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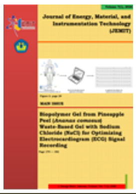

Biopolymer Gel from Pineapple Peel (*Ananas comosus*) Waste-Based Gel with Sodium Chloride (NaCl) for Optimizing Electrocardiogram (ECG) Signal Recording

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Abstract

*Pineapple peel (*Ananas comosus*) as organic waste has potential as a raw material for biomedical gel in electrocardiogram (ECG) recording. ECG gel functions as a conductive medium facilitating electrical transmission between skin and electrodes to improve cardiac signal accuracy. This study developed gel from pineapple peel waste with sodium chloride (NaCl) addition for ECG recording optimization. The process included pineapple peel extraction, gel formulation using carbomer 940, and extract concentration variations of 10-100%. Evaluation was conducted on physical properties including electrical conductivity, viscosity, pH, density, crust thickness, and ECG recording performance. Results showed gel with 20-50% pineapple peel extract had high conductivity, skin-compatible pH (4.5-7), and reduced crust thickness. ECG recording produced well-defined P, QRS, and T waves with minimal noise. These findings demonstrate that pineapple peel waste-based gel is a promising eco-friendly alternative for cardiac diagnostics and sustainable organic waste utilization.*

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Abstrak

Kulit nanas (Ananas comosus) sebagai limbah organik berpotensi sebagai bahan baku gel biomedis untuk perekaman elektrokardiogram (EKG). Gel EKG berfungsi sebagai media konduktif yang memfasilitasi transmisi listrik antara kulit dan elektroda untuk meningkatkan akurasi sinyal jantung. Penelitian ini mengembangkan gel dari limbah kulit nanas dengan penambahan natrium klorida (NaCl) untuk optimasi perekaman EKG. Proses meliputi ekstraksi kulit nanas, formulasi gel menggunakan carbomer 940, dan variasi konsentrasi ekstrak 10-100%. Evaluasi dilakukan terhadap sifat fisika seperti konduktivitas listrik, viskositas, pH, densitas, ketebalan kerak, dan kinerja perekaman EKG. Hasil menunjukkan gel dengan 20-50% ekstrak kulit nanas memiliki konduktivitas tinggi, pH kompatibel dengan kulit (4,5-7), dan ketebalan kerak berkurang. Perekaman EKG menghasilkan gelombang P, QRS, dan T terdefinisi baik dengan noise minimal. Temuan ini menunjukkan gel berbasis limbah kulit nanas merupakan alternatif ramah lingkungan yang menjanjikan untuk diagnostik jantung dan pemanfaatan limbah organik berkelanjutan.

1. Introduction

Indonesia ranks among the world's largest pineapple producers, with total production reaching 3.2 million tons in 2022, representing a 10.99% increase from the previous year's 2.8 million tons. This production growth reflects high demand for pineapples in both domestic consumption and export markets, demonstrating development in Indonesia's agricultural and agroindustrial sectors. Among all pineapple-producing regions in Indonesia, Lampung Province ranks first as the main producer with total production reaching 695.86 thousand tons annually, making it

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the national center of the pineapple plantation industry (Pusat Data dan Sistem Informasi Pertanian, 2023). The pineapple processing industry generates significant waste volume, considering annual pineapple production statistics reach approximately 40 million tons with disposal of inedible parts contributing about 60% of total weight (Gavahian, 2023). This rapid growth in Indonesia's pineapple processing industry presents immediate challenges, as high production volumes directly impact waste generation, particularly pineapple peels often neglected in conventional processing, potentially producing around 4,024,800 kg of pineapple peel waste annually from processing industries (Anggraini et al., 2022).

Various studies have demonstrated that pineapple peel waste (*Ananas comosus*) has significant potential for sustainable utilization across sectors as valuable alternative raw materials. Previous research shows pineapple peels can be utilized for probiotic beverages containing bioactive compounds like bromelain, flavonoids, and tannins, with antibacterial and prebiotic effects beneficial for health (Nurfaizin et al., 2023). Additionally, antioxidant activity studies indicate pineapple peel extracts, particularly with methanol solvents, have potential as strong natural antioxidants (Saka Nugraha et al., 2024). These studies show that pineapple peel waste utilization has evolved from conventional processing to high-value innovations through modern fermentation and extraction, contributing to circular economy, waste reduction, and applications in food, health, and energy sectors.

Recognizing its functional potential, pineapple peel waste is now developed further as gel-based material for technological and medical applications, particularly in electrogel production for medical applications including ECG gel. ECG gel functions as a conductive medium for electrical signals between skin and electrodes, optimizing signal recording quality (Ibrahim et al., 2016). Pineapple peel waste contains various bioactive compounds such as flavonoids, tannins, and bromelain enzyme with proteolytic properties (Salasa, 2019). These contents make pineapple peel waste potential material for ECG gel formulation due to its environmentally friendly and value-added nature. NaCl addition serves as electrolyte enhancing electrical conductivity, enabling better electrical signal transmission between skin and ECG electrodes (Adilah Wirdhani Lubis, 2020).

ECG gel usage is crucial in cardiac electrical signal recording as it enhances conductivity between skin and electrodes, ensuring more accurate and stable signals (Attia et al., 2019). Optimal electrode function requires adhesive gel as conductive medium, creating electrochemical processes between skin surface and electrodes for efficient electrical signal capture (Basuki, 2014). ECG gel contains conductive materials like salts or compounds with high electrical conductivity such as sodium chloride (NaCl), along with thickening agents like carbomer 940 maintaining gel viscosity and stability (Kesehatan et al., 2018). However, conventional commercial ECG gels made from synthetic polymer mixtures, humectants, electrolytes, and chemical additives can cause skin irritation including rashes, bacterial growth, and allergic contact dermatitis from compounds like paraben, formaldehyde, methylisothiazolinone (MIT), benzalkonium chloride, ethanol, isopropanol, sodium lauryl sulfate (SLS), synthetic fragrance, tartrazine, para-phenylenediamine (PPD), propylene glycol, and diethyl phthalate (DEP) (M. Avenel-audran et al., 2003; Soroudi et al., 2019; Wu et al., 2021).

Pineapple peel waste utilization as ECG gel base material has strong potential in medical fields due to chemical properties rich in bioactive compounds and natural electrolytes [4]. Research has successfully developed hydrogels based on agarose and hyaluronic acid reinforced with phenolic compounds from pineapple peels, proving technical validity and formulation stability (Yin et al., 2024). Furthermore, oxidized cellulose from pineapple peels can be used in electric field-responsive hydrogels showing adaptability and structural stability under electrical stimulus, important properties for ECG signal transmission and recording. Flavonoid and phenolic contents in pineapple peels have been utilized in green synthesis of AgNPs, providing antioxidant and antibacterial activities valuable for developing electrogel materials that are not only electrically efficient but also medically safe and beneficial (Das et al., 2019). Therefore, developing ECG gel based on pineapple peel waste with various extract concentrations represents an innovative medical solution, supporting gel stability while NaCl addition enhances electrical conductivity for optimal signal transmission, promoting sustainable and innovative natural material usage applicable in healthcare industries.

2. Research Methods

2.1 Materials and Equipment

This study utilized specific equipment including a blender, oven, beakers, measuring cups, Biobase digital scale, glass stirrer, spatula, Sakurama Electrical Conductivity meter, Brookfield viscometer, metal plates, Philips hair dryer, SH-2 magnetic stirrer, Batavialab pH meter, Avntru digital thickness gauges, and EDAN ECG equipment set. The materials comprised 420 ml of pineapple peel waste extract, Chemical Products NaCl electrolyte salt, Rendys Chemical carbomer 940, distilled water, and 10% Edukanca NaOH. Onemed conventional ECG gel served as the control sample for comparison with the developed pineapple peel waste-based gel (**Figure 1**).

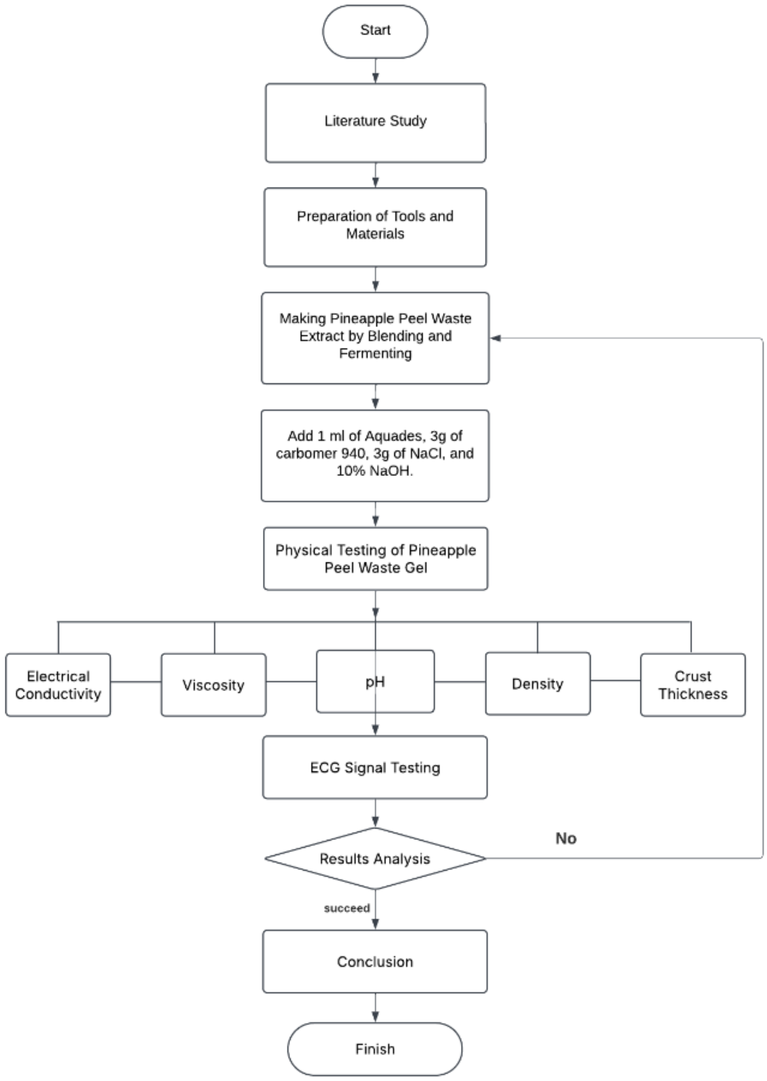

Figure 1. Research process

2.2 Sample Preparation and Gel Formulation

The research process began with pineapple peel waste collection from vendors, followed by thorough cleaning to remove dust, dirt, and pesticide residues. The cleaned peels underwent saltwater immersion for 30 minutes to reduce surface bacterial count, then oven-dried at 70°C for 190 minutes to prevent microbial growth. The dried peels were ground using a blender and fermented for 72 hours to produce the extract. Gel formulation involved mixing varying concentrations of pineapple peel extract (10%, 20%, 30%, 50%, and 100%) in 200 ml total volume with aquadest water, 3 grams of NaCl electrolyte salt, and 3 grams of carbomer 940. The pH was adjusted using 10% NaOH solution to match physiological skin pH levels.

2.3 Physical Parameter Testing

The formulated gels underwent comprehensive physical characterization including electrical conductivity measurement using an EC meter with probe insertion directly into gel samples, with acceptable values ranging from 100 µS/cm to 1000 µS/cm. Viscosity testing employed a Brookfield viscometer at rotational speeds of 2-5 rpm, targeting values below 10,000 cps for optimal performance. pH measurement utilized a calibrated pH meter with direct probe immersion, maintaining values within the 4.5-7 range suitable for skin contact. Density determination involved manual calculation by dividing gel mass (measured using digital scale) by volume (measured using 50 mL graduated cylinder), targeting the standard value of 1.08 g/cm^3. Crust thickness analysis was conducted by placing 1 gram of gel on metal plates, drying with a hair dryer, and measuring thickness using digital thickness gauges, with the standard thickness being 0.0035 cm.

2.4 ECG Signal Analysis

ECG signal evaluation was performed using a complete ECG system consisting of ECG machine, cables, electrodes, computer, and the test gels. Signal quality assessment focused on P wave characteristics (positive in leads

I and II, optimal display in leads II and V1, bifasic in lead V3), with normal duration less than 3 small squares and amplitude less than 2.5 small squares. PR interval measurements ranged from 0.12-0.20 seconds, measured from P wave onset to QRS complex beginning, ensuring clear P, QRS, and T wave definition with minimal noise interference (**Figure 2**).

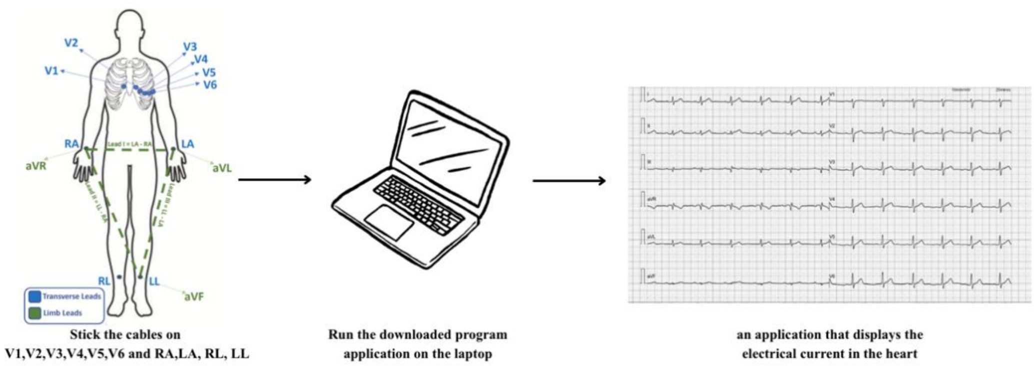

Figure 2 ECG signal acquisition diagram

2.5 Data Analysis and Statistical Methods

Data analysis employed descriptive methods to evaluate and compare physical characteristics of pineapple peel waste-based ECG gel against conventional gel. Statistical analysis included mean calculation for data representation, normalization methods applied to viscosity, density, and crust thickness parameters using the formula 1, standard deviation calculation to assess data variability, and coefficient of variation (CV) determination with values below 5% considered ideal for good precision. All measurements were conducted in triplicate to ensure reproducibility, with results compared against conventional ECG gel standards to assess the effectiveness and feasibility of pineapple peel waste-based gel as an environmentally friendly alternative for cardiac diagnostic applications.

$$Norm = 1 - \frac{X_{variation} - X_{control}}{Biggest\ gap} \quad (1)$$

3. Results and Discussions

3.1 Electrical Conductivity

Electrical conductivity is an important parameter in ECG gel development as it determines the gel's ability to conduct electrical signals from the skin to the electrodes. In this study, the gel base material was derived from fermented pineapple peel waste to obtain active compounds that play a role in enhancing electrical conductivity values (Irani et al., 2018), which was supplemented with 3 grams of NaCl electrolyte salt (Fitrya et al., 2022). Electrical conductivity values were measured using an EC Meter at various concentrations of pineapple peel waste, as shown in **Figure 3**.

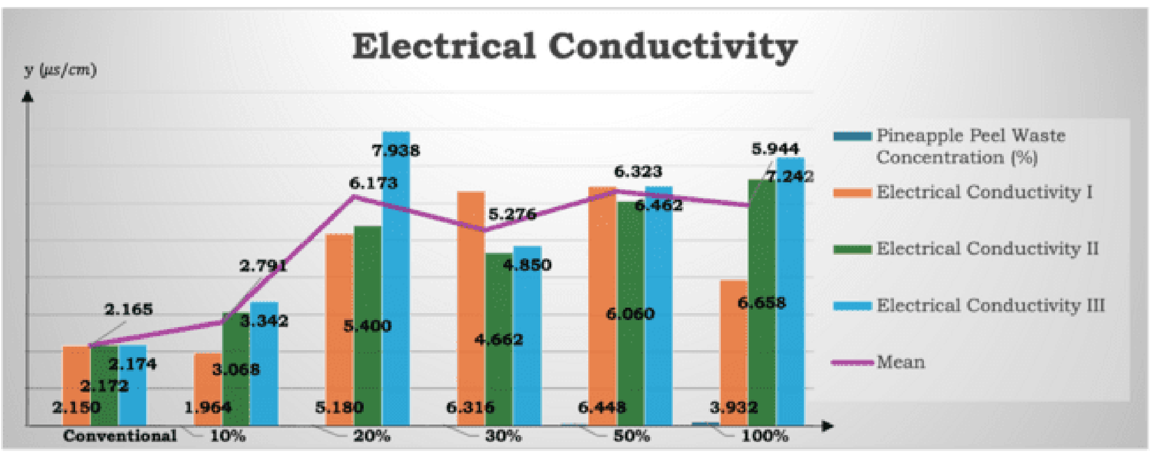

Figure 3. Electrical Conductivity Test Results Diagram

Pineapple peel can be utilized as a conductive medium in ECG gel applications because it contains ionic compounds that enable electrical current conduction. The electrical conductivity in pineapple peel originates from organic acid content such as citric acid which produces H^+ ions, strong electrolyte minerals such as sodium, potassium, and magnesium that dissolve to form charged ions, as well as carbohydrates that can be fermented into additional acid compounds (Sitanggang et al., 2021). Based on the data **Figure 3**, it is known that the electrical conductivity value of conventional ECG gel has an average of 2.165 μS/cm, which serves as a reference in assessing the effectiveness of the developed gel. The formulation with 10% concentration showed increased conductivity compared to the control, averaging 2.791 μS/cm. Although the first measurement was relatively low compared to conventional gel, the second and third measurements showed increases. This indicates that although conductive compounds from fermentation begin to emerge, their quantity is not yet sufficient to significantly outperform conventional gel performance in the initial preparation (Putri & Abdul Halim Daulay, 2021). At 20% concentration, conductivity increased to an average of 6.172 μS/cm, making it a formulation with considerably high conductivity compared to conventional ECG gel.

This result demonstrates synergy between natural electrolyte compounds from fermentation and ions from added NaCl (Navaratnam et al., 2020). This value is nearly three times higher than conventional gel, showing significant superiority in electrical signal transmission efficiency. Formulations with 30% concentration ranging at 5.276 μS/cm and 50% ranging at 6.323 μS/cm also showed high conductivity, both remaining much higher than conventional gel. Meanwhile, the 100% concentration ranging at 5.944 μS/cm still demonstrated electrical conductivity superiority over conventional gel (Zakzak et al., 2024). Variations in each concentration and repetition can occur due to differences in manual stirring, contact duration, or waste distribution in solution, which are commonly found in similar research and highlight the importance of standardizing experimental procedures to obtain consistent results (Djamalu et al., 2019; Rahmasari Pohan, 2021).

3.2 Viscosity Test Results

Viscosity is an important physical parameter in ECG gel formulation as it determines how well the gel adheres to skin and electrodes without easily flowing or drying out. Viscosity values that are too high can complicate application, while viscosity that is too low will cause the gel to spread easily and become unstable during use (Komachi et al., 2017).

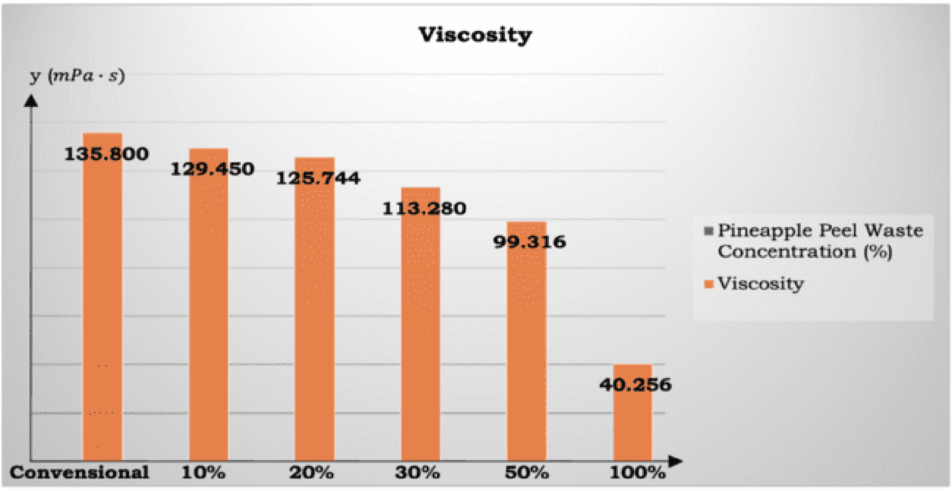

Figure 4. Viscosity Test Results Diagram

Based on **figure 4**, the viscosity of conventional gel available in the market is at 135.800 mPa.s, which serves as a reference comparison in this study. Meanwhile, all gel formulas developed using pineapple peel waste as the base material with the addition of 3 grams of NaCl and 3 grams of carbomer 940, as well as pH adjustment using 10% NaOH, showed varying results. At 10% pineapple peel waste concentration, the resulting viscosity was 129.450 mPa.s, approaching the control gel viscosity. At 20% concentration, the viscosity decreased to 125.744 mPa.s, but this value is still within the ideal range for ECG gel applications (Septiani & Fitriyani, 2025). Conditions began to change significantly at 30% and 50% concentrations, where viscosities decreased to 113.280 mPa.s and 99.316 mPa.s, respectively. A drastic decrease occurred at 100% concentration, with viscosity only reaching 40.258 mPa.s, which is considered too low for medical gel standards as it can cause the gel to flow easily and become unstable when used on electrodes (Fan et al., 2021).

The phenolic and flavonoid content in pineapple peel extract can form both hydrogen and hydrophobic interactions with polar groups on polymers, which can disrupt internal cross-linking between polymer chains, making the gel structure looser and reducing viscosity (Ode et al., 2024). The presence of bromelain, a natural proteolytic enzyme in pineapple peels, also contributes by cleaving protein bonds or other polymer components, which weakens the gel structure and reduces overall viscosity. Although its direct effect on viscosity has not been extensively studied explicitly, logically the reduction in network structure supports the decrease in viscosity (Lourenço et al., 2021).

3.3 pH Gel

The acidity level (pH) is an important parameter in ECG gel formulation as it directly relates to the comfort and safety of gel use on human skin. Generally, skin pH ranges from 4.5 to 7 (Novi Titin Wijayanti, 2018), therefore gel formulation must be within this range to avoid irritation or disruption to the skin's natural balance.

Table 1 shows the measurement results of acidity levels (pH) from the control gel and those formulated with varying concentrations of pineapple peel waste, namely 10%, 20%, 30%, 50%, and 100%. Measurements were conducted three times for each concentration, and pH values were expressed on a pH scale (unitless). In the control sample, pH values were recorded as 7.23, 7.27, and 7.30, indicating neutral characteristics (Infokom PPNI Jaktim, 2021). At 10% pineapple peel waste, pH decreased to 6.49, 6.60, and 6.72. A further decrease was observed at 20% concentration with pH values of 6.15, 6.25, and 6.45. At 30% concentration, pH ranged from 6.49, 6.51, and 6.67. Meanwhile, at 50% concentration, pH was recorded stable at 6.22, 6.23, and 6.24. For the highest concentration of 100%, pH values were 6.28, 6.35, and 6.40. In the pineapple peel waste ECG gel formulation, pH remained within the safe range and approached the physiological pH of skin, which ranges from 4.5 to 7 (Infokom PPNI Jaktim, 2021; Lee et al., 2020).

Table 1. pH's gel

Pineapple Peel Waste Concentration (%)	pH			Mean	STD	KV(%)
	I	II	III			
Conventional	7.23	7.27	7.30	7.27	0.035119	0.48
10	6.49	6.60	6.72	6.60	0.115036	1.74
20	6.15	6.25	6.45	6.28	0.152753	2.43
30	6.49	6.51	6.67	6.56	0.098658	1.50
50	6.22	6.23	6.24	6.23	0.010000	0.16
100	6.28	6.35	6.40	6.34	0.060277	0.95

The pH testing represents a crucial stage to ensure product safety and suitability when applied to human skin. This examination is essential because pH within the physiological skin range (approximately 4.5 to 7) can help reduce irritation potential and maintain gel formulation stability during storage and application (Septiani & Fitriyani, 2025; Setyo Wiyono et al., 2019). At 10% pineapple peel waste concentration, pH values ranged from 6.49–6.72, indicating that at low concentrations, pineapple peel waste fermentation does not cause significant pH reduction and can be controlled with 10% NaOH addition (Nasoha et al., 2023)**.** At 20% and 30% concentrations, pH remained within the 6.15–6.67 range, which also complies with human skin tolerance limits (Novi Titin Wijayanti, 2018). These values demonstrate that fermentation compounds begin to exhibit acidic effects, yet can still be effectively neutralized through adjustment with base solution (10% NaOH). At 50% concentration, pH was slightly lower (around 6.22), but remained within safe limits (Nasoha et al., 2023). At 100% concentration, pH values ranged from 6.28 to 6.40, which remains relatively safe despite approaching the lower limit of normal skin pH (Anisah Putri Yuana Sari et al., 2024). This indicates that increased fermentation material concentration causes increased acidity, but not to the extent of creating strongly acidic gel. The addition of 10% NaOH proved effective in maintaining formulation pH stability (Nasoha et al., 2023).

The pH value differences across various pineapple peel waste concentrations, despite controlled treatment and environmental conditions, are primarily caused by substrate concentration effects on microorganism activity during fermentation processes. Different substrate concentrations result in varied organic acid production by microbes such as Saccharomyces cerevisiae, causing different pH changes, where 10% concentration tends to produce higher pH due to less acid accumulation, while 20% to 100% concentrations generate lower pH due to increased organic acid production (Nurwahyu Chamidy et al., 2023). Additionally, differences in nutrient availability, microorganism density, and metabolic rates at each concentration also contribute to pH variation despite identical procedures and environment (Febriningrum, 2013).

3.4 Density

Density or specific gravity is a physical parameter that describes the amount of mass per unit volume and serves as an important indicator in assessing the physical characteristics of a gel formulation. Density values significantly influence comfort, stability, and ease of gel application on skin surfaces, including medical applications such as ECG signal recording (Grigatti & Gefen, 2022).

Table 2. Density

Pineapple Peel Waste Concentration (%)	Density			Mean	STD	KV (%)
	I	II	III			
Conventional	1.0103	1.0705	1.0648	1.05	0.033233	3.17
10	1.2104	1.2103	1.2039	1.21	0.003724	0.31
20	1.0028	1.0029	1.0031	1.00	0.000153	0.02
30	1.2441	1.2438	1.2438	1.24	0.000173	0.01
50	1.0758	1.0757	1.0757	1.08	0.000058	0.01
100	1.1247	1.1247	1.1248	1.12	0.000058	0.01

From the data in **Table 2**, the highest density was recorded at 30% concentration, with respective values of 1.2441 g/mL, 1.2438 g/mL, and 1.2438 g/mL. Meanwhile, the lowest density was found at 20% concentration, with sequential values of 1.0028 g/mL, 1.0029 g/mL, and 1.0031 g/mL, indicating that this formulation has a balance between liquid and dissolved substances, making the gel sufficiently light yet stable and easy to apply (Kusumawati et al., 2023). The difference in density at each concentration of pineapple peel waste is influenced by the amount of dissolved substances contained in the solution, such as organic compounds, ions, and fermentation products (Garza & Ibarz, 2010). Higher concentrations tend to contain more dissolved solids, which increases the solution's density (Selvanathan & Masngut, 2021).

This increase in density indicates an increase in the number of dissolved substances or solid compounds in the gel, originating from fermented pineapple peel waste and additional contributions from NaCl and carbomer. This high density indicates that the formed gel tends to be denser and more viscous, which could provide better adhesion but also risks being less comfortable if too heavy (Fadillah et al., 2025). Generally, variations in pineapple peel waste concentration in gel formulation affect density values, recorded in grams per milliliter (g/mL). The higher the density value obtained, the greater the possibility of increased solid substances or dissolved compounds in the mixture, although further analysis is needed to draw this conclusion scientifically (Nigen et al., 2019).

Crust Thickness

Crust thickness is a parameter used to assess the physical stability of gel against evaporation when applied to the electrode surface. The thicker the crust formed, the greater the likelihood of gel experiencing dehydration or hardening, which can interfere with ECG signal transmission (Lee et al., 2020). Therefore, measuring crust thickness is important to ensure the gel remains in optimal condition during clinical use.

Measurements were conducted using a thickness gauge on the stainless steel electrode plate surface after the gel was dried using a hair dryer. The fermented pineapple peel gel formulation demonstrated good performance with crust thickness of approximately 0.01 mm, compared to conventional gel which had a thickness of 0.02 mm. This value indicates that the control gel has a tendency to form thicker crust layers, which may indicate water evaporation or solvent evaporation (Mao et al., 2016). The ideal condition from these results was observed at concentrations of 20% to 100%, where all variations showed low and uniform crust thickness (0.01 mm). Meanwhile, at 10% concentration, it still showed a thickness of 0.02 mm. This occurs due to the combination of water-rich pineapple extract and organic components, carbomer as a thickening agent, NaCl as a conductor, and pH adjustment with 10% NaOH that together produce gel, leaving dry residue (Novi Titin Wijayanti, 2018). This indicates that the formulated gel is capable of maintaining moisture well and minimizing crust formation that can interfere with conductivity and comfort during use (Carvalho et al., 2025).

In **Table 3**, all variations of pineapple peel waste concentration produced very low mean values, differences, standard deviation (Std), and coefficient of variation (CV) (<5%), indicating that the measurement precision level is high. These results demonstrate that natural formulations have good resistance to drying, making them ideal for ECG examinations (Sadia Afzal et al., 2022). The sufficiently high water content in the fermented gel and the stable gel bond structure provide distinct advantages in maintaining moisture and minimizing signal transmission interference due to gel drying during the examination process (Sriprablom et al., 2023).

Table 3. Crust thickness

Pineapple Peel Waste Concentration (%)	Crust thickness			Mean	STD	KV (%)
	I	II	III			
Conventional	0.02	0.02	0.02	0.02	0	0
10	0.02	0.02	0.02	0.02	0	0
20	0.01	0.01	0.01	0.01	0	0
30	0.01	0.01	0.01	0.01	0	0
50	0.01	0.01	0.01	0.01	0	0
100	0.01	0.01	0.01	0.01	0	0

In testing the effectiveness of ECG signal recording using conventional gel as a control, examination results showed a heart rate of 82 bpm per minute, which falls within the normal range (Heru Sulastomo et al., 2019). Based on the ECG examination that has been conducted, the cardiac condition shows good and normal results overall (Soliman et al., 2017). ECG or electrocardiogram is an examination that records the electrical activity of the heart to observe how the heart functions, and the examination results indicate that the subject's heart is functioning properly (Gonçalves et al., 2020).

Table 4. ECG signal recording

Parameter	Normal Value	Conventional Gel	Pineapple Peel Gel					Clinical Interpretation
			10%	20%	30%	50%	100%	
Heart rate (HR)	60-100bpm	82bpm	82bpm	73bpm	81bpm	75bpm	75bpm	Normal
P duration	60-120ms	106ms	107ms	105ms	107ms	103ms	101ms	Normal
PR interval	120-200ms	182ms	185ms	186ms	177ms	181ms	181ms	Normal
QRS duration	75-105ms	83ms	83ms	86ms	86ms	85ms	88ms	Normal
QT/QTc	350-450ms	335/393ms	337/395ms	344/380ms	338/394ms	343/385ms	342/384ms	Normal

Based on **table 4** conventional gel, regarding the P wave that indicates atrial activity, the results were very normal with a duration of 106 ms, which falls within the healthy range (60-120 ms) (Chen et al., 2022), with good waveform morphology indicating that both atria are functioning normally (Yasuma & Hayano, 2004)**.** The QRS complex, which is the most important part of the ECG and represents ventricular contraction when the ventricles pump blood throughout the body (Utari, 2016), showed excellent results with a duration of 83 ms within the normal range (60-120 ms), indicating that electrical impulses flow efficiently through the ventricles (Hnatkova et al., 2021).

The T wave, which represents ventricular repolarization after contraction, also displayed normal results, with QT/QTc intervals of 335/393 ms within healthy limits and normal T wave morphology in all examination areas (Rezuş et al., 2015). The quality of the ECG recording was excellent, with high wave clarity and minimal interference (Yadav et al., 2016). There was no noise from body movement or electrical interference that could disrupt result interpretation, with stable baseline recording and all waves clearly identifiable, making the examination results reliable and accurate (Sofie & Rizal, 2016a; Winursito & Korespondensi, 2022). The overall test results demonstrate that conventional gel is capable of providing optimal ECG signal quality for cardiac electrical activity analysis with parameters within normal ranges.

In the effectiveness testing of ECG signal recording using a gel based on pineapple peel waste with a 10% concentration, examination results showed a heart rate of 82 beats per minute, which falls within the normal range (Heru Sulastomo et al., 2019). Based on the ECG results obtained on **Table 4**, the overall cardiac condition of the subject demonstrated good and normal findings, as evidenced by the three main waves that reflect cardiac function (Gonçalves et al., 2020; Soliman et al., 2017). The P wave showed excellent normal results with a duration of 107 ms, falling within the normal range of 60-120 ms (Chen et al., 2022). The waveform morphology also appeared optimal, indicating that the heart beats with proper rhythm originating from the sinoatrial node, demonstrating that the subject's atria function effectively in pumping blood to the heart ventricles (Yasuma & Hayano, 2004). The QRS complex, representing ventricular contraction, also displayed normal results with a duration of 83 ms, remaining within the normal limits of 60-120 ms, indicating that electrical conduction in the ventricles operates efficiently (Hnatkova et al., 2021). The T wave, reflecting the cardiac recovery phase after contraction, showed normal results with QT/QTc values of 337/395 ms within normal limits, indicating proper cardiac recovery processes occurring within appropriate timeframes, along with normal T wave morphology (Rautaharju et al., 2009; Rezuş et al., 2015).

The quality of the subject's ECG recording was excellent, characterized by high wave clarity and minimal interference (Yadav et al., 2016). No disturbances or noise interfered with the reading, and the baseline recording appeared stable and clean across all leads. This enabled physicians to provide accurate and precise interpretations of each cardiac wave component (Sofie & Rizal, 2016b; Winursito & Korespondensi, 2022). Such high recording quality is crucial for ensuring accurate diagnosis. In conclusion, the subject's ECG results demonstrated a healthy heart with normal rhythm and proper electrical function, validating the effectiveness of the pineapple peel-based gel as a viable alternative for ECG electrode applications.

In testing the effectiveness of ECG signal recording using pineapple peel waste-based gel at 20% concentration, examination results showed a heart rate of 73 bpm per minute, which is a normal heart rate within the range of 60-100 bpm (Heru Sulastomo et al., 2019). Based on the ECG results conducted, overall the subject's heart condition showed good and normal results, which can be seen from the three main waves that reflect the heart's functioning (Gonçalves et al., 2020; Soliman et al., 2017). Based on **Table 4**, the examination results showed that the subject's P wave was very normal. The subject's P wave duration was 105 ms, which is within the normal range of 60-120 ms (Chen et al., 2022). The QRS duration in the subject was 86 ms, still within the normal limit of 60-120 ms (Hnatkova et al., 2021). The heart's electrical flow direction was also within the normal range at -11, where normal is -30° to 90°. All of this indicates that the subject's heart chambers pump blood very efficiently and strongly (Kashani & Barold, 2005; Sampson, 2016). The T wave, which describes the heart's resting phase after pumping blood, was also in normal condition. The subject's QT/QTc interval was 344/380 ms, which is within normal limits for heart resting time (Rezuş et al., 2015). The quality of the subject's ECG recording was very good with good signal clarity (Yadav et al., 2016). There was no noise, electrical interference, or vibrations that interfered with the reading. The baseline was stable and all waves were clearly visible, allowing for accurate and precise analysis. This clean recording also supports the certainty that the examination results truly reflect the subject's heart condition (Sofie & Rizal, 2016b; Winursito & Korespondensi, 2022).

In testing the effectiveness of ECG signal recording using pineapple peel waste-based gel at 30% concentration, examination results showed a heart rate of 81 bpm per minute, which is a normal heart rate within the range of 60-100 bpm (Heru Sulastomo et al., 2019). Based on **Table 4**, the ECG results conducted, the subject's heart condition showed very good and normal results. Overall, all measured parameters were within normal limits, indicating that the subject's heart functions optimally (Gonçalves et al., 2020; Soliman et al., 2017). The P wave on the subject's ECG shows electrical activity when the heart's atria contract. The P wave duration was 107 ms, which is within the normal range of 60-120 ms (Chen et al., 2022). The P wave shape also appeared normal and indicated that the heart rhythm originated from the correct location, namely the sinoatrial (SA) node. This was confirmed by the "Sinus Rhythm" diagnosis, which means the subject's heart beats with a normal and regular rhythm (Yasuma & Hayano, 2004). The quality of the subject's ECG recording was very good with optimal wave clarity (Yadav et al., 2016). The ECG baseline appeared stable and clean in all leads, indicating minimal interference or noise during recording. There were no movement artifacts, interference from muscle activity, or electrical interference that could disrupt result interpretation (Sofie & Rizal, 2016b; Winursito & Korespondensi, 2022).

In testing the effectiveness of ECG signal recording using pineapple peel waste-based gel at 50% concentration on **Table 4**, examination results showed a heart rate of 75 bpm per minute, which is a normal heart rate within the range of 60-100 bpm (Heru Sulastomo et al., 2019). Every time the heart beats, it produces an electrical signal that can be seen as a wavy line on ECG paper. The ECG results in this examination showed that the subject's heart works very normally and healthily (Gonçalves et al., 2020; Soliman et al., 2017). P wave had a duration of 103 ms, which is within the normal range of 60-120 ms. The wave shape in the heart rhythm also appeared normal (Chen et al., 2022). The QRS complex duration in the subject's heart was 85 ms, still within the normal limit of 60-120 ms. This indicates that electrical flow through the heart's ventricles proceeded smoothly and efficiently (Hnatkova et al., 2021). The subject's heart axis was also normal at -11 degrees, which is still within the normal range of -30 to 90 (Kashani & Barold, 2005; Sampson, 2016). The T wave represents the ventricular recovery phase after contraction. The corrected QT interval in the subject was 385 ms, which is normal because it falls within the range of 350-440 ms for men (Rezuş et al., 2015). The T wave shape also appeared clear and normal (Rautaharju et al., 2009). The quality of the subject's ECG recording was very good with optimal wave clarity (Yadav et al., 2016). The ECG baseline appeared stable and clean in all leads, indicating minimal interference or noise during recording. There were no movement artifacts, interference from muscle activity, or electrical interference that could disrupt interpretation (Sofie & Rizal, 2016b; Winursito & Korespondensi, 2022).

In testing the effectiveness of ECG signal recording using pineapeel waste-based gel at 100% concentration, examination results showed a heart rate of 75 bpm per minute, which is a normal heart rate within the range of 60-100 bpm. The ECG results in this examination showed that the subject's heart works very normally and healthily (Heru Sulastomo et al., 2019; Soliman et al., 2017). Based on **Table 4**, the P wave shows how the heart's upper chambers (atria) contract. In this ECG, the P wave had a duration of 101 ms, which is still within the normal limit of 60-120 ms. Its shape was also normal and regular, meaning the upper heart chambers work well and normally as they should (Chen et al., 2022; Yasuma & Hayano, 2004). The QRS complex depicts how the heart's lower chambers (ventricles) contract to pump blood. Results showed a duration of 88 ms, which is also normal (60-120 ms), and the wave shape was also normal without any abnormalities (Hnatkova et al., 2021; Sampson, 2016). The T wave reflects how the heart recovers after pumping blood. The measured QT interval was 342/384 ms, still within normal limits. The T wave shape was also normal in all examined areas, meaning the heart recovers well after each beat (Rautaharju et al., 2009; Rezuş et al., 2015). The quality of the subject's ECG recording was very good with optimal wave clarity (Yadav et al., 2016). The ECG baseline appeared stable and clean in all leads, indicating minimal interference or noise during recording. There were no movement artifacts, interference from muscle activity, or electrical interference that could disrupt interpretation (Sofie & Rizal, 2016b; Winursito & Korespondensi, 2022)**.**

4. Conclusions

Based on the results of comprehensive testing and data analysis that have been obtained, it can be concluded that this research has yielded very promising findings regarding the utilization of pineapple peel waste as a base material for alternative ECG gel.

First, the ECG gel with pineapple peel waste as the base material demonstrates competitive physical characteristics compared to conventional gel that has been used in medical practice. From the aspect of electrical conductivity, the research results demonstrate a significant increase at concentrations of 20–50% with a value range reaching ±7,900 µS/cm, indicating excellent electrical conductivity capability for ECG applications. Meanwhile, the best viscosity value was obtained at concentrations of 10–20% with a range of ±125,000–129,000 mPa·s, indicating optimal gel consistency for clinical use. The pH parameter of all tested formulations was within the safe range of 6.1–6.7, ensuring safety for skin application without causing irritation to patients. The optimal density value was observed at 20% concentration with a value of ±1.003 g/mL, showing ideal density, while the formed crust thickness tended to be thin at 0.01 mm, indicating good formulation stability.

Second, variations in pineapple peel extract concentration proved to significantly affect gel properties, where an interesting phenomenon occurred when higher concentrations made ECG signals clearer and sharper, but on the other hand, the gel became more liquid and less viscous. This creates a trade-off condition that requires optimization, so that moderate concentration provides the most balanced and optimal results. This best balance can be demonstrated at 20% concentration which successfully optimizes three main parameters namely viscosity, density, and crust thickness simultaneously, creating a gel formulation that has the best performance from various aspects of physical characteristics.

Third, the pineapple peel waste-based ECG gel at various tested concentrations proved capable of conducting ECG signals with the same quality as conventional gel that has been the standard in electrocardiography examinations. This finding is very significant because it shows that pineapple peel waste can not only be utilized as an environmentally friendly alternative, but also provides performance equivalent to tested commercial products, thus opening great opportunities for implementation in daily medical practice while maintaining the diagnostic accuracy required.

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