

## Prediction of banana quality during ripening stage using capacitance sensing system

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### Abstract

Capacitive property of banana fruit was studied in order to develop a rapid and non-invasive ripening assessment method to control their ripening treatment. A sine wave frequency generator with parallel plates capacitor sample was used to span the difference in capacitance, caused by the introduction of a banana fruit into the sensor. Banana fruits were submitted to measurement before ethylene treatment on first day and after treatment for five days. Relative permittivity was correlated with quality parameters of banana fruit. Green-ripe banana fruits have larger permittivity than the full-ripe ones, the permittivity of which was decreased as a result of the ripening stage. Quadratic regression had higher prediction power of the equations than linear regression. Experiments indicated that the best frequency of sine wave was 1 MHz. Permittivity at this frequency changed from 1.7433 for green-ripe banana fruits to 1.6431 for full ripe ones after a five-day period.

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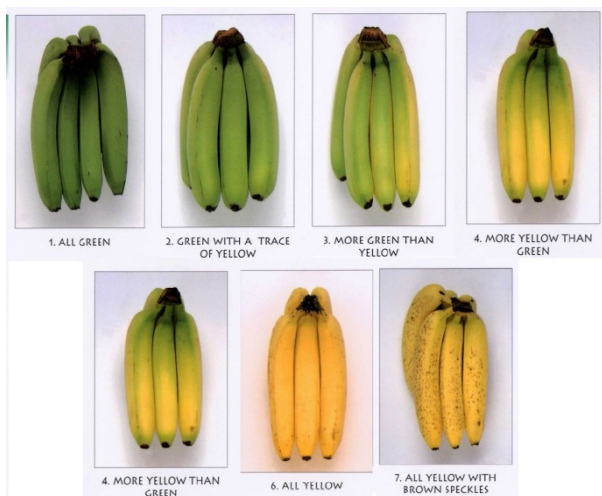
**Keywords:** capacitance; banana fruit; relative permittivity; quality; frequency

**Abbreviations:** F\_Firmness; R\_Relative permittivity; SSC\_Soluble solids content

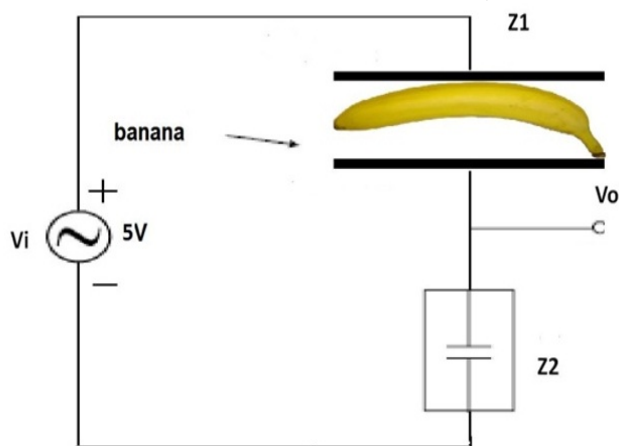
### Introduction

Banana fruits have been one of the favorite fruits in Iran. For preserving a firm pulp texture, good color and flavor and also to avoid from contusion, bananas are cut at a mature-green stage and exported to consumer countries. The imported banana fruits are kept in airtight warehouses with ethylene gas control system. The bananas are typical fruits having a climacteric rise. The climacteric rise is a physiological phenomenon caused by ethylene. The ripening treatment of banana fruits with climacteric rise could be artificially made by using controlled ethylene gas. The quality of ripening banana fruits could be controlled by ethylene treatment in commercial practice (Terai et al., 1973). During banana ripening, the peel color changes, the flavor develops and the pulp softens. The first observable sign of ripening is a color change from green to yellow (Meng et al., 1997). The banana fruits are taken to market when they are at stage six (Fig 1). The ripening treatment of banana fruits has been improved through a tentative method by the empirical of trained laborers into a programmatic ethylene gas control manner. However, this method has not always attained in bringing the uniformed ripening of banana fruits, because of its lacking of any monitoring system to detect the ripening quality of banana fruits (Morita et al., 1992). To estimate the ripening quality of banana fruits during the ripening treatment, it is needed to institute non-destructive detecting method of ripening quality in easy operative application. Employing the dielectric properties to measure the moisture of grain dates goes back to about 100 years ago (Ragni et al., 2006). The primary data on the dielectric parameters of grain appeared only 50 years later

(Nelson et al., 1953). Several studies regarding dielectric characterization were carried out in the past 40 years (Nelson, 1973; Venkatesh et al., 2004). These studies investigated fruits and vegetables (Nelson, 1983), grain and seed (Nelson, 1965) and other products. Many of these researches were carried out by Nelson. He studied dielectric properties of grains, fruits and vegetables and investigated dependence of these parameters on temperature, moisture content and frequency and also studied feasibility of using the dielectric properties to sense quality of these products (Nelson et al., 1953; Nelson, 1965, Nelson, 1983, Nelson et al., 2002). He studied dielectric properties of watermelon and correlated with soluble solids content as a quality factor of fruits (Nelson et al., 2007; Nelson et al., 2008). Ragni et al., (2006) employed dielectric properties of egg to predict its quality parameters. Kato, (1997) deduced correlation of internal quality of watermelon with density. He found that the density depended on the degree of hollowness and the soluble solids content. He employed electric capacity to predict density of watermelons. Sirikulrat et al., (2008) demonstrated that the relative permittivity of the fresh soybean decreases as the bean matures. These researches show employing dielectric properties in sensing quality parameters and other properties of agricultural products. To predict quality factors of banana fruits Finney et al., (1967) measured changing in firmness of banana fruits during the ripening treatment by means of a sonic technique. Chuma et al., (1980) tried to apply a delayed light emission to evaluate ripening quality of banana fruits. Morita et al., (1992) evaluated changes in quality of ripening bananas



**Fig 1.** Color chart of banana fruits in various stages



**Fig 2.** Side view of sensor in a voltage divider setup. A banana is hung between the driving and sensing system

using light reflectance technique. Meng et al., (1997) employed optical chlorophyll sensing system for banana ripening. These attempts were fundamental approaches and they were far from reaching a practical application. Therefore, it is very important to devise an evaluation system for assessing the ripening quality of banana fruits. The purpose of this study were to obtain some basic data to estimate ripening quality of banana fruits during the ripening treatment by capacitance properties, aiming to apply the capacitance technique to an automatic control system for the ripening of banana fruits.

### Materials and methods

Banana fruits (*Cavendish variety*) shipped out from the Ecuador were used in this experiment. The banana fruits have been stored at 14 °C temperature during the transfer. 68 fingers of banana were randomly selected from banana boxes in warehouse. The experiment was carried out at airtight ground-warehouses with a great deal of banana fruits at humidity level of 85% -88 % for five days, the time needed for completing the ripening treatment of banana fruits. On the first day, banana

fruits were at stage one and on the fifth day, they were at stage six (Fig 1). Ethylene gas with 1000 ppm concentration was treated during 24 hours on first day. It is very important to control temperature, humidity and ethylene gas concentration in the warehouse. In order to give a good artificial climacteric rise of banana fruits during the ripening, experiments were carried out in the warehouse. The experiment was conducted in controlled temperature room at 17 °C. Parallel plate capacitor with 25 cm length and 10 cm width was developed as a standard hardware instrument for measurements. The conductive plates selected from aluminum material because of its consistency which would not be easily ionized as a factor that will ruin the measurement using capacitive properties. Fig 2 shows a voltage divider circuit, where  $V_i$  is the input voltage signal,  $V_o$  is the sensing voltage signal,  $Z_2$  is the reference impedance, and  $Z_1$  is the sensing impedance. The effective impedance of the parallel plate capacitor is calculated from the voltage divider equation (1).  $V_o/V_i = Z_2/(Z_1+Z_2)$  To maximize circuit sensitivity,  $Z_2$  is chosen to be close to  $Z_1$ . In this investigation,  $Z_2 = 10$  pF.

### Experimental Procedure

#### Relative permittivity measurement

1. The vacant capacitance of sensor is calculated from the equation (1).
2. Test specimen is hung between the sensor plates, while the whole of the specimen is placed inside the sensing plates.
3. A 5 Volt sine wave, 10K Hz to 10 MHz frequency sweep signal is applied to the circuit in Figure 2 and  $V_o$  is measured.
4. Measurements are taken each day.
5. Capacitance of sensor is calculated from the equation (1).
6. Mean relative permittivity is obtained from dividing the capacitance included banana fruit to the vacant capacitance.

#### SSC measurement

One of the objective quality indicators is the soluble solids content, which currently requires samples from the internal tissues and is a destructive test. The 10 g of flesh was sampled from a whole banana (along length of fruit) and diluted in 50 g of distilled water in a blender for 1 min. Soluble solids content were measured using refractometer with three replications for each stage.

#### Firmness measurement

Pulp firmness was measured using an Instron universal testing machine (Model SANTAM ST-5) with an 8 mm cylindrical probe. Head speed was set at 50 mm/min. Firmness was defined as the maximum force in (N) required until tissue failure. The firmness was measured 2 cm away from the middle of the fruit.

### Results and discussion

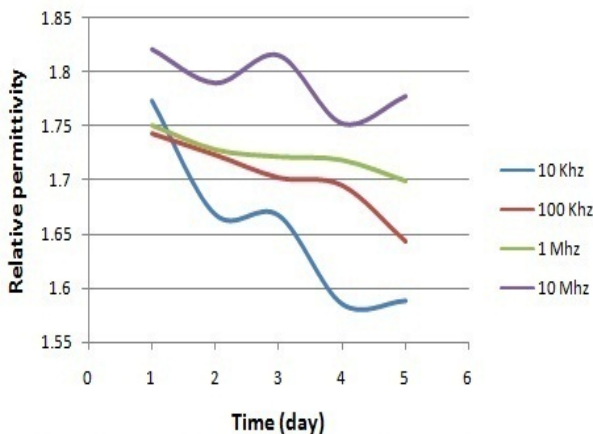
Relative permittivity curves of banana fruits during the ripening treatment are shown in Fig 3. Relative permittivity was measured over the frequency of 10 KHz to 10 MHz on all samples during the ripening. Fig 3 shows that at all frequencies, a decrease was occurred during ripening of banana. At 10 KHz and 10 MHz erratic variations was observed, but at 100 KHz and 1 MHz a consistent decrease in relative permittivity

**Table 1.** Multiple linear regression equations to predict the soluble solids content of banana fruits using the relative permittivity

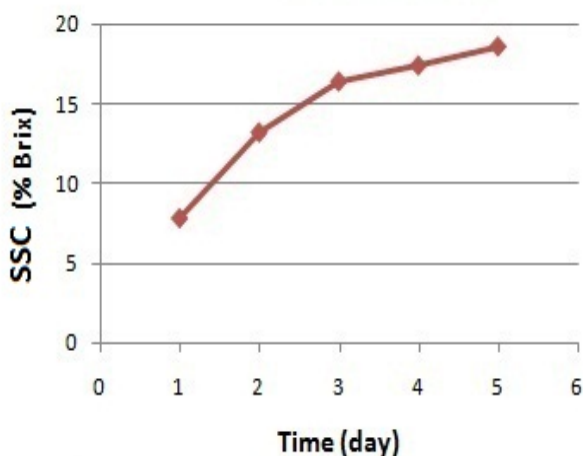
Function	R <sup>2</sup>	Frequency
SSC = - 53.281R + 102.95	0.8980	10 KHz
SSC = - 99.355 R + 183.73	0.7467	100 KHz
SSC = -217.3 R + 389.23	0.9013	1 MHz
SSC = - 101.11 R + 195.84	0.4305	10 MHz

**Table 2.** multiple Non-linear regression equations to predict the soluble solids content of banana fruits using the relative permittivity

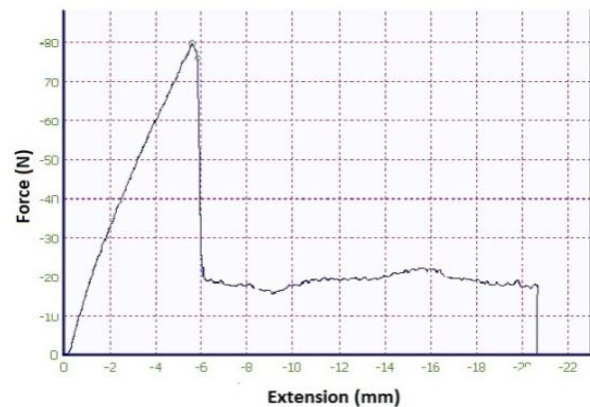
Function	R <sup>2</sup>	Frequency
SSC = -145.91R <sup>2</sup> + 435.87 R - 306.27	0.9784	10KHz
SSC = -1775 R <sup>2</sup> + 5837 R - 4834.2	0.9975	100KHz
SSC = -2949.5 R <sup>2</sup> + 9961.6 R - 83191.9	0.9361	1 Mhz
SSC = 1816.67 R <sup>2</sup> + 6396.8 R - 5613.5	0.4870	10 Mhz



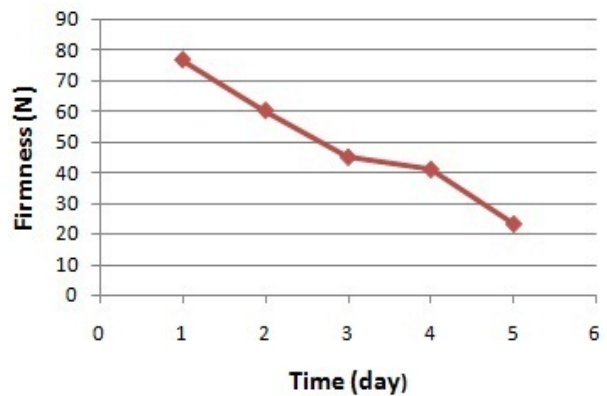
**Fig 3.** Relative permittivity of banana fruits at different frequencies during ripening



**Fig 4.** Changes in solid soluble content of bananas during ripening treatment



**Fig 5.** Compressive force versus displacement curve of banana fruits



**Fig 6.** Changes in firmness during ripening treatment

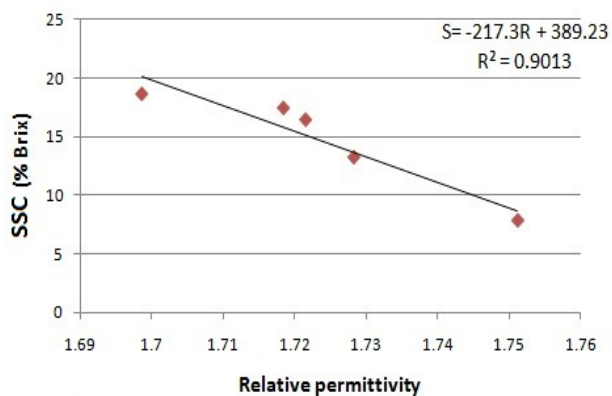
was observed. Soluble solids content is one of the main internal qualities of banana fruits. Fig 4 shows the mean values of soluble solids content of banana fruits during ripening. SSC increased from 7.8 % Brix at stage one (green) to 18.6 % Brix at stage six (full-ripe) in a quadratic form. Similarly, this increase was reported by Marriot et al., (1981). They reported that sugar content increased up to about 20% at stage six (full-ripe). Salvador et al., (2007) reported a quadratic form of increase in soluble solids content of Cavendish variety during ripening. They found soluble solids varied from about 5.5% Brix to 18% Brix. Most of the soluble solids content is sugar. During ripening, the starch of banana is converted to sugar so SSC is increased. Increase of SSC is an important trait of hydrolysis of starch into soluble sugars such as glucose, sucrose and fructose (Marriott et al., 1981). Firmness is another main quality indicator of banana fruits. Firmness versus displacement is shown in Fig 5. As it was noted firmness expresses the ultimate force that causes the banana's failure. Variations in firmness during ripening are shown in Fig 6. The firmness of banana fruits decreased linearly from 76.53 N on day one to 23.22 N on day five. A remarkable change occurred in firmness each day. Likely Morita et al., (1992) reported a linearly decrease in firmness from 4.32 kg/cm<sup>2</sup> (47.9 N) to 0.49 kg/cm<sup>2</sup> (11.1 N). This difference probably was due to the difference in conditions of ripening treatment that carried out at 14° C for nine days and the apparatus used. Thompson, (1996) reported that the softening of banana fruit during ripening treatment is

**Table 3.** Multiple linear regression equations to predict the firmness of banana fruits using the relative permittivity

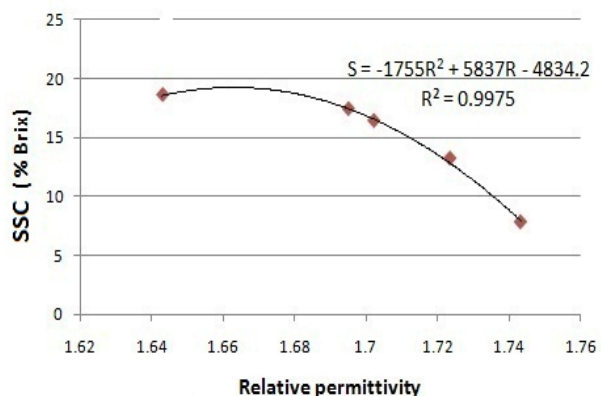
Function	R <sup>2</sup>	Frequency
F = 237.56 R - 344.43	0.8257	10 KHz
F = 5118.35 R - 832.81	0.94	100 Khz
F = 1047.5 R - 1756.5	0.9687	1 Mhz
F = 432.54 R - 725.86	0.3643	10 Mhz

**Table 4.** multiple Non-linear regression equations to predict the firmness of banana fruits using the relative permittivity

Function	R <sup>2</sup>	Frequency
F = -74.222 R <sup>2</sup> + 486.39 R - 552.58	0.8260	10 KHz
F = 3988.4 R <sup>2</sup> - 12973 R + 10571	0.9999	100 Khz
F = 1705 R <sup>2</sup> - 6931.5 R - 6832.4	0.9697	1 MHz
F = 20475 R <sup>2</sup> - 37035 R + 32771	0.4519	10 MHz

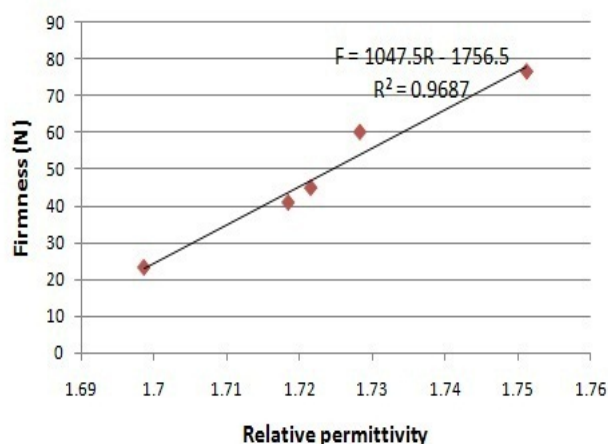


**Fig 7.** Linear curve estimation to predict the soluble solids content of banana fruits

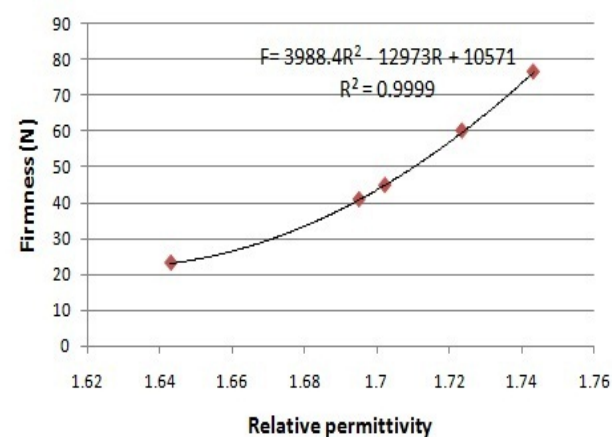


**Fig 8.** Quadratic curve estimation to predict the soluble solids content of bananas

associated with the conversion of starch to sugar, the breakdown of pectin substances and the movement of water from the rind of the banana to pulp during ripening. The equations representing the relationship between soluble solids content and permittivity, for each frequency and their coefficients of determination (R<sup>2</sup>) are presented in Table 1 and Table 2. The best linear predictor function of solid soluble content



**Fig 9.** Linear curve estimation to predict the firmness of banana fruits



**Fig 10.** Quadratic curve estimation to predict the firmness of banana fruits

was obtained at 1 MHz and the best quadratic predictor function was obtained at 100 KHz. Linear and quadratic relation between SSC and permittivity are shown in Fig 7 and Fig 8. Quadratic regression proved a better estimation of SSC. Estimations of firmness as a function of relative permittivity are presented in Table 3 and Table 4. At frequency of 100 KHz, linear regression coefficient was superlative and the best quadratic function predictor was obtained at 1MHz. The relationship between firmness and relative permittivity are shown in Fig 9 and Fig 10. It was also concluded that quadratic functions predicted the banana's internal qualities more accurately. The high correlation between permittivity and quality of banana fruits was considered to indicate that the permittivity could be available as an index of quality of banana fruit. It was found that the changes of the soluble solids content and the firmness of banana fruits were closely related to the ripening. In order to discuss application of capacitive property to a ripening index, the relationships among relative permittivity, soluble solids content and firmness were investigated. It seems that the variations of permittivity at frequencies of 100 KHz and 1 MHz are more vivid, therefore these frequencies are better than 10 KHz and 10 MHz for system calibration.

## Conclusions

In this research, a capacitance sensing system was equipped by a pairs of parallel plate capacitor sensor. This paper studied the ability of this method to predict the quality of bananas during ripening period. Results showed that this technique, which is based on dielectric property, was able to assess changes in the quality parameters of banana fruits during ripening period. Linear regression at 1 MHz provides an acceptable correlation for both SSC and firmness with relative permittivity. So this frequency was selected to develop the sensing system. Further works are needed to conduct researches on this method at higher frequencies to develop a more reliable prediction of banana quality during the ripening treatment.

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