Relationship of pears' dielectric properties and rates of pears' bruise

Mohsen Azadbakht*, Mohammad Javad Mahmoodi, Mohammad Vahedi Torshizi, Peyman Asghartabar Kashi

(Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran)

Abstract: Nowadays, dielectric materials, as one of the nondestructive methods, have drawn the researchers' attention to their diverse array of advantages to the other methods. Before loading and storage, 120 pears were examined using CT-Scan and 81 pears with zero bruise were selected followed by subjecting them to quasi-static and dynamic loading and a 10 days storage period was chosen to investigate the bruise levels and their relationships with dielectric constant. At the end of the storage period, the fruits were measured in their dielectric constant after their bruise levels were determined in CT-Scans. The measurements were undertaken in capacitor plate distances of 8 cm, 11 cm and 14 cm for input voltages of 6 V, 10 V and 14 V and input voltage frequencies of 20 KHz, 60 KHz and 100 KHz for two fruit placement directions. The results showed that the highest dielectric constant, 5.4868, belonged to wide-edge compressive plate for a plate capacitor distance of 8 cm and subject to a 130 N loading and a bruise level equal to 39.563; moreover, the lowest dielectric constant, 5.01651, was found belonging to longitudinal placement direction and subject to a 350 g loading weight exerted in the form of impact for a decay level equal to 5.147. The final result was that the bruise level increases and moisture content decreases with the elevation of the compression force following which the dielectric constant demonstrates higher values.

Keywords: dielectric, pears, bruise, CT-Scan, load, moisture, voltage

Citation: Azadbakht, M., M. J. Mahmoodi, M. V. Torshizi, and P. A. Kashi. 2020. Relationship of pears' dielectric properties and rates of pears' bruise. Agricultural Engineering International: CIGR Journal, 22(1): 169-179.

1 Introduction

Recently, nondestructive methods have been turned into means of doing research and have taken the place of expensive and impractical invented techniques as they are found less costly and more reliable in the evaluation of quality in an online manner. Nondestructive measures are ideal evaluation methods for agricultural products because they result in crops' final cost reductions. Many of the researchers have taken advantage of the nondestructive methods to study the quality and maturity indices of such fruits as apples, avocados, mangos, tomatoes and so forth (Soltani et al., 2011a).

Based on dielectric principles, when a matter is positioned inside an alternating electric field, the positive and negative particles therein are frequently attracted and repelled to and from the field and considering the fact that the cations, anions and polarized molecules' movements are higher in agricultural products in comparison to other particles, they use up the highest energy rates and hence need higher levels of moisture. On the other hand, the mechanical damage of the products, besides causing

Received date: 2018-10-26 **Accepted date:** 2019-10-26

***Corresponding author: Mohsen Azadbakht**, Associate Professor, Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: azadbakht@gau.ac.ir, Tel / Fax: +981732440870

various changes in the products, lead to increase in bruise level that is followed by a reduction in moisture in the agricultural products. Therefore, it is through measuring the dielectric constant of the agricultural products that such moisture variations can be determined (McKeown et al., 2012)

Amongst the nondestructive methods, a dielectric method is largely taken into consideration for such advantages as the relationship between the dielectric constant values and some quality indicators of the agricultural products like moisture, higher handling speed and lower costs as compared to many of the other nondestructive measures as well as high efficiency in the agriculture industry. Also, dielectric properties of the agricultural products can be assessed as a simple, reliable, strong and nondestructive method of evaluation (Soltani et al., 2011b; Nelson, 2005; Naderi-Boldaji et al., 2015).

Dielectric techniques have been employed in various studies on the quality of food materials and agriculture for example in researches about grape juice and drinks, milk, apple ripening, meat quality, banana ripening, egg quality and so forth. Also, it is worth mentioning that the fruit storage period might bring about changes in the dielectric properties (García et al., 2004; Nunes et al., 2006; Guo et al., 2011; Castro-Giráldez et al., 2010; Soltani et al., 2011a; Ragni et al., 2010; Sosa-Morales et al., 2010).

In calculating the fruits and vegetables' electrical properties, the physical characteristics of the agricultural crops like volume, surface area, size, and porosity are investigated (Sirikulrat and Sirikulat, 2008). Mechanical damage to the fruits, usually when harvesting, transporting, sorting lines and packaging of the fruits as well as when being offered in the market can considerably decrease the quality of these products (Opara and Fadiji, 2018; Li and Thomas, 2014).

Nelson and Terablsi (2008) expressed in their results that the dielectric properties of fresh fruit, fresh meat, fresh egg and winter-resistant wheat are substantially different due to the extensive difference in moisture and the materials holding a high level of moisture generally are expected to exhibit higher rates of dielectric constants. They continued that the dielectric constant uniformly decreases with the increase in frequency (Nelson and Trabelsi, 2008).

Sipahioglu and Barringer (2003) measured the dielectric constants of 15 types of fruits and vegetables in 2450MHz frequency and in a temperature ranging from 5°C to 130°C to conclude that dielectric constant is inversely correlated with the moisture content.

Funebo and Ohlsson (1999) reported that the dielectric constants of the fruits and vegetables, such as apples, parsley, mushroom, and strawberries, decrease with the increase in moisture content in 2800 MHz.

Dunlap Jr and Makower (1945) investigated the relationship of dielectric constant and electric conductivity of carrots with their dimensions, moisture, frequency and temperature in frequency rates ranging from 12 to 5 KHz and reported that the dielectric constant was fixed to an 8-percent moisture and then was increased rapidly.

In the present research, the effect of pears' bruise subject to various quasi-static and dynamic loads on the dielectric properties were evaluated and dielectric constants of the study sample volume were measured. Pears' bruise levels were determined in CT-Scans. Such factors as capacitor plate distance, voltage, frequency, and direction were taken into account for a ten-day storage period based on capacitor technique in an automatically controlled system to determine the bruise levels of pears, Espadana cultivars. The final objective of the present research is the determination of the relationship between force, bruise and dielectric constant of the pear fruits. Thus, the dielectric constant can be utilized as a nondestructive test for bruise determination of pears.

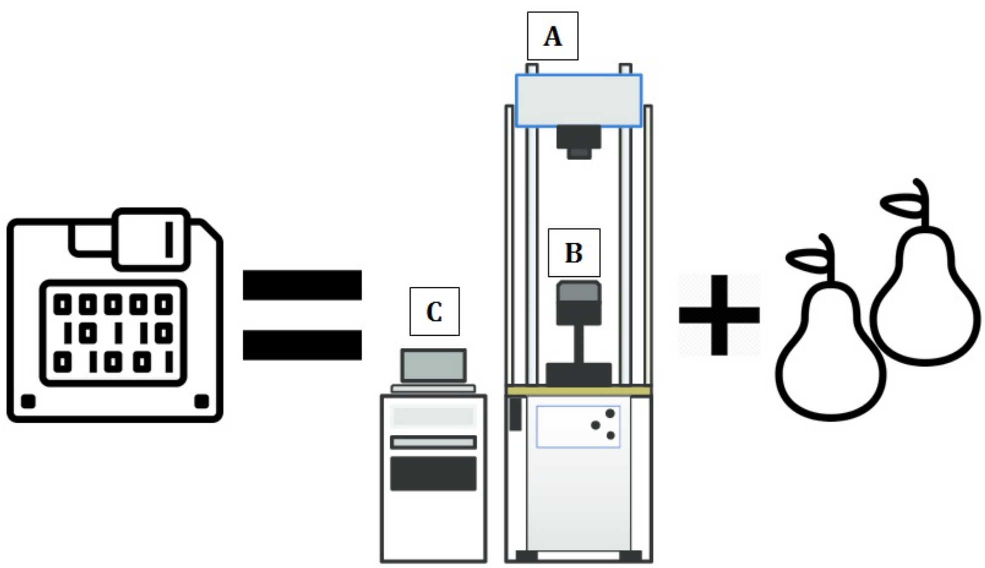
2 Material and methods

2.1 Sample preparation

Pears (Spadana variety) was purchased from the markets of Gorgan, Golestan province, Iran. Samples were taken to the laboratory of Gorgan University of Agricultural Sciences and Natural Resources. They were placed in an oven at 103℃ for 24 hours and their moisture contents were measured (Azadbakht et al., 2016). The moisture content of the pears was calculated to be 77.92%.

2.2 Quasi-Static test

To perform the wide and thin edge compression mechanical test, a pressure-deformation device (the Santam Indestrone -STM5-Made in Iran) with a load cell of 500 N was used. The compression test, where two circular plates were used, was performed at a speed of 5 mm s^{-1} with three forces of 70 N, 100 N, and 130 N at three repetitions. In this experiment, the pear was horizontally placed between the two plates and pressed, with the duration of the measurement recorded. Concerning thin edge compression test, we designed a double-jaw of plastic with a rectangular cross-section dimension of 0.3 cm × 1.5 cm. The test was performed at a speed of 5 mm s^{-1} with three forces of 15 N, 20 N, and 25 N at three repetitions (Figure 1). By moving the movable jaw, the pressure operation was carried out until the force reached the desired level (Razavi et al., 2018).

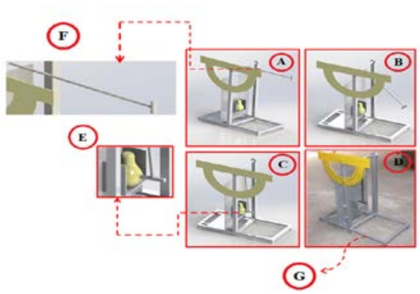


A: the force-deformation device (Inestrone), B: Jaw's Wide edges and thin edges, C: computer

Figure 1 Quasi-Static loading diagram of pear

2.3 Impact test

First, the pendulum and the required masses were made in a workshop in Gorgan Biosystem Mechanics Group (Figure 2).



A: pendulum at a 90 degree angle, B: walking along the path, C: collapse pendulum to pear

D: main device profile, E: place the pear, F: pendulum blow, G: the base of the device.

Figure 2 Schematic of the impact machine

The fruits were placed in the desired position and then the device arm was raised to the desired angle (90°), and in the controlled state of the arm impact the pear. The pendulum had a 200 g arm and three different attachment masses of 100, 150, and 200 g for knocking. It should be noted that air resistance and friction were neglected through this procedure.

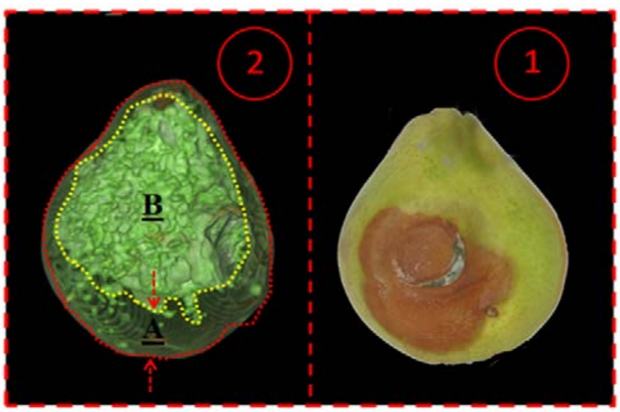
2.4 Imaging via Compute Tomography (CT) scan method

In this experiment, 120 pears were selected based on a non-destructive CT scan. Next, 81 pears without any bruises were chosen. Following dynamic and quasi-static loading, pears were stored for 10 days. The storage conditions were similar to those of sale centers so that the fruits could be studied during storage and consumption.

The ambient temperature was 14 ℃ and the relative humidity was 66%.

Ten days after the quasi-static and dynamic loading, each pear was scanned with the Siemens CT Scans of the SOMATOM Emotion 16-slice model, made in Germany. This device is a third-generation CT device in which the tube and detector are placed opposite to each other 360° around the pears in a series of turns to create the image. Also, the pitch was locked for the test; i.e., pitch 1. Images were recorded at 80 kV and 120 mAcurrent, and 1 mm slices were used to create full images. The images created by the Syngo CT 2012 software were recorded and extracted in the form of two-dimensional and grayscale images. Convolution kernel, which shows image resolution level, was B31Smooth and the images were created by 512 × 512 matrixes (Diels et al., 2017).

In Figure 3, No. 1 and No. 2 present the bruise location and the image created by the CT scan, respectively.



1: present the bruise location, 2: the image created by the CT scan

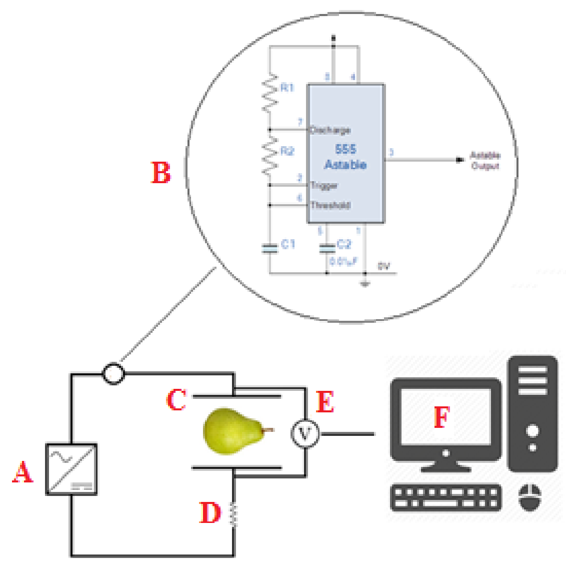
Figure 3 Two-dimensional view of pear prior to and following image processing

2.5 Dielectric constant measurement mechanism

Two capacitor plates, made of aluminum, were selected because aluminum does not undergo oxidation when exposed to moisture and air and it is considered as a stable metal so having no adverse effect on the measurements. The capacitor plate was selected of a 10 × 10 dimension to fit the pear completely horizontally and vertically. The capacitor body was designed and selected so as to allow adjustment of the distance between the capacitor plates. The device was made of plastic in its body so as not to influence the electric field. Experiments were conducted in 8.7°C and a relative humidity of 81%.

2.6 Measuring circuit

Figure 4 illustrates the circuit used herein. The input current was sourced from a frequency amplification circuit (conversion circuit in short) and it was increased from a 50-hertz value to the intended amount. The intended values included input voltages for values 6 V, 10 V and 14 V, frequency values for 20 KHz, 60 KHz and 100 KHz and plate distances equal to 8 cm, 11 cm and 14 cm and the pears were aligned in both longitudinal and transversal orientations between the capacitor plates. After the pears were placed between the two capacitor plates, the voltages on two capacitor ends were recorded in a multimeter device (Compact Digital Multi Meter ST-941) and then the device readings were inserted in the corresponding relations.



A. power supply, B. conversion circuit, C. capacitor plates, D. resistance, E. multi meter, F. computer.

Figure 4 The circuit used in the experiment

The capacitive sensor's capacity was calculated using Equation 1 for this circuit (Soltani et al., 2011a).

$$C = \frac{1}{2\pi Rf}\frac{V_0}{\sqrt{V_i^2 - V_0^2}} \qquad (1)$$

Where, C=Capacitance (F), R=Resistance value (Ω), f=Frequency input voltage (Hz), V_i=Input voltage (V), V_0=Output voltage (V).

Equation 2 was applied to obtain the equivalent dielectric constant (Soltani et al., 2011a).

$$K = \frac{C}{C_0} = \frac{V_0}{V_0'} \frac{\sqrt{V_i^2 - V_0'^2}}{\sqrt{V_i^2 - V_0^2}} \quad (2)$$

Where, *K*=Equivalent dielectric constant, *C*=Capacitor capacity with fruit (F), C_0=Capacitor capacity without fruit (F), V'_0=Sensor output voltage without fruit (V).

The values obtained in the above relations were subject to air presence between the plates and the Equation 3 was used to obtain the dielectric constant of the fruit sizes (Wang et al., 2005).

$$e^{k_b} = e^{ka} + e^{kb} + e^{kv} \quad (3)$$

Where, K_b=Dielectric constant of fruit, *K*=Equivalent dielectric constant, *a*=Fruit volume ratio to capacitor volume, *b*=Fruit length ratio to capacitor length, *v*=Fruit thickness ratio to distance between capacitor plates.

2.7 Statistical analysis

Eighty one pear samples were stored for 10 days after quasi-static and dynamic loading, followed by the imaging process. All experiments were performed in three replications and the results were analyzed using a factorial experiment in a completely randomized design with SAS statistical software.

3 Results and discussion

According to Tables 1 and 2 presenting the results of the variance analysis of the effect of bruise levels obtained from the compression stress, capacitor plate distances, input voltage, input voltage frequency and fruit orientations between the capacitor plates on the dielectric constants of the pears for wide-edge and thin-edge compression and impact stresses, a significant effect was found for the compression force, plate distances, input voltages and orientation of fruits in a 1% significance level on the dielectric constants in all of the three modes of loading; furthermore, the frequency effect was only found significant for wide-edge and impact and no significant effect was evidenced for the thin-edge compression.

Table 1 Analysis of variance analysis of force, distance, frequency, voltage and sample directions between dielectric plates factors for thin edge and wide edge pressure

Quasi-Static Loading						
	Thin Edge Pressure			Wide Edge Pressure		
Variables	DF	Mean Squares	F value	DF	Mean Squares	F value
Force	2	1.7392406	72.52**	8	1.2845658	286713**
Distance plate	2	61.0096585	2543.98**	2	61.6839276	1.377E7**
Frequency	2	0.0003119	0.01ns	2	0.0003038	67.81**
Voltage	2	1.6971437	70.77**	2	2.2832289	509613**
Sample directions between dielectric plates	1	57.6662210	2404.57**	1	56.4785406	1.261E7**
Force × Distance plate	4	0.0423428	1.77ns	16	0.0423924	9461.90**
Force× Frequency	4	0.0000032	0.00ns	16	0.0000003	0.06ns
Force × Voltage	4	0.1358958	5.67**	16	0.0007871	175.67**
Force × Sample directions between dielectric plates	2	0.1901684	7.93**	8	0.4574568	102104**
Distance plate × Frequency	4	0.0000082	0.00ns	4	0.0000057	1.27ns
Distance plate × Voltage	4	0.0258770	1.08ns	4	0.0324605	7245.13**
Distance plate × Sample directions between dielectric plates	2	0.0000019	0.00ns	2	0.0000020	0.45ns
Frequency × Voltage	4	0.0000757	0.00ns	4	0.0000752	16.78**
Frequency × Sample directions between dielectric plates	2	0.0002300	0.01ns	2	0.0002002	44.70**
Voltage × Sample directions between dielectric plates	2	0.0204589	0.85ns	2	0.0362269	8085.79**
Error	1272	0.0000045		1380	0.0239819	

Note: ** Significant difference at 1% level (p <0.01), ns not significant difference

Table 2 Analysis of variance analysis of force, distance, frequency, voltage and sample directions between dielectric plates factors for dynamic loading

	Dynamic Loading		
Variables	DF	Mean Squares	F value
Variables	2	2.0513433	190.20**
Force	2	74.6909093	6925.42**
Distance plate	2	0.1249092	11.58**

Frequency	2	5.3047479	491.86**
Voltage	1	48.4621787	4493.46**
Sample directions between dielectric plates	4	0.0067698	0.63ns
Force×Distance plate	4	0.1142772	10.60**
Force × Frequency	4	0.1261978	11.70**
Force × Voltage	2	2.0044699	185.86**
Force × Sample directions between dielectric plates	4	0.0020748	0.19ns
Distance plate × Frequency	4	0.0752038	6.97**
Distance plate × Voltage	2	0.0000035	0.00ns
Distance plate × Sample directions between dielectric plates	4	0.0836265	7.75**
Frequency × Voltage	2	0.0008144	0.08ns
Frequency × Sample directions between dielectric plates	2	0.0650852	6.03**
Error	1380	0.0107850	

Note: ** Significant difference at 1% level ($p < 0.01$), ns not significant difference

3.1 Quasi-Static loading mode

3.1.1 Wide-Edge compression

Figure 5 had been showed the significance of compare the mean effect of compression forces on bruise percentage for the wide-edge compression. According to the obtained results, the bruise levels increase with the increase compression force for the ten-day storage period.

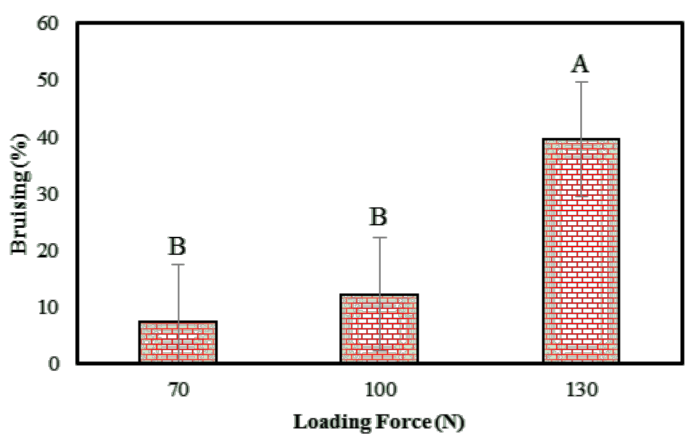


Figure 5 The mutual effects of compression forces on bruise percentage in wide-edge compression mode

3.1.1.1 The mutual effect of compression force and fruits orientation on dielectric

Based on the Figure 6 that displays the mutual effect of the compression force and the pears orientation on dielectric constant, the dielectric constant undergoes a significant decrease with the change in the pears orientation from transversal to longitudinal placement for a fixed compression force. It was also figured out that for a fixed orientation, the increase in compression force causes an increase in the pears' dielectric constants. The highest and the lowest dielectric constants were equal to 5.2274 (130 N compression force-transversal placement) and 4.7561 (70 N compression force-longitudinal placement), respectively. These values were found higher as a result of the increase in bruise stemming from the elevation of compression force followed by a reduction in the fruits' moisture content in higher compression forces and also as a result of enhancement of the fruits' dielectric properties subject to loading. This latter result was consistent with the findings by Sipahioglu and Barringer (2003) who studied 15 types of fruits and vegetables.

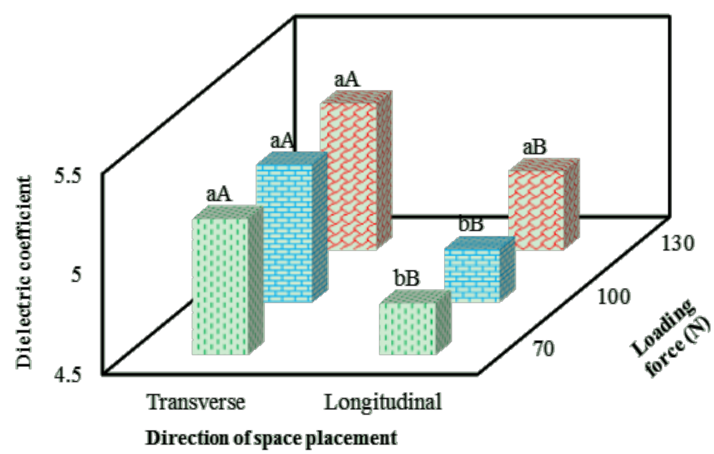


Figure 6 The mutual effect of the compression force and the pears orientation on dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each Sample directions between dielectric plates

3.1.1.2 The mutual effect of compression forces and plate distances on dielectric

According to Figure 7 that exhibits the mutual effect of compression forces and the capacitor plates' distances on the dielectric constants, the increase in the plates' distances for all of the forces brings about a reduction in dielectric constant. Also, the dielectric constant was found increased for 8 cm and 11 cm plate distances with the increase in the compression force from 100 N to 130 N. The highest and the lowest dielectric constants were 5.4868 (130 N compression force-8 cm plate distance) and 4.6727 (70 N compression force-14 cm plate distance). This is due to the decrease in the charged particles between the capacitor's plates followed by the reduction of the energy used by the charged particles to travel and also as a result of an increase in the dielectric constant. This latter finding conforms to the results obtained by Sipahioglu and Barringer (2003) that was conducted in 2003 on 15 types of fruits and vegetables.

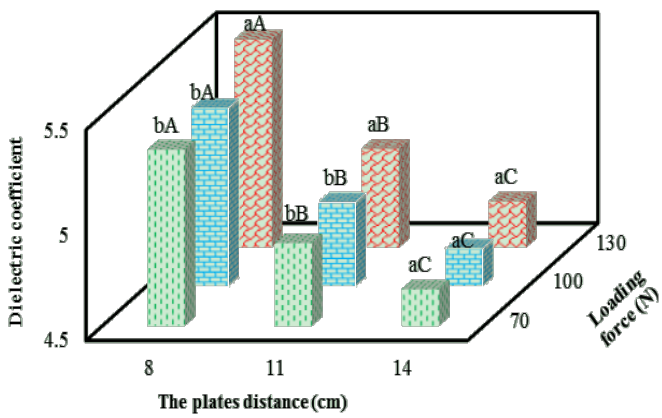


Figure 7 The mutual effect of compression forces and the capacitor plates' distances on the dielectric constants

Note: The same lowercase letters indicate the non-significance in distance and the same capital letters indicate the non-significance of each loading force

3.1.1.3 The mutual effects of compression forces and voltages on dielectric

According to Figure 8 that demonstrates the mutual effect of the compression forces and the voltage on the dielectric constant, the pears' dielectric constants did not significantly change with the increase in compression forces for fixed input voltages. Also, only the increase in input voltage from 6 to 10 V brought about significant reductions in pears' dielectric constant for fixed compression forces. The highest and the lowest dielectric constants were 5.1389 (6 V input voltage-130 N compression force) and 4.922 (14 V input voltage-70 N compression force), respectively. Due to the reduction in the energy used by the charged particles to migrate as a result of the extent charged particles reduction, the capacitor stored a larger deal of energy following which the dielectric constant was increased. This is in compliance with the results obtained by Funebo and Ohlsson (1999) who performed studies in 1999 on such products as apples, parsley, mushrooms and strawberries.

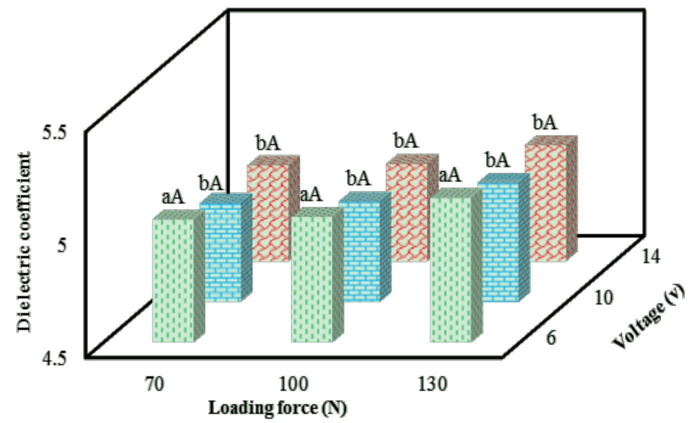


Figure 8 The mutual effect of the compression forces and the voltage on the dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each voltage

3.1.2 Thin-Edge compression

Figure 9 illustrates compare the mean effect of compression forces on the bruise levels in thin-edge compression plate. According to the results obtained for a ten-day storage period, the increase in the compression force causes an increase in the bruise percentage.

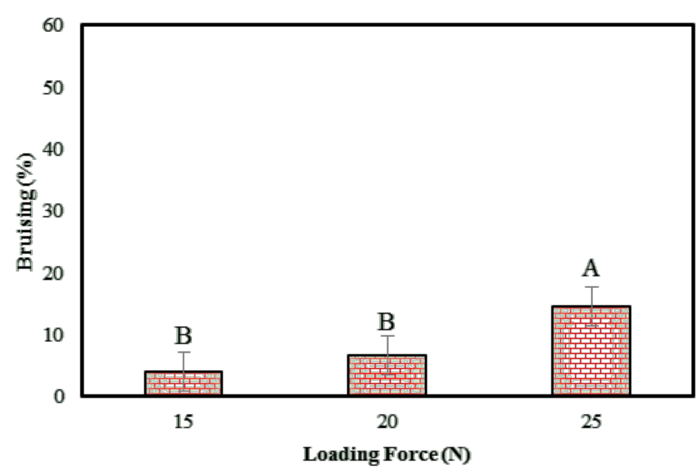


Figure 9 The mutual effect of compression forces on the bruise levels in thin-edge compression plate

3.1.2.1 The mutual effect of compression forces and the fruits' orientations on dielectric

According to Figure 10 that displays the mutual effect of the compression forces and the fruits' orientations on the dielectric constant, the dielectric constants are found reduced with the change in pears' orientation from transversal to longitudinal for a fixed compression force. Also, the increase in the compression force causes irregular and significant changes in the dielectric constant for a fixed orientation of pears. The highest and the lowest dielectric constants were 5.24799 (25 N compression force-transversal orientation) and 4.7523 (20 N compression force-longitudinal orientation).

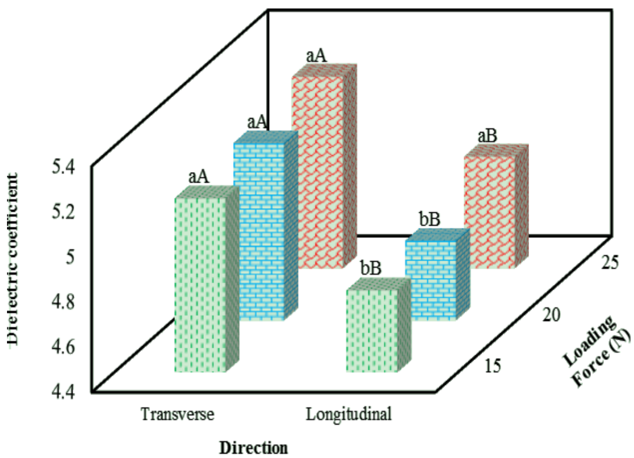


Figure 10 The mutual effect of the compression forces and the fruits' orientations on the dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each Sample directions between dielectric plates

3.1.2.2 The mutual effect of compression forces and voltages on dielectric

According to Figure 11 that depicts the mutual effect of the compression forces and voltage values on dielectric constant, the increase in the compression brings about significant and regular changes in the dielectric constants for a fixed voltage. Also, dielectric constants were found decreased with the increase in input voltage from 6 V to 10 V for a fixed compression force. The highest and the lowest dielectric constants were 5.15892 (25 N compression force-6 V input voltage) and 4.9182 (20 N compression force-14 V input voltage).

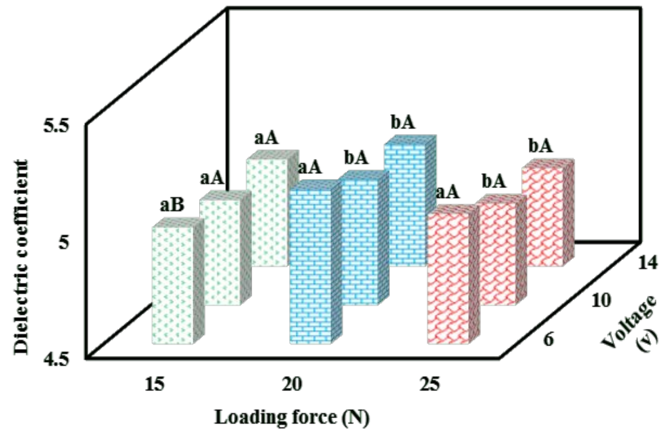


Figure 11 The mutual effect of the compression forces and voltage values on dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each voltage

3.2 Dynamic impact mode

Figure 12 displays the mutual effect of compression forces on the bruise percentage for the dynamic impact mode. According to the results obtained, bruise levels undergo increase with the increase in the compression force for a ten-day storage period.

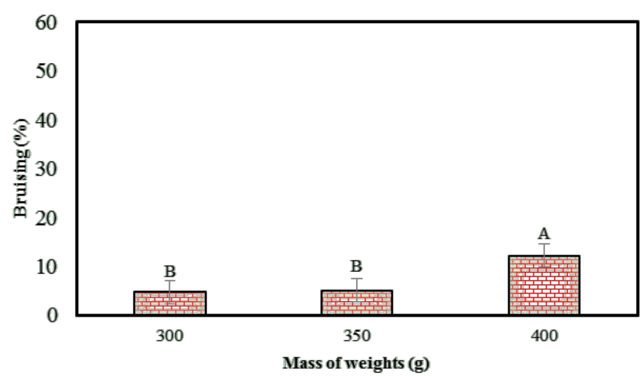


Figure 12 The mutual effect of compression forces on the bruise percentage for the dynamic loading

3.2.1 The mutual effect of compression force and the fruit orientation on dielectric

According to Figure 13 that exhibits the mutual effect of the compression forces and the orientation on the dielectric constant, the dielectric constant was found reduced with the change in pears' orientation from transversal to longitudinal for a fixed compression force; in addition, the increase in the loading force caused an increase in the dielectric constant for a fixed orientation of pear fruits. The highest and the lowest dielectric constants were 5.53469 (400 g weight-transversal orientation) and 5.01651 (350 g weight-longitudinal orientation). Such an incident was due to the more reduction in moisture with the increase in the compression force followed by the increase in the dielectric constant. This result is in accordance with the findings by Funebo and Ohlsson (1999) who performed studies in 1999 on such products as apples, parsley, mushrooms and strawberries.

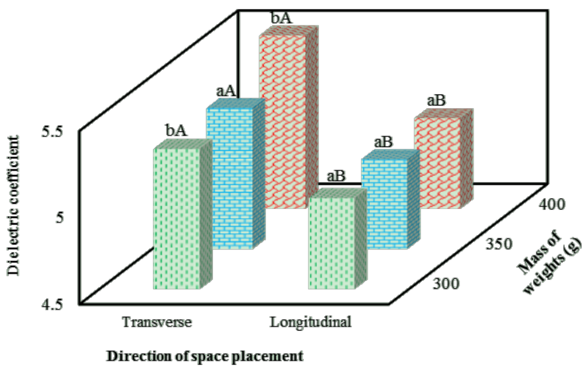


Figure 13 The mutual effect of the compression forces and the orientation on the dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each Sample directions between dielectric plates

3.2.2 The mutual effect of compression force and frequency on dielectric

According to Figure 14 that demonstrates the compression force and the frequency mutual effects on the dielectric constant, the increase in the pendulum mass impact from 350 g to 400 g brings about an increase in the dielectric constant for a fixed frequency.

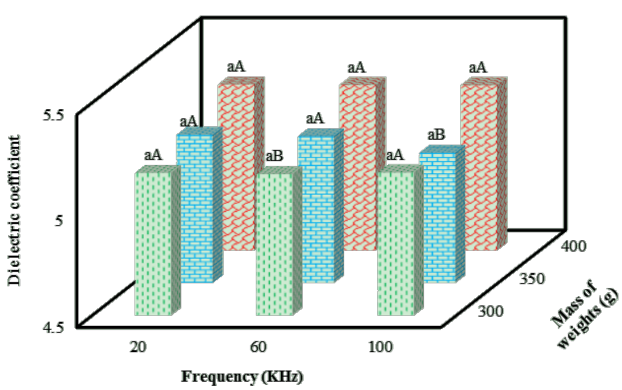


Figure 14 The mutual effects of compression force and the frequency of mutual effects on the dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each frequency

The highest and the lowest dielectric constants were 5.28039 (400 g weight-20KHz frequency) and 5.11047 (350 g weight-100 KHz frequency), respectively. This was due to the reduction in moisture content and charged particles and resultantly the reduction in the energy used by the charged particles and consequently an increase in the dielectric constant. This finding is consistent with the results obtained in the studies by Sipahioglu and Barringer (2003) for 15 various types of fruits and vegetables.

3.2.3 The mutual effect of compression force and voltage on dielectric

According to Figure 15 that displays the mutual effects of compression force and the voltage on the dielectric constant, the increase in the input voltage from 6 V to 10 V brings about a decrease in the dielectric constant for a fixed compression force. Also, the increase in the compression force caused significant and irregular changes in the dielectric constant for 6 V and 10 V voltages. The highest and the lowest dielectric constants were 5.39663 (400 g weight-6 V input voltage) and 5.066 (350 g weight-10 V input voltage), respectively. The reason why the dielectric constant was increased was the reduction in moisture content of the fruits subject to higher compression forces.

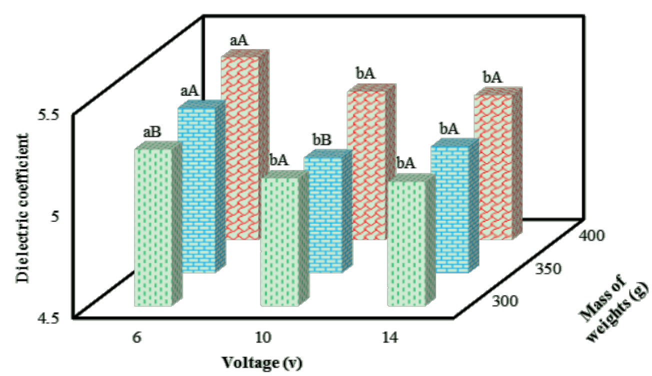


Figure 15 The mutual effects of compression force and the voltage on the dielectric constant

Note: The same lowercase letters indicate the non-significance in a loading force and the same capital letters indicate the non-significance of each voltage

4 Conclusion

The present research investigated the effect of bruise resulting from the exertion of various external forces on dielectric constant in regard to various parameters. The study results indicated that the changes in the frequency and voltage parameters in some of the cases and also the changes in the plates' distances and fruits' orientations in all of the cases are effective on the dielectric constant. Also, the increase in the amount of the compression forces exerted onto the fruits causes an increase in the bruise levels and subsequently a reduction in the moisture content and inversely influences the dielectric constant. Generally, it was made clear in the investigation of the results obtained in cases similar to the present study's condition that the fruits exhibit higher dielectric constants subject to wide-edge compression forces in contrast to the thin-edge compression forces; furthermore, it was documented that the fruits exhibit higher dielectric constants subject to thin-edge compression forces as compared to impact. So, it can be stated that the pears' bruise levels can be figured out through dielectric constant measurement as a non-invasive test. The higher the dielectric constants obtained for fruits, the higher the level of bruise will be.

References

Azadbakht, M., M. V. Torshizi, A. Ziaratban, and E. Ghaiariazi. 2016. Application of Artificial Neural Network (ANN) in predicting mechanical properties of canola stem under shear loading. *Agricultural Engineering International*, 18(2): 413–425.

Castro-Giráldez, M., P. Botella, F. Toldrá, and P. Fito. 2010. Low-frequency dielectric spectrum to determine pork meat quality. *Innovative Food Science and Emerging Technologies*, 11(2): 376–386.

Diels, E., M. van Dael, J. Keresztes, S. Vanmaercke, P. Verboven, B. Nicolai, W. Saeys, H. Ramon, and B. Smeets. 2017. Assessment of bruise volumes in apples using X-ray computed tomography. *Postharvest Biology and Technology*, 128: 24–32.

Dunlap Jr, W. C., and B. Makower. 1945. Radio-frequency dielectric properties of dehydrated carrots. Application to moisture determination by electrical methods. *The Journal of Physical Chemistry*, 49(6): 601–622.

Funebo, T., and T. Ohlsson. 1999. Dielectric properties of fruits and vegetables as a function of temperature and moisture content. *Journal of Microwave Power and Electromagnetic Energy*, 34(1): 42–54.

García, A., J. L. Torres, M. De Blas, A. De Francisco, and R. Illanes. 2004. Dielectric characteristics of grape juice and wine. *Biosystems Engineering*, 88(3): 343–349.

Guo, W., X. Zhu, S. O. Nelson, R. Yue, H. Liu, and Y. Liu. 2011. Maturity effects on dielectric properties of apples from 10 to 4500 MHz. *LWT - Food Science and Technology*, 44(1): 224–230.

Li, Z., and C. Thomas. 2014. Quantitative evaluation of mechanical damage to fresh fruits. *Trends in Food Science and Technology*, 35(2): 138–150.

McKeown, M. S., S. Trabelsi, E. W. Tollner, and S. O. Nelson. 2012. Dielectric spectroscopy measurements for moisture prediction in Vidalia onions. *Journal of Food Engineering*, 111(3): 505–510.

Naderi-Boldaji, M., M. Fazeliyan-Dehkordi, S. A. Mireei, and M. Ghasemi-Varnamkhasti. 2015. Dielectric power spectroscopy as a potential technique for the non-destructive measurement of sugar concentration in sugarcane. *Biosystems Engineering*, 140: 1–10.

Nelson, S. O. 2005. Dielectric spectroscopy in agriculture. *Journal of Non-Crystalline Solids*, 351(33–36): 2940–2944.

Nelson, S. O., and S. Trabelsi. 2008. Dielectric spectroscopy measurements on fruit, meat, and grain. *Transactions of the ASABE*, 51(5): 1829–1834.

Nunes, A. C., X. Bohigas, and J. Tejada. 2006. Dielectric study of milk for frequencies between 1 and 20 GHz. *Journal of Food Engineering*, 76(2): 250–255.

Opara, U. L., and T. Fadiji. 2018. Compression damage susceptibility of apple fruit packed inside ventilated corrugated paperboard package. *Scientia Horticulturae*, 227: 154–161.

Ragni, L., C. Cevoli, and A. Berardinelli. 2010. A waveguide technique for non-destructive determination of egg quality parameters. *Journal of Food Engineering*, 100(2): 343–348.

Razavi, M. S., A. Asghari, M. Azadbakh, and H. A. Shamsabadi. 2018. Analyzing the pear bruised volume after static loading by Magnetic Resonance Imaging (MRI). *Scientia Horticulturae*, 229: 33–39.

Sipahioglu, O., and S. A. Barringer. 2003. Dielectric properties of vegetables and fruits as a function of temperature, ash, and moisture content. *Journal of Food Science*, 68(1): 234–239.

Sirikulrat, K., and N. Sirikulat. 2008. Dielectric properties of different maturity soybean. *KMITL Science and Technology Journal*, 8(2): 12–18.

Soltani, M., R. Alimardani, and M. Omid. 2011a. Evaluating banana ripening status from measuring dielectric properties. *Journal of Food Engineering*, 105(4): 625–631.

Soltani, F. M., R. Alimardani, and M. Omidi. 2011b. A feasibility study of employing a capacitance based method in banana ripeness recognition. *Iranian Journal of Biosystems Engineering*, 42(1): 21-27.

Sosa-Morales, M. E., L. Valerio-Junco, A. López-Malo, and H. S. García. 2010. Dielectric properties of foods: Reported data in the 21st century and their potential applications. *LWT - Food Science and Technology*, 43(8): 1169–1179.

Wang, S., M. Monzon, Y. Gazit, J. Tang, E. J. Mitcham, and J. W. Armstrong. 2005. Temperature-dependent dielectric properties of selected subtropical and tropical fruits and associated insect pests. *Transactions of the ASAE*, 48(5): 1873–1881.