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Understanding the Effect of Fruits Maturity Level on Its Effectiveness as a Dielectric for Parallel Plate Capacitors for Senior High School Student

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Yerika Puspa Rosanti[1*], Raden Manzilah Mubarokah Fahra[2], Siti Nurul Khotimah [3]

[1]Master of Physics Teaching, Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung, Bandung, Indonesia

[2] Master of Physics Teaching, Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung, Bandung, Indonesia

[3]Faculty of Mathematics and Natural Sciences,
Institut Teknologi Bandung, Bandung, Indonesia

Corresponding Email: *yerikapuspa@gmail.com

Abstract

Indonesia is an agrarian country that produces fruits in abundant quantities and in various variations. Fruits contain diverse contents, one of which can be utilized as a dielectric capacitor. This research is conducted to provide senior high school students with an understanding of the influence of dielectrics from several fruits on capacitance. This experiment analyzed the maturity level of fruits and their effectiveness as dielectric capacitors for parallel plate capacitors. Due to the maturity level of fruits being composed of many variables, this study is focused on differences in water content, sugar concentration, and acidity level. Through laboratory experiments, researchers examined these factors in guava, papaya, pear, mango, and apple fruits. The capacitance value of parallel plates is measured using an LCR meter, and it is found that the capacitance of parallel plates with air dielectric increases significantly when infiltrated with fruit dielectric. Water content has a significant influence. The capacitance value is also high in fruits with high water content and vice versa. Meanwhile, the influence of sugar concentration is less significant in this study, only noticeable in papaya fruits. However, this is supported by the fruit's acidity level as seen from its pH value. Fruits with high pH values also have high capacitance. Experiments found that as fruits ripen, their water content, sugar concentration, and pH value tend to increase. This causes mature fruits to be more effective when used as dielectric capacitors.

Keywords: Parallel plate capacitor, Dielectric, Maturity level of fruits, Senior high school

INTRODUCTION

Indonesia is an agrarian country, and most of its population works in the agricultural sector. Located along the equator, Indonesia has fertile soil that is easy to cultivate, resulting in a diverse and abundant supply of natural resources, including fruits. In our society, fruits are usually only used as a food source. However, the diverse contents of fruits can be utilized for much more (Mohsenin, 1970). For example, the glucose and ethanol content from rotten fruits can be used as bioethanol (Rifaldin & Kusuma, 2019), the ellagic acid content in strawberries can nourish the scalp and increase hair growth, making it useful as a hair tonic (Rizqullah *et al.,* 2021) , or the acidic content in fruits can generate electrical energy (Atina, 2015; Juansah & Irmansyah, 2007; Sosa-Morales *et al.,* 2017; Wijayono & Putra, 2020).

In addition, the diverse contents of fruits can also be utilized as dielectric materials for parallel plate capacitors. Many experiments have studied the quality and maturity indices of fruits, including apples, avocados, mangoes, tomatoes, bananas, etc. (Lee, 1981; Lien *et al.,* 2009; Kim *et al.,* 2009; Soltani *et al.,* 2011; Fahruri *et al.,* 2017; Rizza *et al.,* 2019) The capacitors are energy storage devices and an element of electrical loads (Makihara *et al.,* 2006), used to collect electrical energy by generating a potential difference (Blooming & Carnovale, 2007; Nurmasyitah, 2017; Tahalyani *et al.,* 2020). A parallel plate capacitor is an electronic component that can store electrical charge (Halliday *et al.,* 1997; Andelman, 2011; Qi *et al.,* 2014). It is based on Curie's empirical law of 1889, which states that the current is through a capacitor (Westerlund & Ekstam, 1994). A capacitor consists of two metal plates separated by a dielectric material (Sarjeant, 1989; Kaiser, 2012; Wang & Wang, 2017; Siagian *et al.,* 2021; Ortigueira *et al.,* 2023). Faraday made major contributions to capacitor technology, including the concept of dielectric constant (Ho *et al.,* 2010). His contributions are recognized in the unit for capacitance. A dielectric is a material that has very low or negligible electrical conductivity (Gulita *et al.,* 2015). The dielectric constant is a characteristic of a substance, meaning that each substance with different factors will have a different dielectric constant (Lusiando *et al.,* 2012; Adnan *et al.,* 2021; Ariessaputra *et al.,* 2020; Didik, 2020).

In previous research, the dielectric properties of bananas at different ripeness levels were identified by Gulita *et al.* (2015) using an RLC circuit. They developed a capacitance measurement tool to determine the ripeness level of bananas and found a positive correlation between the two: the riper the banana, the higher the capacitance value (Gulita *et al.,* 2015; Harefa & Pato, 2017; Rizza *et al.,* 2018). This study will further investigate the influence of fruit ripeness on its effectiveness as a dielectric material for capacitors using a variety of fruits. Fruit ripeness is composed of many variables (Mohsenin, 1970; Rizza *et al.,* 2018). This research will focus on water content, sugar concentration, and acidity level.

Teaching high school students about the effect of fruit maturity levels on the effectiveness of parallel plate capacitors is important for several reasons. First, it integrates practical, hands-on learning with theoretical physics, making more relatable abstract concepts like capacitance and dielectric materials (Yehya *et al.,* 2019; Suma *et al.,* 2018). By exploring how natural materials, such as fruits at different maturity levels, can affect the capacitance of a capacitor, students can better understand the principles of dielectric constants and energy storage in capacitors (Kharel *et al.,* 1996; Dorai, 2020; Lotfi et al., 2021, Vallverdu-Queratt *et al.,* 2012). This approach enhances their understanding of physics and encourages them to see the connections between science and everyday life (Restrepo *et al.,* 2022; Ariffin *et al.,* 2024). Additionally, such lessons can inspire students to think creatively about using natural materials in technological applications, fostering innovation and a deeper appreciation for the role of science in solving real-world problems (Guisasola *et al.,* 2002; Mohamad *et al.,* 2012).

METHOD

This research was conducted using samples of five different fruits, cut into pieces measuring (5 x 5) cm^2 with a thickness of 2 mm to fit the parallel plates. The fruits used as samples include: (1) guava (*Psidium guajava*), (2) papaya (*Carica papaya*), (3) mango (*Mangifera s*p.), (4) pear (*Pyrus pyrifolia*), and (5) apple (*Malus domestica*). The parallel plate capacitor used iron plates measuring (5 x 5) cm^2 with a thickness of 3 mm. This research was conducted using a laboratory experimental method, with data collection and analysis following the steps outlined in Figure 1.

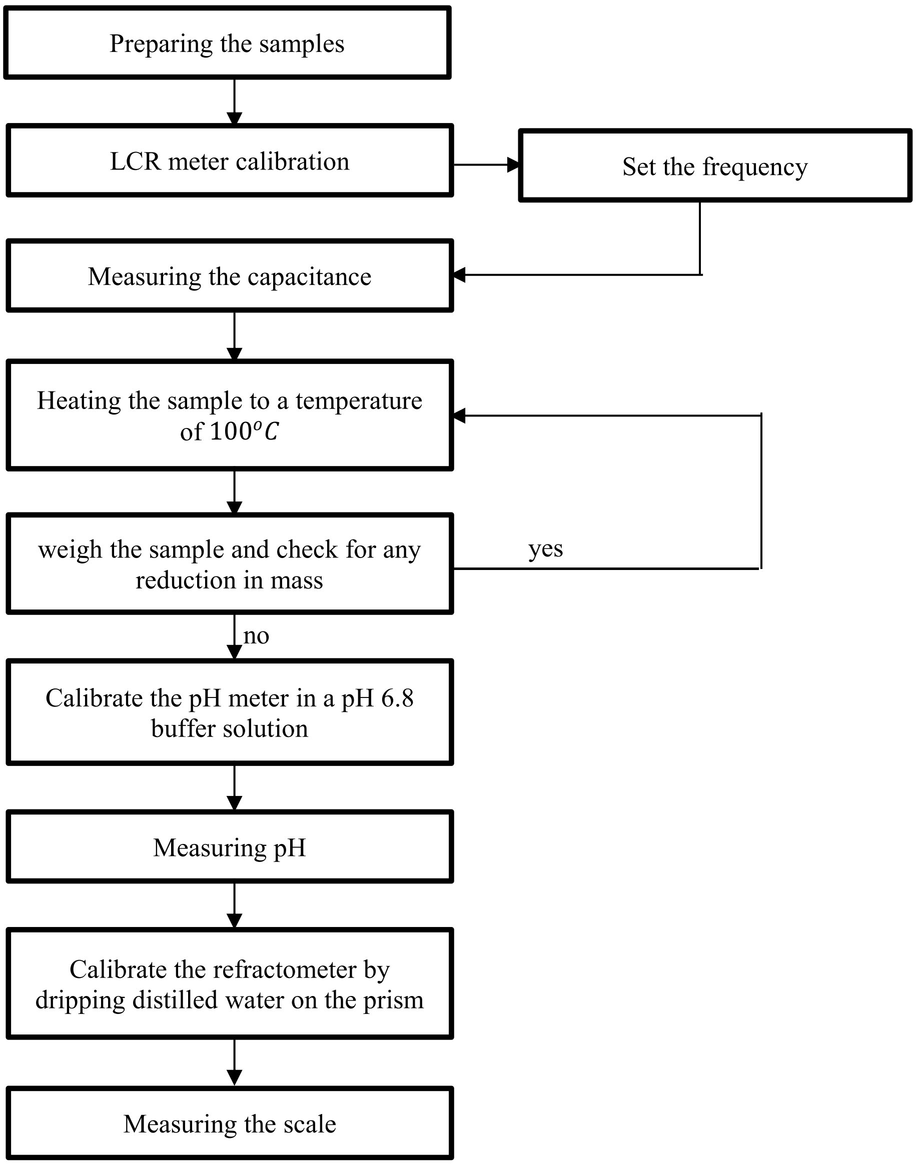

Figure 1. Data Collection and Processing Scheme

The capacitance data was collected using an LCR meter arranged as follows.

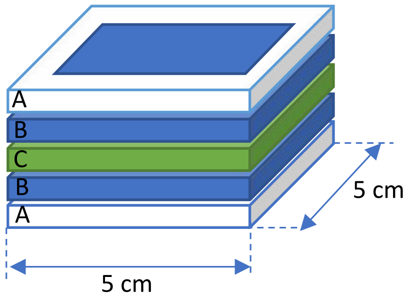

Figure 2. Experimental Setup Scheme

Part A of Figure 2 is an acrylic plate used as an insulator. Part B is the parallel plate capacitor. To measure the initial capacitance or capacitance without a dielectric, the space between the two parallel plates is left empty with a gap of approximately 2 mm, maintained by small pieces of paper at the edges to keep the plates in position. When inserting the fruit dielectric, the fruit samples are cut to a size of 5 x 5 cm² with a thickness of approximately 2 mm. While measuring the sugar concentration using a tool called a Brix refractometer, as well as a pH meter to measure the acidity level

RESULTS AND DISCUSSION

Data Collection Results

Table 1. Data of Capacitance Measurement

Frequency (kHz)		**1**		**10**		**100**	
		C (nF)	D	C (nF)	D	C (nF)	D
without dielectric		0.020	0.495	0.013	0.156	0.011	0.040
Mango	Unripe	5307.200	2.150	775.133	1.477	197.970	1.117
	Ripe	3701.083	2.575	497.580	1.847	119.692	1.797
	Very Ripe	5867.600	1.635	1254.708	1.659	272.983	1.375
Papaya	Unripe	10086.000	2.200	1718.029	2.206	253.360	1.186
	Ripe	9102.889	2.187	1596.162	2.191	227.250	1.147
	Very Ripe	7827.560	2.744	1382.182	3.330	202.580	1.598
Pear	Unripe	2006.692	1.826	355.014	1.009	133.618	1.088
	Ripe	2143.600	1.837	403.040	1.241	163.437	2.600
	Very Ripe	2917.909	1.713	560.600	0.966	221.456	1.226
Apple	Unripe	2407.929	2.268	329.733	1.488	84.861	1.352
	Ripe	2547.588	1.921	428.100	1.022	173.095	1.404
	Very Ripe	4026.154	1.888	718.282	1.120	254.589	1.469
Guava	Unripe	5185.727	2.560	904.021	2.888	101.861	1.612

Frequency (kHz)		**1**		**10**		**100**	
		C (nF)	D	C (nF)	D	C (nF)	D
	Ripe	5186.077	2.733	771.900	2.663	88.115	1.243
	Very Ripe	9227.909	2.677	1634.250	3.310	152.986	1.572

Table 1 shows the capacitance values of parallel plate capacitors (C) in nano Farads (nF) when without dielectric (air) and when infused with five types of fruits at three different ripeness levels. Additionally, the dissipation factor (D) measured on the LCR meter is also included. According to the experimental results, although not observed in all samples, when the capacitance of the capacitor increases with ripeness level, the dissipation factor tends to decrease. This occurred in mango samples across all frequencies and in ripe to very ripe stages of papaya, pear, and apple.

The relationship between dissipation factor and capacitance in parallel plates is that capacitance (C) measures the capacitor's ability to store electric charge, while dissipation factor (D) measures how quickly the capacitor releases energy during changes in charge. In practice, capacitors with low dissipation factors tend to have higher capacitance because they can store energy more efficiently. Conversely, capacitors with high dissipation factors may have lower capacitance because more energy tends to be wasted as heat or unwanted energy.

The capacitance of parallel plate capacitors with air as the dielectric increases significantly when infused with fruit dielectric. Inserting fruit as a dielectric material in capacitors can enhance capacitance values, especially if the fruit has a high dielectric constant. To understand the factors influencing this phenomenon, further analysis will be conducted in the following subsection.

Then, a decrease in the capacitance of parallel plate capacitors was observed when measured using an LCR meter at higher frequencies. This was evident in the experimental results without dielectric (air) and dielectric (all fruits). Firstly, particles within the dielectric may not have sufficient time to fully align with the changing electric field at higher frequencies, leading to less effective polarization. This can reduce the dielectric's contribution to overall capacitance, thus causing a decrease in capacitance at higher frequencies. Dielectric losses can become more significant at higher frequencies, resulting in decreased capacitance. Thirdly, some materials exhibit dispersion properties and hysteresis effects that can cause variations in capacitance depending on the frequency.

Table 2. Measurement Data of Fruit Maturity

Fruit	**Condition**	**Sugar Concentration (%)**	**Acidity Level**	**Water Content (%)**
Mango	Unripe	60	5.66	83.84

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Fruit	Condition	Sugar Concentration (%)	Acidity Level	Water Content (%)
	Ripe	80	6.03	84.10
	Very Ripe	90	6.36	88.51
Papaya	Unripe	80	5.83	86.65
	Ripe	90	5.38	87.20
	Very Ripe	95	5.53	87.00
Pear	Unripe	75	5.04	88.42
	Ripe	80	5.13	87.49
	Very Ripe	90	5.88	87.26
Apple	Unripe	90	4.73	86.39
	Ripe	90	4.23	88.72
	Very Ripe	100	4.11	87.14
Guava	Unripe	65	4.39	82.57
	Ripe	70	4.15	86.52
	Very Ripe	70	4.15	87.14

Table 2 shows the components of fruit ripeness investigated in this study, namely moisture content, glucose concentration, and acidity level. To clarify their trends, graphs were created, as shown in Figure 3, Figure 4, and Figure 5.

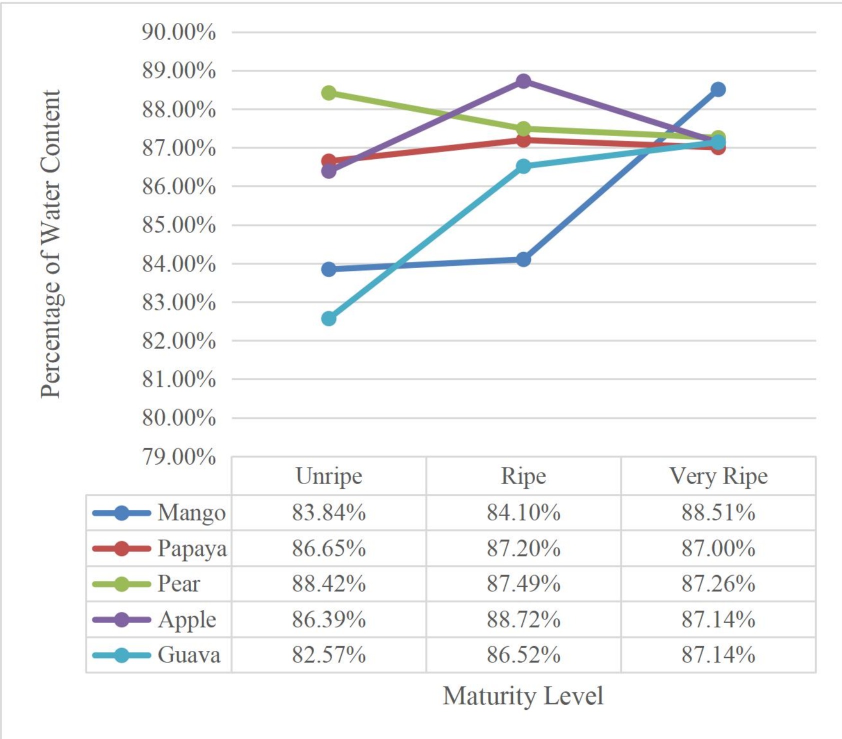

Figure 3. Water Content Graph

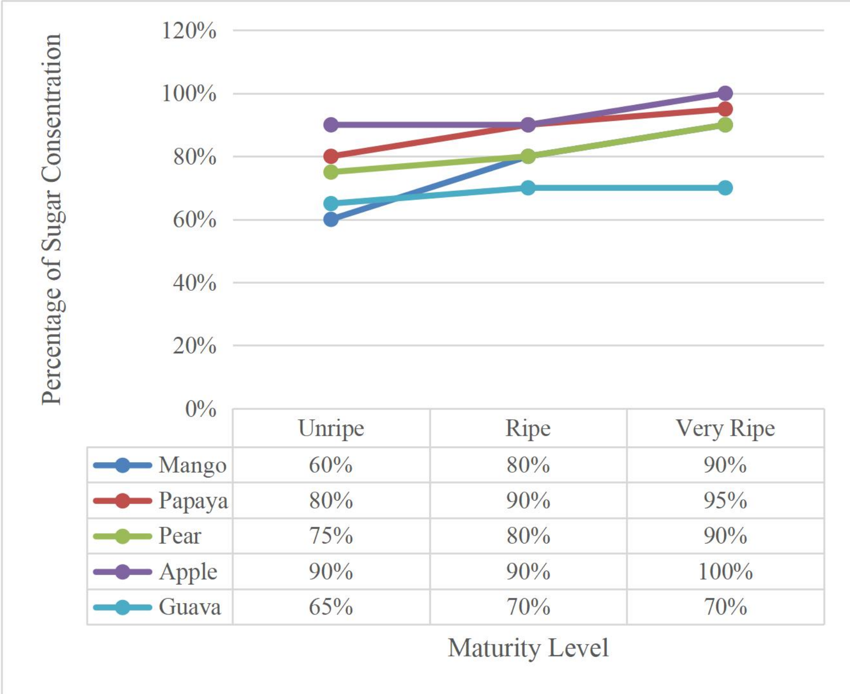

Figure 4. Sugar Concentration Graph

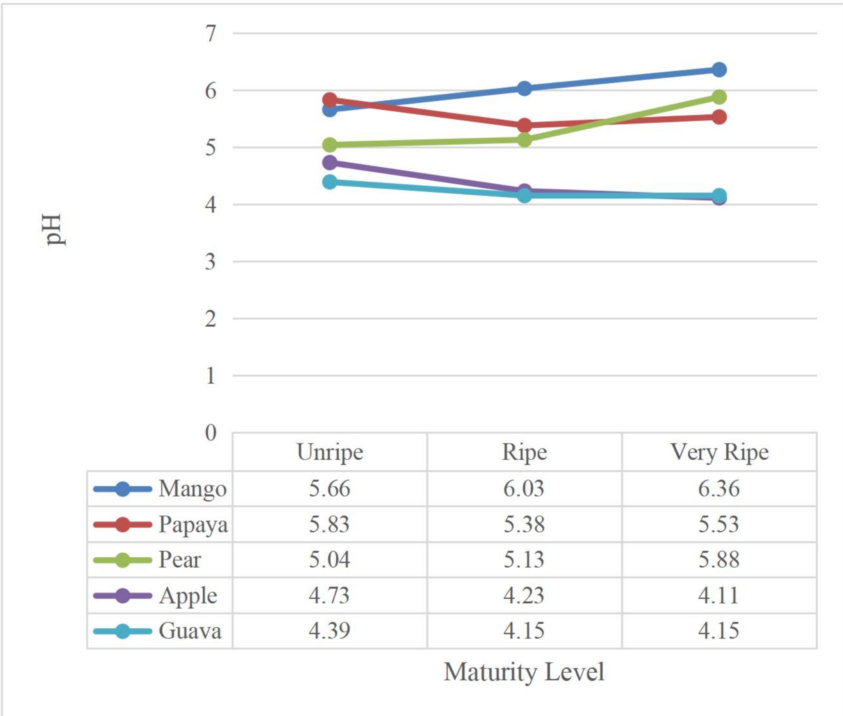

Figure 5. Acidity Level Graph

Analysis of the Influence of Water Content on Capacitance

Moisture content represents the sample's water percentage (Aventi, 2015 & Shivamurthy *et al.,* 2017). The research results on water content using heating methods, as shown in Table 2, indicate that in Mango, Papaya, Apple, and Guava fruits, there is an increase in water content as the fruits ripen. This suggests that the ratio of fruit pulp to skin increases as the ripeness level increases. The increase in the ratio of fruit pulp to skin is due to the higher water content in the fruit pulp, which results from the respiratory process that breaks down starch into sugar and water.

The water content in fruits used as dielectric material in parallel plate capacitors can affect capacitance due to several factors, including the role of water as a dielectric. For example, suppose the water content in the sample is represented by the blue circle, as shown in Figure 6. In that case, the capacitance of the capacitor is the parallel value of the capacitance of water and fruit (Lusiando *et al.,*2012).

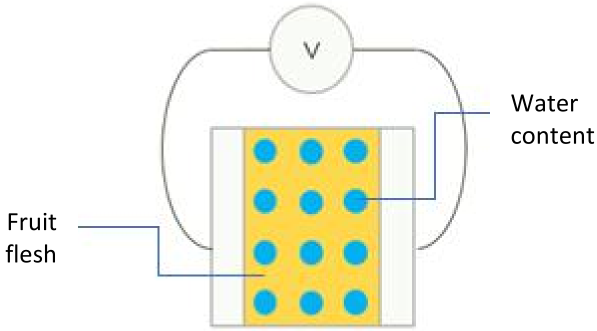

Figure 6. Illustration of a Capacitor Infused with Fruit

The dielectric constant of water is 80, so the higher the water content, the larger its capacitance value. Secondly, water is a polar molecule with an orientation that an applied electric field can influence. When water inside the fruit is influenced by the electric field between the parallel plates, water molecules can polarize, increasing capacitance. This effect is more significant when the water content in the fruit is high. Although water has a high dielectric constant, it also has a loss factor that affects capacitance. At certain frequencies, dielectric losses in water can cause a decrease in the overall capacitance of the capacitor. This study found that there is generally a positive correlation between the capacitance of parallel plates and the water content inside the fruit.

Analysis of the Effect of Sugar Concentration and Capacitance

The sugar concentration in fruits, measured with a brix refractometer, is quite high. From Table 2, it is evident that as fruits mature, their sugar concentration also increases. This is observed in mangoes, papayas, pears, and guavas, which show increased glucose concentrations at more mature stages. An increase follows this factor in the capacitance value of the plates infused with these fruits.

Glucose is a polar compound with an orientation that an applied electric field can influence. The sugar concentration in fruits often correlates with their water content. Changes in glucose concentration can affect the water content of the fruit, which in turn can affect capacitance due to changes in the dielectric contribution from water.

Analysis of the Effect of Acidity Level on Capacitance

The pH value of each sample solution represents the acidity level. A lower pH value indicates higher acidity, often implying higher levels of acid content in the fruit. Acids in fruits, such as citric acid or ascorbic acid, can affect molecular polarization in the dielectric material when influenced by an electric field. Similar to glucose concentration, this polarization can affect capacitance by causing changes in the material's response to the electric field.

The fruit's acidity level or pH value correlates with its chemical composition, influencing its electrical properties. Acidity can affect conductivity or the ability of a substance to conduct electrical current. Acidic substances or those with low pH tend to act as electrolytes. An electrolyte is a substance that can dissociate into ions when dissolved in water, allowing electric current to flow through the solution. Therefore, higher acidity levels can enhance a material's ability to act as an electrolyte and conduct electrical current.

In addition, some acid compounds can form dipoles, which are molecules with partial positive and negative charges at their ends. This can affect the dielectric properties of the material, including the material's ability to produce an electric voltage in an electric field. So, the acidity level of a material can affect the electrical properties or ability of the material to produce an electric voltage or current.

To support this conclusion, suppose two capacitors are inserted into the sample with pH A being smaller than pH B, then the voltage on capacitor A is greater than on capacitor B.

$$V_A > V_B \quad (1)$$

From the capacitor formula,

$$E = V.d = \frac{E_0}{\kappa} \quad (2)$$

$$C = \kappa\, C_0 \quad (3)$$

So if the pH of the material is greater, it will produce a large capacitance of the capacitor, and vice versa. This supports the previous statement that there is an increase in capacitance in dielectrics with higher pH values.

In pears, the effect of water content on capacitance has not been seen. Likewise with papaya fruit. However, if you look at the acidity level at each level of maturity, it turns out that there is a positive correlation between the two. The capacitance value is also high in fruit with a higher pH value, and vice versa.

CONCLUSION

From the experiments that have been carried out, it was found that the use of fruit as a dielectric material for parallel plate capacitors resulted in a significant increase in the capacitance. The water content, sugar concentration, and acidity level of the fruit used as a parallel plate capacitor dielectric sample can jointly influence the overall passivity.

Water content has a considerable influence on the properties of the sample as a dielectric. Samples that have a high water content will increase the capacitance value of the parallel plate into which they are inserted. Meanwhile, the sugar concentration did not show much influence on the results, although the glucose concentration was correlated with the water content in the fruit. Meanwhile, the acidity level of the sample shows a positive correlation with parallel plate capacitance because acidic materials can act as electrolytes that affect conductivity and capacitance. Where the higher the pH value of the sample, the higher the capacitance of the parallel plates, and vice versa.

So overall, papaya fruit with high water content, glucose concentration, and a large pH value has better effectiveness than other fruits when used as a dielectric in parallel plate capacitors. This can be seen from the capacitance value of the inserted parallel plate, which has a high value too.

Teaching the effect of fruit maturity on parallel plate capacitors helps students connect physics concepts with real-world applications, making abstract ideas more relatable and inspiring creative thinking in technology.

SUGGESTIONS

To carry out experiments involving measuring the capacitance of parallel plates using fruit as a dielectric material, paying attention to the choice of fruit used as a sample is necessary. Fruits with different characteristics in terms of water content, sugar concentration, and acidity level would be good to use to get more accurate results. Apart from that, further tests need to be carried out to determine the correlation between the glucose concentration of the sample and the parallel plate capacitance value. The Brix refractometer used to measure sugar concentration in this study had less accurate results, so it is recommended that another method be used to measure it.

To ensure high school students' understanding of physics concepts, I suggest incorporating a hands-on laboratory experiment where they explore this experiment. This practical approach will help solidify their grasp of theoretical principles, foster critical thinking, and encourage a deeper interest in physics through real-world applications.

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