Application of Electrical Resistance in Nondestructive Postharvest Quality Evaluation of Apple Fruit

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ABSTRACT

Nondestructive physical tests can be considered as recent trends for quality evaluation of agricultural products. Required information on postharvest quality of fruits and vegetables makes it possible to use their electrical properties as a novel method for nondestructive quality evaluation purposes. In this study, the electrical resistance of harvested apple fruits (Golden Delicious variety) was nondestructively measured by developing and employing special plate electrodes using a load cell to adjust the force holding the samples between two electrodes. Electrical resistance measurements were performed at two frequencies; 120 Hz and 1 kHz. Precise fruit weight was also measured along with electrical resistance measurements. The relationship between the electrical resistance and the weight loss was investigated during the storage period. The experiment ran for a total of 24 days. Results showed that in the 15 initial days of experiment, the electrical resistance decreased by increasing the storage period. But with further increase in the storage period, the electrical resistance also increased. The loss of the fruit moisture content, during the early stage of storage, may be attributed to the decrease of the fruit electrical resistance. However, as the stored apples lost more moisture, the concentration of ions, in soft tissues of samples, highly increased and this could be responsible for the increase of apple electrical resistance during the final days of the experiment.

Keywords: Electrical resistance, Electrical properties of apple, Plate electrode, Storage period of apple, Weight loss.

INTRODUCTION

In recent decades, numerous studies have been performed to carry out accurate and precise food quality evaluation techniques. Increasing consumer demand for internal quality features of fruits and vegetables such as freshness, sweetness and nutritional content, coupled with industry demand for innovative tools for nondestructive and cost-effective detection and monitoring of physiological disorders, have spurred considerable interest among researchers on the application of size and shape analysis (Du and Sun, 2004; Ergun, 2012; Naeem Abadi *et al.,* 2014), color measurements (Pathare *et al.,* 2013), hyperspectral imaging (Lorente *et al.,* 2012), near-infrared spectroscopy (Magwaza *et al.,* 2012), ultrasound analysis (Awad *et al.,* 2012), and extraction of electrical properties (Jha *et al.,* 2011; Yue *et al.,* 2015).

Electrical properties measurements are of relatively new methods applied for food quality assessment. In general, if there are charged ions with mobile carriers present within a sample of fruit material, then if a voltage potential is applied across the sample, an electric current will flow

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through the sample, as part of an electric circuit (Dev and Raghavan, 2012). Thus, electrical properties of fruits and vegetables such as; electrical resistance, electric impedance and reactance and capacitance values are recently, more common parameters which researches prefer to measure in fruit quality studies. These measurements are carried out very fast and accurate with least expenses which are very crucial in agricultural production costs (El Khaled et al., 2015).

The strength of electrical current is inversely related to the electrical resistance of a fruit sample. Factors influencing the electrical resistance of foods are the concentration of charge carriers' salinity, formulation charge, the number of charge carriers and their mobility, their aggregate state, molecular mass, and the type of bonding (Jha et al., 2011).

Recent researches have shown that electrical resistance approach can detect fruit quality factors and is sensitive to variations in fruit moisture content level (Fang et al., 2007). Therefore, it can be associated with maturity, damage, overripe condition, decay or other quality factors (Jha et al., 2011). The analytical relationships between electrical resistance properties and quality criteria of foods have not yet been fully developed. One reason is that quality parameters of agricultural products do not have clear definitions. Therefore, further exploration is needed to acquire more data on electrical resistance, characteristics of fruits, and also employing new approaches for determination of their quality.

Ando et al. (2014) used electrical impedance spectroscopy to explore the changes in the cell physiological status of potato tissues during hot air drying. They reported that due to the loss of moisture, the impedance magnitude increased rapidly as drying proceeded.

In another research, carried out by Juansah et al. (2014), Garut citrus fruits were analyzed for electrical properties related to physicochemical properties using

low alternating current with a frequency varying from 50 Hz to 1 MHz. The fruits were placed between two plate electrodes and treated as dielectric materials. In this study, electrical parameters including impedance, resistance, and reactance per unit of fruit weight were used to compensate variations in weight. The results showed that these electrical parameters decreased by increasing the current frequency.

Furthermore, electrical resistance was also used to determine the extent of tissue damage that occurred as a result of bruising the apple fruit (Puchalski, 1994; Jackson et al., 2000). In a similar study, Puchalski and Brusewitz (2000) measured electrical resistance of the bruised and un-bruised tissue of apple at the frequency of 1 kHz using a universal impedance bridge. The results of both studies indicated that the electrical resistance of un-bruised tissue was higher than bruised tissue and larger bruise volume had lower electrical resistance.

Jha and Matsuoka (2004) measured changes in electrical resistance of eggplant with gloss indices, fruit weight and postharvest storage periods. The results showed that surface electrical resistance increased quadratically with the increase in storage period and decrease in both weight and gloss index of eggplant, during the storage period.

Moreover, the capacitance value was also used as a factor for detecting fruit quality. For example, Benjakul et al. (2013) proposed the use of capacitance value and electrical resistance of mangosteens to determine the fruit defect, nondestructively. The data were then analyzed to evaluate the performance of this method for classification of fruits into two groups: those with and without translucent defect. The accuracy of this method appeared to be 87.3% in classification.

Juansah et al. (2012) studied the electrical behavior of Garut citrus fruits using electrical impedance measurement at various levels of fruit acidity and firmness.

They showed that membrane electrical capacitance and tissue electrical resistance changes were accompanied by firmness and acidity changes in citrus fruits. The changes of these electrical parameters indicated the changes in mobility of ion in cells and physiological changes of fruits during ripening.

Most of these investigations have shown that the electrical resistance decreased with the increase of fruit storage period. In most of the previous researches, the electrodes were pushed into the fruit therefore injuring it and as a result samples had to be replaced in each individual test. The purpose of this study was to evaluate the effects of storage period and weight loss on electrical resistance of apple fruits. In this experiment, especial plate electrodes have been developed for measuring electrical resistance without damaging the fruits. The main objective of this research was to assess a new method to determine the freshness of apple fruits nondestructively using their electrical properties.

MATERIALS AND METHODS

The experiment was carried out in 2013 at Abouraihan College, University of Tehran. To obtain the electrical resistance of apple fruits, an apparatus, originally built at the University of Tehran, was utilized. Figure 1 shows the schematics of the complete system of the apparatus used in this research. The dimensions of this apparatus were 410 mm (length)×350 mm (width)×330 mm (height). As shown in Figure 1, the main components of the unit are as follows:

Base: (1) All of the parts were assembled on the base. The dimensions of the base were considered in such a way that, the apparatus can be adjusted to measure electrical resistance of larger fruits such as rock melon. Once the fruit is placed between the two probes, part of its weight stands on the base, providing more stable contact between the fruit and the copper plates; Square flange bearing: (2) The rotation of the frame was available using the square flange bearing (UCF204). This provides better flexibility for the apparatus to be positioned horizontally or vertically, depending on the fruit dimensions; Frame: (3) Probes and the load cell were set on the frame. The horizontal position of the frame could be changed through the provided pivot, Probes: (4) Probes were consisted of four parts: regulating screws, circular nut, chamber, and copper plate (Figure 2).

These screws are used to connect the probes to the frame. In addition, regarding the size of the fruit sample, the proper distance between two probes can be
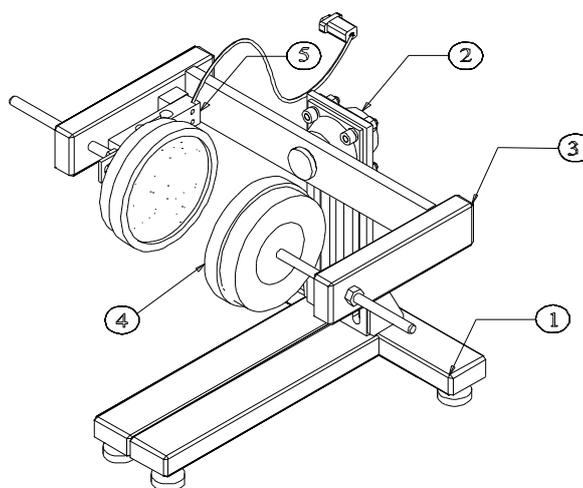

Figure 1. The schematics of the apparatus.

provided by adjusting these screws.

Circular Nut

A polyethylene circular nut was threaded on the chamber and fixed the copper plate on the chamber.

Copper Plate Electrodes

Two copper plate electrodes with 0.03 mm thickness and 140 mm in diameter were used for electrical resistance measurement in this experiment. The thickness of plate electrodes provided a suitable solidity and flexibility for applying required force. The diameter of the copper plate is bigger than the internal diameter of the circular nut (about 4 mm), thus providing enough flexibility for following the fruit curvature. The plate electrodes were placed between the circular nut and chamber. Each copper plate was connected to a LCR meter through a copper wire with 3 square mm in cross section. The fruit electric resistance would transfer to LCR meter through these wires.

Chambers

Two chambers were made of polyethylene and were attached to the frame by the regulating screws (Figure 2). The regulating screws are also used to adjust the distance between two chambers according to the fruit dimensions.

Each circular nut along with its chamber provides a cavity so that the copper plate electrode could cover the fruit curvature. The chambers push the electrodes on the fruit.

Load cell (5): The applied force was measured with a beam type load cell (DBBP, 100 N capacity, Bongshin, South Korea) equipped with a digital weighing indicator. The load cell was connected to an indicator and the applied force to the fruit was adjusted manually in each experiment. The applied force to apple fruits through the copper plates were kept constant in measurements (20±0.2 N).

In this study, 10 fresh apple fruits (Golden Delicious variety) with an average weight of 141.4 g were selected. They were harvested, transferred to the laboratory and stored in 22±2°C immediately. During the storage period, the measurements were carried out every 12 hours. In this experiment, electrical resistance of the apple samples was measured with LCR meter (41R, Lutron, Taiwan). The LCR meter was operated at two frequencies, 120 Hz and 1 kHz with 0.5% accuracy. Weight loss of apples was determined by precision electronic balance (Packet Scale, 600 gr, China). The moisture content of the samples was measured using the oven-dry method (Karathanos, 1999). The final moisture content of the samples was determined in an oven at a temperature of 70°C for 48 hours.
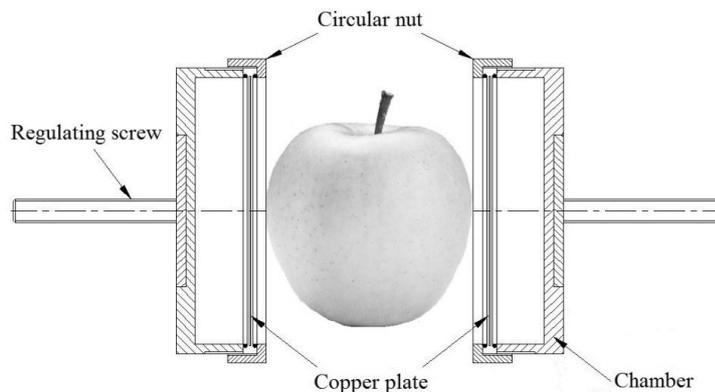

Figure 2. The schematics of the probes.

The main advantage of the apparatus for measuring the fruit electric resistance is that, the fruit is placed between 2 plates and no probe is pushed inside it. Therefore, no damage is done to the samples. Whereas, in most of the experiments related to fruit electric resistance measurement, fruit samples were harmed through the apparatus probes (Desai and Liang, 1977; Puchalski, 1994)

RESULTS AND DISCUSSION

The experiment ran for 24 days. The obtained mean value of moisture content (wb) was 0.82 at the beginning of the experiment and reduced to 0.79 at the end of the experiment (after 24 days) (Figure 3-a). Accordingly, the weight loss, caused by decreasing moisture content during the storage period, is shown in Figure 3-b. Since the storage temperature was close to the room temperature, the trend of moisture content loss for fruit samples was linear ($R^2= 0.99$), similar to the results of Gaware *et al.* (2010).

Figure 4 shows the effect of storage period on electrical resistance of samples, at two different frequencies. The mean values of electrical resistance for the samples, at 1 kHz frequency, varied between 151.7 and 106.04 kΩ during the storage period, whereas it varied between 929.39 and 738.33 kΩ at frequency equal to 120 Hz. As it is shown in this figure, the trend of this change was down until day 10 and then it increased with lower slope during the late storage period.

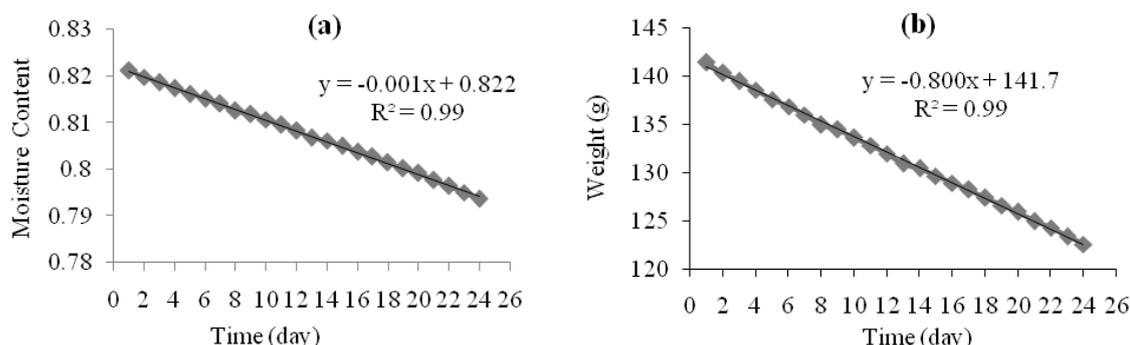The use of 1 kHz frequency resulted in

Figure 3. Effect of storage period on samples': (a) Moisture content and (b) Weight.
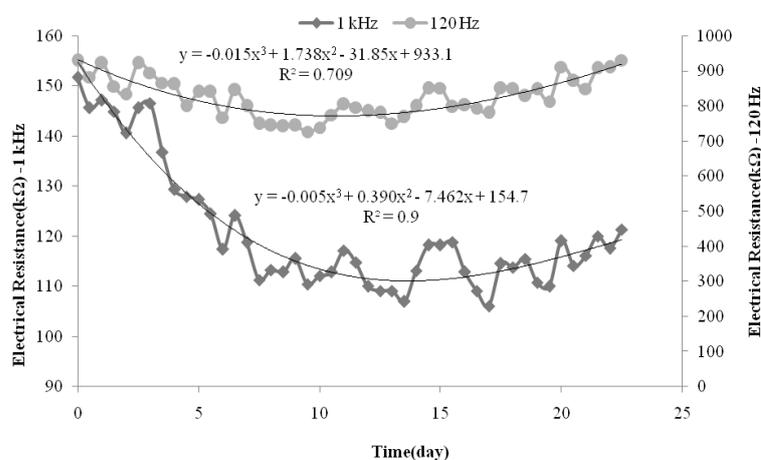

Figure 4. Electrical resistance versus storage period, measured at 1 kHz and 120 Hz frequencies.

better correlation between samples electrical resistance and storage period ($R^2= 0.90$), compared with 120 Hz frequency ($R^2= 0.71$). It seems that at higher frequencies, electric current is able to pass the fruit tissues faster and easier, resulting in more precise measurement of electrical resistance.

The sharp decrease of electrical resistance of apple fruits during the early storage time, and the following moderate decrease shown in Figure 4 can be attributed to the effect of fruit moisture content. As the storing time increased, the moisture content and accordingly, the fruit weight decreased due to the continual transpiration (Figure 3). Similar results were achieved by other studies (Jha and Matsuoka, 2004). As it is clear from Figure 4, the fruits electrical resistance first decreased at both 120 Hz and 1 kHz frequencies with the increase of storage period. However, the slope of the curves in early days of storage was much sharper than the later days. Consequently, after 15 days of storing, the electrical resistance of the fruit not only stopped decreasing, but also tended to increase (Figure 4).

To study the effect of moisture content of apple fruits on their electrical resistance, the electrical resistance versus weight is plotted in Figure 5. Loss of moisture content within the final days of storage increased the electrical resistance of apple because of the increase in the mass of dry matter which is not a proper condition for conducting electricity.

Similar results are reported by different studies (Puchalski, 1994; Harker and Forbes, 1997; Liu, 2006). Figure 3 indicates that the apple's moisture content and accordingly, its weight decreased linearly as the storage period increased. However, it seems that as the stored apples lost further moisture, the concentration of ions in their electrolyte highly increased and this could be responsible for the increase of apple electrical resistance during the final days of the experiment. It is suggested that at lower ion movement, the fruit electrical resistance would increase significantly (Liu, 2006). Harker and Dunlop (1994) reported similar findings during nectarines fruit drying. The results may also suggest that further increase of storage period (15 days in the condition of this experiment) would lead to some kind of decomposition in apple tissues. Although there has been no sighted decay in apple fruit, but slight decomposition of the fruit tissue may change its electrical resistance. Recent studies have showed that electrical resistance of agricultural products is correlated to changes in fruit texture, particularly firmness and apparent juice content (Harker and Forbes, 1997; Juansah
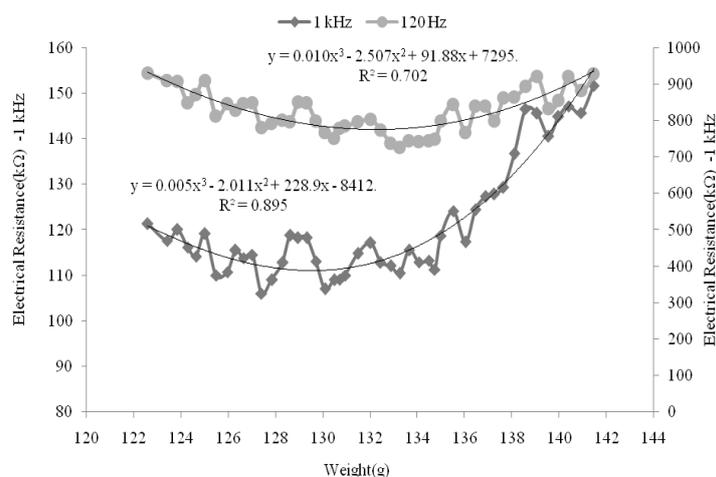

The chart shows Electrical Resistance (kΩ) - 1 kHz on both axes with equations:
$y = 0.010x^3 - 2.507x^2 + 91.88x + 7295.$ $R^2 = 0.702$
$y = 0.005x^3 - 2.011x^2 + 228.9x - 8412.$ $R^2 = 0.895$

Figure 5. Electrical resistance versus weight, measured at 1 kHz and 120 Hz.

et al., 2014).

The changes in tissue of fruits could be better monitored at higher frequencies (more than 200 kHz) compared with lower frequencies (Harker and Dunlop, 1994). Resistance at higher frequencies reflects the properties of extra cellular regions of the tissue, whereas the resistance at lower frequencies reflects the properties of the entire tissue (Harker and Forbes, 1997). In fruit cells, electrical resistance mainly reflects the ionic content of the vacuole, which represents more than 90% of the cell volume and has high concentrations on ions.

CONCLUSIONS

This investigation indicates that the electrical resistance measurement has a great potential in assessing the freshness of apple fruits during the storage. In this study, special electrical plate electrodes were developed and used to measure the electrical resistance changes of apple fruits stored for 24 days at 22±2°C. This was performed without any physical damage to the samples. Results showed that measuring the nondestructive electrical features of fruit samples at high frequencies (e.g. 1 kHz) is an appropriate way to indicate the postharvest quality of apple fruits during the storage period. It is quite possible to use a non-destructive approach through measurement of fruit electrical resistance and analysis of its apparent shape to determine the freshness of apple fruits. Authors suggest further research in this area to estimate proper storage periods for apple fruit at different storage temperatures. Further study is also suggested to find a proper range of apple moisture-electrical resistance relationship, providing acceptable quality for marketing purposes.

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کاربرد مقاومت الکتریکی در ارزیابی غیر مخرب کیفیت سیب

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چکیده

آزمایش‌های غیرمخرب، روشی نو در بررسی کیفی محصولات کشاورزی می‌باشد. مطالعات بیشتر روی خصوصیات الکتریکی میوه‌ها و سبزیجات، استفاده از خصوصیات الکتریکی را به عنوان یک روش غیرمخرب جدید ممکن می‌سازد. در این مطالعه، مقاومت الکتریکی سیب انبارشده(واریته گلدن دلیشز) به صورت غیر مخرب با استفاده از الکترودهای صفحه‌ای طراحی شده و لودسل مناسب به منظور اندازه‌گیری نیروی وارده الکترود به نمونه ها، اندازه‌گیری شد. مقاومت الکتریکی در دو فرکانس ۱۲۰هرتز و یک کیلو هرتز اعمال شد. وزن دقیق میوه ها نیز در طول اندازه‌گیری مقاومت الکتریکی اندازه‌گیری شد. ارتباط بین مقاومت الکتریکی و کاهش وزن در مدت نگهداری بررسی شد. آزمایش‌ها در ۲۴ روز انجام شد. نتایج نشان داد در ۱۵ روز اولیه آزمایش، مقاومت الکتریکی با گذشت زمان کاهش یافته است. اما پس از آن با گذشت زمان مقاومت الکتریکی افزایش یافته است. کاهش رطوبت میوه در روزهای ابتدایی دوره نگهداری مهمترین دلیل کاهش مقاومت الکتریکی میوه است. در حالیکه با گذشت زمان و کاهش بیشتر رطوبت سیب ها، غلظت یونی بافت نمونه‌ها افزایش یافته و این می‌تواند دلیل افزایش مقاومت الکتریکی سیب در روزهای پایانی آزمایش باشد.