Electrochemical Analysis of Fruit and Vegetable Freshness

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Abstract: - Fruits and vegetables are natural sources of electrolytes. A voltaic cell consisting of a fruit or vegetable and two dissimilar electrodes may show a detectable potential difference. Seven different fruits and vegetables are studied for analyzing their freshness. At first, a few experiments are conducted on the vegetables and fruits using two different sets of electrodes, copper-iron probe and gold-iron probe, in order to select one. Additional experiments are then carried out on the fruit and vegetable samples with the copper-iron probe only over a period of four days as the samples decay in order to investigate the effect of aging or rotting. It is observed that the open circuit potential (OCP) values for all seven samples are increasing with the aging process. This study indicates that a voltaic cell made of a natural fruit or vegetable and a set of two dissimilar electrodes develop an open circuit potential (OCP) difference that is measurable with an inexpensive voltmeter. The freshness of any fruit or vegetable is directly related with its age (preservation time) and this nature is found to be present in all of the fruit/vegetable electrodes system. This study further indicates that the OCP measurement technique is a good choice for designing a sensor to check fruit/vegetable freshness.

Key-Words: - Open Circuit, Voltage, Potential, Probes, Electrodes, and Voltmeter.

1 Introduction

Fruit and vegetable preservation methods and their quality control process are always a big challenge for produce industry. There is a great need to identify whether a fruit or vegetable is good or bad in a storage area. Usually, a huge amount of fruits and vegetables are stored in an open area for a short period of time and in a controlled area (cold storage) for a longer period. Very often workers in produce industry deal with a situation where they have to check the fruit/vegetable conditions (partially rotten or completely rotten). This is a difficult task and an expensive operational process in business if proper tools are not available. There are some fruit sensors that are available for commercial use, but most of these sensors are expensive or unfriendly [1-5]. The OCP methods have been used in different areas for a long time, but nobody has paid a serious attention to use these in the fruit/vegetable preservation process.

An electrical voltage is produced due to a chemical reaction when certain substances are exposed to an electrolyte. The voltage (potential) develops when a metal is in contact with an electrolyte; it is a function of the metal, electrolyte and temperature and is known as a half-cell potential. It is not possible to measure the potential of a single electrode. In most cases, a standard hydrogen electrode is used as a reference in order to measure the potential at any test electrode. Potentials with respect to this standard hydrogen electrode for commonly used electrodes are summarized in the literature [6]. The potential difference between two electrodes is possible to determine with a voltmeter, but it would be zero if both electrodes are made of the same material and kept at the same temperature in contact with the same electrolyte.

It has been proven from different studies that a fruit or vegetable can be used to generate an electric potential (voltage) when two dissimilar electrodes are directly inserted into it. Typical electrolytes are also known as electrolytic solutions that usually contain some salts or some acids or a combination of both. The juices in the fruits or vegetables can play the role of the electrolyte in a fruit cell. It is well known that lemons and oranges have acidic juices and they are good candidates for designing a fruit cell. An electrolyte can be either a paste or a liquid solution. In either case, if two different metallic plates or rods (electrodes) are immersed in an electrolytic solution, complex electrochemical phenomena occur. There is a tendency for metal ions to migrate into the electrolytic solution and for ions in the electrolyte to combine with the metal. This generates some electrical charges around the immediate vicinity of the immersed metal surface inside the solution.

The amount of charge distribution around the electrode surface depends on the type of metal used and nature of the electrolytic solution at a constant temperature. The overall chemical reaction process is very complex, but the potential (voltage) difference exists between two dissimilar electrodes immersed inside the same electrolyte which attain an equilibrium state quickly. This voltage difference can easily be measured with a voltmeter and is known as open circuit potential (OCP). If these electrodes are connected externally with a conducting wire, then electrons flow from one electrode to another through the wire. This setup is known as a primary cell [6, 8]. In principle, basic fruit cells are very similar to the commercial cells available in the market. A typical primary cell is illustrated in Figure-1.

The amount of OCP difference between the electrodes depends on the materials of electrodes and electrolytic solution used in the cell [6, 8]. There are two common types of primary cells: 1) a wet cell and 2) a dry cell. In a wet cell the electrolyte is a liquid solution and a good example of this kind is an automotive battery. A battery is formed when two or more cells are connected together in a series and generate a higher output voltage. The batteries used in portable electrical and electronic devices (flashlights, radios, toys, etc) are good examples of this kind. The details of electrochemical cell theories and experimental methods can be found in many published materials [6-10].

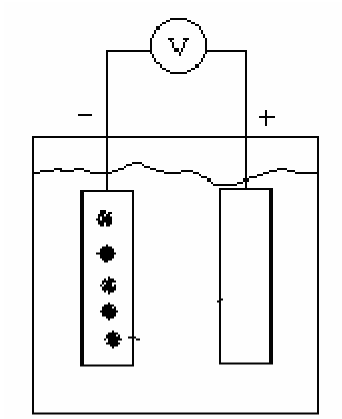

Figure-1. Configuration of a Wet Voltaic Cell

The OCP difference between two electrodes can be expressed by the Nernst Equation under an equilibrium condition. This potential difference is sensitive to the types of electrolyte and electrodes and the ambient environment (temperature, pressure and humidity)[6-10]. An OCP measurement and its value are reported by Carboni [9].

The use of OCP measurement methods is an important means of evaluating the reacting species responsible for the interfacial charge transfer phenomena between the electrode/electrolyte systems [6-8]. In this technique there is no external voltage applied across the sample and no current passes through the circuit. A sandwich of wet electrolytic mixture or solution between two dissimilar electrodes (forming an electrochemical cell) shows a potential difference when electrodes are externally connected to a voltmeter. It has been found in several studies that the noble metals (gold, platinum, palladium and silver) are less reactive with the electrolytes and produce stable voltages around them. These metals are good candidates for electrodes [7]. A three-probe configuration (one electrode acts a reference electrode) is a better choice for potential measurement if the electrolyte has a very low conductance [6-8]. So far, many papers have been published that deal with the electrical properties and the measurements of biological systems [9, 11, 12]. It has been reported that the conductance of a seed changed during the germination process [10, 11]. As of today, many reports on fruit and vegetable batteries have been published and some of these reports are available on the Internet [9, 13, 14].

2 Instruments And Materials Used

In this project, two different test probes are designed and prepared in the laboratory. The dimensions of both electrochemical cells are expected to keep unchanged. These test probes are shown in the figures of 2a and 2b: (1) iron nail and gold pin are mounted on a small plastic fixture (shown in the figure-2a) and (2) two crocodile clips made of copper and iron are mounted firmly on a plastic fixture (shown in the figure-2b). Both fixtures are good insulators.

a) Au-Fe Electrodes b) Cu-Fe Electrodes
Figure-2: Configurations of Two Different Test Probes

An inexpensive digital voltmeter which ranges from 1mV to 2000mV is used to measure the OCP difference of fruit and vegetable cells.

A total of seven fresh fruits and vegetables are obtained from a local market for the experiments. The vegetables are avocado, orange, kiwi, apple, lemon, tomato and potato. All experiments are carried out at room temperature and pressure and all samples are kept outside for aging.

3 Hypothesis and Methods

3.1 Hypothesis

It is expected that the OCP will vary from fruit to fruit and will depend primarily on the following factors: materials of electrodes, environmental factors (temperature, pressure and humidity) and aging time. If all these factors remain unchanged except aging time then it is expected to see the changes in the OCP with the aging process.

3.2 Methods

Figure-3 and 4 show an experimental setup and a measurement technique.

Figure-3: A Student is Preparing a Sample

First, two dissimilar electrodes are inserted into a sample such as potato and then the other ends of these electrodes are connected to a digital voltmeter. A total of seven different fruit/vegetable specimens and two different test probes are used for voltage measurements. In all these cases, the voltmeter's initial readings changed rapidly, but a stable reading is observed after about a minute.

Figure 4: OCP Measurement in Progress

For each experimental measurement, a new sample is prepared with two clean electrodes inserted into a fruit. After taking a voltage reading (data), the probe is taken out from the fruit and is reinserted into the same fruit for a second reading. This procedure is repeated five times for each sample in order to obtain more reliable information. Table-1 records all these data (an average value of five readings) for fresh samples and Figure-5 shows the corresponding column graph.

Long term experiments on all seven samples are carried out to check how the OCP of different samples depends on the aging time. Figure-6 shows a graph of three different sets of data obtained from all seven samples aged for different time periods. All samples are aged in an open environment under normal temperature and pressure. In this study, samples are considered to be fresh when they are bought from the supermarket and experiments are conducted on the same day for the first set of data. The second set of data is obtained after two days and the third set of data is obtained after three days. The avocado and apple started to rot and ruin their freshness faster than others fruits/vegetables.

4 Results And Discussions

In this study, OCP differences for all seven fruits and vegetables are found to be significant and sensitive to the materials of the probes, the (electrolyte) fruit juice and the aging time (under normal temperature, pressure, and humidity). It is also clearly observed that the electrolytic solution for each individual fruit/vegetable is its own characteristic. The concentration and constituents of these electrolytes vary from fruit to fruit (or vegetable to vegetable).

Table-1: Seven fruits/vegetables with corresponding voltages

Electrodes Two-probe Materials	**Orange** Voltage in mV	**Kiwi** Voltage in mV	**Apple** Voltage in mV	**Avocado** Voltage in mV	**Lemon** Voltage in mV	**Potato** Voltage in mV	**Tomato** Voltage in mV
Gold/Steel (Au/Fe)	615	425	490	279	306	287	630
Copper/Steel (Cu/Fe)	692	699	760	587	691	678	703

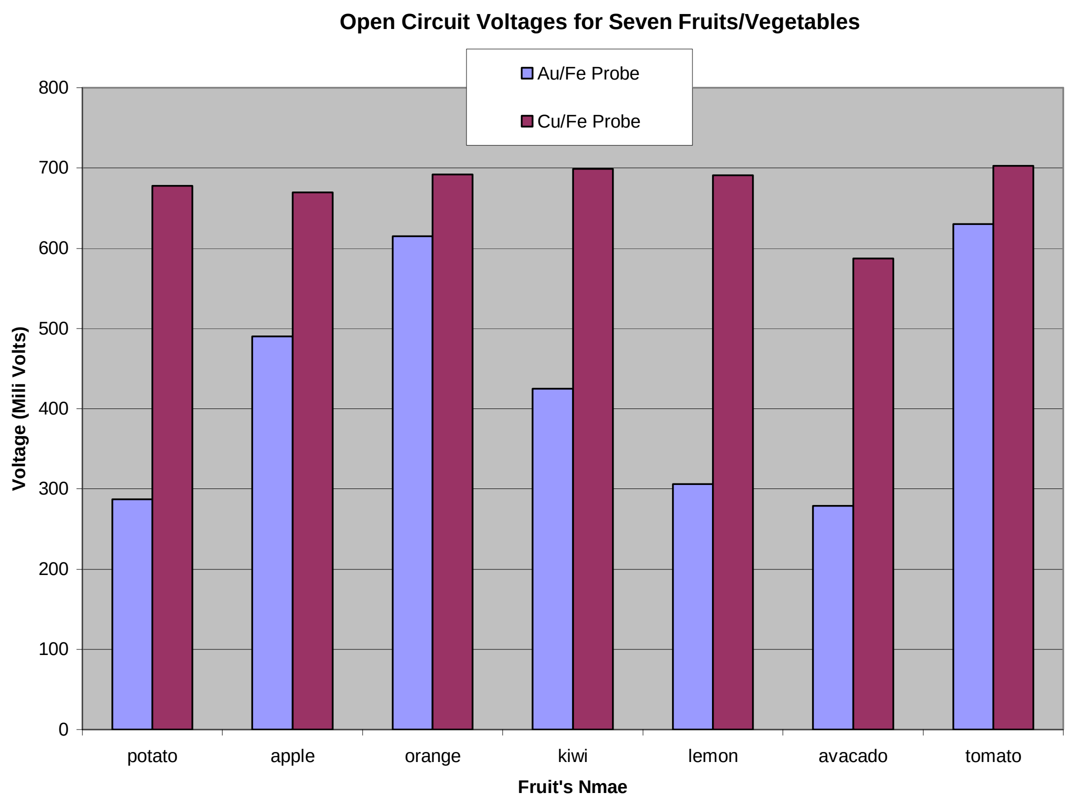

Figure-5: Column graph for seven fruits and vegetables using two different probes

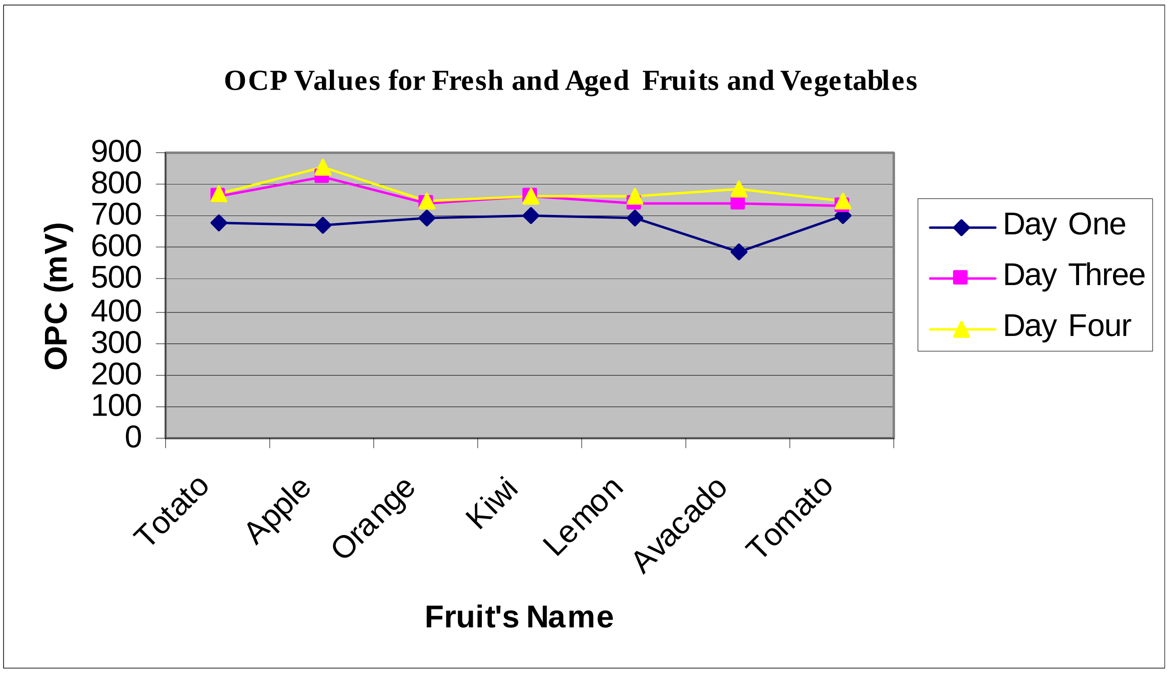

Figure-6: Aging-time Versus Voltage for Fruits and Vegetables

Figure-5 shows OCP values for all fresh fruits and vegetables. The freshness of any fruit depends on its storage or preservation time that is known as aging time. In this study, it is observed that the fresh avocado has the lowest voltage difference compared to other fruits and vegetables. In all cases, data obtained with a Cu-Fe probe showed higher potential difference than the data obtained for the same sample with an Au-Fe probe. Figure-5 further indicates that the Au-Fe probe configuration produced inconsistent values which are found to be difficult to interpret. Surprisingly, it is also noticed that the Au-Fe test fixture is not able to hold its tiny electrodes (length = 1cm and diameter = 0.1mm) firmly. As a result, the cell dimensions using Au-Fe electrodes system for different measurements are not the same for all the times. But the second probe made of Cu-Fe electrodes is found to be good for experimental measurements and produced reliable and consistent data. The surface area is about $1cm^2$ for each of these electrodes. This probe is very easy to use for data collection and the cleaning process is relatively simple.

Figure-6 shows three sets of data obtained from all seven specimens with the Cu-Fe probe on different days (fresh, two-day old and three-day old samples). It is assumed that all specimens are fresh on the day of purchase. It is obviously understood that the freshness of any fruit or vegetable starts declining with the aging time (preservation time on the shelf).

When a fruit/vegetable starts to rot, a chemical process occurs which is known as fermentation. During this process, fruits and vegetables produce either more acidic solution or alkaline solution or a combination of both that enhances the electrolytic strength in the fruits/vegetables. As a result, the juice of an aged fruit/vegetable becomes more reactive with the electrodes and generates a higher OCP reading than the juice of a fresh fruit/vegetable of the same kind. Figure-6 consistently exhibits lower OCP values for freshness of all seven fruit/vegetable specimens. That is, the OCP values are higher for all aged fruits/vegetables which are considered to be either partially or completely rotten, indicating a clear difference between freshness and aged.

5 Concluding Remarks

This study indicates that the OCP measurement techniques can be useful for detecting freshness of fruits and vegetables. A sensor can be developed that may be used during fruit preservation processes for quality control. Further investigations are needed to create an appropriate database which contains sufficient data to make “go and no go” decisions for each individual fruit or vegetable. With proper design and further investigation, it is possible to develop a new sensor will be inexpensive, accurate, and easy to operate for commercial use in the produce industry.

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References:

[1] Food Freshness and 'Smart' Packaging, Carol Lewis, U.S. *Food and Drug Administration, FDA Consumer magazine*, U.S.A., September-October 2002.

[2] J. Abbott, Quality measurements of fruit and vegetables. *Postharvest Biology and Technology*. 15(3). pp. 207-225, 1999.

[3] A. Peirs, J. Lammertyn, J. De Baerdemaeker, Non-Destructive Quality Measurements of Apples by Means of NIR-Spectroscopy, *Acta Horticulturae* Vol. 517 pp. 435, 2000.

[4] Seong-Min Kim, Pictiaw Chen, Michael J. McCarthy, NMR Sensor for Fruit Internal Quality Evaluation, Sensors for Nondestructive Testing: Measuring the Quality of Fresh Fruits and Vegetables, NRAES-97, in the proceedings of an international conference held in Orlando, Florida, 1997.

[5] Sensor Fusion and Classification of Fruit Quality, Bernard A. Engel, Project Leader, 1996, https://engineering.purdue.edu/ABE/Research/research95/engel.ozer.96.whtml

[6] Electrochemical Reactions, http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch20/electroframe.html

[7] M. Amin, *Electrical Characterization of Flux/Substrate Interface,* Doctoral Dissertation, Marquette University, Milwaukee, Wisconsin, 1997.

[8] K.B. Oldham and J.C. Maryland, *Fundamentals of Electrochemical Science,* Academic Press, New York, NY, 1994.

[9] Giorgio Carboni, *Experiments in Electrochemistry*, translated by G.L. Stuart, http://www.funsci.com/fun3_en/electro/electro.htm.

[10] Allen J. Bard and Larry R. Faulkner, *Electrochemical Methods : Fundamentals and Applications*, Wiley; 2 edition, 2000

[11] J. Ackmann and M. Seitz, Methods of Complex Impedance Measurements in Biologic Tissue, CRC Circuit Reviews in *Biomedical Engineering*, Vol. 11, Issue, pages:281-3

[12] M. Seitz, Study of Heterogeneous Composite Materials Via Lumped Parameter/Complex Plane Analysis, *The International Journal for Hybrid Microelectronics*, Vol. 3, No. 1 (1980).

[13] Science Projects: http://www.science-projects. com/RedoxPot/ RedoxPotentials.htm

[14] Electricity and Magnets : Homemade Batteries: http://van.hep.uiuc.edu/van/qa/section/Electricity_and_Magnets/Homemade_Batteries/