in honey by cyclic voltammetry were pH 5, a deposition time of 5 seconds and a scan rate of 0.5 V/s, yielding an LOD of 2.642 ppm, an LOQ of 8.808 ppm, and a recovery of 101.112%. The fructose content determined by cyclic voltammetry was 27.667 ppm for honey A, 20.355 ppm for honey B, and 16.403 ppm for honey C, while the fructose content determined by UV-Vis spectroscopy was 25.047 ppm for honey A, 18.380 ppm for honey B, and 15.523 ppm for honey C. A comparison of fructose measurement results in honey using cyclic voltammetry and UV-Vis spectrophotometry showed no significant difference, as indicated by a significance value (sig. 2-tailed) of 0.694 > 0.05, confirming the reliability and validity of the developed MIP-modified electrode as a selective and sensitive analytical method for fructose determination in honey.

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LIST OF REFERENCES

Asni, N. K., & Sianita, M. M. (2020). Pengaruh jumlah *crosslinker* terhadap

persen ekstraksi pada sintesis *molecularly imprinted polymer* sebagai adsorben untuk kloramfenikol. *Unesa Journal of Chemistry*, *9*(3), 179–188. https://doi.org/10.26740/ujc.v9n3.p179-188

Barry, S. C. L., Franke, C., Mulaudzi, T., Pokpas, K., & Ajayi, R. F. (2023). Review on surface-modified electrodes for the enhanced electrochemical detection of selective serotonin reuptake inhibitors (SSRIs). *Micromachines*, *14*(7), 1334. https://doi.org/10.3390/mi14071334

Carballido, L., Karbowiak, T., Cayot, P., Gerometta, M., Sok, N., & Bou-Maroun, E. (2022). Applications of molecularly imprinted polymers and perspectives for their use as food quality trackers. *Chem*, 8(9), 2330–2341. https://doi.org/10.1016/j.chempr.2022.05.021

Codex Alimentarius. (2022). S *Standar for honey* (CXS 12-1981). FAO/WHO.

Silva, P. M., Gauche, C., Gonzaga, L. V., Costa, A. C. O., & Fett, R. (2016). Honey: Chemical composition, stability and authenticity. *Food Chemistry*, *196*, 309–323. https://doi.org/10.1016/j.foodchem.2015.09.051

Fransiska, S., & Sianita, M. M. (2021). Pengaruh suhu pada sintesis *Molecularly Imprinted Polymer* (MIP) terhadap kemampuan adsorpsi kloramfenikol. *Unesa Journal of Chemistry*, *10*(3), 209–219. https://doi.org/10.26740/ujc.v10n3.p209-219

Harmita. 2004. Petunjuk Pelaksanaan Validasi Metode dan Cara Perhitungannya. *Majalah Ilmu Kefarmasian.* 1(3).117 – 134. Departemen Farmasi FMIPA. Universitas Indonesia. Jakarta

Hasaneen, N., Akhtarian, S., Pulicharla, R., Brar, S. K., & Rezai, P. (2024). Surface molecularly imprinted polymer-based sensors for antibiotic detection. *TrAC Trends in Analytical Chemistry*, *170*, 117389. https://doi.org/10.1016/j.trac.2023.117389

Herlina, H., Ritonga, A. H., Andy Febriady, Asvia Rahayu, & Sinaga, N. G. (2025). Pengembangan material polimer cetak molekul sebagai elemen pengenalan selektif pada sensor elektrokimia meropenem. *Jurnal Farmasimed (JFM)*, *8*(1), 265–274. https://doi.org/10.35451/j884sv81

Inggriani, F. & Setiarso, P. (2020). Synthesis of graphene oxide-nanozeolite composite electrode for aspirin analysis by cyclic voltammetry. *Asian Journal of Chemistry*, *32*(10), 2541–2544. https://doi.org/10.14233/ajchem.2020.22556

Inggriani, F., & Setiarso, P. (2021). Pembuatan elektroda pasta karbon untuk analisis parasetamol secara differential pulse voltametri. *Indonesian Chemistry and Application Journal*, *4*(2), 27–31. https://doi.org/10.26740/icaj.v4n2.p27-31

Irdhawati, I., Indrayani, V. E., & Sahara, E. (2019). Teknik voltammetri pelucutan anodik menggunakan elektroda glassi karbon dalam penentuan kadar logam Fe dalam terong ungu. *Jurnal Kimia Riset*, *4*(2), 111–120. https://doi.org/10.20473/jkr.v4i2.15897

Jupri, R., Fauziah, S., & Taba, P. (2022). Sintesis dan karakterisasi *molecularly imprinted polymers* menggunakan metil metakrilat dan etilen glikol dimetakrilat sebagai adsorben di-(2-etilheksil) ftalat. *Journal of Pure and Applied Chemistry*, *5*(3), 105–120. http://dx.doi.org/10.26418/indonesian.v5i3.59132

Oktaningtias, E. F., & Sianita, M. M. (2025). Effect of extraction temperature of molecularly imprinted polymer in chloramphenicol adsorption using UV-Vis spectrophotometry based on diazotation reaction. *Jurnal Pijar Mipa*,

20(1), 29–34. https://doi.org/10.29303/jpm.v20i1.8001

Rao, H., Lu, Z., Ge, H., Liu, X., Chen, B., Zou, P., Wang, X., He, H., Zeng, X., & Wang, Y. (2017). Electrochemical creatinine sensor based on a glassy carbon electrode modified with a molecularly imprinted polymer and a Ni@polyaniline nanocomposite. *Microchimica Acta*, *184*(1), 261–269. https://doi.org/10.1007/s00604-016-1998-x

Rusnadi, W. R., & Setiarso, P. (2020). Pembuatan elektroda nano karbon untuk analisis logam Pb(II) secara siklik voltametri. *Unesa Journal of Chemistry*, *9*(1), 72–77. https://doi.org/10.26740/ujc.v9n1.p72-77.

Ruswandi, Oktavia, B., & Azhar, M. (2018). Penentuan kadar fruktosa hasil hidrolisis inulin dengan DNS sebagai pengoksidasi. *Eksakta*, *19*(1), 1–20. https://doi.org/10.24036/eksakta/vol19-iss01/102

Se, K. W., Wahab, R. A., Syed Yaacob, S. N., & Ghoshal, S. K. (2019). Detection techniques for adulterants in honey: Challenges and recent trends. *Journal of Food Composition and Analysis*, *80*, 16–32. https://doi.org/10.1016/j.jfca.2019.04.001

Shi, Z., Xia, L., & Li, G. (2023). Recent progress of electrochemical sensors in food analysis. *Chemosensors*, *11*(9), 478. https://doi.org/10.3390/chemosensors11090478

Sianita, M. M, Puspaningsih, N. N., Khazanah, M., & Supriyanto, G. (2019). Comparison of the method used for extraction chloramphenicol from its Molecularly Imprinted Polymer (MIP) using chloroform as porogen. *Atlantis Highlights in Chemistry and Pharmaceutical Sciences*, 1, 17-18. https://doi.org/10.2991/snk-19.2019.5

Sihombing, V. H., & Hakim, A. S. (2020). Penggunaan wolfram pada potensiometri untuk mendeteksi baffer pospat dan enzim urease. *Einstein Journal*, *9*(1), 46–52.

Sirumapea, L., Zulfikar, M. A., Amran, M. B., & Alni, A. (2021). Selective solid-phase extraction of meropenem from human blood plasma using a molecularly imprinted polymer. *Indonesian Journal of Chemistry*, *21*(5), 1167–1179. https://doi.org/10.22146/IJC.64025

Softic, S., Cohen, D. E., & Kahn, C. R. (2016). Role of dietary fructose and hepatic de novo lipogenesis in fatty liver disease. *Digestive Diseases and Sciences*, *61*(5), 1282–1293. https://doi.org/10.1007/s10620-016-4054-0

Taleuzzaman, M. (2018). Limit of Blank (LOB), Limit of Detection (LOD), and Limit of Quantification (LOQ). *Organic & Medicinal Chemistry International Journal*, *7*(5), 555722. https://doi.org/10.19080/omcij.2018.07.555722

Taskinen, M. R., Packard, C. J., & Borén, J. (2019). Dietary fructose and the metabolic syndrome. *Nutrients*, *11*(9), 1–16. https://doi.org/10.3390/nu11091987

Zulfikar, M. A. (2022). *Material fungsional polimer bercetakan molekul: Aplikasi dan tantangannya di masa depan* [Orasi Ilmiah Guru Besar]. Institut Teknologi Bandung.