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Non-Destructive Measurement on Kwini Mango Fruit using Capacitive Sensing Technique at 250kHz to 2MHz for Ripeness Determination

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ABSTRACT

This study aims to evaluate the characteristics and quality of Kwini mango fruit using non-destructive capacitive sensing methods. Unlike other fruits, identifying ripe Kwini mangoes can be challenging due to their green appearance and unfamiliar characteristics to consumers. Despite the growing interest in non-destructive fruit quality assessment techniques, there has not been significant prior exploration of capacitive sensing in the context of Kwini mangoes. Therefore, in this experiment, a parallel plate was used to measure the capacitance of Kwini mango fruit at frequencies ranging from 250 kHz to 2 MHz. Results showed that the moisture content and pH level decreased within 15 days of investigation. This technique was able to predict Kwini maturity with significant precision by applying the capacitance formula. Because of its high R2 value and sensitivity in linear regression, 500kHz was determined to be the most efficient operating frequency for Kwini mango fruits among the frequencies evaluated. In this experiment, the relationship between capacitance and Brix also yielded encouraging findings. The study also includes the development of a GUI application for determining the sweetness and maturity of Kwini mangoes. Overall, this research demonstrates the potential of capacitive sensing technology as a non-destructive approach to measuring Kwini mango fruit ripeness.

1. Introduction

Kwini mango fruit, also known as Mangifera Odorata, is a tropical fruit originating from West Malaysia and is widely grown in Borneo, Sumatra, Jawa, and southern Vietnam. The medium-sized, round fruit grows on trees that can reach heights of 10-30 meters. As the fruit matures, it changes from green to yellowish green with dark brown spots, and the flesh becomes orange yellow in colour, sourish-sweet, and juicy in flavour. Due to their perishability, Kwini mangoes require careful handling to retain their freshness and quality. However, transportation and storage can lead to premature spoilage, which is a significant concern for the fruit's freshness and quality [1].

Fruits, including Kwini mangoes, are essential parts of a healthy diet as they provide various nutrients such as vitamins and calcium. Quality and safety are also critical in the food market, and

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the expanding industrialization and agriculture make technology necessary. However, traditional manual sorting methods are inefficient and unreliable, as quality factors such as appearance, flavour, and texture rely on human judgment. Additionally, many traditional fruit measurement procedures are destructive and ineffective, making the development of non-destructive and effective measurement tools crucial.

One important quality aspect of fruit is ripeness, which is usually determined by changes in skin colour, softening, starch conversion to sugars, acidity reduction, and the production of flavours and aromas. In the case of Kwini mangoes, their greenish appearance can make it difficult for consumers to determine their ripeness, leading them to wait for days or even weeks before consuming the fruit. Thus, there is a need for research and experimentation to understand the characteristics and behaviour of Kwini mangoes during the ripening process.

The objective of this project is to understand the characteristics of the Kwini mango fruit and classify their ripeness using the capacitive sensing technique. The project aims to provide consumers with information on the characteristics of Kwini mangoes to help them select the best fruit. The capacitive sensing technique measures the capacitance produced in the experimental product and is applicable to determine the sweetness level in Kwini mangoes. This research focuses on the behaviour of this method at selected frequency when used with Kwini mango fruit.

2. Literature Review

Currently, the most common method for determining the ripeness of mango and similar fruits is to measure their firmness using a penetrometer [4]. However, this method has some drawbacks, such as its dependence on the user of the device, leading to significant variations in hardness levels of fruit tested with a penetrometer. To overcome these limitations, alternative methods for fruit ripeness estimation have been proposed. Capacitive sensing techniques are one such alternative that can meet the standards of fresh produce and reduce waste. A non-destructive, fully automatic approach has been proposed to determine mango ripeness using capacitive sensing. This approach allows for the evaluation of multiple surface areas with a single touch and can distinguish between ripe and unripe fruits. These advances in non-destructive fruit ripeness estimation techniques can greatly benefit the industry by reducing waste and ensuring the delivery of high-quality products to consumers.

2.1 Mango Fruit Classification

Mango, a well-known tropical fruit, has been a crucial plant in Ayurvedic and traditional medicinal systems for more than 4000 years. According to Ayurveda, different parts of the mango tree have unique medicinal properties. Mangiferin, a polyphenolic antioxidant and glucosyl xanthone found in mango, possesses wound healing, antioxidant, and antidiabetic properties.

In addition to its medicinal properties, fully ripe mango fruit is considered invigorating and refreshing. Despite its popularity, few people realize that mango has made significant contributions to biology and medicine. Mango juice is believed to be a cooling tonic that can help alleviate heat exhaustion, while mango seeds are used for their astringent and asthma-relieving properties [5]. Inhaling smoke from burning mango leaves is said to alleviate hiccups and throat problems.

Mangoes come in a variety of weights, sizes, shapes, and densities, making classification difficult. Current manual classification methods are not only inaccurate and costly but also pose health risks. Critical factors such as sweetness, hardness, age, and brittleness can only be determined by external or human perception, requiring artificial or machine systems to overcome these challenges.

Although mango classification studies based on colour, size, and volume have been completed in the laboratory, they have yet to be put into practice [6]. The issue of mango fruit quality remains unresolved, necessitating further research using image processing technologies, computer vision, and artificial intelligence.

2.2 Capacitive Sensing Technique

The introduction of capacitive imaging technology in 2006 brought about non-destructive inspections of objects composed of diverse materials using a non-contact and non-invasive technique. A pair of capacitive electrodes generates an electrostatic field within an object, and the type of material and shape of the object determines its dielectric characteristics [7]. Capacitive sensing detects capacitance, which is the capacity to hold the charge in an electric field between two or more conductors, to assess physical qualities like touch, proximity, or deformation. The conductors, or electrodes, can be made of various materials like solid metal parts, foils, transparent films, plastics, rubbers, textiles, inks, and paints. In some cases, electrodes can even be the human body or objects in the environment [8].

Capacitive sensing has become ubiquitous, and it is challenging to imagine life without it. Capacitive sensors are present everywhere, from the touchscreens and touchpads on our phones, tablets, and laptops to capacitive "buttons" in consumer electronics and commercial equipment. Capacitive sensing has a broad range of applications in human-computer interaction research.

2.3 Visual and Physical Experiments on Mangoes

Having clear objectives is crucial in any experiment, and previous researchers have always emphasized this. In fruit classification, researchers rely on a vast amount of information and data from books and articles to determine the visual and physical quality of fruits. Appearance and colour are important factors that draw a customer's attention to a product, which can result in impulse purchases. Consumers use these appearance factors to judge the freshness and flavour quality of fruits. While the external appearance of whole fruit is often used as an indicator of ripeness, it can be misleading. For example, consumers may assume that mangoes should turn yellow when they are ripe, but not all types of mangoes follow this pattern. Therefore, more attention needs to be given to educating consumers about ripeness indicators in mangoes to avoid confusion.

Colour is a crucial quality component that affects consumer preferences and choices in the food and bioprocessing industries. Chemical, metabolic, microbiological, and physical modifications that take place during post-harvest handling and processing, as well as during development and maturation, have an impact on food colour [9]. Colour evaluation is one of the most often studied quality indicators in post-harvest handling and food processing studies since it is frequently employed as an indirect predictor of other quality attributes. However, because colour measurements are frequently reported using various colour indices, it is challenging to compare the findings of various studies. To improve measurement traceability and transferability, standardization is required. The nutritional content of fresh and processed foods may be predicted using objective, non-destructive colour measurement, even though there is a known association between colour and other sensory quality factors [10].

3. Methodology

The methodology section of this paper outlines the proposed approach for conducting the project. To achieve accurate and desirable results, it is essential to follow a set of instructions and processes. This section will provide an overview of the capacitive sensing technique and its application, which is a critical area to be investigated to obtain precise outcomes. The primary objective of this project is to represent the unique characteristics of the Kwini mango using capacitive sensing.

3.1 Basic Capacitive Sensing and Application

Capacitive sensing is a capacitive coupling-based technique that uses the capacitance generated by the human body as an input. It enables a more trustworthy solution for applications such as liquid level measurement, material composition, mechanical buttons, and human-to-machine interactions. A basic capacitive sensor detects anything that is conductive or has a dielectric constant different from air and is made of metal or a conductor. Capacitance is the ability of a capacitor to store an electrical charge. Table 1 below shows the value used in the experimental phase.

Table 1
The measuring variable and the value used for the capacitive sensing experimental phase

Measuring variable	Value
Dielectric constant (ε_r)	(8.85×10^{-12} F/m)
Area (A)	100mm x 100mm
Distance (d)	80mm

A parallel plate capacitor has two conductor plates, and its capacitance (measured in Farads) as shown in Figure 1 is computed as follows:

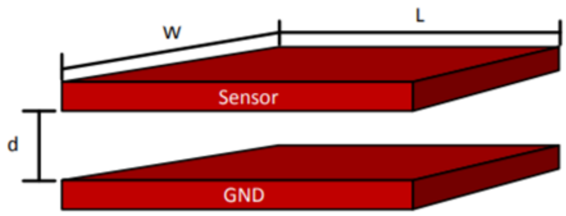

Fig. 1. Parallel Plate Capacitor

$$C = (\varepsilon_r \times \varepsilon_0 \times A)/d \quad (1)$$

where :
- A is the area of the two plates (in meters)
- ε_r is the dielectric constant of the material between the plates
- ε_0 is the permittivity of free space (8.85 x 10-12 F/m)
- d is the separation between the plates (in meters)

To predict the Brix or sweetness level in the Kwini mango fruit, the ε_r needs to be rearranged by:

$$\varepsilon_r=(c \times d)/(\varepsilon_0 \times A) \quad (2)$$

A charged parallel plate capacitor's plates have an equal but opposite charge distributed uniformly across their surfaces. The electric field lines begin on the charged plate with a higher voltage potential and end on the charged plate with a lower voltage potential.

Capacitive sensing is becoming an alternative technique to replace optical detection methods and mechanical designs in applications such as proximity/gesture detection and liquid level monitoring [11]. Hence, it is favourable for researchers to use capacitive sensing techniques in their findings of materials and fruits.

3.2 Capacitance Measurement

The circuit diagram in Figure 2 shows how to obtain voltage across by using the Voltage Divider Rule (VDR).

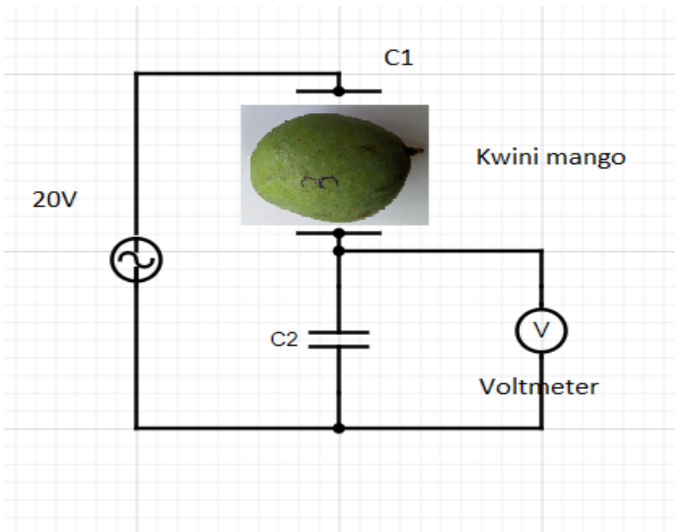

Fig. 2. The capacitance measurement for the Kwini mango

$$V_0/V_1 = C_1/(C_1+C_2) \quad (3)$$

A copper plate of 20 x 10 cm will be applied to get the capacitance value in the Kwini mango. The Kwini mango will be placed between the parallel plates.

C_1 is a series of capacitance Kwini mango and two air gaps at each side represents the electrical equivalent circuit as shown in Figure 3. The capacitance value of mango can be calculated by using the capacitance formula.

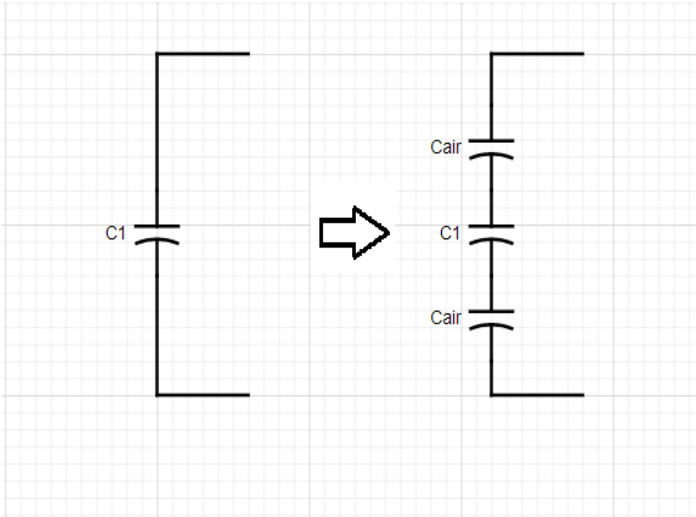

Fig. 3. The series of C_1 (Kwini mango) and two C_{air} (air gaps)

3.3 Kwini Mango Sampling

Figure 4 shows the flowchart of conducting the experiment. The Kwini mango fruits were obtained from local sellers. The fruits will be taken care of to maintain their quality. A few steps will be conducted such as measuring the diameter and weight of the fruits before performing further experiments. The sampling takes about 4 to 5 days for the mango to ripe naturally.

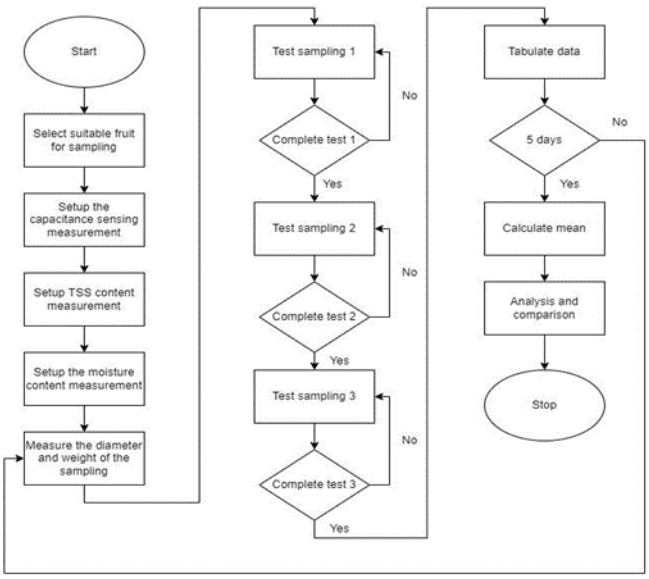

Fig. 4. Flowchart of the Kwini mango fruit classification experiment using the capacitive sensing technique

The experiment on this Kwini mango will focus on the level of total soluble solids (TSS) or ^{o}Brix in the fruits throughout a certain period. Another experiment will focus on the moisture content against capacitance at different values. Both experiments will be conducted on different frequencies, to get permittivity readings from unripe to ripen Kwini mango fruit.

4. Results

4.1 Measurement on Capacitance

In this study, capacitive sensing was utilized to assess the ripeness of Kwini mangoes. The experiment was conducted by generating 10 V_{pp} at 5 different frequencies, namely 250kHz, 500kHz, 750kHz, 1MHz, and 2MHz, using a function generator as shown in Figure 5. The purpose of the different frequencies used is to select the best-collected data that will provide the highest regression coefficient, while the value of voltage supply may vary, and any suitable voltage value can be used. A multimetre was then used to measure the output voltage of the voltage divider circuit. The dimensions of the parallel plates were 10cm x 10cm, and the distance between the plates was based on the width of the mangoes being tested. The thickness of the copper plate used in the experiment was 2mm, which was chosen to fit and adequately suit the size of the mangoes. The use of these dimensions and frequencies allowed for accurate and consistent readings to be taken, which were crucial for the successful assessment of the ripeness of the mangoes.

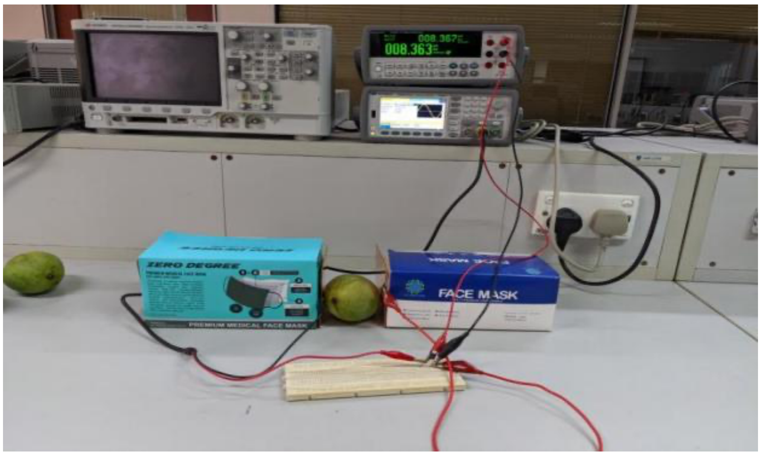

Fig. 5. Experimental setup of capacitive sensing measurement

The sweetness level of a juice sample can be determined by measuring its ^{0}Brix level as in Figure 6. This approach serves to assess the quality of fruits, specifically by evaluating their sweetness. In this study, a refractometer is utilized to measure the ^{0}Brix content of mango samples.

Fig. 6. The ^{0}Brix measurement from the juice sample

The mangoes are weighed and measured before the experiment, which will subsequently proceed with the capacitive sensing measurement. The juice will be extracted to obtain its Brix content and pH value as in Figure 7.

Fig. 7. pH Measurement

Afterward, the samples are subjected to a drying oven set at 75^{o}C for 24 hours. Once the drying process is complete, the samples are allowed to cool down at room temperature for approximately 3 to 5 minutes before being weighed again [12]. The moisture content (m.c%) is subsequently calculated using the following equation.

$$m.c\% = \frac{mass_{initial} - mass_{after}}{mass_{initial}} x100\% \quad (4)$$

4.2 Experimental Results

The experiments yielded results indicating a gradual decrease in the Brix level throughout the study as shown in Figure 8. The mango samples exhibited a range of Brix content between 4 and 17.

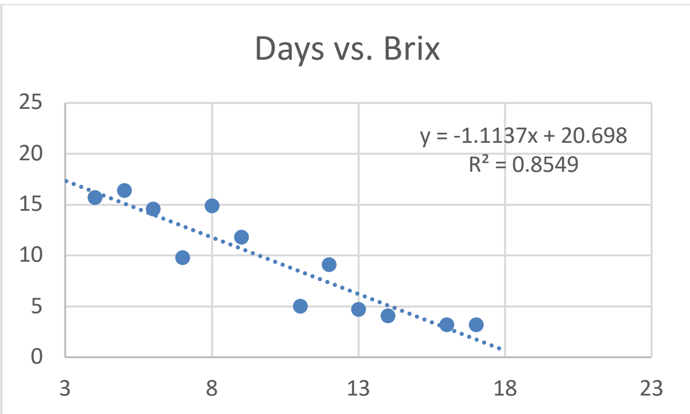

Fig. 8. The Brix content relationship over days

Similarly, as in Figure 9, the pH value obtained also demonstrated a gradual decrease. These changes can be attributed to the ripening process that occurred during the experiments. Both the Brix content and pH value consistently decreased throughout the experiment. However, the moisture content (m.c%) showed an increase from the initial day of the experiment to the final day as shown in Figure 10 to Figure 12, respectively. This can be attributed to the fact that unripe fruits typically lack juice. The measurement of fruit weight before and after the 24-hour oven drying process was employed in conducting these experiments.

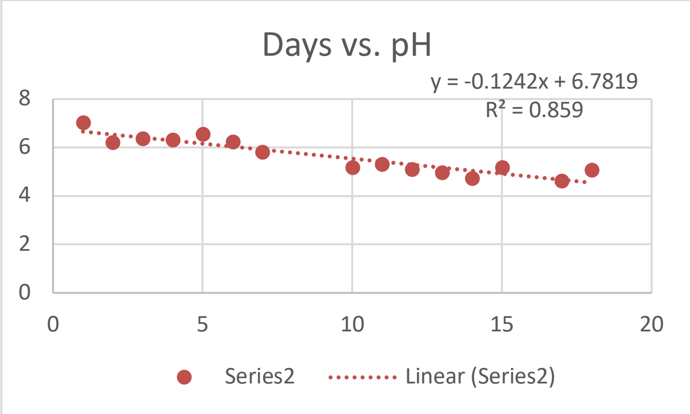

Fig. 9. The pH value relationship over days

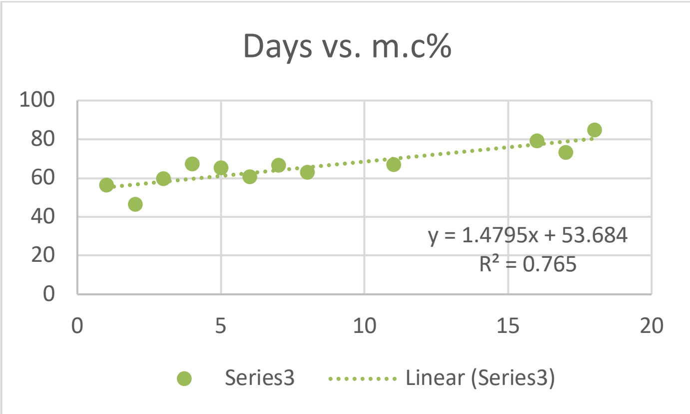

Fig. 10. The m.c% content relationship over days

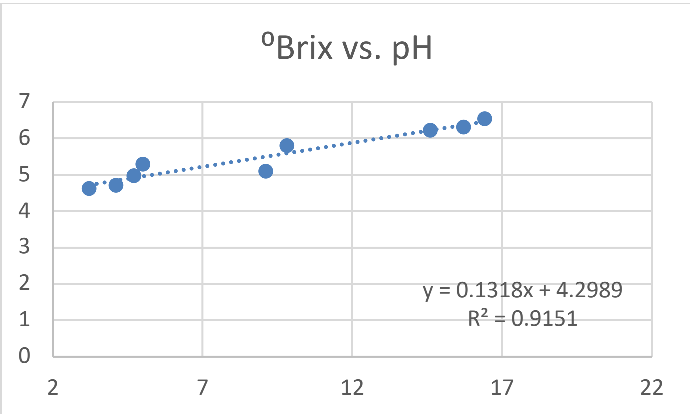

Fig. 11. The Brix relationship over pH value

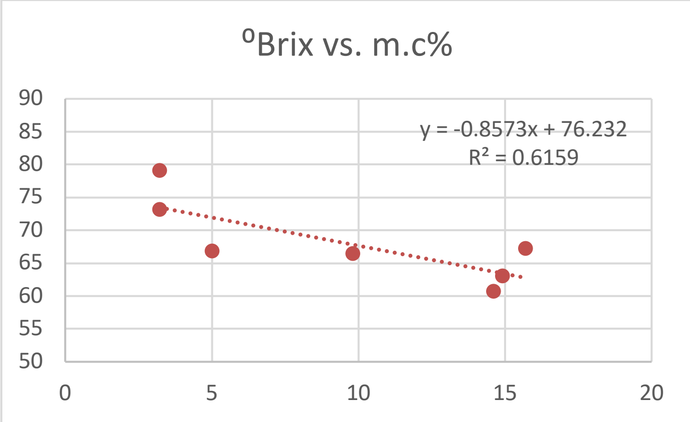

Fig. 12. The Brix relationship over m.c% content

Figure 13 to Figure 19 show the results of which relationship between days and capacitance, Brix and capacitance, pH and capacitance, and also m.c % content and capacitance, respectively. Based on the results obtained, 750kHz has the best operating frequency tested in mango fruits.

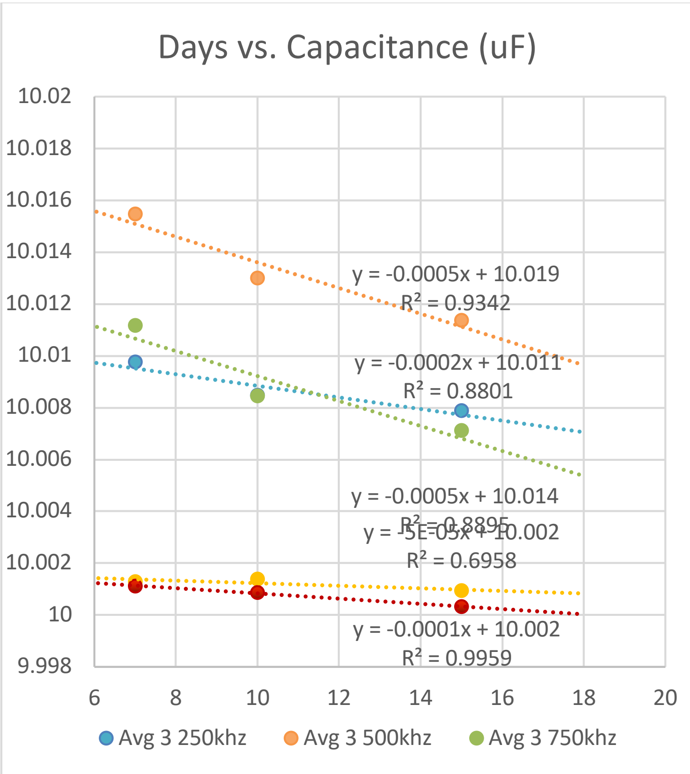

Fig. 13. The Capacitance relationship over days

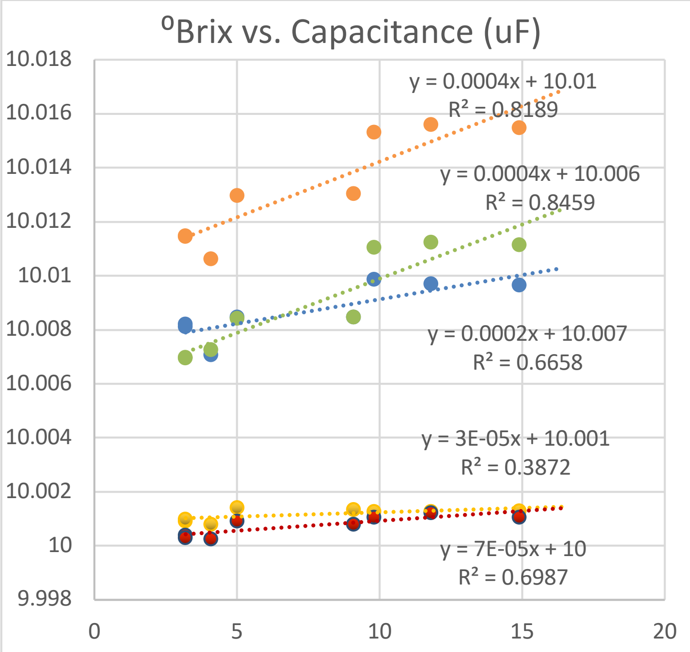

Fig. 14. The Capacitance relationship over Brix content

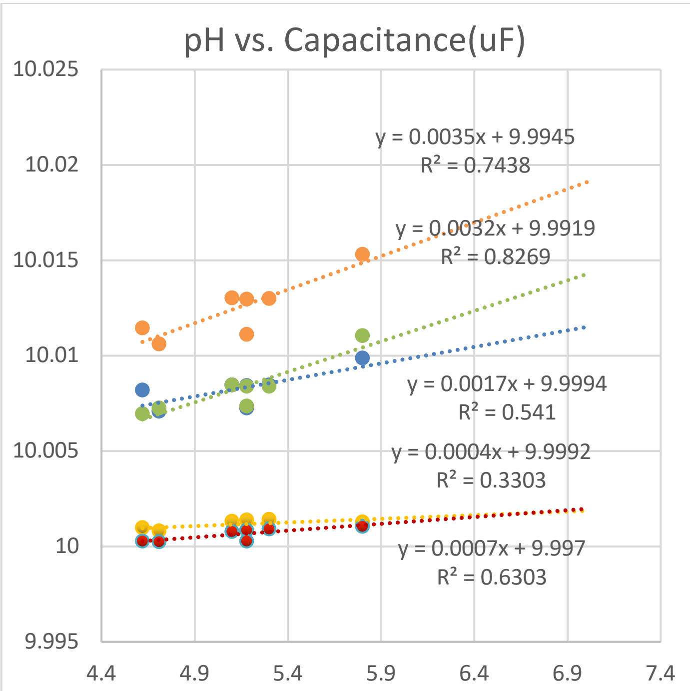

Fig. 15. The Capacitance relationship over pH

Figure 16 to Figure 18 shows the results of which relationship between days and dielectric, brix and dielectric, pH and dielectric, and also m.c% content and dielectric.

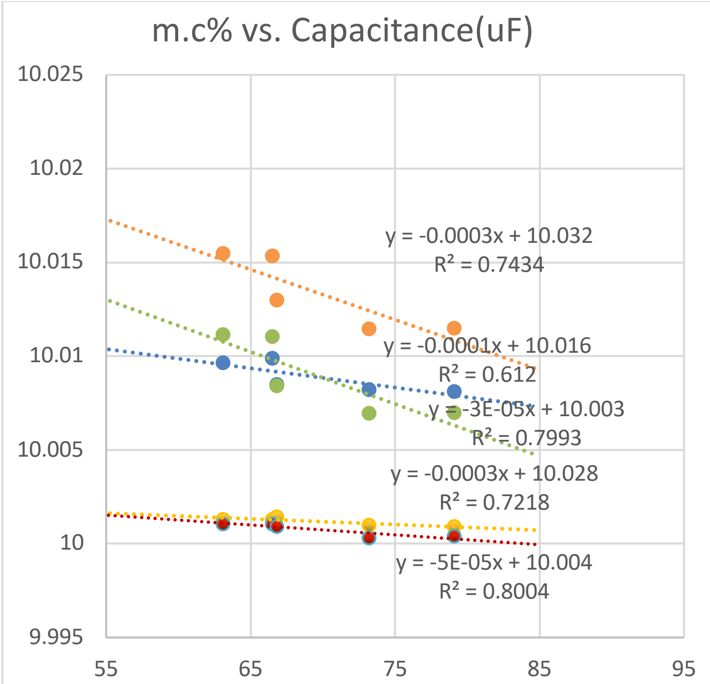

Fig. 16. The Capacitance relationship over m.c% content

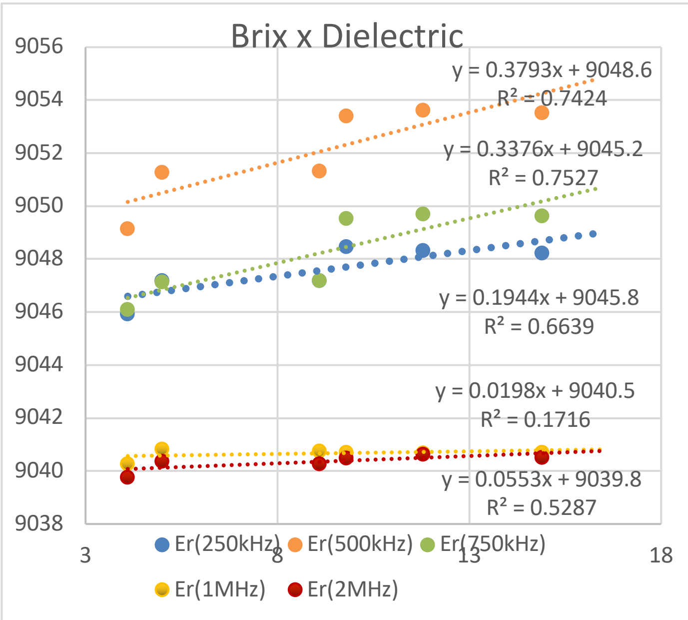

Fig. 17. The Dielectric relationship over Brix

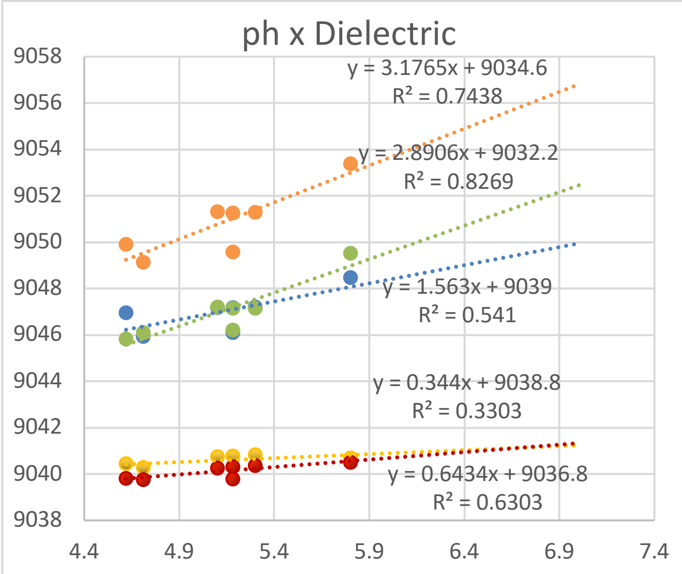

Fig. 18. The Dielectric relationship over pH

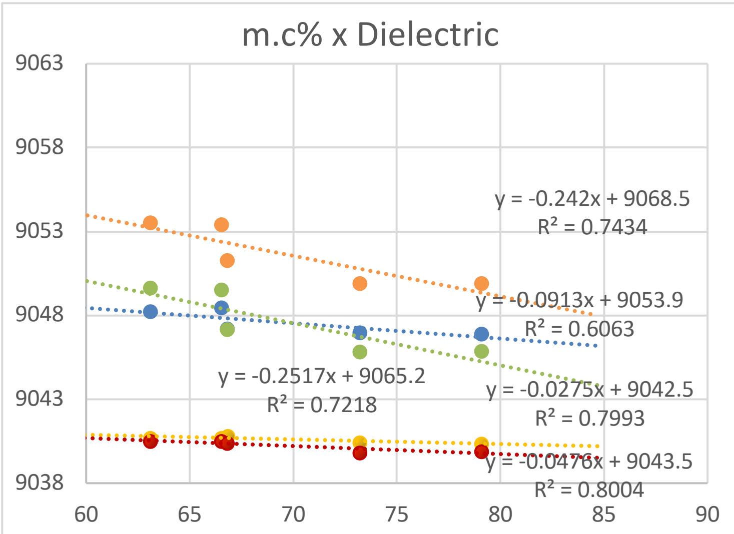

Fig. 19. The Dielectric relationship over *m.c%* content

4.3 Matlab Estimation Calculator Apps

In this section, a Graphical User Interface (GUI) application is developed using Matlab to estimate the Brix, pH, and moisture content (m.c%) in Kwini mango fruits. This application aims to provide an estimation of these values based on the collected data. To create this app, the collected results are required, and they will be incorporated into the Matlab code, which involves utilizing the slope-intercept form depicted in the figures presented earlier in the experimental results. The computation of the slope-intercept form is performed as follows:

$$y = mx + c \tag{5}$$

Where *y*, in this case, is the capacitance value, *m* is the gradient of the line and *c* is the *y*-intercept. While *x* is the value of estimation that is needed in the formula. The *x* will represent Brix, pH, and m.c% content which need to be rearranged by:

$$x = \frac{y-c}{m} \quad (6)$$

Below figure display the visual representations of the estimation calculator app developed in Matlab. Users can input the capacitance value of Kwini mango, select the desired frequency, and observe the corresponding output value. The applications provide visual representations of unripe, ripe, and overripe Kwini mangoes, offering a comprehensive picture of the estimation results as in Figure 20 to Figure 22, respectively.

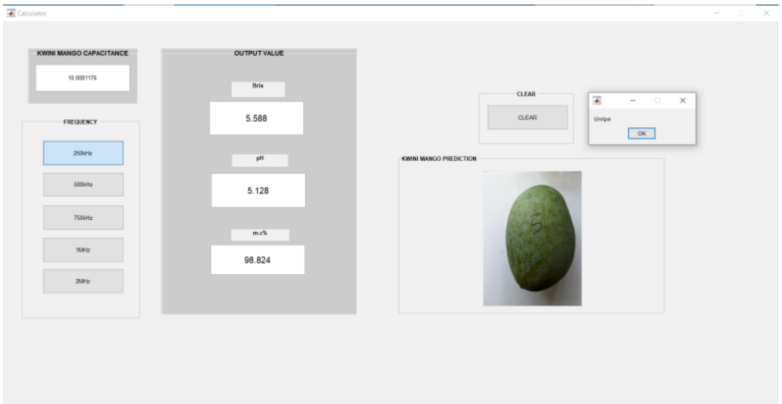

Fig. 20. Unripe Kwini Mango in Estimation Calculator App

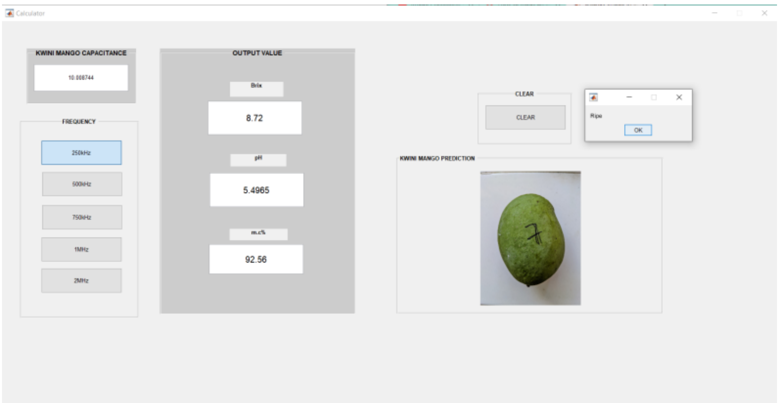

Fig. 21. Ripe Kwini Mango in Estimation Calculator App

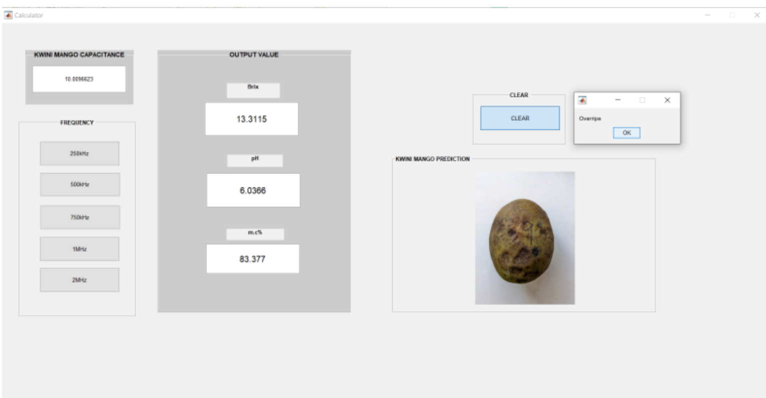

Fig. 22. Overripe Kwini Mango in Estimation Calculator App

The outcomes of this project have provided support for the initial hypothesis, which aims to preserve fruit quality and extend its storage life to ensure consumers receive high-quality produce.

A crucial aspect of this research involved investigating the capacitive sensing technique to achieve precise and anticipated outcomes while minimizing fruit damage. In addition to that, various experiments were conducted in the laboratory setting to assess the quality of fruits in terms of total soluble solids (TSS) or Brix, moisture content, and pH value. All the results and data obtained in this project were obtained through laboratory experiments.

5. Conclusions

In conclusion, this technical paper demonstrated the successful application of the capacitive sensing technique as a low-cost, non-destructive method for determining the ripeness of Kwini mango fruit. By using the capacitance formula, the technique was able to predict fruit ripeness with high accuracy. Among the frequencies tested, 500kHz was found to be the most effective operating frequency for Kwini mango fruits due to its high R^2 value and sensitivity in linear regression. The correlation between Brix and capacitance also produced promising results in this project. The non-destructive nature of this technique provides a valuable tool for the agriculture sector to meet local market demand. As a future recommendation, increasing the number of samples tested would lead to more precise and accurate data. Overall, this study demonstrates the potential for capacitive sensing as a valuable tool for non-destructive fruit ripeness determination.

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