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Full Research Paper

Investigating the Effects of Qualitative Properties on Pears Dielectric Coefficient

M. J. Mahmoodi[1], M. Azadbakht[2*]

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Abstract

Nowadays, the dielectric properties of food and biological products have become a valuable parameter in foodstuff engineering and coating technology, covering a remarkable spectral domain from 10^{-6} to 10^{12}. In the present study, 27 completely healthy pears were selected and subjected to quasi-static and dynamic loading. The storage period was ten days. In this study, the qualitative characteristics and their relationship with changes in dielectric coefficient were investigated. At the end of the storage period, the fruits' dielectric coefficient values and their qualitative characteristics were measured. The measurements were carried out for a capacitor plates' distance interval of 11 cm, 10 V input voltage and 60 kHz input voltage frequency. According to the results, in the dynamic loading mode of 400 N, the highest dielectric coefficient with a value of 5.2989 was obtained. In dynamic loading mode of 400 N, the qualitative property had the minimum value. The antioxidant, phenol content, Vitamin C content and firmness were 33.925%, 14.523 mg/100g, 5.7 mg/100g and 5.5333 g, respectively. The results of the study indicated that increasing the loading force on the pear reduces all qualitative indicators for all loading modes and an increase in dielectric coefficients of the products was observed.

Keywords: Dielectric, Nondestructive test, Pears, Quality, Qualitative properties

Introduction

Destructive methods are currently being applied for the evaluation of the internal quality attributes as well as the unique contents existent in fruits. However, the method is time-consuming, needful of specialized preparation of the specimens and non-applicable to the classification and sorting of fruits in commercial packages. Moreover, both the internal and external properties of fruits might be considerably different due to the differences in varieties, gardens, waste management methods, fruit maturation, and region. Thus, the large deal of changes in the quality attributes of the fruits from various varieties or even similar varieties has led to the development of nondestructive methods for the identification, [quality] prediction, and categorization of fruits in laboratories and rating them based on their qualities. These methods can usually predict and measure both the internal and external structure of fruits (Arendse *et al*., 2016).

The dielectric properties of food and biological products have become a valuable parameter in food engineering and technology. Dielectric spectrometry is an old instrument that is presently covering a remarkable spectral domain from 10^{-6} to 10^{12}. Dielectric spectrometry is a technique used for the study of the interaction between a matter of a type and the exerted electric field and it is extensively employed as an instrument for the recognition of the materials' senescence and error recognition for the insulation systems and it has consequently turned into a popular and powerful method. The method works based on polarity and electric conductance in materials and describes the interaction between a matter of a sort and the electromagnetic field. It examines the structural and physicochemical characteristics of such materials as water and soluble solids or the aqueous activities of a matter (Khaled *et*

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[1] MSc Graduated, Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[2] Associate Professor of Department of Bio-System Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

(*- Corresponding Author Email: azadbakht@gau.ac.ir)

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al., 2015). In an experiment on tomatoes, with increasing soluble solids, organic acids and parameters of tomato flavor determination, the amount of electrical conductivity increased. As the strength of the fruit tissue decreased, the amount of this factor increased. The results of regression analysis in this experiment showed that there was a significant correlation between the level of electrical conductivity and dependent variables including the weight of a fruit, soluble solids, absorbable acids and antioxidant capacity and phenols (Krauss *et al*., 2006). In a study on grape fruit, weight and moisture content parameters were measured during storage. The results showed that with increasing storage period from 0 to 10 days and temperature at 4 and 25 °C, weight and moisture content of grape samples decreased significantly in all cases (Khodamoradi and Ahmadi, 2019). Sipahioglu and Barringer (2003) measured the dielectric properties of 15 types of vegetables and fruits in 2450 MHz frequency and under the temperature range between 5 and 130°C. Equations were obtained as functions of temperature, moisture and water activity. Finally, it was concluded that the fruit moisture content was inversely related to the dielectric coefficient (Sipahioglu and Barringer, 2003). In another study, dielectric measurements were carried out during apples' maturity for finding the interrelationships of qualitative and dielectric properties. All the dielectric measurements were undertaken at 30°C from 500 MHz to 20 GHz. These experiments were carried out to make use of dielectric spectrometry for determining the maturity of the fruits. The results highlighted the good correlation between the intended index and dielectric index and it was pointed out as a nondestructive control method for forecasting the maturity of aquatic fruits like apples, bananas, mangoes and tomatoes (Fito *et al*., 2010). Guo *et al.* (2007) measured the dielectric properties of three fresh apple varieties in 24°C for 10 weeks and at 4°C in storage. The constant numerical correlation of the dielectric of fruits in a range of 10 MHz to 1800 MHz was calculated at 51 frequencies. Although there was a strong correlation between the dielectric coefficient and the soluble solids content and the dielectric coefficient of this relationship could be well predicted, no clear relationship was observed between the dielectric properties and the soluble solids content (Guo *et al*., 2007). Considering the time consuming and unusable in the subsequent stages for classification in order to commercialize and the need for specialized product in the evaluation of malware, the importance of the non-destructive evaluation of fruits was felt. By conducting this research and further research on this study, a comprehensive and non-destructive approach can be found to evaluate the qualitative properties of the fruit using their dielectric properties.

The objective of the present study is the investigation of the effect of pears' qualitative properties on their dielectric coefficient following the exertion of quasi-static and dynamic loading in various amounts. The dielectric coefficient was measured after applying quasi-static and dynamic loading and storage period for ten days using capacitive technique. The distance between the capacitor plates, input voltage, frequency and the orientation of the fruit were specified. Then, methods pertinent to qualitative properties measurement were utilized to obtain the antioxidant percentage, phenol and vitamin C contents and firmness of the pears, Spadana variety.

Materials and Methods

Sample preparation

Pears from Spadana variety were obtained from markets in Golestan-Gorgan province, Iran. The samples were then transferred to the laboratory of Gorgan University of Agricultural Sciences and Natural Resources. It was also placed in the oven to measure the amount of moisture content. According to Equation (1), 40 g of samples were placed in an oven at 105°C for 5 hours and then their moisture content was measured (Jahanbakhshi *et al.*, 2019). The moisture content of pears was measured as 77.92%**.** Environmental conditions for testing were conducted at a temperature of 18°C and relative humidity of 72%.

$$MC = \frac{M_W - M_D}{M_W} \times 100 \quad (1)$$

Where, M_W=Initial mass of fruit (g), M_D=Mass of dried fruit (g), MC=Moisture content of the fruit, wet basis (%)

Quasi-static test

In order 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 employed. Two circular plates were used for compression testing. This test was performed at a speed of 5 mm min^{-1} with three forces of 70, 100 and 130 N with three replications (Figure 1). For this experiment, the pear was placed horizontally between the two plates and pressed and the measurement time of this process was recorded. It was also designed to conduct a double-jaw thin edge test that a plastic object with a rectangular cross-section measuring 0.3 cm×1.5 cm at 5 mm min^{-1} with three forces of 15, 20 and 25 N was used in three replications. By moving the movable jaw, the pressure operation was carried out until the force reached the desired level (Razavi *et al*., 2018).

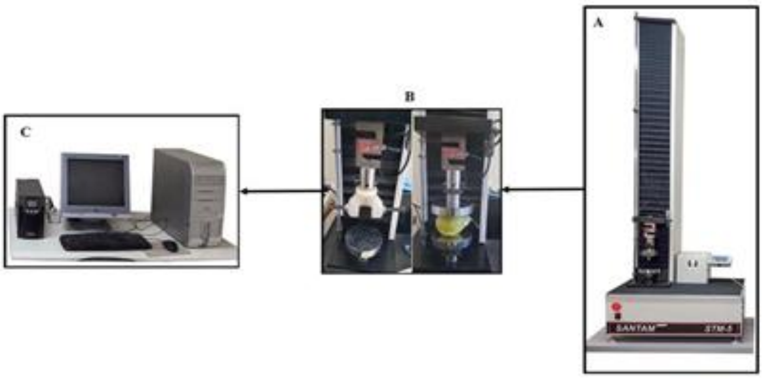

Fig.1. Static quasi-load diagram of pear
A: The force-deformation device (Indestrone); B: Jaw's wide-edges and thin-edges; C: Computer

Impact test

At first, the pendulum device and the required weights were made at the workshop of the Gorgan Biosystem engineering department (Figure 2). Then the fruits were placed in the desired place and the arm of the machine has been raised to the desired angle (90 degrees) and in the controlled state, the arm is dropped and the pear is hit. The pendulum had an arm of 200 g and three different connecting weights of 100, 150 and 200 g to hit. The air resistance and friction is ignored (Barriga-Téllez *et al*., 2011).

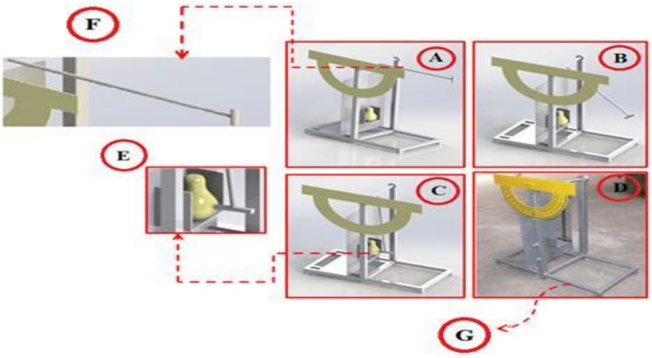

Fig.2. Schematic of the impact machine
A: Pendulum at a 90° angle; B: Walking along the path; C: Collapse pendulum to pear; D: Main device profile; E: Place the pear; F: Pendulum blow; G: the base of the device

Dielectric constant measurement mechanism

Two capacitive plates of aluminum were chosen because the metal is not oxidized in the vicinity of moisture and air, and is stable. For this reason, the measurement does not have an unpleasant effect. The capacitor plate was selected for a 10×10 cm^2 dimension so that the pears could be wholly placed therein. 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% (Soltani *et al*., 2010).

Measuring circuit

Figure 3 shows the used circuit. The input power to the system was increased by a frequency of 50 Hz, up to 60 kHz, by increasing the frequency vibration. The input voltage was also 10 V, the distance between the capacitor plates was 11 cm. After placing the pears between the two capacitors, the two-head magnetic voltage was measured with a multi meter equipped with a Compact digital multi-meter ST-941 specification, and then related relationships were used.

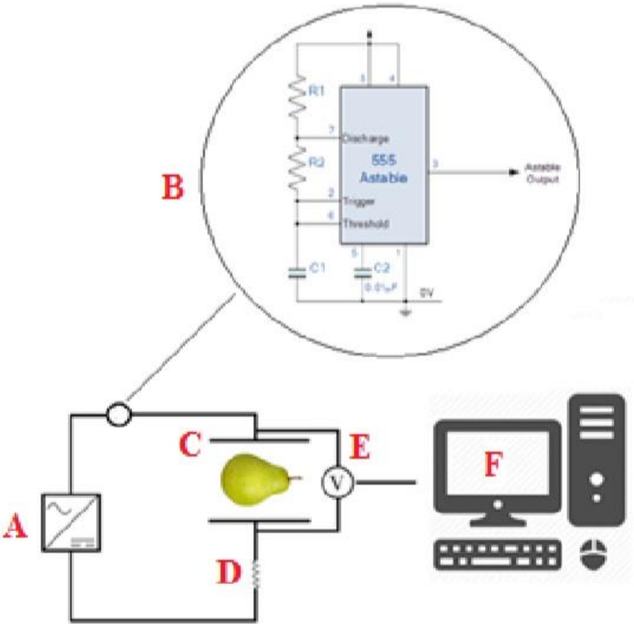

Fig.3. The circuit used in the experiment

A. Power supply; B. Conversion circuit; C. Capacitor plates; D. Resistance; E. Multi meter; F. Computer

The capacitive sensor’s capacity was calculated using Equation (2) for this circuit (Soltani and Alimardani, 2011).

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

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

Equation (3) was applied to obtain the equivalent dielectric constant (Soltani and Alimardani, 2011).

$$K = \frac{C}{C_0} = \frac{V_0}{V'_0}\frac{\sqrt{V_i^2 - V_0'^2}}{\sqrt{V_i^2 - V_0^2}} \tag{3}$$

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 (4) was used to obtain the dielectric constant of the fruit sizes (Soltani and Alimardani, 2011).

$$e^{k_b} = e^{ka} + e^{kb} + e^{kv} \qquad (4)$$

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.

Biochemical properties measurement

To measure the total phenol content and the percentage of free radicals' neutralization, specimens equal to 0.5 g of each sample's wet callus were ground and homogenized using 5 ml of methanol 80% (for a 1:10 ratio) in a cold mortar. The homogenized mixture was placed on a shaker device in a dark room for 24 hours and then subjected to the centrifugal force in 3000 rpm for 5 min. The upper part of the extract was used for measuring the biochemical characteristics.

Percentage of free radicals neutralization based on DPPH method

In this experiment, the percentage of DPPH free radical neutralization was measured based on the method proposed by Bandet *et al.* (1997). At first, 2 ml of DPPH with a concentration of 0.1 mmol (4 mg of DPPH in 100 ml of methanol) was admixed to the experiment tube and 2 ml of the prepared methanolic solution was next added thereto following which the experiment tubes were placed in a dark environment and the absorption rates were immediately read using spectrophotometer in 517 nm wavelength. The evidence specimen contained 2 ml of DPPH and 2 ml of methanol. Methanol was applied to calibrate the spectrophotometer. The figures outputted from Equation (5) substitutions were converted to neutralization percentages (Li *et al.*, 2012).

$$DPPH = \frac{A_C - A_S}{A_C} \times 100 \qquad (5)$$

As= specimens absorption rates

Ac= evidence specimen absorption rate

Total phenol

Folin-Ciocalteu (F-C) reaction was used to measure the total phenol content. To do so, 20 µl of methanolic extract (0.5 g in 5ml 80% methanol) was mixed with 100 µl of F-C and 1.16 ml of distilled water following which 300 µl of 1molar sodium carbonate (10.6 g in 100 ml of distilled water) was added thereto after 8 min resting time. The aforesaid solution was placed in a vapor bath, 40°C, in a dark room for 30 minutes. In the end, the specimens were read in 765 nm wavelength. The absorption number of the specimen was replaced for y in the line equation to obtain the phenol amount (x) in milligram Gallic acid per gram (Jaramillo-Flores *et al.*, 2003).

Vitamin C

Vitamin C was calculated using 2, 6-dichlorophenol indophenol titration method in such a manner that 5 g of sample was mixed and extracted using 40 ml of citric acid 8% in the first stage. Then, 10 ml of the filtered extract was picked up and mixed with 40 ml of citric acid 8% and subjected to titration using 2, 6-dichlorophenol indophenol reagent. The termination point of titration was the appearance of a pale purple that lasted for about 15 s. The vitamin C amount is expressed in milligram per 100 g of the sample weight. The vitamin C amount can be obtained by Equation (6) (Jaramillo-Flores *et al.*, 2003).

$$\text{Vitamin C} = \frac{\text{sample weight} \times \text{standard volume of reagent consumed}}{\text{volume of extract obtained} \times \text{volume of reagent used} \times 10 \times 2} \qquad (6)$$

Firmness

A barometer device or penetrometer, Model EFFEGI, made in Italy, was used to measure the firmness of the flesh of pear specimens without having their skin peeled through the exertion of pressure in grams. According to the extant guidelines, the penetrometer probe was placed on the intended part of the pear which was next subjected to the required pressure, so that the probe could enter the fruit flesh and then the displayed value indicating the fruit firmness was read from the barometer gauge and recorded.

Statistical analysis

27 pears were selected without any bruising. The samples were exposed to three levels of quasi-static loads of wide-edge and thin-edge and impact dynamic load and in a storage room for 10 days. Then, dielectric coefficient measurement was carried out and the intended qualitative properties were measured immediately afterward.

Subsequently, the qualitative properties of pear samples, including antioxidants, phenol content, vitamin C, and firmness were measured.

The entire experiments were replicated thrice and the results were analyzed in SAS software using factorial test within a complete randomized block design.

Results and Discussions

Table 1 presents the results of variance analysis of the effect of the various amounts of the forces exerted on the dielectric coefficient of pear for wide-edge and thin-edge static compression and impact dynamic compression modes. According to Table 1, it can be concluded that the effect of the forces on the dielectric coefficient is indicative of significant differences in all three loading states in a 1% level.

Table 1-variance analysis of dielectric coefficient subject to various loading

		Variable	**DF**	**Mean squares**	**F-value**
Static loading	**Wide-edge pressure**	**Loading force**	2	0.0117	144876**
	Thin-edge pressure	**Loading force**	2	0.0327	185501**
Dynamic loading	**Impact mode**	**Loading force**	2	0.0089	292755**

** Significant difference at 1% level (p <0.01)

Quasi-static loading mode

Wide-edge compression

Figure 4 exhibits the effect of loading force on the amounts of qualitative properties and dielectric coefficients in wide-edge compression. According to the obtained results for the ten-day storage period, the increase in the force causes reductions in the Vitamin C, firmness, phenol, and antioxidant values.

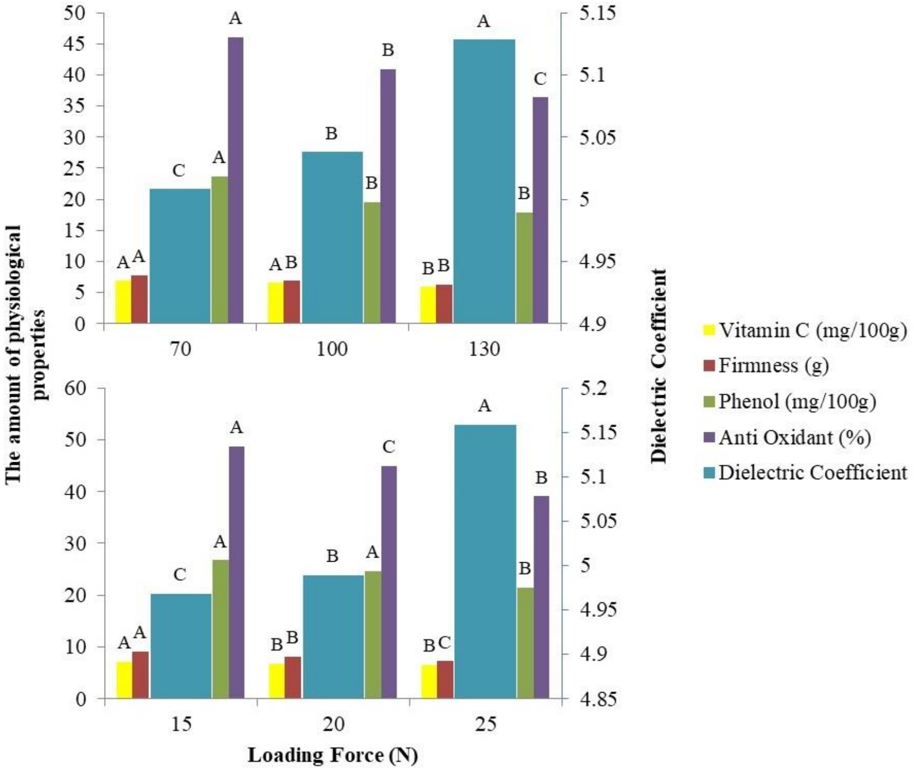

Fig.4. The effect of loading forces on the qualitative properties and the dielectric coefficient in wide-edge compression and thin-edge compression

Similar letters of every property indicate the absence of significant difference.

Vitamin C level did not decrease in 70 N and 100 N forces but it was significantly decreased in 130 N in contrast to the other two compressive forces exerted. The firmness of the pears was significantly decreased with the increase in the compressive force from 70 N to 100 N but no significant reduction was observed in 130 N compressive force. The increase in the exerted compressive force from 70 N to 100 N caused a significant reduction in the phenol content but an insignificant reduction in phenol content reduction was observed with the increase in the compressive force from 100 N to 130 N. As for the amount of existent antioxidant, a significant reduction was documented for all of the exerted compressive forces with the increase in the amount thereof.

Thin-edge compression

Vitamin C content significantly reduced as the compression force increased from 15 N to 20 N and an insignificant reduction was evidenced in 25 N compression force as compared to the two prior modes. Significant reduction in the fruit firmness was documented in thin-edge compression following the increase in the loading force for all of the three modes. No significant reduction was scored for the 15 N and 20 N compression forces in firmness but the increase in the force to 25 N caused a significant reduction in firmness; furthermore, the increase in the compression force was found reducing the antioxidant activities for all of the three loading modes.

Dynamic impact mode

Figure 5 demonstrates the significance of the loading forces on the qualitative properties in dynamic impact mode. According to the results obtained for the ten-day storage period, the increase in the loading force causes reductions in Vitamin C, phenol and antioxidant values.

Vitamin C amount is insignificantly reduced in 300 N and 350 N compression but the increase in the compression up to 400 N causes significant reductions in the fruit contents such as antioxidant activity percentage. The fruit firmness and phenol content significantly decreased in all the loading levels.

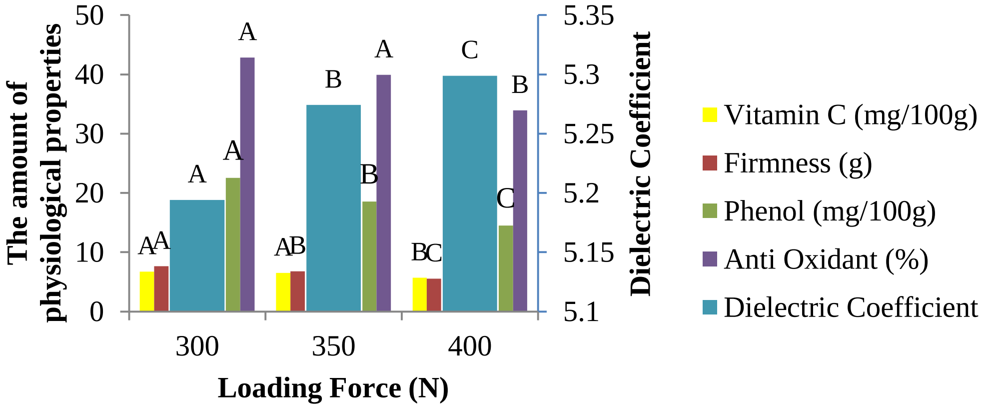

Fig.5. The effect of loading forces on the qualitative properties and the dielectric coefficient in dynamic impact mode

Similar letters of every property indicate the absence of significant difference.

Quasi-static loading mode

Wide-edge compression

In regard to the percentage of antioxidant existing in the fruits for all of the force levels exerted, the increase in the compressive force was found causing a significant reduction. Generally, the increase in the wide-edge compression brought about reductions in the Vitamin C, firmness, phenol, and antioxidant values. Such findings can be attributed to the increase in the rottenness for such a reason as the increase in the amount of exerted load and the resultant increase in the decaying of the fruit, destruction of the cells featuring food value and containing minerals (Altisent, 1991). Similar results were also found in experiments on cherries for which case it has been shown that a reduction in antioxidant capacity comes about with the pass of more time since storage date (Navgaran *et al.*, 2014). It was also observed that the increase in the compression force causes an increase in the dielectric coefficient for such a reason that the moisture content is more reduced in the higher loading forces and that there is an inverse relationship between the moisture content and the dielectric coefficient (Funebo and Ohlsson, 1999).

It can be discerned from the above-presented results that the increase in the amount of compression force causes a reduction in the qualitative properties followed by a significant increase in dielectric coefficient (Krauss *et al.*, 2006).

Thin-edge compression

Figure 4 displays the significance of the effect of loading forces on the qualitative properties in thin-edge compression. According to the results obtained for the ten-day storage period, the increase in the loading forces brings about reductions in Vitamin C, firmness, phenol and antioxidant values. It was observed in a similar study on tomatoes that the increase in the rot values causes a reduction in the Vitamin C content (Moretti *et al.*, 1998). The reduction in Vitamin C content subject to loading can be attributed to the reduction in fruit moisture and the resultant oxidation and reduction of the Vitamin C content. Similar results have also been found in the studies by other researchers on Kiwi (Tavarini *et al.*, 2008; Amodio *et al.*, 2007).

Moreover, the figure illustrates the effect of loading force on the dielectric coefficient and it can be accordingly concluded that the increase in the thin-edge compression causes a significant increase in the dielectric coefficient. In addition, the increase in the dielectric coefficient following the increase in the compression force is due to the reduction in the moisture content in the loading forces (Funebo and Ohlsson, 1999).

Based on the abovementioned results, it can be understood that the increase in the loading force in the thin-edge static mode causes a reduction in the qualitative properties followed by an increase in the dielectric coefficient (Krauss *et al.*, 2006).

Dynamic impact mode

The reason for the obtained results regarding the reduction in phenol content can be attributed to the releasing of most of the phenolic ingredients as a result of the increase in the percentage of the damage subject to loading forces that has appeared in the form of fruit tissue browning and the subsequent reduction in the phenolic content of the fruit (Li *et al.*, 2012). The figure is additionally reflective of the loading forces’ effects on dielectric coefficient and it can be seen that the increase in the dynamic loading force causes reductions in the qualitative properties during the ten-day storage period.

According to the above-cited results pertaining to the dynamic loading, it can be concluded that the increase in the dynamic loading force causes a reduction in the qualitative properties’ values following which the dielectric coefficient is significantly increased.

Conclusions

The present study investigated the effect of qualitative properties variations resulting from the exertion of various external loads on the dielectric coefficient value. The experiment results indicated that the qualitative properties variations are effective on the dielectric coefficient values in such a manner that the increase in the loads exerted onto the fruits brings about reduction in all of the intended values of the qualitative properties including phenol, antioxidant, vitamin C and firmness following which dielectric coefficient was found increased in all of the cases. Generally, it can be concluded in an investigation of the obtained results under similar conditions that the qualitative properties' levels are reduced in thin-edge, wide-edge and impact loading, respectively, following which the dielectric coefficient is inversely increased. So, it can be concluded that the measurement of dielectric coefficient as a non-destructive test provides for the prediction of the increase or decrease in the qualitative properties of the pears. The higher the dielectric coefficient, the lower the qualitative properties. The proper nutritional quality of the pears can be figured out through devising an appropriate scale for the measurement of the changes in the future experiments.

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مقاله علمی-پژوهشی

تاثیر خواص فیزیولوژیکی گلابی بر مقدار ضریب دی‌الکتریک میوه

محمدجواد محمودی[۱]، محسن آزادبخت[۲]*

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چکیده

امروزه خواص دی‌الکتریک محصولات غذایی و بیولوژیکی به پارامتری ارزشمند در مهندسی مواد غذایی و فناوری تبدیل شده است که محدوده طیفی فوق‌العاده‌ای از $۱۰^{-۶}$ تا $۱۰^{۱۲}$ هرتز را پوشش می‌دهد. در این تحقیق ابتدا تعداد ۲۷ گلابی کاملاً سالم به‌وسیله آزمون غیرمخرب سی‌تی اسکن انتخاب و سپس تحت بارگذاری شبه‌استاتیکی و دینامیکی قرار گرفتند و انبارداری ۱۰ روزه به‌منظور بررسی میزان خواص فیزیولوژیکی و ارتباط آن با تغییرات ضریب دی‌الکتریک انتخاب شد. در پایان دوره انبارداری مقدار ضریب دی‌الکتریک میوه‌ها و پس از آن مقدار خواص فیزیولوژیکی آن‌ها اندازه‌گیری شد. اندازه‌گیری‌ها در فاصله صفحات خازن ۱۱ سانتی‌متری، ولتاژ ورودی ۱۰ ولت، فرکانس ولتاژ ورودی ۶۰ کیلوهرتز انجام شد. طبق نتایج حاصل شده حالت بارگذاری دینامیکی ۴۰۰ نیوتنی دارای بیشترین ضریب‌دی‌الکتریک در بین همه حالت‌های بارگذاری با مقدار ۵/۲۹۸۹ و به دنبال آن این حالت بارگذاری دارای کمترین مقادیر خواص فیزیولوژیکی در بین تمام حالت‌های بارگذاری با مقادیر آنتی‌اکسیدان ۳۳/۹۲۵ درصد، محتوای فنلی ۱۴/۵۲۳ و ویتامین C 5.7 میلی‌گرم بر ۱۰۰ گرم و سفتی ۵/۵۳۳۳ گرم بود. نتایج آزمایش‌ها نشان دادند که با افزایش مقدار نیروی بارگذاری بر روی میوه گلابی، همه مقادیر خواص فیزیولوژیکی مورد نظر در تمام موارد بارگذاری کاهش یافته و در نهایت، مقدار ضریب دی‌الکتریک محصول افزایش می‌یابد.

واژه‌های کلیدی: آزمون غیرمخرب، خواص کیفی، دی‌الکتریک، کیفیت، گلابی

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[۱] ۱- دانش‌آموخته کارشناسی ارشد، گروه مهندسی مکانیک بیوسیستم، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گرگان، ایران

[۲] ۲- دانشیار گروه مهندسی مکانیک بیوسیستم، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گرگان، ایران

(*- نویسنده مسئول: Email: azadbakht@gau.ac.ir)

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