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Arduino Uno-Based Automatic Fruit Maturity Detection System for Orange (*Citrus sp.)* and Bell Fruits (*Syzygium aqueum*) Using Electrical Conductivity

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Abstract:

Accurate determination of fruit ripeness is essential to maintain product quality, flavor, and market value. However, traditional manual assessment methods, which rely on sensory observation (color, aroma, and texture), are often subjective and inconsistent. This study aims to design and develop an automatic fruit ripeness detection system based on electrical conductivity measurement in oranges and bell fruits. The system utilizes a three-electrode stainless steel needle probe connected to an ADS1115 Analog-to-Digital Converter (ADC) module and an Arduino Uno microcontroller. A refractometer was used for system calibration and reference data acquisition. Measurements were performed by inserting the probe into the fruit pulp to read the voltage value of the fruit's fluid. This electrical signal was correlated with the reference sugar content (%Brix) and subsequently classified into three categories: ripe, half-ripe, and unripe. Results show that the average voltage range for oranges in the ripe, half-ripe, and unripe categories was 2.74 V, 2.58 V, and 2.32 V, respectively. For bell fruits, the corresponding voltage ranges were 2.48 V, 2.26 V, and 2.08 V. These voltage values were derived from the experimental data presented in Table 1 and Table 2. The abstract reports the average voltage for each ripeness category, whereas the tables list individual measurement values, resulting in slight differences between the summarized and detailed data. The average relative error of the measurement was found to be approximately 5 %, which is considered acceptable for practical field application. This indicates that the developed system is capable of classifying fruit ripeness in a non-destructive, accurate, and rapid manner.

1. Introduction

Fruits are natural food sources containing essential nutrients for human health, such as vitamins, minerals, water, and dietary fiber [1]. Two tropical fruit varieties widely consumed in Indonesia are orange (*Citrus sp.*) and bell fruits (*Syzygium aqueum*). Oranges are well-known for being rich in Vitamin C, essential minerals (e.g., potassium), and natural sugars (glucose, fructose, and sucrose), which are vital for immune function and electrolyte balance [2] . Conversely, bell fruits are characterized by high water content, various vitamins (A, B, C), and minerals (such as calcium, magnesium, and phosphorus), supporting hydration, immunity, and metabolic processes. The diverse nutritional profile of these two fruits underscores their importance in meeting the community's daily vitamin and mineral requirements.

The prevalence of these fruits is supported by Indonesia's tropical climate, which provides ideal temperature and humidity conditions for their growth. Consequently, the production of oranges and bell fruits occurs almost year-round across various regions. This ensures the fruits are abundantly available in the market, establishing them as a leading commodity for both direct consumption and industrial processing. Despite their abundance, accurately assessing the ripeness level remains a challenge for consumers. Ripeness determination is typically performed subjectively, based on visual (skin color) and sensory (aroma and texture) cues, leading to inconsistent and unreliable assessment between individual fruits [3]. Furthermore, external factors such as lighting conditions, fruit variety, and storage history can influence the perception of maturity, potentially introducing assessment errors.

To address this subjectivity, an objective ripeness detection method is required that can quantify changes in the fruit's physical or chemical properties during maturation [4]. One relevant parameter is electrical conductivity, defined as the capacity of a material to transmit an electric current. The conductivity value in fruit is highly influenced by ion concentration, water content (moisture), and the concentration of dissolved solids, such as sugars and organic acids. As ripening progresses, changes in tissue structure and cellular ion levels occur, leading to a corresponding alteration in conductivity values. Therefore, conductivity measurement serves as a reliable quantitative indicator for assessing fruit ripeness.

Objective methods for fruit ripeness detection have been extensively explored, primarily utilizing approaches such as digital image processing and machine learning (ML). For instance, Fan (2022) combined the YOLOv5 algorithm with the Dark Channel method to achieve 90% accuracy in classifying strawberry ripeness, though the model's flexibility is limited across different fruit types or lighting conditions [5]. Similarly, Filoteo-Razo (2023) implemented an Artificial Neural Network (ANN) for orange ripeness detection, which yielded an accuracy of 96.4% but required extensive training datasets for robust performance [6]. Bagaskara (2023) analyzes the ripeness of peaches through a statistical approach to sugar content, fruit size, and firmness [7]. Furthermore, Lu (2022) demonstrated the influence of nutrient solution conductivity on tomato plant growth, which indirectly affects fruit quality and ripeness. Overall, while these studies underscore the importance of objective methods, most remain heavily reliant on visual imaging techniques or large training datasets [8]. Unlike previous studies that rely heavily on image bases or machine learning based optical systems which require large datasets and are sensitive to lighting variations this study introduces a direct electrical conductivity measurements approach integrated with Arduino and ADS1115. This enables a rapid, low cost, and dataset novelty of the present work.

This study presents applies direct electrical conductivity measurements approach to determine the ripeness level of oranges and water guavas using a simple, low-cost Arduino-based system. This method differs from most previous studies that rely visual techniques, as it focuses on developing a practical electronic device capable of preforming automatic and rapid *on-site* ripeness classification. In addition, the storage of calibration data in EEPROM and the analysis of the relationship between voltage and sugar content (%Brix) using linear regression serve as additional features that enhance the reliability of the developed device.

2. Theoretical Framework

2.1. Electrical Conductivity

Electrical conductivity (σ) is a physical quantity that describes the ability of a material to conduct an electric current. Microscopically, the electric current (I) in a conductor is defined as the number of electrons (charges) flowing through the conductor's cross-section per unit of time. The relationship between current (I) and current density (J) is as follows:

$$J = \frac{I}{A} \tag{1}$$

Where is the area of the conductor's cross-section. In solid materials such as metals (conductor wires), the electrons moving at the terminal velocity ($\mathcal{V}$), which are found to be directly proportional to the strength of the electric field (E) in the material, are formulated as follows:

$$\mathcal{V} = \mu E. \tag{2}$$

This comparative constant μ is known as electron mobility.

Based on the microscopic definition and the relationship of the electron velocity to the electric field, the current density (J) in the conductor can be lowered. If is the density of electrons (the number of electrons per unit volume) and e is the charge of one electron, then the flowing electric current can be expressed as $I = neA\mu E$. Therefore, the current density (J) is the current of each cross-sectional unit, the equation of which becomes:

$$J = \frac{I}{A} = ne\mu E = \sigma E \tag{3}$$

This equation is known as the microscopic form of Ohm's Law, where $\sigma = ne\mu$ is electrical conductivity. The greater the conductivity value (σ), the easier it is for the material to conduct electricity. The SI unit for electrical conductivity is Siemens per meter (S/m) [9].

In addition to solid materials, the concept of conductivity is highly relevant in electrolyte solutions. An electrolyte solution contains electrically charged ions, namely cations (positive ions) and anions (negative ions), which serve as charge carriers for electric current. When a potential difference (voltage) is applied across two immersed electrodes, cations migrate toward the negative electrode while anions migrate toward the positive electrode. The conductivity of such a solution is dependent on the type of electrolyte; strong electrolytes are fully ionized, yielding a greater concentration of charge-carrying ions compared to weak electrolytes, which are only partially ionized [4]. Consequently, conductivity measurement constitutes a fundamental method for determining the ion concentration and the overall conductive properties of a solution.

During fruit ripening, physicochemical changes occur, including the breakdown of cell-wall polysaccharides, increased membrane permeability, and a rise in soluble ion and sugar concentration. These processes have been widely reported in fruit-ripening studies, particularly the degradation of pectic polysaccharides and the release of ions during tissue softening [10][11]. Additionally, the accumulation of soluble sugars and electrolytes increases the concentration of charged molecules in the fruit sap, thereby enhancing electrical conductivity [12]. Thus, electrical conductivity provides a physically grounded quantitative indicator of fruit ripeness.

2.2. Probe Sensor

The sensor probe is the physical component designed to directly interact with the object or medium under measurement. Specifically, in the context of electrical measurement, the sensor probe refers to the electrode utilized for detecting or measuring current. One common configuration for this conductivity application is the needle sensor. Conductivity probes operate on the fundamental principle that any solution or material containing ions is capable of conducting an electric current. Accordingly, electrical conductivity increases proportionally with the ion concentration within the measured material. These needle sensors are widely employed as electrodes in various studies to quantify electrical conductivity levels in both fluid systems and biological tissues[13][14].

Needles commonly used as conductivity probes are typically fabricated from Stainless Steel. This material is selected due to several key advantages, particularly in biomedical and corrosive environment applications. Stainless Steel provides electrical conductivity values that are within the specified operational range[15]. Furthermore, this material is notably resistant to corrosive environments, including both acidic and alkaline conditions. This inherent corrosion resistance is attributed to the alloying elements, specifically chromium and nickel, which form a protective layer on its surface.

The use of stainless steel in sensor needles is also supported by its non-toxic properties. This non-toxic property makes it a safer and more reliable choice, especially for applications that require direct contact with food or biological tissue [16]. Consequently, the stainless steel needles function as input transducers that convert the detected physical energy (ion conduction) into measurable electrical signals. These signals are then processed further to provide quantitative conductivity information to the user.

3. Method

3.1. Tools and Materials

This study uses several main components in the design of a fruit ripeness detector based on electrical conductivity. The main control components used are an Arduino Uno microcontroller, an ADS1115 external ADC module, jumper cables, single cables, USB cables, three stainless steel needles, push buttons, a 16x2 LCD, and a refractometer. In addition, the materials used in this study were alcohol, 2 mm thick acrylic, duct tape, PCB and PVC boards, tin, and the samples used were oranges and bell fruits.

3.2. Preliminary Design of Systems

The block diagram illustrating the various parts of the developed system is shown in Figure 1

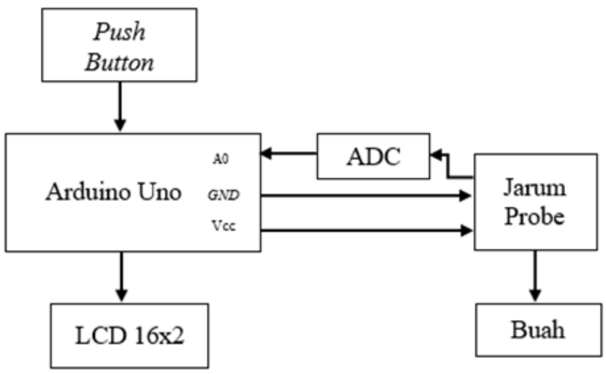

Figure 1. *The Scheme of Fruit Ripeness Detection Systems*

Following the diagram shown in Figure 1, each component fulfils a dedicated function within the system. The Push Button serves as the manual input interface, enabling the selection of the fruit type under test and providing structured control throughout the measurement process. The Arduino Uno functions as the central control unit, responsible for receiving and processing the voltage data streamed from the ADS1115 Analog-to-Digital Converter (ADC) to determine the fruit's ripeness level. The ADS1115 ADC module is specifically utilized to capture the low voltage signal generated by the electrical conductivity between the inserted electrodes, converting this analog measurement into digital data. The sensing mechanism consists of three *stainless steel* electrode needles connected to the ADS1115 ADC input, the Arduino's VCC, and the Arduino's GND, respectively, as detailed in Figure 2.

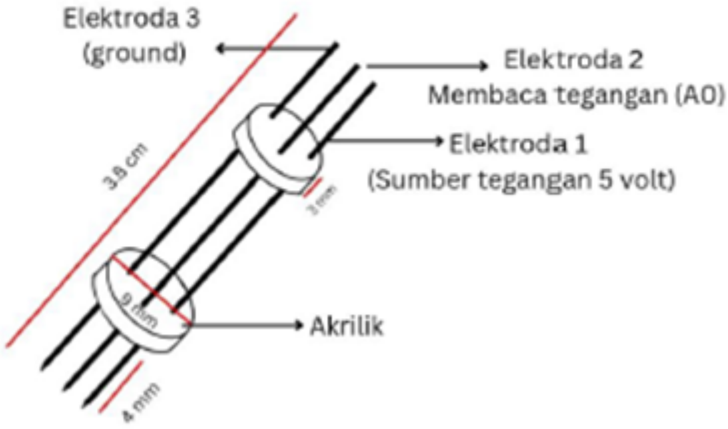

Figure 2. *The Design of Electrode's Needles*

Furthermore, the 16x2 Liquid Crystal Display (LCD) serves as the primary output interface, displaying the fruit name, the measured voltage reading, and the determined fruit ripeness status in real-time. The samples utilized for testing were oranges (*Citrus sp.*) and water guavas (*Syzygium aqueum*). These fruits were categorized and tested across three distinct ripeness levels: unripe, semi-ripe (or half-ripe), and ripe.

3.3. Devices Testing

Testing of the device and corresponding control program was conducted directly on the two fruit varieties: oranges and bell fruits. The primary objective of this validation was to ensure the device operated optimally in classifying ripeness based on pre-established reference voltage values. The data acquisition protocol commenced with measuring and establishing the reference voltage thresholds for each fruit type. Subsequently, the electrode needle was inserted into the fruit pulp to a depth of approximately 4 mm. To minimize potential errors arising from local fruit variations, the voltage measurement was repeated five times at different points on each fruit sample. The voltage (V) readings, generated by the fruit's internal electrical conductivity, were processed by the ADS1115 and the Arduino Uno, with the resultant ripeness status displayed in real-time on the LCD. A push button was utilized to sequence the testing process and select the next fruit sample. Concurrently, the reference sugar content (%brix) for each fruit was measured using a refractometer to serve as comparative validation data.

Following the acquisition of all voltage and reference glucose level data, the next step involved analyzing the results using linear regression. This analysis was performed to quantitatively evaluate the correlation between the two primary variables: the reference glucose content and the voltage measurements obtained from the developed device. In the regression model, the glucose level (x) was designated as the independent variable, while the corresponding measured voltage value (y) served as the dependent variable. The output of this regression analysis yields the following simple linear equation:

$$y = a + b \cdot x \tag{4}$$

The coefficients a and b are calculated using the following equations:

$$a = \frac{(\Sigma y)(\Sigma x^2) - (\Sigma x)(\Sigma xy)}{n(\Sigma x^2) - (\Sigma x)^2} \tag{5}$$

$$b = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2} \tag{6}$$

Subsequent to obtaining the linear regression in equation 1, the correlation coefficient (R) and the coefficient of determination (R^2) were calculated. This was performed to quantify the strength of the correlation between the device's voltage output and the reference glucose level. The resulting (R) and (R^2) values serve as the basis for evaluating the overall validity and accuracy of the developed fruit ripeness detection device.

4. Result

4.1. Voltage Measurement Results

Measurements were performed on orange (*Citrus sp.*) samples, which were categorized into three distinct ripeness levels: unripe, semi-ripe (or half-ripe), and ripe. To ensure data reliability, each sample underwent five replicate measurements to determine the average voltage value. Subsequently, the reference sugar content of the fruits was quantified using a refractometer, with results expressed in % brix units. These % brix values served to validate the electrical conductivity (voltage) data obtained from the developed device, as summarized in Table 1. The detailed measurement results, including both voltage readings and reference sugar level of orange (*Citrus sp.*), are presented in Table 1.

Table 1. *Measurement Data on Voltage and Sugar Content in orange (*Citrus sp.*)*

Classification	Voltage (V)	Sugar Level (%)	Flavor
Unripe	2,32	8,1	Sour
Half-ripe	2,58	9	Sour
Ripe	2,74	10	Sweet

Table 1 indicates that unripe oranges exhibited voltage readings between 2,32 – 2,46 Volt, corresponding to a sugar content range of 8,1 – 8,5%. The relatively high initial voltage is likely attributed to the fruit's dense tissue structure coupled with high water content, factors known to increase electrical conductivity. For half-ripe oranges, the voltage range increased to 2,56 – 2,58 Volt, with a sugar content of 9 – 10%. This transition suggests that the fruit has commenced the sweetening process, accompanying a decrease in organic acid content [2]. Ripe oranges showed the highest voltage range, from 2,66 – 2,74 Volt, corresponding to a sugar content of approximately 10%. This maximum voltage reflects a significant increase in the concentration of dissolved ions and the enzymatic breakdown leading to cell wall softening, thereby facilitating better electrical conduction within the fruit matrix [16].

Table 2. *Measurement Data on Voltage and Sugar Content in Bell Fruits (*Syzygium aqueum*)*

Classification	Voltage (V)	Sugar Level (%)	Flavor
Unripe	2,08	6	Tasteless
Half-ripe	2,26	7	Sweet
Ripe	2,48	8,3	Sweet

Measurements for the voltage and sugar content in bell fruits (*Syzygium aqueum*) are detailed in Table 2. In unripe bell fruits, the measured voltage ranged from 2,08 – 2,14 Volt, corresponding to a sugar level of approximately 6%. This initial low conductivity is primarily due to the low concentration of sugars and dissolved ions, despite the fruit's inherently high water content [12]. At the half-ripe stage, the voltage increased to 2,26 – 2,32 Volt, with a sugar level of 6 – 7%. This increase signifies that the ripening process has begun to affect conductivity, largely through tissue softening and a resultant increase in free ions [10]. Conversely, ripe bell fruits exhibited a voltage of approximately 2,48 Volt and a level of 8 – 8,3%. At this maturity level, the fruit structure is significantly softer, and the higher sugar concentration leads to a noticeable increase in electrical conductivity. Overall, as the bell fruit ripens, both the voltage and the sugar content increase, though this progression is gradual [11].

4.2. Analysis of The Electrical Signal Correlation with Brix Value

The relationship between the measured voltage and the fruit's sugar level was analyzed using linear regression. The linear correlation between sugar content and voltage in orange (*Citrus sp.*) samples is graphically represented in Figure 3, which includes the calculated regression line. This plot demonstrates a strong, direct correlation wherein an increase in the sugar content consistently leads to a corresponding increase in the measured voltage value.

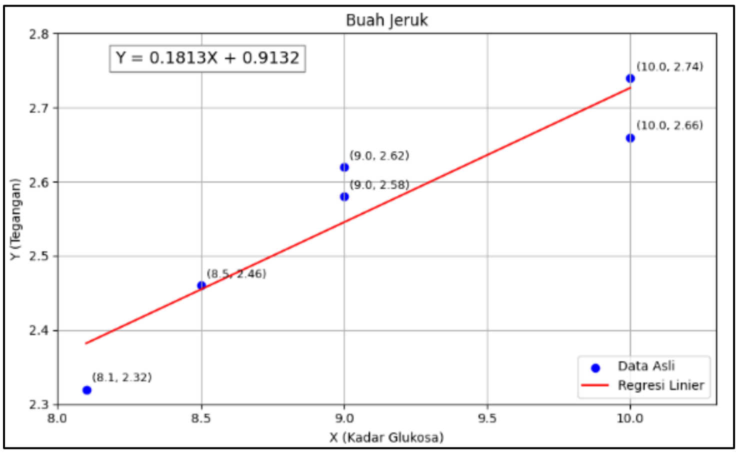

Figure 3. *Correlation Between Voltage and Sugar Level of Orange* (Citrus sp.)

Figure 3, which illustrates the relationship between voltage and sugar level in oranges, shows a strong positive correlation. An increase in the sugar level consistently results in a greater voltage output from the device. The distribution of data points confirms a consistent upward pattern, spanning sugar contents from 8,1% to 10% and voltage readings from 2,32-2,74 Volt. For instance, a reference sugar content of 8,1% yielded a voltage of 2,32 Volt, whereas a 10% sugar level correlated with a voltage increase to approximately 2,66 – 2,74 Volt. The calculated linear regression line possesses a positive slope, defined by the equation $y = 0{,}1813x + 0{,}9432$. This indicates that every 1% increase in sugar level corresponds to an approximate voltage increase of 0,1813 Volt. The close proximity of the empirical data points to the regression line confirms that the relationship between soluble solids content and electrical conductivity in oranges is linear and consistent.

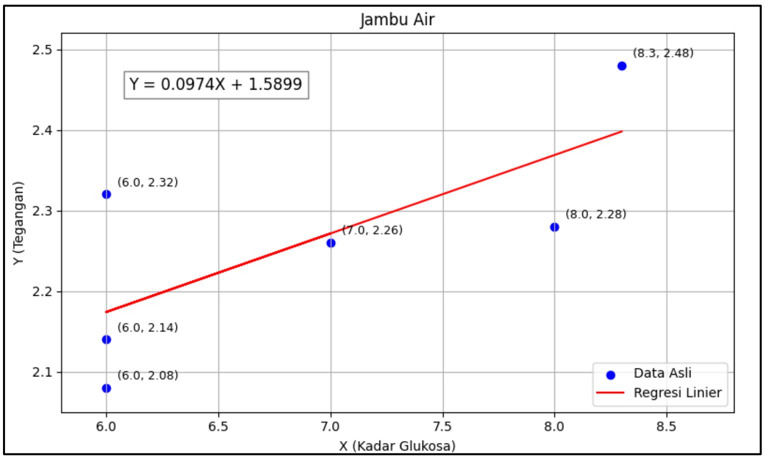

Figure 4. *Correlation Between Voltage and Sugar Level of Bell Fruits* (Syzygium aqueum)

The linear relationship between sugar level and voltage in bell fruits (*Syzygium aqueum*) is visualized in Figure 4, which presents a graph with the calculated regression line, illustrating the pattern of correlation between the two variables. The x-axis represents the sugar level (%), while the y-axis shows the measured voltage (V). The data shows that the sugar level of bell fruits ranged from 6 – 8,3%, corresponding to a measured voltage between 2,08 – 2,48 Volt. For instance, a 6% sugar level recorded a voltage of 2,08 Volt, increasing to 2,48 Volt at a concentration of 8,3%. Although minor variations exist between the data points, the overall graph pattern exhibits an upward trend, indicating that greater ripeness in bell fruits correlates with a higher voltage output. The calculated linear regression equation is $y = 0{,}0974x + 1{,}5899$. This positive slope confirms a linear relationship between sugar level and electrical conductivity, suggesting that every 1% increase in sugar content raises the voltage by 0,0974 Volt. This relationship is primarily influenced by the increased concentration of simple sugars, such as glucose and fructose, during the ripening process. Furthermore, the inherent high water content and soft tissue structure of the water guava contribute to the stability of the voltage readings recorded by the electrodes.

4.3. Error Calculation Results

Data processing included the calculation of the average relative error (ER_{avg}) which quantifies the deviation of the measured data from the standard reference value. According to Ihzaniah et al. (2023), the average relative error (%) is computed using equation 7 [17].

$$ER_{avg}(\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|Tool\ Result_i - Reference\ value_i|}{Reference\ value_i} \times 100\%\right). \tag{7}$$

The specific calculation of the relative error between the refractometer sugar content (Reference Value) and the sugar content predicted from the voltage regression equation (Tool Result) for oranges is presented in Table 3.

Table 3. *The Calculation of Relative Error in Orange Ripeness*

x	y	x_{pred}	ER
8.0	2,32	7.76	2.96 %
8.5	2,46	8.54	0.47 %
9.0	2,60	9.31	3. 44 %
9.5	2,62	9.42	0.84 %
10.0	2,64	9.53	4.70 %
9.5	2,74	10.09	6.21 %

$$ER_{average} = \frac{\sum ER}{n}$$

$$= \frac{2{,}96+0{,}47+3{,}44+0{,}84+4{,}70+6{,}21}{6}$$

$$= 3{,}10\%$$

The error analysis for oranges revealed smaller and more stable relative errors. This stability is attributed to the internal structure of the oranges, which is generally homogeneous and uniform concerning both water content and sugar distribution. Furthermore, the consistent utilization of a single citrus variety during the experimental phase contributed to the stability of the voltage readings. Consequently, the measurement results for oranges consistently remained within the acceptable field testing error range of $\pm 5\%$ to $\pm 10\%$, even when simulating less-controlled testing conditions.

The calculation of the relative error between the refractometer sugar level and the voltage prediction results derived from the linear regression equation for bell fruit (*Syzygium aqueum*) is presented in Table 4.

Table 4. *The Calculation of Relative Error in Bell Fruit Ripeness*

x	y	x_{pred}	ER
6.0	2.08	5.03	16.17 %
6.0	2.14	5.66	5,67%
7.0	2.22	6.46	7,71%
7.0	2.30	7.29	4,14%
7.5	2.42	8.51	13,47%
7.8	2.48	9.13	17,04%

$$ER_{average} = \frac{\sum ER}{n} \tag{8}$$

$$= \frac{16.17+5.67+7.71+4.14+13.47+17.04}{6}$$

$$= 10{,}70\%$$

The error analysis for bell fruits revealed varying, yet generally moderate, deviations, influenced primarily by the fruit's ripeness level and inherent water content. Bell fruits naturally possess a high water content, particularly in the unripe stage, but initially contain a low concentration of dissolved ions, such as glucose. As the fruit matures, tissue softening and a sharp increase in sugar concentration occur, resulting in a drastic change in electrical conductivity. This dynamic shift in ionic concentration and structural integrity can directly impact the accuracy and stability of the voltage measurements recorded by the device. Nevertheless, the calculated errors for water guavas remain acceptable within the established tolerance range, provided the measurement protocol is strictly adhered to.

The intrinsic characteristics of each fruit, notably type, moisture content, and sugar level, significantly influence their electrical conductivity values and subsequent measurement outcomes. Consequently, these variations constitute critical determinants of the magnitude of measurement deviation or error. This is because electrical conductivity in biological tissues is strongly governed by ionic concentration, membrane integrity, and moisture distribution, all of which vary naturally across fruit ripes and maturity levels [18].

In the context of on-site (field) testing, a relative error range of $\pm 5\%$ to $\pm 10\%$ is generally deemed reasonable and acceptable. This tolerance is particularly relevant when employing simpler, more portable instrumentation. Thus, this defined error limit represents a practical compromise between measurement accuracy and instrument practicality (portability and simplicity) [19].

5. Conclusion

This study successfully concludes the design and validation of a novel fruit maturity detector founded on the principle of electrical conductivity. The operational mechanism involves measuring the internal voltage of the fruit's liquid matrix upon insertion of an electrode into the fruit pulp. This measured voltage is subsequently compared against pre-calibrated reference values to accurately categorize the fruit's maturity into distinct levels (unripe, half-ripe, and ripe).

Significantly, the device demonstrated a clear correlational trend: an increase in voltage magnitude positively correlates with advancing ripeness in both oranges and bell fruits. The device exhibits satisfactory accuracy, which was substantiated by its consistency with complementary sugar content measurements using a digital refractometer. Furthermore, linear regression analysis revealed a strong, positive relationship between the measured voltage values and the total sugar level, unequivocally establishing that electrical conductivity is a robust predictor of fruit maturity. Finally, the system's practical implementation is enhanced by storing these crucial reference values in Electrically Erasable Programmable Read-Only Memory (EEPROM), ensuring data persistence even upon system power-off.

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