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Research Article

ELECTRICAL PROPERTIES OF INDIAN BANANA CULTIVARS DURING RIPENING

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Abstract- The study was undertaken to determine electrical properties of three Indian banana cultivars during ripening. Capacitance, relative permittivity, impedance and admittance were measured at different frequency ranges from 10 kHz to 1 MHz for each stage of ripening. The observed results showed that capacitance, relative permittivity and admittance values increase with the time duration of ripening for all three varieties. However, the impedance value was found to be decreasing linearly for all varieties during ripening. Robusta cultivar had maximum values of all the properties followed by Poovan and Karpuravalli. In the frequency ranges of 10 kHz to 1 MHz, the electrical properties of Indian banana are correlated linearly to ripening stages. Results of this study are highly use-full for development of a non destructive banana quality measuring device.

Keywords- electrical properties, banana, frequency, ripening stages, relative permittivity

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Introduction

Banana is a popular fruit belonging to the family Musaceae. India is the largest producer of banana, contributing to 27% of world's banana production. In 2015–16, India exported around 4.5 billiontones of fresh banana which were valued at 91.54 million rupees [1]. Indian banana varieties are preferred worldwide due to their strong aroma, more intense peel colouration, delicious taste and high nutritional value [9].

In commercial banana production, fruits are harvested at mature green stage when they are still green and firm. To attain superior marketable quality, ripening process can be induced by ethylene gas under controlled temperature and humidity conditions. During ripening, banana undergoes a complicated ripening process that involves various physical and biochemical changes, including softening, loss of chlorophyll, change of the peel color, conversion of starch to sugars and alteration of aroma and flavor [11]. In order to get maximum marketable price, banana quality should be maintained throughout the supply chain. Determining and monitoring of quality parameters like colour, firmness, pH and total soluble solids (TSS) in the orchard, pack house and delivery points important in achieving the delivery of banana to the market. Currently, banana fruit quality assessment is accomplished based on skin color using colour charts which was standardized based on peel colour of banana with various stages of ripeness. The commercial ripening facilities involved automation and programmatic ethylene gas control systems operated by trained laborers. Sometimes, due to lack of monitoring practice, fruits are ripened at high temperatures and low relative humidity conditions. This could cause the fruits to retain their green peel colour even though ripening has already commenced internally, creating a non-homogeneous situation whereby the peel colour (chlorophyll) does not reflect the internal changes [4]. Therefore, human visual colour stage judgments by using a chart scale is purely subjective (sensory) and many commercial growers and packers are not able to obtain highly consistent and accurate results.

Electrical measurement provides the opportunity for simple, low cost, and quick assessment of product quality. Studies of electrical properties for the purpose of commodity grading are not new concept. Over the last five decades, many research studies were conducted and documented for a large variety of fruits and vegetables. Particularly, Kato [8] developed a new non-destructive method to grade the watermelon by its density. The study revealed that fruit density was highly correlated with electrical capacitance of watermelon. Cylindrical capacitive sensor was developed to measure the volume of various fruits and vegetables by [6]. The results of this study confirmed that a correlation exists between dielectric constant and volume of fruit. Parallel plate capacitor was developed to measure the different grain moisture content [13]. The sensor performs well an accuracy of ± 1% to measure the 5 to 25% of grain moisture. Egg quality measurement was done by using parallel plate capacitive sensor during the storage period of eggs. The results of this study showed that dielectric sensing method had profound effect to predict the egg quality.

Soltani [16] developed a capacitive sensing system to predict the quality of banana during ripening period. In this method, banana fruit was placed in the capacitive sensor as a dielectric material and then capacitance of banana was measured. Results showed that relative permittivity obtained from sine wave of 100 kHz frequency provide acceptable correlation for both soluble solids content and firmness. Sirikulrat [14] investigated various ages of banana (young banana to mature unripe and ripe banana) dielectric properties by using a two parallel plate model. Results of this study clearly indicate that the high moisture content and the ripening stage affect the relative permittivity over the frequency range of 100 Hz to 1 MHz.

In order to develop an efficient non destructive quality measuring system for banana based on electrical characteristics, it is very essential to determine theelectricalproperties of banana at different stages of ripeness. Therefore, this investigation was carried out to study the dielectric properties of three commercially grown banana cultivars of India by using low voltage electrical signals with a frequency range of 10 kHz to 1 MHz.

Materials and Methods

Sample preparation

Three varieties of commercially grown matured (firm and green) Indian banana namely Robusta (AAA), Poovan (Mysore AAB) and Karpuravalli (ABB) were harvested from horticultural department farm at Tamil Nadu Agricultural University, Coimbatore, India during July to December 2016. The bananas were transported immediately to the laboratory and hands were marked and then detached from the bunch. Hands were immersed in a water bath for 20 min to remove latex and then allowed to evaporate the water from the banana surface. Ripening of fruits was initiated at 20^0 C and85% relative humidity in a ripening chamber containing ethylene gas at a concentration of 100 ppm (0.01% by volume in air). After 24 h, the bananas were left to ripen at ambient temperature. Subsequently, dielectric properties of banana were measured every day from unripe stage (i.e. stage 2) to senescence stage (i.e., stage 7).

Measurement of dielectric properties of banana

The dielectric properties of banana were measured using newly developed parallel plate capacitive sensing system as shown in [Fig-1]. It consists of a function generator (Scientific, SM 5078A), Oscilloscope (Scientific, SMO502), Industrial True-rms Multimeter (RISHABH 616), sample holder and a voltage divider circuit. The function generator was used to produce an ac current with variable magnitude and frequency, while the oscilloscope displayed the resultant sinusoidal wave form. The industrial multimeter was used for measuring current flow in the circuit. Two aluminum plates of dimensions 21 cm x 7 cm x 3 cm were fixed to the sides of a wooden box which served as sample holder as shown in [Fig-1]. The distance between two conductor plates is3 cm. To get a maximum contact between conductive plates and banana, one plate was fixed with wooden casing and another plate loaded with the helical compression spring (1.5 cm outer diameter, 4.5 cm free length and 0.08 cm wire thickness). While banana samples were introduced between the capacitor plates the spring arrangements automatically adjust the plate distance according to the fruit thickness. A 5 V peak to peak sine wave over the frequency range of 10 kHz to 1MHz was generated from the function generator and sent to the voltage divider circuit as shown in [Fig-2].The input (V_i) and output (V_o) voltage were measured continuously for banana and empty chamber during the ripening period. The measurement time (i.e. the charging time of the banana) for each sample was nearly 30 s. Before starting the actual experiments, the sensing system was allowed to run for 10 min so as to get the constant voltage output signal.

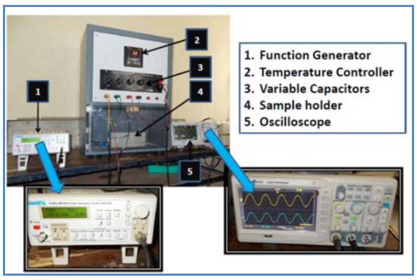

Fig-1 Parallel plate capacitive sensing system

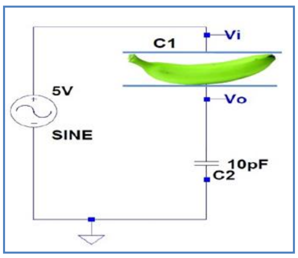

Fig-2 Capacitive sensing system circuit diagram

The dielectric properties such as capacitance, relative permittivity, impedance and admittance during the ripening process were calculated from the formula given by [16]. The capacitance of banana in the sensor can be calculated from the [Eq-1]

$$\frac{Vo}{Vi} = \frac{C1}{C1+C2} \quad \text{-------------- [1]}$$

C_2 is chosen as 10 pF to maximize the circuit sensitivity.

Relative permittivity of banana calculated from the [Eq-2] as follows

$$C = \frac{\varepsilon o * \varepsilon r\ A}{D} \quad \text{----------- [2]}$$

Impedance (Z_1) of the sensing capacitor is calculated from the [Eq-3]

$$\frac{Vo}{Vi} = \frac{Z2}{Z1+Z2} \quad \text{-------------- [3]}$$

Admittance is measured using following formula

$$Y = \frac{1}{Z1} \quad \text{---------------- [4]}$$

Statistical Analysis

The experiments were conducted with three replications for each frequency and variety, and the mean values are reported. In order to study the relation between dielectric properties and ripening stages with studied frequency range linear regression analysis was performed using SPSS 20.0 (IBM Corp., USA).

Results and Discussions

Changes in capacitance during ripening

The changes in capacitance of banana at different ripening stages are given in [Fig-3a, 3b, and 3c]. From the graph it was observed that capacitance values of three Indian banana cultivars increased linearly with ripening stages for all studied frequencies. The mean capacitance values of Robusta, Poovan and Karpuravalli banana cultivars ranged from 1.84×10^{-11} – 4.2×10^{-10}F, 9.93×10^{-12} – 1.07×10^{-11} F and 9.7×10^{-12} – 1.03×10^{-11}F respectively. The increase in capacitance is observed due to the increase in moisture content of the fruit pulp. Because, with increase in moisture content, the ionic conduction of banana is gradually increased which lead to increase in electrical conductivity. Among all the varieties studied, Robusta had the maximum capacitance followed by Poovan and Karpuravalli. This may be due to the fact that larger fruit surface area holds more electrical charge. The regression equations and their respective coefficients of determination (R^2) for the measured capacitance value of three Indian banana cultivars at different frequencies are presented in [Tables-1, 2 and 3]. These equations and coefficients confirm a linear behavior for all varieties. Moreover, Robusta and karpuravalli had maximum R^2 values (0.93 and 0.96) at 100 kHz whereas Poovan had maximum R^2 value (0.98) at 50 kHz frequency. Previous studies also reported an increase in capacitance value during the ripening stages for banana [15], apple [2] and Papaya [3].

Changes in relative permittivity during ripening

The relative permittivity is associated with the ability of a material to store energy in the electric field. Relative permittivity of three Indian banana cultivars namely Robusta, Poovan and Karpuravalli during their ripening period over the frequency range of 10 kHz to 1 MHz is presented in [Fig-4a,4b, and 4c] respectively. It was found that relative permittivity increased linearly during ripening period. For each stage of ripening, relative permittivity decreased with frequency. The mean values of relative permittivity for Robusta, Poovan and Karpuravalli banana cultivars ranged from 2.45 – 60.80, 0.93 – 10.65 and 1.50 – 13.44 respectively. Highest relative permittivity value was observed for Robusta followed by Karpuravalli and Poovan. [Table-1, 2 and 3] summarized the linear regression analysis which was carried out to investigate the relationship between ripening stages and relative permittivity over the frequency ranges from 10 kHz to 1 MHz. From the Tables, it was observed that coefficients of determination (R^2) was adequately high for all studied verities, it seems that the relative permittivity had remarkable influence on the measured parameter. A similar trend was observed by for banana [15], for apple, carrot, and cucumber [10].

Table-1 *The relationships, y = A + Cx, between the dielectric properties and ripening stages of Robusta banana at different frequencies*

Frequency KHz	Capacitance			Relative permittivity			Impedance			Admittance		
	A	C	R2	A	C	R2	A	C	R2	A	C	R2
10	67.8	-17.8	0.91	9.44	-0.3	0.92	-0.18	1.30	0.95	0.67	-0.17	0.92
50	56.3	-22.2	0.92	7.96	-1.4	0.92	-0.05	0.28	0.94	2.82	-1.09	0.92
100	51.1	-29.2	0.93	7.26	-2.9	0.94	-0.03	0.19	0.95	5.12	-2.90	0.94
200	48.5	-45.8	0.91	6.94	-5.7	0.91	-0.02	0.20	0.95	9.71	-9.15	0.91
300	41.2	-41.5	0.87	5.90	-5.2	0.87	-0.02	0.05	0.94	12.3	-12.4	0.87
400	39.4	-43.9	0.83	5.64	-5.7	0.84	-0.01	0.07	0.94	15.7	-17.5	0.83
500	36.3	-41.4	0.83	5.21	-5.3	0.83	-0.02	0.10	0.96	18.1	-20.6	0.82
600	32.7	-34.0	0.77	4.67	-4.8	0.79	-0.01	0.12	0.94	19.5	-22.1	0.78
700	28.9	-33.5	0.81	4.13	-4.4	0.81	-0.01	0.09	0.93	20.2	-23.4	0.80
800	23.1	-23.7	0.86	3.31	-3.0	0.86	-0.01	0.08	0.87	18.5	-18.9	0.85
900	19.4	-17.1	0.88	2.78	-2.1	0.88	-0.01	0.08	0.86	17.4	-15.3	0.88
1000	16.7	-12.4	0.86	2.4	-1.5	0.85	-0.01	0.08	0.78	16.7	-12.4	0.86

Table -2 *The relationships, y = A + Cx, between the dielectric properties and ripening stages of Poovan banana at different frequencies*

Frequency KHz	Capacitance			Relative permittivity			Impedance			Admittance		
	A	C	R2	A	C	R2	A	C	R2	A	C	R2
10	6.0	1.76	0.96	1.5	0.42	0.96	-1.62	11.2	0.84	0.06	0.02	0.96
50	5.0	3.14	0.98	1.3	0.78	0.98	-0.34	2.39	0.80	0.25	0.16	0.98
100	4.7	3.26	0.98	1.2	0.82	0.97	-0.19	1.33	0.73	0.47	0.34	0.97
200	3.5	3.80	0.88	0.9	0.96	0.88	-0.10	0.74	0.74	0.70	0.78	0.88
300	2.8	4.44	0.87	0.7	1.13	0.87	-0.06	0.51	0.74	0.85	1.35	0.87
400	2.3	4.36	0.84	0.6	1.11	0.84	-0.05	0.43	0.68	0.93	1.77	0.84
500	2.2	4.11	0.75	0.5	1.05	0.76	-0.04	0.37	0.66	1.09	2.07	0.75
600	2.1	3.56	0.71	0.5	0.91	0.71	-0.05	0.37	0.63	1.26	2.15	0.71
700	1.9	3.18	0.71	0.5	0.81	0.71	-0.04	0.33	0.67	1.34	2.52	0.71
800	1.6	3.17	0.69	0.4	0.81	0.69	-0.04	0.30	0.70	1.35	2.55	0.69
900	1.6	2.03	0.64	0.4	0.51	0.64	-0.04	0.32	0.82	1.51	1.84	0.64
1000	1.9	0.63	0.87	0.5	0.15	0.87	-0.04	0.32	0.89	1.99	0.66	0.87

Table-3 *The relationships, y = A + Cx, between the dielectric properties and ripening stages of Karpuravalli banana at different frequencies*

Frequency KHz	Capacitance			Relative permittivity			Impedance			Admittance		
	A	C	R2	A	C	R2	A	C	R2	A	C	R2
10	10.0	-0.16	0.93	2.48	-0.16	0.93	-1.39	8.95	0.86	0.10	-0.001	0.93
50	8.22	0.912	0.95	2.03	0.11	0.95	-0.29	1.93	0.88	0.41	0.045	0.95
100	8.13	-0.70	0.96	2.01	-0.27	0.97	-0.15	1.04	0.91	0.81	-0.070	0.96
200	7.51	-0.90	0.92	1.85	-0.31	0.93	-0.08	0.55	0.92	1.50	-0.180	0.92
300	6.75	-0.40	0.93	1.66	-0.18	0.94	-0.05	0.40	0.90	2.02	-0.122	0.93
400	6.08	-0.61	0.93	1.47	0.04	0.94	-0.04	0.32	0.87	2.38	0.197	0.93
500	5.70	-1.36	0.83	1.40	-0.40	0.84	-0.40	0.28	0.95	2.85	-0.682	0.83
600	4.78	-0.64	0.82	1.17	-0.22	0.84	-0.03	0.25	0.97	2.86	-0.384	0.82
700	4.50	-0.99	0.75	1.09	-0.30	0.77	-0.03	0.23	0.98	3.15	-0.698	0.75
800	4.22	-1.29	0.66	1.04	-0.36	0.68	-0.02	0.22	0.95	3.37	-1.039	0.66
900	3.51	0.051	0.67	0.86	-0.04	0.68	-0.02	0.19	0.93	3.16	0.046	0.67
1000	3.30	0.227	0.64	0.81	.001	0.66	-0.02	0.17	0.92	3.30	0.227	0.64

Changes in impedance during ripening

[Fig-5a, 5b and 5c] represents the changes in impedance values in three different Indian banana cultivars during ripening at different frequency ranges from 10 kHz to 1 MHz. It was observed that impedance value decreased during ripening period for all studied varieties. Further, the unripe banana has higher impedance value than ripe banana. The average impedance values vary from 8.06 kΩto 1.16 MΩ, 76.56 kΩto 11.46 MΩ and 36.95kΩ to 8.70 MΩ for Robusta, Poovan and Karpuravalli respectively. Among the varieties studied Poovan had highest impedance value followed by Karpooravalli and Robusta. This may be due to at very low frequencies the reactance will be large and therefore impedance also was large. When the frequency is increased, the reactance will decrease and thus decreasing the impedance. The regression analysis was carried out to determine the relation between impedance and ripening stages of three banana cultivars and results are presented [Table-1, 2 and 3]. From the table it was observed that Karpuravalli had higher coefficients of determination (R^2) 0.98 at 700 kHz followed by Robusta (0.96) at 500 kHz and Poovan (0.89) at 500 kHz respectively. These results agree with the impedance observed for Berangan variety banana [5]and Garut citrus [7].

Changes in admittance during ripening

Admittance is an expression of how easily a circuit or device will allow a current to flow through a complex circuit or system. Changes in admittance of three Indian banana cultivars during the ripening process are shown in [Fig-6a, 6b and 6c]. It was found that the admittance of banana increased continuously till the end of ripening period for all studied varieties. Mean values of admittance ranges from 0.85 μ℧ - 123.93 μ℧, 0.08 μ℧ – 13.05 μ℧, 0.54 μ℧ – 27.05 μ℧ for Robusta, Poovan and Karpuravalli respectively. Highest values of admittance observed at 1MHz frequency for Rubosta. It is due to decrease in impedance of the fruit during ripening process which facilitate more electromagnetic energy inside the biomaterial [10]. Linear regression analysis was conducted to predict the relation between admittance and ripening stages of banana for frequencies ranging from 10 kHz to 1 MHz and results are presented in [Table-1, 2 and 3]. The observed results revealed that more R^2 value such as 0.98, 0.96 and 0.94 for Poovan at 50 kHz frequency, Robousta and Karpuravalli at 100 kHz frequency respectively. From the statistical analysis it is be concluded that admittance values have a significant effect on ripening stages and frequency.

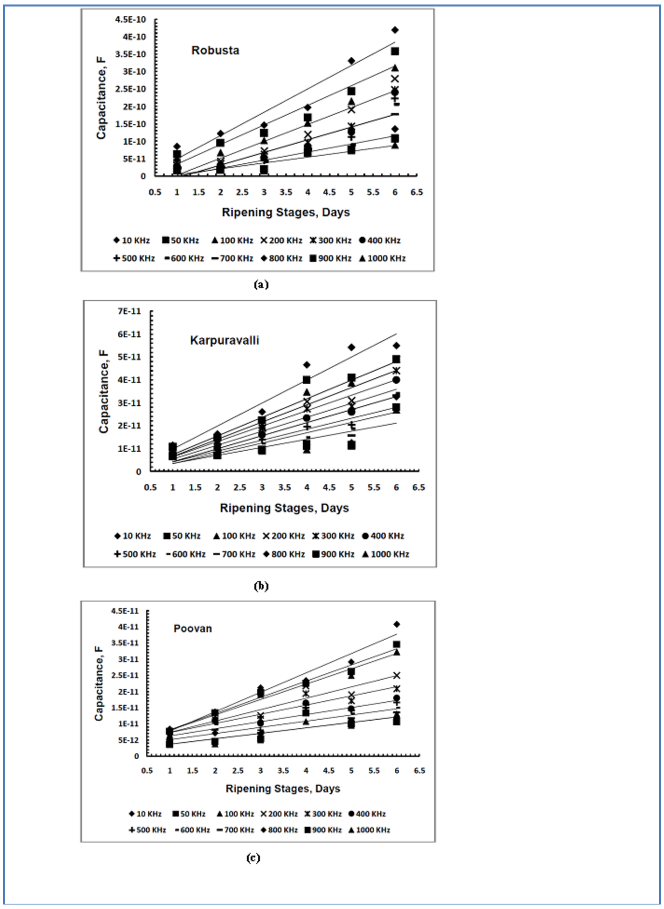

Fig-3 Capacitance of banana at different frequencies during ripening stages; (a) Robusta; (b) Poovan; (c) Karpuravalli

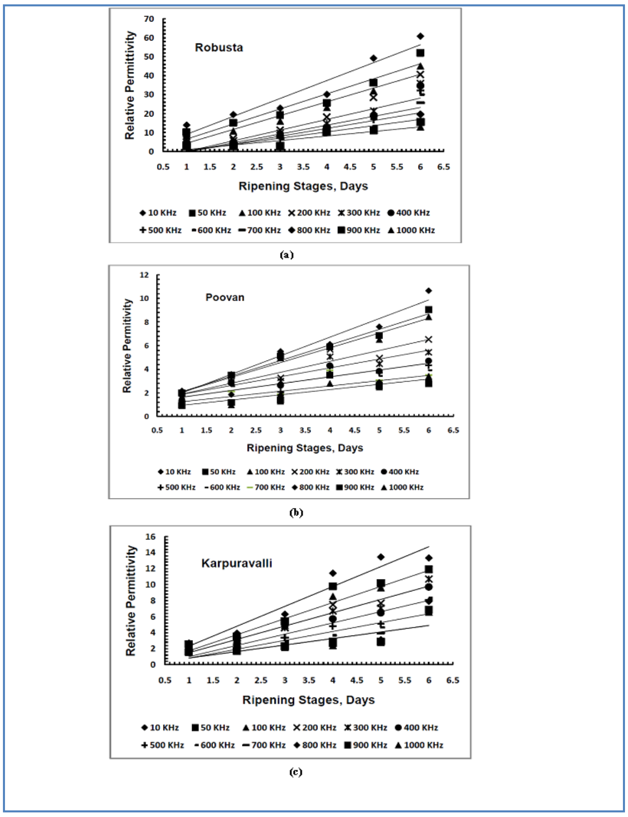

Fig-4 Relative permittivity of banana at different frequencies during ripening stages; (a) Robusta; (b) Poovan; (c) Karpuravalli

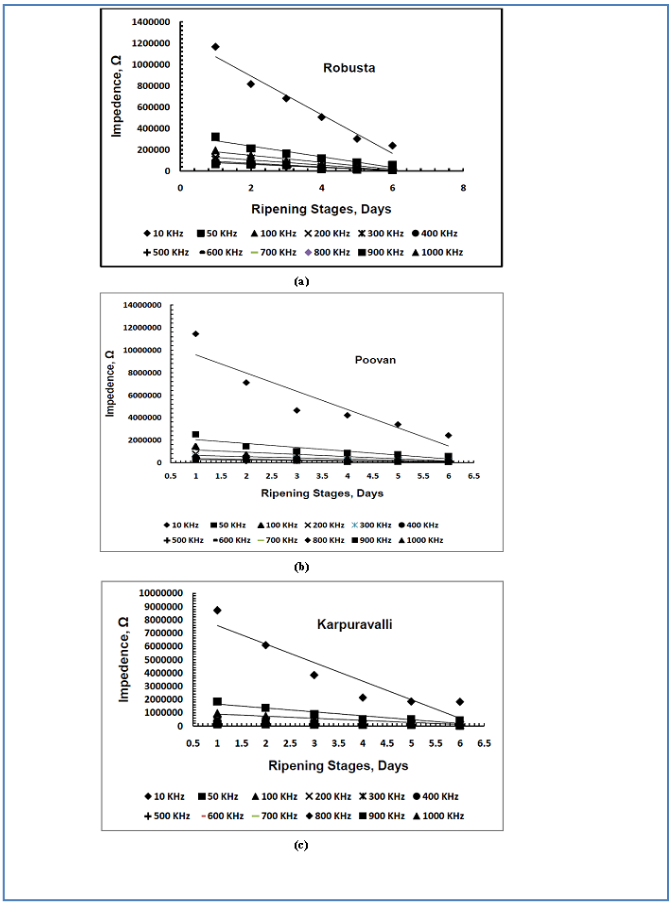

Fig-5 Impedance of banana fruits at different frequencies during ripening stages; (a) Robusta; (b) Poovan; (c) Karpuravalli

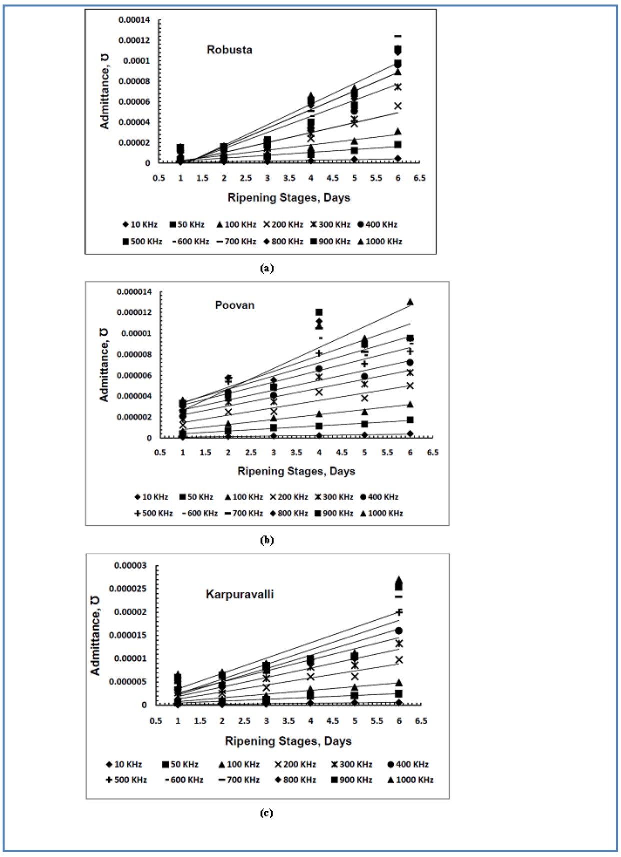

Fig-6 Admittance of banana fruits at different frequencies during ripening stages; (a) Robusta; (b) Poovan; (c) Karpuravalli

Conclusion

The result from this study has shown that Robusta banana has higher capacitance and relative permittivity values. The results and measurement techniques developed from this study could be used as a simple nondestructive test for indication of banana ripeness, and it is expected that similar techniques could be beneficial for further applications with other kinds of crops. Further works are needed to conduct researches on this method at higher frequencies to develop a more reliable prediction of banana ripeness stages.

Application of research: Electrical properties could offer price measurements of banana ripeness stages. To monitor temporal changes in quality during banana ripening, banana growers and packers need a non-destructive quality measuring instrument which can be used for management decisions related to storage, transportation and marketing. Therefore findings of this research could be used to develop a non-destructive banana quality testing instrument to assess the physiological changes during ripening

Research Category: Electrical properties, banana ripening

Abbreviations

V_O = Output voltage of the circuit, in Volts
V_i= Input voltage of the circuit = 5 V
C_1= Sensing capacitance, in pF
C_2 = Reference capacitance =10 pF
C = Capacitance of banana, Farad
ε_o= Permittivity of free space, 8.854 x 10^{-12} F/m
ε_r = Relative permittivity of banana
A = Surface area of the banana, m^2
D = Thickness of the banana, m
Z_1 =Impedance of sensing capacitor, Ω
Z_2 =Impedance of reference capacitor= $1/\omega C2$
ω =Input frequency, Hertz
Y = Admittance of sensing capacitor, ℧

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Author statement: All authors read, reviewed, agree and approved the final manuscript

Conflict of Interest: the authors declare no conflict of Interest

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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