# 16. Electrical Impedance Analysis on Orange During Storage and Ripening

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## ABSTRACT

*This paper describes the physiological changes that occur in fruits during the storage and ripening period, using EIS technique. Electrical Impedance Spectroscopy technique as clear from the name is used to analyze the electrical properties of the fruits and thereby assists a lot in investigating the relationship between the Nyquist plot obtained from the impedance spectroscopy and the equivalent circuit. Electrical equivalent circuit has been modeled relative to the Nyquist plot obtained. Followed by modeling of electrical equivalent circuit the suitable fit has also been obtained. In the present work Non destructive technique has been used for estimating the impedance of orange. Here in this paper, Electrical Impedance Spectroscopy (EIS) studies on orange tissues has been conducted over a wide range of signal frequencies starting from 50Hz and ending up to 1MHz.The number of points between start to end frequency are 100. The Nyquist plot obtained for the orange tissue sample shows that the electrical equivalent circuit of the tissue sample contains a Constant Phase Element. Variations in weight of the fruit with ripening have also been analyzed in this paper. The impedance as well as the weight measurements was monitored once a day for six days.*

**Keywords—***Non–destructive technique, Electrical Impedance Spectroscopy.*

## INTRODUCTION

Fruits are rich source of nutrition and contribute a lot in human healthy diet. Fruits are not only known for their colorful appearance and flavor, but they also serve a lot as a source of energy, vitamins, minerals, and dietary fiber [1-3]. Day by day with the increased standard of living demands for fresh fruits in markets is also increasing. Thus before bringing the fruits to market it must be assured that the fruits that are to be sold are free of damage. As the physiological conditions of fruits are greatly influenced by certain environmental factors such as temperature, humidity, and hence it is necessary to monitor the changes in the physiological status of fruits. Damage in fruits may be due to various reasons (surface injuries, impact bruising, vibration bruising etc.)[3]. If the damage is external i.e. due to fall from height or chilling injury, it is visible but sometimes the damage is internal and cannot be seen. Therefore technique of physiological assessment is not always possible and hence in order to check the internal properties of fruits a very popular technique called impedance spectroscopy (EIS) or AC impedance has been used.EIS technique has proved its usefulness not only in the biological field but also in the field of Chemistry. All the biological tissues are composed of complex impedance [4]. Complex impedance consist of both the resistive and the capacitive elements [5].Electrical impedance measurements were also conducted in some agricultural products such as in apple [6-7], nectarines [8-9], persimmon fruit [10], Kiwifruit [11], cucumber [12-13] ,graut citrus [14], potato [15], banana [16], avocados [17] and many others. Due to conductive behavior of the fruits it has been possible to perform the EIS technique on fruits as well. Electrical impedance spectroscopy (EIS) measures the electrical properties of subject of interest as a function of frequency.EIS technique for quality assessment of fruits has been advantageous over technique of physiological assessment for quality determination because of being simple and non-destructive [18-20].Thus impedance is a complex quantity and changes with variations in the signal frequencies.EIS technique is used for measuring the impedance, of the biological tissue and thereby reveals the electrical properties of the biological material. By analyzing the impedance of the biological material it is possible to relate the measured electrical values of the subject under test to their physiologic equivalents. The analysis of EIS measurements at different frequencies assists a lot in understanding the intrinsic properties of the sample of intrest.EIS technique has been in use since several years for investigating the fundamental electrical properties of subject of interest and has proved itself as useful tool in detecting the changes in behavior under different physiological conditions. Due to EIS technique it has been possible to built electrical models of the measured material in the form of an electrical circuit consisting of resistors and capacitors and analyze its response to alternating current source signals of variable amplitude and frequency [21].EIS technique is very powerful and easy to use and provides information about all the passive components i.e. resistive, capacitive and inductive within very short span of time with the help of appropriate equivalent circuit model [22]. Modeling of electrical equivalent circuits is very much necessary in order to characterize experimental frequency response of impedance [23][24].Once the Equivalent electrical circuit is obtained it is important to obtain the best possible fit in order to obtain the best values of the unknown parameters of the circuit. But before building any electrical model, it is necessary to be familiar with the investigated sample structure.

## BASIC STRUCTURE OF PLANT CELL

The word ‘cell’ was first coined by British scientist Robert Hook in the year 1665. All the living objects either plant, animal or human bodies are comprised of cells and tissues. Body of every organism is made up of cell, and each cell arises from pre-existing cell. Cell is the basic structural and functional unit of life. Plant cells are eukaryotic cells which contains membrane bound organelles and nucleus. Generally plant cells are larger than animal cells and are mostly similar in size but different in structures. Plant cells are similar to animal cells in being eukaryotic and they have similar cell organelles. Basic cell structure consists of cell membrane also known as plasma membrane bounded by a rigid cell wall made up of cellulose and chitin. The basic function of the cell wall is to provide shape to the cell. Cell membrane is thin, elastic, living, double layer, and permeable membrane, made up of protein and lipid molecules. The basic function of cell membrane is to regulate the movement of molecules inside and outside the cells. The presence of molecules inside is responsible for the conductive properties of biological tissues. The basic cell structure mainly comprises three important elements which are cell membrane, intracellular fluids and extra cellular fluids. Cell membrane maintains ion concentration gradient between the intracellular and extra cellular spaces. The extracellular fluids conduct at high frequency as well as low frequency range, whereas the intracellular fluids show the conductive property only at high frequency range. The intracellular fluids containing the cytoplasm and nucleus shows resistive behavior to the alternating current signal. The cell membrane consists of a layer of a layer of non-conductive lipid material sandwiched between two layers of conductive protein molecules and hence it behaves like a capacitance contributing a capacitive reactance to the alternating current path [25].Hence the equivalent circuit model of the biological samples is comprised of intracellular fluid resistance, extracellular fluid resistance and a cell membrane capacitance.

### A. MATERIALS AND METHODS

The experiments were carried out on a matured unripe orange which was brought from local market. The experiment was carried out for six days. A big green orange was chose and stored at room temperature till ripening. Impedance measurement was done using Impedance Analyzer. The readings were taken at the frequency range starting from 50Hz and ending upto1MHz.Experiments was carried out using non-destructive technique. Electrical contact with the orange was made using ECG electrode. Before placing the ECG electrodes, the orange was cleaned properly with distilled water. The position of ECG electrodes was arranged properly for accurate reading. A constant current source of 1mA was applied, and the number of points taken was 100.Application of constant current source is very much important for estimating the impedance of the sample of interest. Impedance of the orange was estimated by measuring the voltage source that developed on account of constant current source injection through the electrodes. Experiments were performed using two-terminal method.

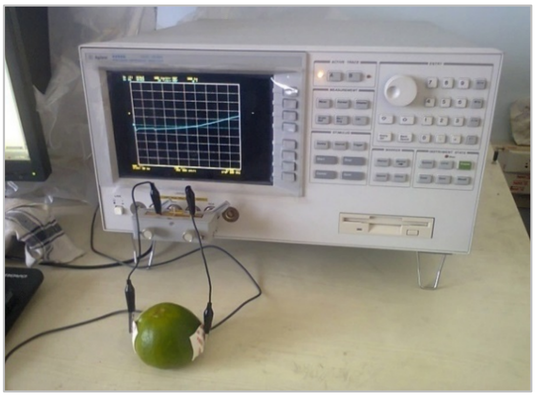

*Figure 16-1 Experimental Setup for impedance measurements.*

The surface electrode through which the current is injected is called the current electrode or driving electrode and the one on which the frequency dependent ac potential is measured is called the voltage electrode or the sensing electrode.Here in these Experiment two terminal methods was used where two electrodes were used for impedance measurement and hence current injection and voltage detection was conducted with the same pair of electrodes. The Experimental setup for obtaining the impedance parameters as a function of frequency of orange tissues has been shown in Fig.16-1 Weight of orange was also measured till the orange was not overripe, as the overripe fruit is not desirable. So the weight was measured for six days using weight measuring instrument. Both the impedance as well as weight measurements were monitored once a day for six days.

## CONSTANT PHASE ELEMENT (CPE)

In biology, an equivalent circuit model is a circuit yielding the same impedance as a biological tissue in a given frequency domain. The most commonly used model to characterize electrical properties in tissues is composed by two resistors and capacitor which behaves like a CPE where the capacitor has a Laplace variable with an exponent called fractional power(pseudo capacitor). As, tissues composed of many cells produces time constant distribution therefore Cole-Cole plot is described as distorted semicircle in a vertical direction. Thus in order to model this distorted semicircle, Constant Phase Element was introduced. The Constant phase element (CPE) is a non-intuitive circuit element that was discovered while looking at the response of real-world system.CPE can provide a useful modeling element, even if the true nature of the system is known. An ideal CPE is defined as an element whose admittance or impedance has constant phase over the entire frequency band from 0 to ∞ and that is why the name given is constant phase element [26].The ideal CPE is a two- terminal network. Impedance of an ideal CPE is given by.

$$Z_{CPE} = \frac{1}{Q(s)^{\alpha}} \qquad (1)$$

Where $j$ is the imaginary unit and $\omega$ is the angular frequency in $s = j\omega$. The parameters α and Q in the CPE impedance are the exponent factor and the CPE constant respectively. CPE exponent is the factor within the range of 0 to 1 which describes time constant distribution in the system. When $\alpha = 1$ the system is described by a single time-constant and the parameter Q has units of capacitance; otherwise, Q has units of $s^{\alpha} / \Omega cm^{2}$ Its name is in the reference to the phase angle, which is independent of frequency and dependent only on the order α, given as $\alpha\frac{\pi}{2}$. The values of α from experimentally calculated are typically in the range of $0 < \alpha < 1$.

## RESULTS AND DISCUSSIONS

It is observed that at the end of six days of monitoring the weight decreases each day with ripening as shown in Fig.16-2. After this, result of impedance parameters $Z(\omega),\ R(\omega),\ X(\omega), \theta(\omega),$ with respect to the signal frequency is shown in fig.16-3, 16-4, 16-5 and 16-6 respectively.

It is observed from fig .16-3 that the magnitude of impedance of $1^{st}$ day is higher at low frequencies and then decreases slowly as the frequency increases. On the $2^{nd}$ day of observation again the same variation with respect to frequency is observed but with increased magnitude of impedance as compared to $1^{st}$ day.

Similarly on the $3^{rd}$ and $4^{th}$ day there was slight increase in the magnitude of impedances as compared to the $1^{st}$ and $2^{nd}$ day but on the $5^{th}$ and $6^{th}$ day it is observed that there is greater rise in magnitude of impedances as compared to other days. Larger variations are seen in magnitude of impedances of different days at lower frequencies whereas at higher frequencies the variations are very less. Variations in magnitude of impedances are very high on the $5^{th}$ and $6^{th}$ day of observation.

Again in Fig.16-4 the variations in magnitude of resistance for different days are seen with respect to frequency. The variations in magnitude of resistance are found almost similar as that of variations in magnitude of impedance up to six days of observations.

Here again the magnitude of resistance as seen on the $1^{st}$ day is high at low frequencies and then decreases slightly with increase in frequencies. On the $2^{nd}$ day again the magnitude is found high at low frequency and then decreases slowly as the frequency increases but with higher rate as compared to the $2^{nd}$ day.

Similarly, the variations increases on the $3^{rd}$ and 4th day of observation but again rapid variations in magnitude of resistances with frequencies is seen on the $5^{th}$ and $6^{th}$ day of observations as compared to other days. Observation up to six days from the fig. reveals that every day the magnitude of resistance goes on increasing.

Now in fig.16-5 variations of reactance with respect to frequencies up to six days is shown. It is observed from the fig. that the magnitudes of reactance on $1^{st}$ day increases gradually at lower frequencies and at the frequency range of 500 Hz-600Hz it attains its maximum position thereby forming a peak and then again starts decaying constantly at higher frequencies.

On the $2^{nd}$ day of observation again the magnitude of reactance increases with increase in frequency, attains maximum value in the frequency range of 500Hz-600Hzand then again decreases constantly with increasing frequencies but the magnitude of reactance increases as compared to the $1^{st}$ day. Same variations in magnitude of reactance with frequency is observed up to four days but every day a little increase in peak is observed. But on the $5^{th}$ and $6^{th}$ day of observation it is seen that there is rapid increase in the peak of $5^{th}$ and $6^{th}$ day as compared to the other four days. Thus it can be concluded from the fig.16-5 that every day the reactance increases with increase in frequencies attains maximum value at frequency range (500Hz-600Hz) and starts decaying at a constant rate thereafter but at the same time it is also observed that the value of reactance increases continuously with days.

Fig.16-6 shows the variation of phase angle (theta) with respect to the applied frequency response. On the $1^{st}$ day of observation it is seen that the phase angle value increases constantly with frequency, attains maximum value in the frequency range of 70-80 kHz and starts decaying and decays constantly at higher frequencies.

Similarly on the $2^{nd}$ day the variations in theta with respect to frequency are same but the values of theta increases compared to the $1^{st}$ day.

On $3^{rd}$ day the variation of theta with frequency is almost same but the value of theta decreased compared to the $2^{nd}$ day and hence the curve of $3^{rd}$ day falls down the $2^{nd}$ day at lower frequencies but again in the frequency range of 40-50KHz the values of theta becomes almost the same and hence the two curves overlaps in this range and thereafter the values of theta for the $3^{rd}$ day increase with respect to the $2^{nd}$ day at higher frequencies.

On the $4^{th}$ day the theta rises slowly at lower frequencies region attain the peak somewhere in the frequency range (60-70 KHz) and then gradually decreases thereafter with increasing frequencies. On $5^{th}$ day value of theta increases as compared to other days at lower frequency regions and then somewhere in the range of (50-60 KHz) attains nearly same values as that of 4th day and thereafter decreases very rapidly at higher frequency regions.

The curve of the 6th day as clear from fig.16-6 is same as that is seen that the values of theta of 5th and 6th day are very near to each other at lower frequency regions and then increases rapidly and attains peak at 55kHz and then decrease gradually at higher frequency regions.

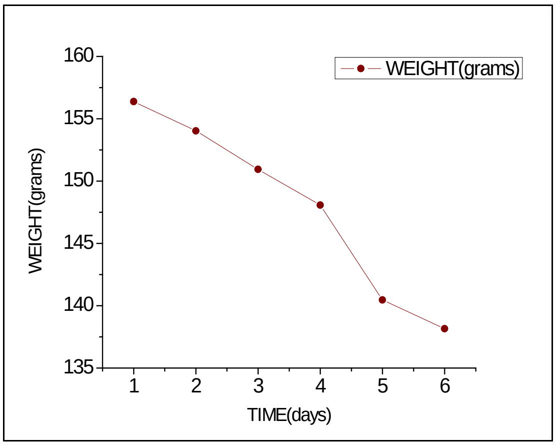


*Figure 16-2 Variations in weight with ripening*

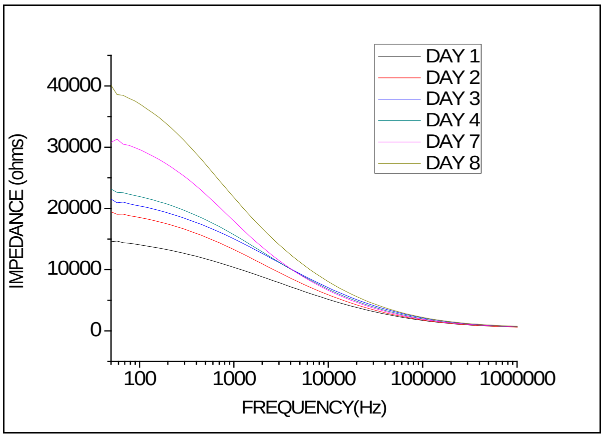


*Figure 16-3 Variations in impedance with frequency for different days*

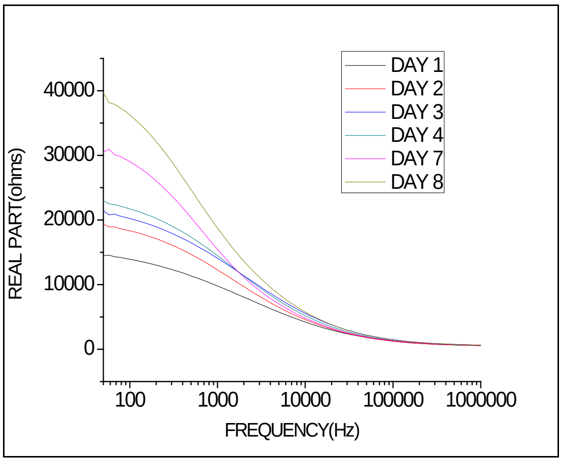


*Figure 16-4 Variations in real part with frequency for different days.*

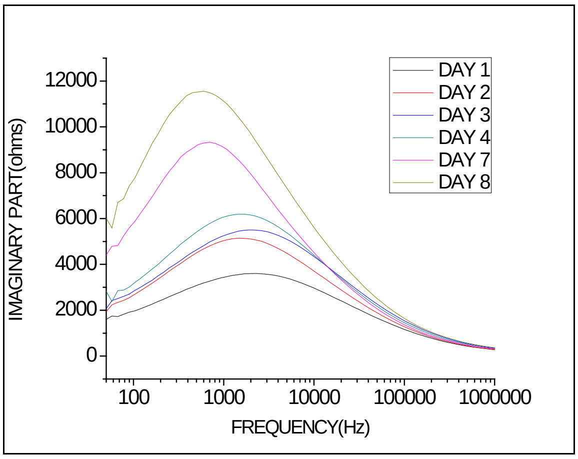


*Figure 16-5 Variations in imaginary part with Frequency for different days.*

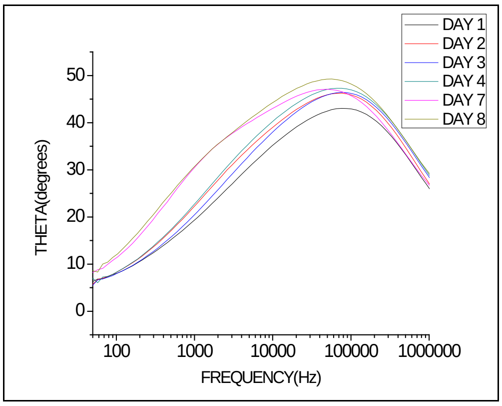


*Figure 16-6 Variations in Phase angle (theta) with frequency for different days.*

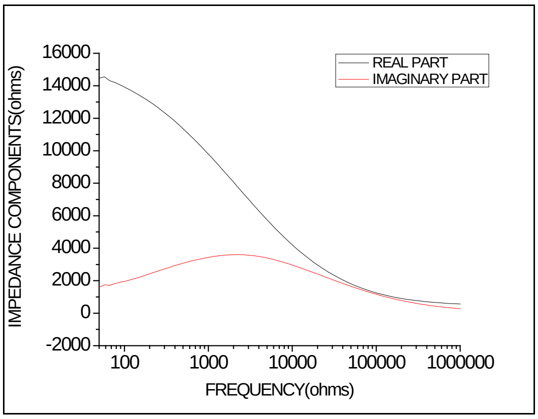


*Figure 16-7 Variation of impedance components with frequency.*

Fig 16-7. Shows the variations of the real (resistance) as well as the imaginary (reactance) part of the electrical impedance with respect to the applied frequency response. It is very clearly observed from the fig. that the variations in both the real as well as the imaginary part of the complex impedance is greater at lower frequencies and very less at higher frequencies. The Nyquist plot obtained for the orange tissue is one complete semicircle. The Nyquist plot obtained for the orange tissue demonstrates that the equivalent model of the tissue sample contains a constant phase element (CPE).Fig.16-8.shows the electrical equivalent model of orange.

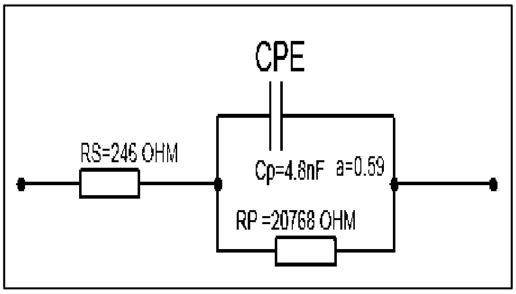


*Figure 16-8 Equivalent model of orange.*

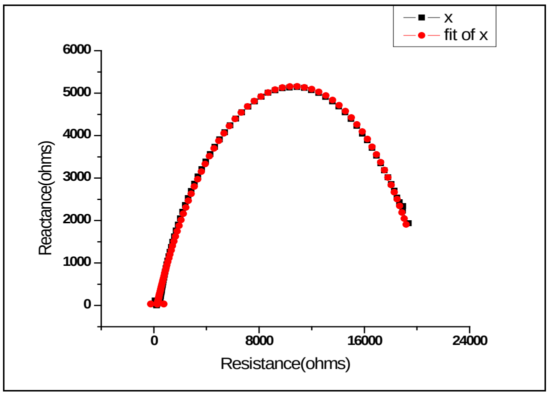


*Figure 16-9 Nyquist plot fit of orange showing the relationship between reactance and resistance.*

Here R1 is the series resistance, R2 is the parallel resistance, and C1 is the capacitance and α is the Constant phase element. Once the Equivalent model is obtained seeing the Nyquist plot, it is helpful to fit the experimental data with that model. Here non-linear fitting has been done using the origin pro 8 software. Fig.16-9 shows the Nyquist plot and its fit. The dotted points of black color represent the experimental results and the dotted points of red color are the fitted results. From the fitted results we get the values of R1, R2, C1 and α as 235Ω, 15789Ω, 5.04nF and 0.56 respectively.

*Table 16-1 Day wise variation in electrical parameters alongwith standard error*

| Sl. No. | ELECTRICAL PARAMETERS | STANDARD ERROR |
|---|---|---|
| DAY 1 | $R_s$ = 234Ω<br>$R_p$= 15789Ω<br>$C_p$=5.04nF<br>CPE(α)=0.56 | 12.28089<br>56.05283<br>5.2E-11<br>0.00268 |
| DAY 2 | $R_s$ = 246Ω<br>$R_p$=20768Ω<br>$C_p$=4.9nF<br>CPE(α)=0.59 | 10.4847<br>50.719<br>3.1E-11<br>0.00188 |
| DAY 3 | $R_s$ = 247Ω<br>$R_p$=22789Ω<br>$C_p$=3.6nF<br>CPE(α)=0.59 | 16.49941<br>73.86186<br>3.3E-11<br>0.00259 |
| DAY 4 | $R_s$ =247Ω<br>$R_p$=24623Ω<br>$C_p$=4.1nF<br>CPE(α)=0.60 | 11.27265<br>54.07745<br>2.44E-11<br>0.00172 |
| DAY 7 | $R_s$ =333Ω<br>$R_p$=34947Ω<br>$C_p$=6.3nF<br>CPE(α)=0.60 | 21.78491<br>118.71724<br>5.06E-11<br>0.0028 |
| DAY 8 | $R_s$ = 266Ω<br>$R_p$=44883Ω<br>$C_p$=5.6nF<br>CPE(α)=0.60 | 20.73482<br>168.93582<br>4.8E-11<br>0.00212 |

## CONCLUSIONS

In summary we can say that the variations in electrical properties of orange tissues are monitored here. It is concluded from the above results that the, electrical parameters of orange tissue including impedance, resistance ,reactance and phase angle shows large variations in the lower frequency range ,however at higher frequencies also slight variations are observed. It is observed from the above results that the impedance parameters decrease with increasing frequency but increases continuously with days. Thus it is concluded that according to the tissue properties the magnitude of Z (ω), R (ω), X (ω) and θ (ω) are changed with the change in frequency and hence the nature and behavior of any biological tissues can be closely distinguished by plotting the impedance parameters with respect to the applied signal frequency. Moreover from the equivalent electrical model obtained for orange it is also observed that the value of constant phase element (CPE) remains almost constant.

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## REFERENCES

[1] Brady, C.J.1987.Fruit Ripening.Annu.Rev.Plant Physiol., 38:155-178.

[2] Eskin, N.A.M. (ed.).1991.Quality and Preservation of Fruits.CRC Press, Boca. Raton, FL, 212PP.

[3] Gross, J.1987. Pigments in Fruits. Academic Press, Inc., Orlando, FL, 303PP.

[4] Ackmann JJ, Complex Bioelectric Impedance measurement System for the Frequency Range from 5 Hz to 1 MHz, Annals of Biomedical Engineering. 21:135-146, 1993.

[5] Ackmann JJ, Seitz MA., Methods of complex impedance measurements in biologic tissue, Crit Rev Biomed Eng. 1984; 11(4): 281-311.

[6] Cha K, Chertow GM, Gonzalez J, Lazarus JM, and Wilmore DW, Multifrequency Bioelectrical impedance estimates the distribution of body water, J Apple Physiol. 1995; 79:1316-1319

[7] Jackson, P.J., Harker, F.R.,' Apple Bruise Detection by Electrical Impedance Measurement', HortScience 35(1), 104-107.

[8] Harker, F.R., Maindonald, J.H. 1994a. Ripening of Nectarine Fruit. Plant Physiol.106, 165- 171.

[9] Harked, F.R., Dunlop, and J. 1994b. Electrical Impedance Studies of Nectarines during Cool stage and Fruit Ripening. Postharvest Biology and Technology 4, 125-134.

[10] F. Roger Harker and Shelley K. Forbes, 'Ripening and development of chilling injury in Persimmon fruit', New Zealand Journal of Crop and Horticultural Science, 1997, Vol.25: 149-157.

[11] Bauchot, A.D., Harker, F.R., Arnold, W.M. 2000. "The Use of Electrical Impedance Spectroscopy to Assess the Physiological Condition of Kiwifruit", Postharvest Biology and Technology 18, 9-18.

[12] A. Inaba, T. Manabe, H.Tsuji and T. Iwamoto, 'Electrical Impedance Analysis of Tissue Properties Associated with Ethylene Induction by Electric currents in Cucumber (Cucumis sativus L) fruit, Plant Physiol. (1995) 107: 199-205.

[13] X. Liu, Q. Fang, S. Zheng, I. Cosic and P. Cao, 'Electrical impedance spectroscopy Investigation on Cucumber Dehydration' International Society for Horticulture Science Acta Horticulture 804: Europe-Asia Symposium on Quality Management in Postharvest Systems – Eurasia 2007.

[14] J. Juansah, I W. Budhiastra, K.Dahlan and K.B. Seminar, 'Electrical behavior of Garut Citrus Fruits during ripening changes in Resistance and capacitance models of internal Fruits', IJET-IJENS Vol: 12 No: 04, August 2012 .

[15] R. I. Hayden, C. A. Moyse, F. W. Calder, D. P. Crawford, D.S. Fensom, 1969. "Electrical Impedance studies on potato and alfalfa tissue," Journal of Experimental Botany, vol 20, No 63, pp 177–20.

[16] A. Chowdhury et al,'studying the Electrical Impedance variations in Banana ripening using Electrical Impedance Spectroscopy (EIS)' 3rd International Conference on Computer Communication, Control and Information Technology (C3IT-2015) [Accepted]

[17] R. C. Bean, J. P. Rasor, G. G. Porter, 1960. "Changes in electrical characteristics of Avocados during ripening," California Avocado Society, Yearbook vol 44, pp 75-78.

[18] J. Juansah, I W. Budhiastra, K.Dahlan and K.B. Seminar,'the prospect of electrical Impedance spectroscopy as Non-destructive Evaluation of Citrus Fruits acidity, IJETAE, Vol 2, Issue 11 November 2012.

[19] A.R. Varlan, and W. Sansen, 1996. "Nondestructive electrical impedance analysis in fruit: Normal ripening and injuries characterization," Electro-Magneto biology, vol 15, pp 213– 227.

[20] E. Vozáry, and P. Benkő, 2010. "Non-destructive determination of impedance spectrum of Fruit flesh under the skin," Journal of Physics: Conference Series, vol 224, no 012142.

[21] H. P. Schwann, "Electrical properties of tissue and cell suspensions: mechanisms and Models," Proc. IEEE Adv. Biol. Med. Soc., vol. 1, pp. A70-A71, Aug. 2002.

[22] Retheep Raj, Nikhil Binoy C, 2013. "Bio Impedance Spectroscopy for the Assessment of Quality of Fruits by Constructing the Equivalent Circuit." International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 11, and November - 2013, ISSN: 2278-0181.

[23] Cole KS, Electric phase angle of cell membranes, J Gen Physiol.1932; 15:641-649.

[24] B.K. Van Kreel, N. Cox-Reyven and P. Soeters, 'Determination of total body water by multifrequency bioelectric impedance: development of several models', Med. Biol. Eng.Comput., 1998, 36, 337-345.

[25] Tushar Kanti Bera, 'Bioelectrical Impedance Methods for Noninvasive Health Monitoring', Journal of Medical Engineering Volume 2014, Article ID 381251.

[26] Bryan Hirschorn,, Mark E. Orazem,, Bernard Tribollet,Vincent Vivier,Isabelle Frateur, and Marco Musianid, 'Constant-Phase-Element Behavior Caused by Resistivity Distribution Films',journal of The Electrochemical Society, 157_12_C452-C457_2010_0013-4651/2010/ 157 _12_/C452/6/$28.00 © The Electrochemical Society.

[27] F. Gómez, J. Bernal, J. Rosales and T. Cordova, 'Modeling and Simulation of Equivalent Circuits in description of Biological Systems - A Fractional Calculus Approach', journal of Bioelectrical impedance, vol.3. (2012).