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Design and Simulation of Interdigital Capacitive (IDC) Sensing for Daily Non-Destructive Ripeness Monitoring of *Manilkara zapota* (*Ciku*) at Frequencies Below 1 kHz

N.S.N. Mohd Hanafi[1], R. Rosman[1,3*], K. Velaiyudam[2] and A. Abdul Aziz[1,3]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

[2]ORNET Sdn Bhd, No.16, Level: 3A, Block: D, One South, Jalan OS, Taman Serdang Perdana, 43300 Seri Kembangan Selangor, MALAYSIA

[3]Integrated Microelectronic System and Applications (IMSaA) Research Initiative Group, UiTM, 40450 Shah Alam, Selangor, MALAYSIA

Postharvest handling of tropical fruits requires a reliable and non-destructive method for assessing the degree of ripeness. This paper proposes an IDC sensing technology to address the limitations of the conventional subjective methods used in the Malaysian fruit industry. IDC sensor measures changes in capacitance during fruit ripening based on a correlation between fruit maturity and dielectric properties. Capacitance values are obtained via a voltage divider at 340 Hz, 500 Hz and 1 kHz frequencies and a 10 Vpp supply and then compared with traditional destructive analysis of firmness, Brix and pH. CST Studio Suite was used to simulate four IDC sensor designs to demonstrate their performance. Design 2 (finger length = 11 mm, finger width = 5 mm, finger gap = 2 mm) and Design 4 (finger length = 7 mm, finger width = 5 mm, finger gap = 1 mm) were selected for further study as the best field performance design. Capacitance of Design 4 at 340 Hz was most closely related (R^2= 0.9771) to markers of ripeness. The experimental results show that the IDC sensor offers fast and accurate ripeness estimation, 25% more accurate compared to visual inspection. The combination of sensor data and known destructive methods helps to establish firm predictive models. The non-destructive nature of the IDC technique brings great benefit to the preservation, quality and reduction of postharvest waste of fruit.

Keywords: interdigital capacitive sensing; *Manilkara zapota*; non-destructive; postharvest

I. INTRODUCTION

Malaysia is a tropical country thus it has the good growing environment for large variety of fruits, including the economically important *Manilkara zapota*. The *ciku* fruit (*Manilkara zapota*) holds significant economic value in local and export agricultural markets due to its high consumer preference, sweetness and nutritional content. However, the complexities involved in the assessment of maturity are great challenges for the *ciku* industry because the fruit quality and market value can only be maximised when the fruit maturity is well taken care of.

Precise and quick ripeness assessment is crucial to ensuring customer satisfaction and optimising postharvest management. Traditional methods such as visual inspection and destructive measurements often lead to inconsistent results and significant financial losses (Anjali *et al.*, 2024). In response to these limitations, there is an increasing demand for swift, precise and non-destructive methods to assess fruit development.

Technology advancements have led to the development of a few non-destructive techniques but not much research has been done on the use of interdigital capacitive (IDC) sensors

*Corresponding author's e-mail: rafidah504@uitm.edu.my

to assess *ciku* ripeness. The present initiative aims to fill this knowledge gap by developing and testing an IDC sensing system for assessing *ciku* maturity. The purpose of this study is to compare IDC sensor data with traditional quality indicators to provide a reliable and unbiased method for ripeness prediction. The effective use of this technology might significantly improve *ciku* quality control, reduce postharvest losses and boost the competitiveness of the Malaysian *ciku* industry.

A. Literature Review

Non-destructive evaluation of fruit maturity is important for improving postharvest handling, maintaining fruit quality and reducing economic losses during storage and transportation. Conventional destructive methods such as firmness, Brix and pH measurements are widely used to evaluate fruit ripeness. However, these methods damage the fruit and are unsuitable for continuous monitoring. Therefore, various non-destructive techniques including capacitive sensing, image processing and spectroscopic methods have been developed for fruit quality assessment.

1. Non-Destructive Capacitive and Dielectric Sensing Approaches

Capacitive and impedance-based sensing techniques have shown strong potential for fruit quality evaluation because they are sensitive to internal changes that occur during fruit ripening. Changes in moisture content, tissue structure and biochemical composition directly affect the electrical properties of fruit tissues.

Masoumi *et al.* reported that low-frequency series capacitance (Cs) measurements could effectively monitor banana ripening and detect mechanical damage in nectarines (F. Masoumi *et al.*, 2024). Their study also showed that temperature compensation and statistical analysis improved measurement reliability and reduced environmental interference. These findings demonstrate the potential of capacitive sensing for non-contact fruit quality monitoring.

To improve prediction accuracy, electrical sensing methods have also been combined with machine learning techniques. Zhang and Liu developed a non-destructive firmness prediction model for Korla fragrant pears using impedance, capacitance and inductance measurements collected during ripening (Zhang, Liu *et al.*, 2022). Principal Component Analysis (PCA) was used to extract important features from the electrical data while a Generalized Regression Neural Network (GRNN) model was used for prediction. The GRNN model achieved high prediction accuracy with R^2=0.9628 and RMSE = 0.383, demonstrating the effectiveness of combining electrical sensing with machine learning methods.

Electrical Impedance Spectroscopy (EIS) and dielectric spectroscopy have also been investigated for evaluating internal fruit quality. EIS has been used to estimate moisture and oil content in oil palm fruitlets at frequencies such as 100 kHz (Chin-Hashim *et al.*, 2022). Similarly, dielectric spectroscopy has shown promising results for predicting sugar content in melons through frequency-dependent dielectric analysis (Liu *et al.*, 2021). However, despite their high accuracy, these methods often require expensive equipment and complex measurement systems, limiting their suitability for portable and low-cost applications.

2. Computer Vision and Optical Spectroscopic Techniques

Computer vision techniques are widely used for fruit ripeness classification because they are fast, non-contact and easy to implement. Most image-based approaches evaluate external characteristics such as colour, texture and shape to determine maturity stages (S. A. Tajuddin *et al.*, 2021).

A review involving more than 1,500 studies on automated fruit ripeness assessment found that colour analysis remains the most commonly used method for banana ripeness classification (Saranya *et al.*, 2022). Farhan developed a smartphone-based application using transfer learning with a pre-trained CNN model to classify banana ripeness in real time. The system achieved an accuracy of 98.25%, demonstrating the potential of mobile-based ripeness monitoring systems. However, image-based methods are limited because they mainly evaluate external appearance and may not accurately reflect internal fruit quality (Mohamedon *et al.*, 2021).

Visible and near-infrared spectroscopy (VNIRS) is another important non-destructive technique for internal fruit quality evaluation. VNIRS measures the interaction between light and fruit tissues to estimate properties such as sugar content, pigment concentration and acidity (Ping *et al.*, 2023; Owino *et al.*, 2024). Seehanam *et al.* used VNIRS to detect internal browning in mangoes while Guo *et al.* applied the method for maturity prediction in apples. Although VNIRS provides accurate results, the high cost of optical equipment limits its practical application in low-cost agricultural systems (Seehanam *et al.*, 2022; Guo *et al.*, 2024).

II. MATERIALS AND METHOD

In this section, the study approach used to understand how the ripeness of *ciku* fruit affects its electrical properties. Data from *ciku* fruit samples was methodically gathered using an experimental design. An interdigital capacitive (IDC) sensor was created for the study to measure the electrical characteristics of the fruit at different stages of ripening. Simultaneously, traditional quality measures like firmness, sugar content (Brix), and acidity (pH) were recorded. To determine relationships between electrical characteristics and ripeness markers, statistical analysis was performed on the data gathered from these observations.

A. Ripeness Assessment Workflow

Figure 1 illustrates the overall workflow for developing and evaluating a ripeness prediction model for Manilkara zapota (*ciku*). The process begins with defining the target fruit and designing interdigitated capacitive (IDC) sensors using CST Studio Suite. The simulated designs are evaluated based on their electric field strength and penetration depth. If a design does not meet the required performance, the sensor geometry is modified and optimised again. Once the sensor selection criteria are successfully satisfied, the chosen design proceeds to fabrication. Fruit samples are then prepared for both non-destructive and destructive measurement. Non-destructive capacitance is measured using the fabricated IDC sensor across multiple low frequencies while firmness, Brix and pH values are assessed through conventional destructive methods. The collected data are analysed using regression techniques to establish correlations between capacitance and ripening indicators. If the correlation coefficient (R^2) achieves the required accuracy, the process continues to the next stage. Otherwise, the measurement setup and testing frequencies are reviewed and adjusted for better calibration. Ultimately, the verified correlation data are utilised to build and evaluate the final predictive model for automated *ciku* ripeness estimation.

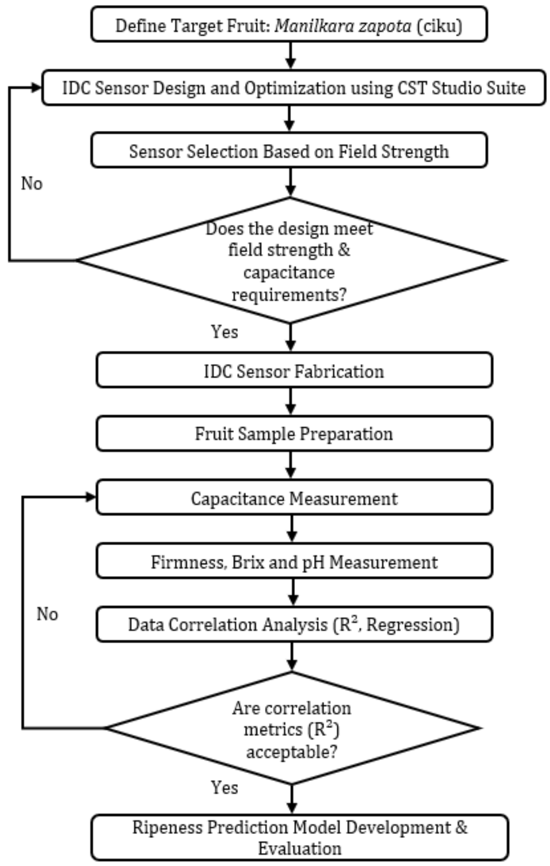

Figure 1. Flowchart of the *ciku* fruit ripeness assessment process

B. IDC Sensor Design Methodology and Performance Simulation

This section outlines the design and simulated performance of the IDC sensor, which served as a foundation for the fabrication process. The sensor's dimensions including length, width and gap were optimised through analytical calculations.

1. Interdigital Capacitive Sensor Design

Ciku fruit's dielectric characteristics, which vary as it ripens were measured using interdigital capacitive (IDC) sensors. To maximise electric field dispersion and sensitivity, four various IDC sensor designs with variations in finger length (L), width (W) and gap (G) have been created using CST

Studio Suite. The thickness of the copper is 0.032 mm and the thickness of the substrate is 1.6mm. Using "Leiterplatten-Kopierfrasen" (LPKF) technology, the chosen designs were created using copper interdigitated electrodes on a FR-4 substrate. The significant variables for the two chosen designs are displayed in Table 1 below.

Table 1. Experimental parameters for interdigital capacitive sensors

Design	Length (L)	Width (W)	Gap (G)
2	11 mm	5 mm	2 mm
4	7 mm	5 mm	1 mm

2. Process of Simulation

CST Studio Suite was used to simulate the sensor designs in order to analyse their capacitance and electric field distribution. The material characteristics of the *ciku* fruits and the ambient air were determined to define the simulated environment. To evaluate each design's efficacy and sensitivity, electric field variations were examined. Because of their superior capacitance and electric field penetration values, Design 2 and Design 4 were chosen for additional testing according to the simulation results.

Figures 2 and 3 depict the energy properties and electric field distribution for Designs 2 and 4 of the IDC sensors, respectively. Each figure consists of three subplots: the distribution of the electric field with an automatic scale, the distribution of the electric field with a maximum value of 5 V/mm and the total electric field energy. Plots of electric field distributions use a colour scale to indicate electric field strength, with red colour representing higher values and blue colour representing lower values.

Design 4 has a total electric field energy of 6.4088e-10 J, representing a 16.23% increase over Design 2, which has a total electric field energy of 5.5138e^{-10} J. Moreover, the visual analysis of the electric field distribution suggests that a more concentrated field pattern in Design 4 could lead to higher sensitivity. This notion must be confirmed by more experimental studies, such as evaluating how the sensor responds to fruits of varying ripeness degrees.

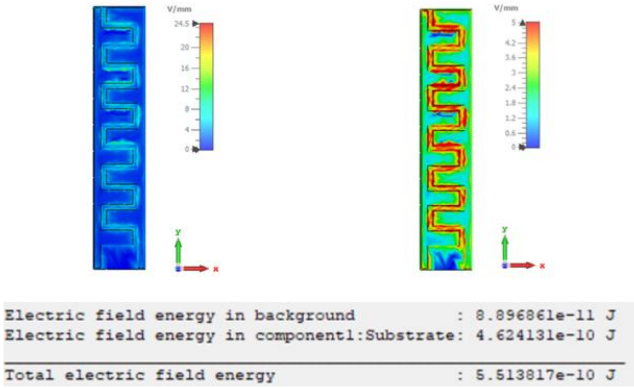

Figure 2. Total electric field energy for Design 2

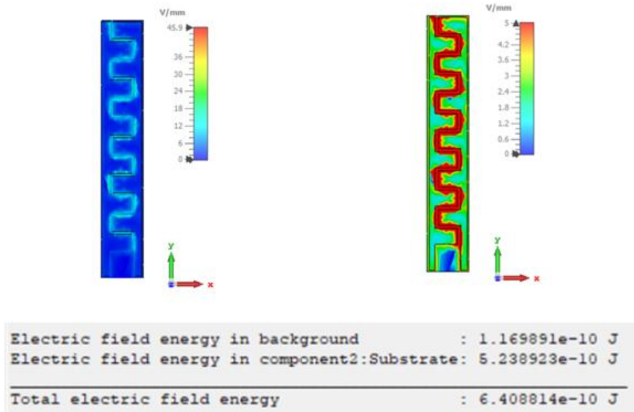

Figure 3. Total electric field energy for Design 4

C. Fabrication

After designing and simulating the sensors, the next step was fabrication. The LPKF approach utilised to produce the IDC sensors is explained in this section.

1. Fabrication Method

Figure 4 illustrates how Interdigital Capacitive (IDC) sensors are manufactured using LPKF technology. Figure 4 and Figure 5 depict the production machinery in operation, highlighting the level of accuracy and complexity needed to develop a complex sensor design. The workpiece, a FR-4 substrate, is shown next to the cutting tool that specifies the interdigitated electrode pattern. The completed IDC sensors for Design 2 and Design 4 in Figure 6, respectively, show that the manufacturing process was successfully completed.

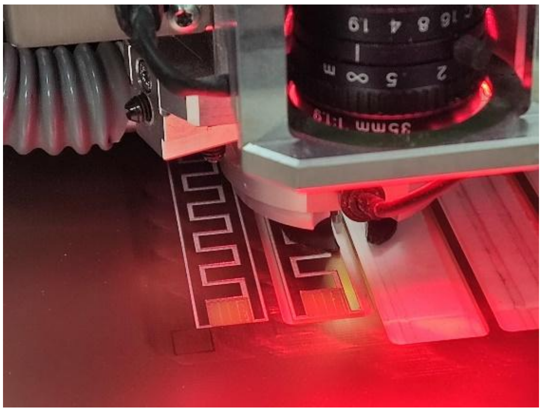

Figure 4. LPKF machining process

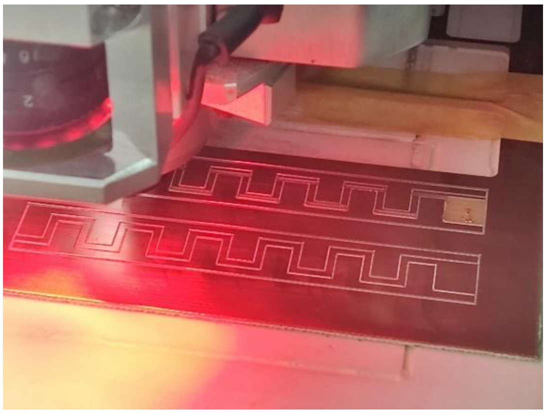

Figure 5. LPKF machining process

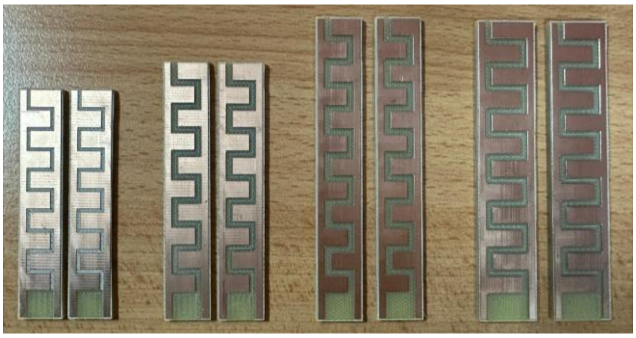

Figure 6. Fabricated sensors

D. Setup for Experimentation

This section describes the experimental setup used to investigate the relationship between capacitance measurements and *ciku* fruit ripeness. The study involved non-destructive measurements using the IDC sensor and destructive measurements including firmness, Brix and pH analysis. Detailed procedures are presented in the following subsections.

1. Preparation of Samples

To get a representative sample of the fruit variety, *ciku* fruits were procured from the Selangor Fruit Valley (SFV). Based on visual evaluation, unripe fruits with a firm texture and green skin colour were chosen. Fruits with obvious flaws, blemishes or disease symptoms were not included. To reduce microbial contamination, the fruits were carefully washed with water.

All experiments were conducted in a stable indoor laboratory environment maintained at 25 °C and 50% relative humidity. Measurements were performed at room temperature under controlled conditions without direct exposure to sunlight. The fruits were maintained under these controlled conditions for 21 days, with daily measurements recorded from the initial unripe stage (Day 1) to the overripe stage (Day 21) to monitor ripening progression and ensure measurement consistency and reproducibility. The dimensional variance of about 90 unripe *ciku* fruits, totalling about 10 kg in weight, as shown in Figure 7. Fruits ranged within width from 4.60 to 5.90 cm with a length between 5.83 to 5.87 cm.

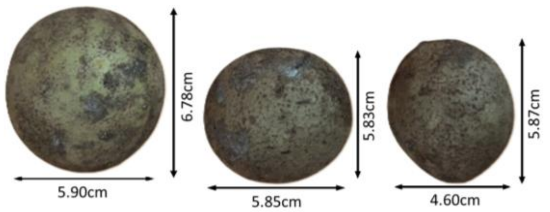

Figure 7. Size chart of unripe *ciku* fruits

2. Configuration for Capacitance Measurement

Figure 8 depicts a basic circuit design for capacitance measurement, utilising the voltage divider principle.

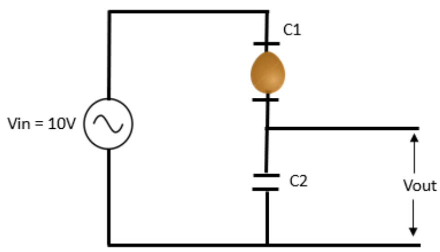

Figure 8. Schematic diagram of the voltage divider circuit for capacitance measurement

There are several crucial components in the circuit. The overall structure, water content and sugar concentration of the fruit under study represented by C1, all have an impact on its capacitance. A reference capacitor called C2 is employed in calibrating. Resistors R1 and R2 generate a network of voltage dividers. Eq. (1) represents the voltage divider rule (VDR):

$$V_{out} = V_{in} * (\frac{X_{C2}}{X_{C1} + X_{C2}}) \quad (1)$$

Where Vin is the input voltage applied to the series circuit, Vout is the output voltage across capacitor C2, Xc1 is the capacitance reactance of capacitor C1 and Xc2 is the capacitance reactance of capacitor C2.

By determining the output voltage (Vout) and having the values of R1, R2 and C2, capacitance of the fruit (C1) can be measured. Using the voltage division principle, this method enables an indirect analysis of the fruit's capacitance.

A thorough overview of the design and operation of an interdigitated capacitor (IDC) is shown in Figure 9. The cross-section reveals several areas that contribute to the capacitance while the top view displays the interdigitated pattern.

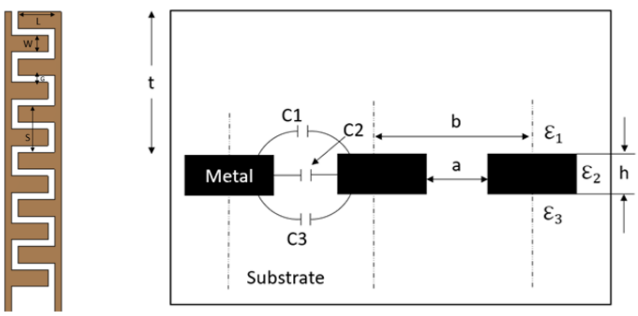

Figure 9. IDC sensor design and equivalent circuit model

To measure capacitance divergences with changes in sugar content, a printed circuit board (PCB) is used to fabricate the interdigital capacitor (IDC) sensor (Khan *et al.*, 2023). Eq. (2) determines the capacitance of the sensor by adding the capacitances of the individual unit cells.

$$C = (N - 1) * L * C_{uc} \quad (2)$$

Where C is the total capacitance of the IDC sensor, N is the number of unit cells, L is the length of the electrode and Cuc is the capacitance of a single unit cell.

Eq. (3) provides more details for the unit cell capacitance (Cuc):

$$C_{uc} = C1 + C2 + C3 \quad (3)$$

Where C1 is refers to the capacitance between the electrodes' dielectric, C2 is represents the capacitance linked to the dielectric layer and C3 is indicates the capacitance contributed by the PCB substrate.

Eq. (4) calculates the capacitance between interdigitated electrodes, which is influenced by the electric field between them.

$$C_1 = \frac{2\varepsilon_0\varepsilon_1 K(k)}{K(\sqrt{1-k^2})} \quad (4)$$

Where C_1 is the capacitance associated with the dielectric between electrodes (pF), ε_0 is represented by the product of the permittivity of free space (≈8.854 x $10^{-12}\, F/m$), ε_1 is represented the relative permittivity of the medium, K(k) is the complete elliptic integral of the first kind (calculated based on k), K ($\sqrt{(1-k^2)}$) is the complete elliptic integral of the first kind (calculated based on the square root of 1 minus k^2) and k is the modulus a ratio, defined as the width of an electrode (a) divided by the spacing between electrodes (b).

The capacitance generated by the dielectric layer positioned between the electrodes is represented by Eq. (5):

$$C_2 = \frac{\varepsilon_0\varepsilon_2 h}{a} \quad (5)$$

Where C_2 is the dielectric layer's capacitance (pF), ε_0 is the free space permittivity (≈8.854 x $10^{-12}\, F/m$), ε_2 is the dielectric layer's relative permittivity (dimensionless) and h is the dielectric layer's thickness (mm).

C3, or the capacitance resulting from the PCB substrate material, is defined by Eq. (6):

$$C_3 = \frac{\varepsilon_0\varepsilon_2 b}{a} \quad (6)$$

Where is the PCB substrate's capacitance (pF), ε_0 is the free space permittivity (≈8.854 x $10^{-12}\,{}^{F}/_{m}$), ε_3 is the PCB substrate's relative permittivity (dimensionless), b is the distance between the electrodes (mm)and a is the electrode's gap (mm).

E. Data Acquisition

The methodology used for data acquisition in the research are described in depth in this section. Capacitance values were measured at specific frequencies of 340 Hz, 500 Hz and 1 kHz using a non-destructive technique. Meanwhile, conventional quality parameters such as firmness, Brix and pH were determined using destructive methods. By integrating these approaches, the study adopts a holistic strategy to analyse fruit ripeness and its relationship to capacitance.

1. Measurement of Capacitance

Figure 10 shows the schematic diagram and Figure 11 shows the actual setup used to measure capacitance in *ciku* fruit. This experiment uses a non-destructive method to measure capacitance, which helps monitor fruit ripeness and its related properties. In the setup, the *ciku* fruits are placed on a platform with metal electrodes to create electrical contact. A function generator produces sinusoidal signals with a voltage of 10 Vpp at frequencies of 340 Hz, 500 Hz and 1 kHz to activate the system. The capacitance values are then measured and recorded using a multimeter.

The goal of this method is to find a relationship between the measured capacitance and the fruit's ripeness. The non-destructive nature of this setup allows continuous monitoring without damaging the fruit. Figure 10 shows the diagram of how the components such as the function generator, multimeter and electrodes are connected. Figure 11 shows the real setup, confirming how the design was applied in practice. This setup helps analyse how capacitance measurements can be used to track fruit ripening.

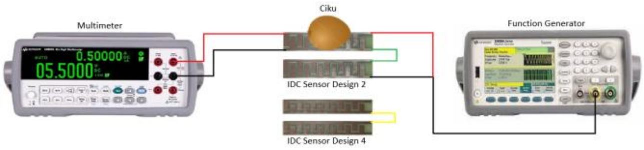

Figure 10. Schematic diagram setup

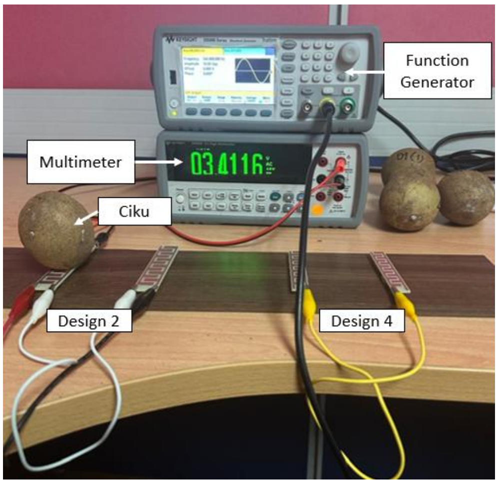

Figure 11. Capacitive sensing measurement experimental setup for Designs 2 and 4

2. Conventional Measures of Ripeness

A GY-03 Sclerometer Farm Hardness penetrometer was used to measure the destructive firmness of *ciku* fruit, as shown in Figure 12. To determine the varying firmness of *ciku* fruit in different maturity stages, an 8mm probe was used for unripe fruit (firmness range: 1–24 kg/cm²) and an 11mm probe was used for ripe fruit (firmness range: 0.5–12 kg/cm²). To ensure accurate readings, a little section of the *ciku* skin was removed prior to the probe being inserted.

Figure 12. Measurement of the *ciku*'s firmness

An Atago PAL-BX | ACID F5 refractometer, a popular tool for determining fruit sugar content is used to measure the Brix level of a *ciku* fruit as shown in Figure 10. A syringe is used to dispense a few drops of fruit juice onto the prism of the refractometer in Figure 13. The refractive index of the juice, which is directly correlated with its sugar concentration is determined by the device. The refractometer display with the measured Brix value is shown in Figure 14. Fruit with a greater Brix rating has a higher concentration of sugar.

Figure 13. Applying the fruit's juice to the refractometer prism

Figure 14. Reading the Brix value on the refractometer

A traditional *ciku* juice pH measuring setup is shown in Figure 15. The alkaline or acidic level of the juice sample is assessed using a pH meter. The *ciku* juice in an appropriate vessel is submerged in the electrode of the pH meter. The pH value that results from the device's conversion of the observed electrical potential is shown on a digital readout.

Figure 15. Measurement of pH

III. RESULT AND DISCUSSION

This section presents and interprets the experimental findings, divided into destructive and non-destructive analysis methods. The dual approach enables a comprehensive evaluation of *ciku* fruit ripening combining traditional quality indicators with capacitive sensing data to assess the feasibility of a non-destructive monitoring technique.

A. Results of the Experiment

The 21-day study evaluated the performance of two IDC sensor designs, Design 2 and Design 4, in monitoring the ripening of Manilkara zapota (*ciku*) fruit. A non-destructive capacitive sensing method was implemented at operating frequencies of 340 Hz, 500 Hz and 1 kHz. Destructive tests were conducted to measure fruit firmness, pH and Brix levels, serving as reference indicators to validate the sensor data.

1. Analysis of Destructive Methods

Figures 16, 17 and 18 illustrate the changes in firmness, Brix and pH values over the 21-day period. Destructive measurements were conducted using different fruit samples each day as the testing procedures permanently altered the fruit structure. Firmness decreased steadily ($R^2 = 0.9336$), reflecting cell wall degradation and tissue softening. Brix increased progressively ($R^2 = 0.9725$), consistent with starch-to-sugar conversion. pH declined gradually ($R^2 = 0.9579$), indicating increased acidity from organic acid metabolism. Among the destructive methods, Brix emerged as the most sensitive indicator of ripening as its progressive increase demonstrated the highest consistency across fruits ($R^2 = 0.9725$). This reliability makes Brix particularly effective for distinguishing between unripe, ripe and overripe stages compared to firmness and pH.

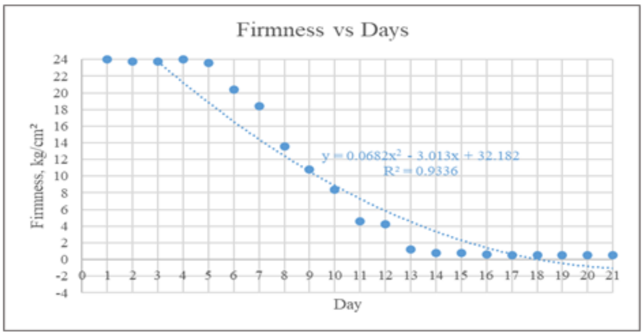

Figure 16. The firmness value relationship over days

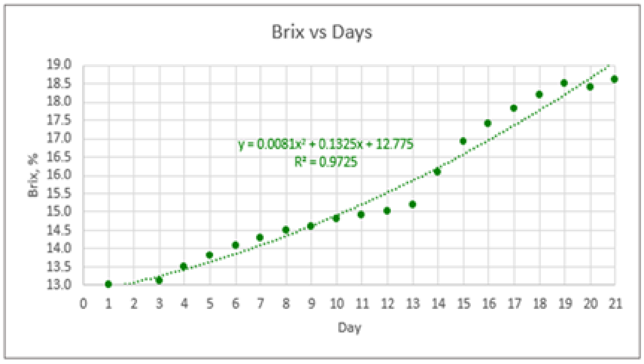

Figure 17. The Brix content relationship over days

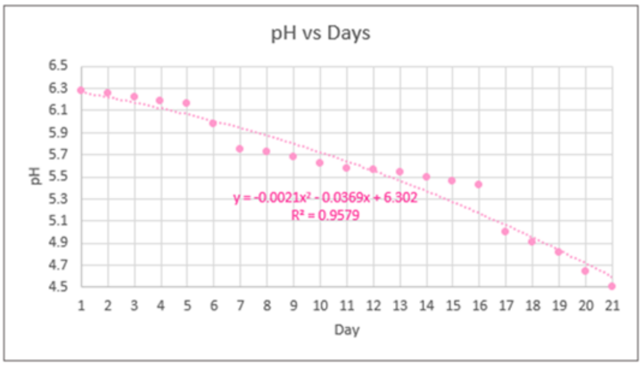

Figure 18. The pH value relationship over days

2. Analysis of Non-Destructive Methods

Capacitance measurements for Design 2 and Design 4 are shown in Figures 19 and 20. Both designs exhibited increasing capacitance over time, reflecting dielectric changes in the fruit. Among the tested frequencies, 340 Hz showed the strongest correlation with capacitance variation due to deeper electric field penetration into the fruit tissue. Design 4 consistently outperformed Design 2, particularly at 340 Hz ($R^2 = 0.9771$ vs. $R^2 = 0.9750$). Its narrower electrode spacing 1 mm and optimised geometry enhanced sensitivity to moisture and sugar content changes.

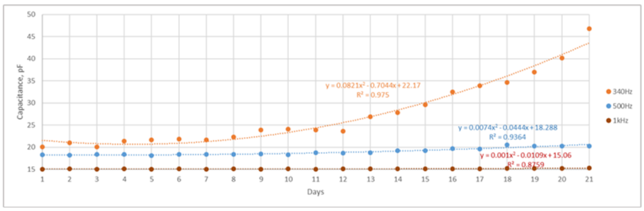

Figure 19. Capacitance of Design 2 versus days

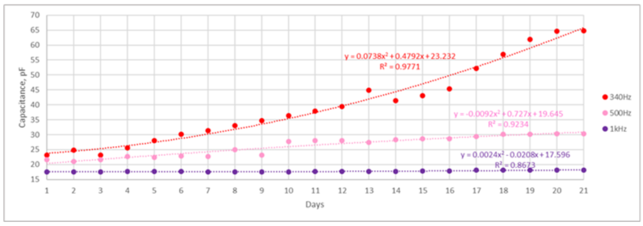

Figure 20. Capacitance of Design 4 versus days

Figure 21 offers a comparative analysis of Design 2 and Design 4 concerning their capacitance changes over time at 340 Hz. In this comparison, Design 4 exhibited a stronger correlation ($R^2 = 0.9771$) between capacitance and time when compared to Design 2, indicating its enhanced sensitivity to the dynamic processes of fruit ripening.

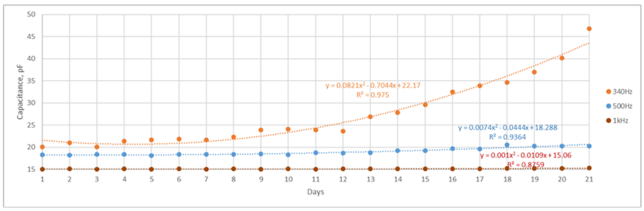

Figure 21. Capacitance of Design 2 and Design 4 (340Hz) versus days

3. Relationship Between Destructive and Non-Destructive Analyses

Figures 22, 23 and 24 illustrate the correlation between capacitance and destructive ripening markers. Figure 22 demonstrates a strong inverse relationship between firmness and capacitance. As the fruit softens over time (indicated by decreasing firmness values), cell wall breakdown increases water mobility and dielectric constant. Figure 23 reveals a positive correlation between Brix (sugar content) and capacitance, driven by sugar accumulation and increased ionic conductivity. Figure 24 indicates a less pronounced relationship between pH and capacitance as acid degradation affects dielectric properties less directly.

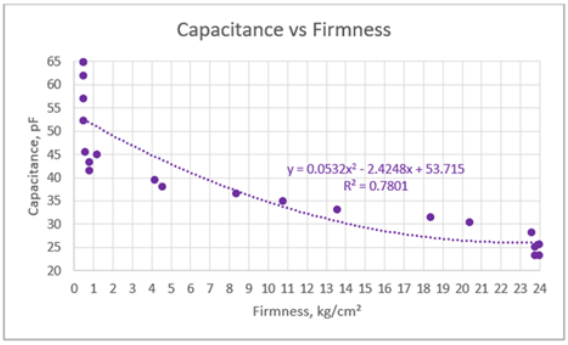

Figure 22. Capacitance versus firmness

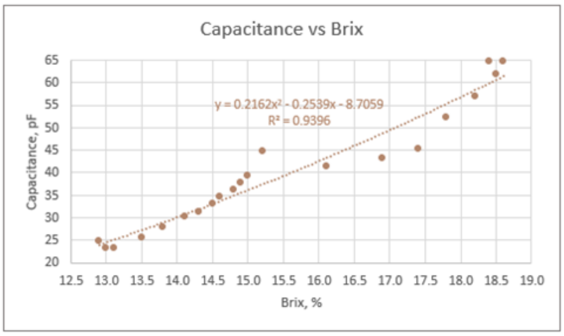

Figure 23. Capacitance versus Brix

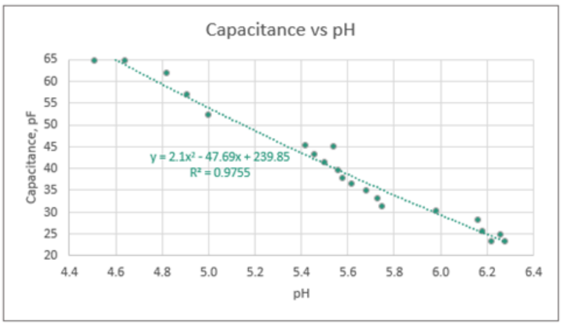

Figure 24. Capacitance versus pH

4. Predictive modelling

Table 2 shows the quadratic equations that model the correlations between capacitance, the independent variable x and three essential ripeness markers of *ciku* fruit, firmness, Brix and pH, the dependent variables y. Each equation allows for the estimation of a specific fruit attribute by substituting the observed capacitance value into the relevant equation.

The equation for firmness is $y = 0.0275x^2 - 3.0446x + 83.038$. This quadratic relationship shows that firmness of the *ciku* diminishes as capacitance increases over the days. The physiological process of fruit softening during ripening is in accordance with this trend. Brix value can be calculated using the equation $y = -0.001x^2 + 0.2318x + 8.0307$. According to the negative quadratic term, capacitance first rises with Brix concentration peaking before perhaps plateauing or slightly declining. This is consistent with the buildup of sugars and the ensuing metabolic alterations that occur during fruit ripening. For pH, the equation is $y = 0.0001x^2 - 0.0495x + 7.3398$. This equation shows that the pH decreases slightly nonlinearly as capacitance increases. This pattern illustrates how fruit ripens and organic acids are broken down which usually results in a decrease in acidity.

These equations collectively demonstrate that capacitance values obtained from the IDC sensor can be directly used to estimate the firmness, Brix and pH of *ciku* fruit. This strongly supports the feasibility of a non-destructive and predictive approach to monitor ripeness using capacitance as a reliable indicator.

Table 2. Relationships between firmness, Brix and pH with capacitance in *ciku*

Parameters	**Equations**
Firmness, kg/cm²	$y = 0.0275x^2 - 3.0446x + 83.038$
Brix, %	$y = -0.001x^2 + 0.2318x + 8.0307$
pH	$y = 0.0001x^2 - 0.0495x + 7.3398$

IV. CONCLUSION

This research established that IDC sensors can provide a rapid, precise and non-invasive means of determining *ciku* fruit ripeness. An optimal sensor design for monitoring fruit maturation was identified through a comparative analysis of capacitance values at various frequencies and an evaluation of two distinct sensor prototypes. It is noteworthy that Design 4 showed the strongest correlation with important fruit ripening indicators especially at a frequency of 340 Hz and Position A, which is the upper location, highlighting its effectiveness in monitoring changes in fruit quality. The validity of this methodology is supported by the strong correlations found between capacitance and traditional quality indicators including firmness, Brix and pH. Capacitance sensing is a useful tool for the fruit industry because of its non-destructive nature, which gives it significant advantages over conventional damaging methods.

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