Original papers

Determination of mango ripening degree by electrical impedance spectroscopy

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A B S T R A C T

The kinetics of ripening of fruits, followed by subsequent degradation process represent important biochemical mechanisms with high aggregate value for agribusiness sector. In contrast to the destructive assays for identification of ripening degree of fruits, the development of non-invasive techniques introduces potential advantages concerning to the development of new methods for fruit production control. In this direction, the electrical impedance spectroscopy was used for the identification of the maturation degree of fruits based on variation of bulk resistance dependence with maturation of fruits, due to the variation in the liquid content in fruit fibers. The results revealed the strong correlation between mechanical assays and electrical parameters, characterizing an important advantage in terms of a non-invasive and non-destructive method for ripening identification degree.

1. Introduction

The increasing demand from agribusiness introduces important requirement on control level of fruit production. The mango culture represents a strong source for economy if considered its importance justified by the increasing international demand. In this direction, the reduction in the post-harvest losses represents an important aspect to be considered. Biochemical and physiological deterioration that take place during ripening introduce risk for production, as clearly identified in the visual appearance of the fruit, reducing the product market value. A more complete study about physical properties of fruits introduces a key role in the development of adequate tools for measurement of harvesting, packaging, storage and transportation process. The physical properties of fruits can be explored as important parameters for determination of optimal fruit harvest time. Among different parameters explored, it is noteworthy to refer: mass, size, shape, color, firmness, and number of days after flowering. In addition, the mechanical properties of fruits are also important for determination of the maturation degree. Consequently, compression tests have been currently explored in order to determine force-deflection curves, applied in the measurement of fruit firmness such as reported for papaya, banana (Torres et al., 2012) and pumpkin (Figueiredo Neto et al., 2013).

In addition to these aspects, the nondestructive determination of characteristics of agricultural products is extremely important for producers, handlers and processors. Electrical properties of fresh fruits and vegetables have been considered convenient and a nondestructive sensing method for determination of parameters such as maturity in peaches and chilling injury in sweet potatoes (Nigmatullin et al., 2006).

Different number of sensorial analysis techniques are based on electric variables such as voltage, current, and electrical charge accumulation measurement, providing robust methods for characterization (Escarpa, 2012; Cortes et al., 2015). Impedance spectroscopy is a simple and powerful technique that can be conveniently applied in the analysis of different biological tissues, including fruits (Chowdhury et al., 2015).

Electrical impedance spectroscopy (EIS) of biologic systems return valuable information about electrical transport and charge separation at interface in the frequency domain, contributing to the determination of intrinsic properties of materials. The fruits ripening process involves a lot of information about the physiological and biochemical changes (Chowdhury et al., 2015). The direct measurement of EIS of external surface consider a complex bioelectrical system (Schwann, 2002) which depends on a tissue composition, anatomy and health.

With the degradation in tissue composition, tissue structure and health, corresponding changes in the electrical impedance of fruits may vary according to the frequency of external electrical field. So, electrical parameters from fitting circuits can be conveniently explored in order to describe the response of interfaces and bulk of samples.

Based on these important aspects, we have explored the novelty related to the use of EIS on characterization of ripening degree of mango. In addition, we stated the most adequate parameter that can be
correlated with conventional methods - mechanical characterization.

2. Materials and methods

2.1. Samples preparation

The experiments explored ’Tommy Atkins’ type mangoes. Fruits were collected manually from a commercial orchard at Fazenda Special Fruit Import and Export Ltda, located in Juazeiro, Bahia, in a climatic region of the type BSwh (semi-arid, steppe type, hot, with summer rainy season) according to Koppen. This region lies at 9°24′45.85″ S and 40°30′53.51″ W, at an altitude of 374 m.

Fifty plants were selected and distributed along five rows in the orchard. Fruits (1 2 0) were collected on separate days in correspondence with phases: 80, 95, 110, 125, 127, 130 and 133 days after flowering (DAF). Harvesting was done in the morning, using pruning shears to cut off the stalk.

Fruits were harvested in August 2016 at maturation stage 2 (external appearance of the fruit being 75% green and 25% red). Then, fruits were transported from the farm to the packing house, where they were washed and pre-selected according to their ripeness stage, color, size, uniformity, mass, and absence of injuries or diseases. After this step, selected fruits were packed in plastic boxes.

Before each experiment the samples were washed in tap water, and immersed into a solution of 150 mg of chlorine per liter of water for 15 min. They were rinsed in order to remove excess chlorine and then dried at room temperature.

The fruits were distributed in batches of eight into cardboard boxes (350 mm × 285 mm × 105 mm), arranged in B.O.D at 12 ± 1 °C and 58 ± 2% RH, on laboratory bench under laboratory temperature of 26 ± 3 °C and 68 ± 4% RH for 15 days.

The mass of mangoes was measured in an analytical balance model AC10K (Marte) while diameter was determined using a digital paquimeter pantec (Panambra).

For all of measurements the bar errors represent the standard deviation of triplicates for each of three different fruits ion the corresponding ripening degree.

2.2. Mechanical tests

The compression test was done by means of an electro mechanic universal machine EMIC model DL 10,000, conducted by a micro-computer furnished with a TESC software version 3.04 adapted for experiments with agricultural products. Mangoes were placed to rest between the parallel plates (diameter 30 cm) of the equipment subjected to a compression of 5 mm/min till the final strength was reached as to the variety limit in the analyzed stage i.e., until the complete epicarp disruption, providing a direct relationship between force (N) and deformation (mm) for samples.

The modulus of elasticity (E) of the fruit can be found according to the Eq. (1), which makes use of the Hertz contact theory, applied in the determination of the maximum surface pressure and elastic modulus of a body pressed between two flat plates (Timoshenko and Goodier (1951) and applied to the second spherical fruit (Dantas et al. (2017)),

\[ E = 0.75F(1 - \mu^2) \times \frac{1}{D^{3/2}} \times \frac{1}{R^{1/2}} \]  

(1)

where F is the force in Newtons, \( \mu \) is the Poisson’s ratio, R is the radius of the sphere (m) and D is the deformation in meters.

2.3. Electrical characterisation

The electrochemical characterisation of samples was performed in a Potentiosstat/Galvanostat Metrohm Autolab AUT302N with AC voltage of 100 mV and frequency range of 1 Hz to 1 MHz. The dependence of real and imaginary parts of impedance as a function of frequency were modelled from equivalent circuit from which corresponding mechanisms such as electrical double layer capacitance, bulk resistance and charge transfer resistance were determined. The electrical contact with surface of fruit was provided by two electrodes of Ag/AgCl (MedLevensohlh) disposed on opposite side of fruit (equatorial zone of samples) – as shown in Fig. 1.

The corresponding fitting parameters obtained from equivalent electric circuit returned important information relative to bulk capacitance, charge transfer resistance and bulk resistance. The most adequate parameter for determination of ripening degree was identified as bulk resistance (obtained from fitting of results with a \( R_1-R_2//C \) circuit) divided by fruit diameter.

3. Results and discussion

The climate conditions along experiment were collected at the meteorological station of Embrapa Semiárido, as shown in Table 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>T (°C)</th>
<th>RH (%)</th>
<th>Pt (mm)</th>
<th>SR (ly/day)</th>
<th>I (hours)</th>
</tr>
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<tbody>
<tr>
<td>May</td>
<td>25.6</td>
<td>61.93</td>
<td>2</td>
<td>461</td>
<td>7</td>
</tr>
<tr>
<td>June</td>
<td>24.8</td>
<td>60.98</td>
<td>2</td>
<td>501</td>
<td>8.1</td>
</tr>
<tr>
<td>July</td>
<td>26.7</td>
<td>55.11</td>
<td>0</td>
<td>558</td>
<td>9.5</td>
</tr>
<tr>
<td>August</td>
<td>28.7</td>
<td>52.36</td>
<td>0</td>
<td>623</td>
<td>9.7</td>
</tr>
<tr>
<td>Average</td>
<td>26.4</td>
<td>57.59</td>
<td>–</td>
<td>535.7</td>
<td>8.5</td>
</tr>
</tbody>
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T = air temperature; RH = relative humidity; Pt = precipitation; SR = solar radiation; I = insolation.
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