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Effects of Different Loading Forces and Storage Periods on the Percentage of Bruising and Its Relation with the Qualitative Properties of Pear Fruit

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Abstract
Nowadays, due to the necessity of increasing quality awareness in the food sector and its health, the non-destructive computed tomography (CT) method, which is one of the most widely used methods because of the ability to detect internal bruise in a non-destructive way, attracted so much attention. By using the non-destructive CT method a total of 81 healthy pears was selected and then subjected to quasi-static and dynamical loading. The experiment was performed on wide edge quasi-static pressure of 70, 100, 130 N and thin edge of 15, 20, 25 N and dynamic load of 300, 350, 400 g and storage period for 5, 10 and 15 days, to investigate the different effects of loading forces and storage periods on the percentage of the bruise and its relation with the qualitative properties such as phenol, antioxidant and vitamin C contents and firmness. The results of the experiments showed that the highest and lowest percentages of the bruise were related to a load of 400 N of 15 days and a 15 N 5-day thin line with values of 47.36 and 0.007, respectively. The highest and lowest physiological values were 15 N load of the 5-day thin edge and the 400 N of 15-day impact. Finally, the highest antioxidant content was 51.5% for 300 g dynamic loading force and 5- day storage, 28.86 mg/100g phenol for loading force of 70 N wide edge and 5 day storage and 7.4 mg/100ml vitamin C for loading force of 70 N wide edge and 5 day storage. Finally, according to the obtained results, there was an inverse relationship between the amount of bruising and chemical properties of pear.

Keywords: Bruise, Chemical Properties, Loading Force, Pear, Phenol.

Introduction

The pear has attracted the attention of the food industry and research as an excellent product due to the presence of compounds such as antioxidants, phenols, anthocyanins, and vitamin C. It is also important because of the increased use of antioxidant compounds in fresh fruits, including the benefits of preventing diseases such as cancer and cardiovascular disease (Li et al., 2012). The bruising of fruits often occurs during the stages of displacement, transportation, packing due to shock and external loads. Mechanical loads are known as the main and effective factors in post-harvest losses. During the post-harvest phases, dynamic loads affect the bruise generation on the products, because dynamic loads in terms of quantity and occurrence have more effects than the static loads (Kupferman, 2006; Mohsenin, 1986). In recent years, the development of fast and non-destructive methods has increased the ability to assess

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food quality quickly. Regarding the production of fresh pears, determining the quality of fruit involves great problems that the development of non-destructive method can help us to analyze more fruits and to reduce sampling problems. Also, for the effectiveness of non-destructive methods was given a large number of fruits produced by manufacturers and industry, the non-destructive methods should be fast enough (Camps and Christen, 2009; Chen and Sun, 1991; Mahhou et al., 2006).

By using the CT and X-ray method everyone can check the bruising on the fruit in time changes, which is used as non-destructive method because measuring bruise with this method does not make it difficult to measure even in complex cases (Diels et al., 2017). Techniques such as magnetic resonance imaging, nuclear magnetic resonance, near-infrared spectroscopy, optical tomography as well as ISO-quality tomography is used to evaluate the non-destructive internal properties of various gardening products (Defraeye et al., 2013; Herremans et al., 2013; Kotwaliwale et al., 2014; Lammertyn et al., 2003; Magwaza et al., 2013, 2014; Verboven et al., 2013; Zhang and McCarthy, 2013).

Diels et al. (2017) have used a non-destructive CT scan method, to measure the amount of bruise on different varieties of apples in a wide range. Two and three-dimensional visualizations of bruising lead to bruises (from a pendulum with a spherical impactor) and can display a very irregular shape. These irregular shapes indicate a very high sensitivity based on CT method measurement (Diels et al., 2017).

Clark et al. (1998) investigated the growth and development of Kiwi fruit and concluded that a more general view of what is happening in the tissue is required for a quantitative interpretation of biological samples that CT is one of the most valuable methods for detecting internal disorders in fruits (Clark et al., 1998).

Navgaran et al. (1990) conducted an experiment on cherry storage and concluded that as the storage period increases, the amount of antioxidant of cherries decreases (Navgaran et al., 2014). Tian et al. (1990) in their experiments on Shishia fruit, showed that the content of vitamin C decreased rapidly by longer storage period (Tian et al., 1990).

Therefore, the purpose of this study was to investigate the chemical properties of pear bruise. In a more detailed explanation, this study investigated the effect of bruise caused by various quasi-static and dynamic loads and the storage period on the chemical properties (such as antioxidants, phenol and vitamin C) and firmness of pear fruits.

Materials and methods

Samples preparation

Pears from Spadana variety were purchased from the markets in Gorgan, Golestan, Iran and samples were taken to the laboratory of Gorgan University of Agricultural Sciences and Natural Resources and washed and then placed in the oven to measure their moisture. The samples were placed in an oven at 103 °C for 24 h and then their moisture content was measured in accordance with the standards (Azadbakht et al., 2016)(Lanza et al., 2015). The pears moisture content was 77.92%.

Quasi-Static test

To perform a mechanical test of the wide edge pressure and thin edge was used for the force-deformation device with the trade-name Insrton Santam-STM5 with a 500N load cell. For compression testing, two circular plates were used. This test was performed at a speed of 5 mm/s with three forces of 70, 100 and 130 N with three replications (Fig. 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/s with three forces of 15, 20 and 25 N was used in three replications.

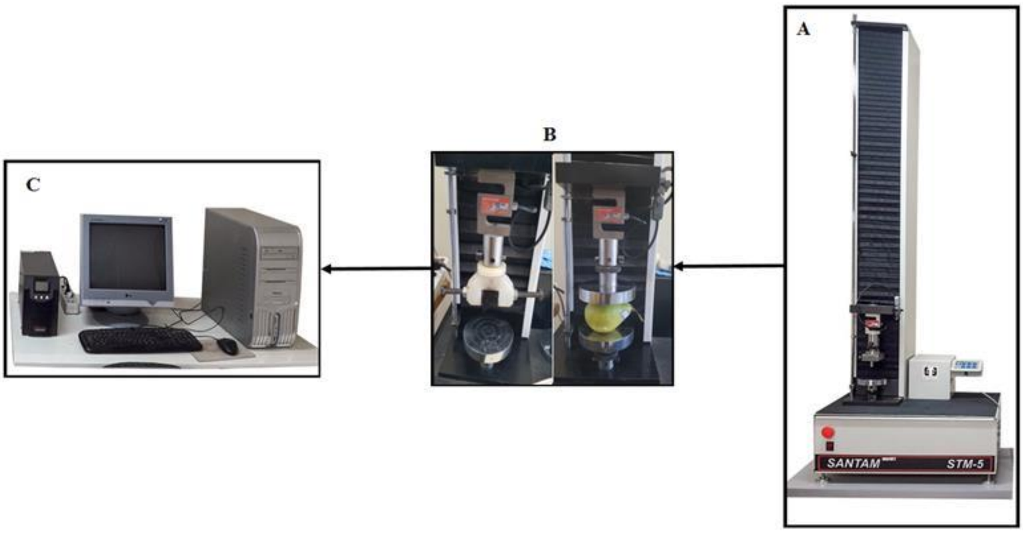

Fig. 1. quasi-static load diagrams on pears

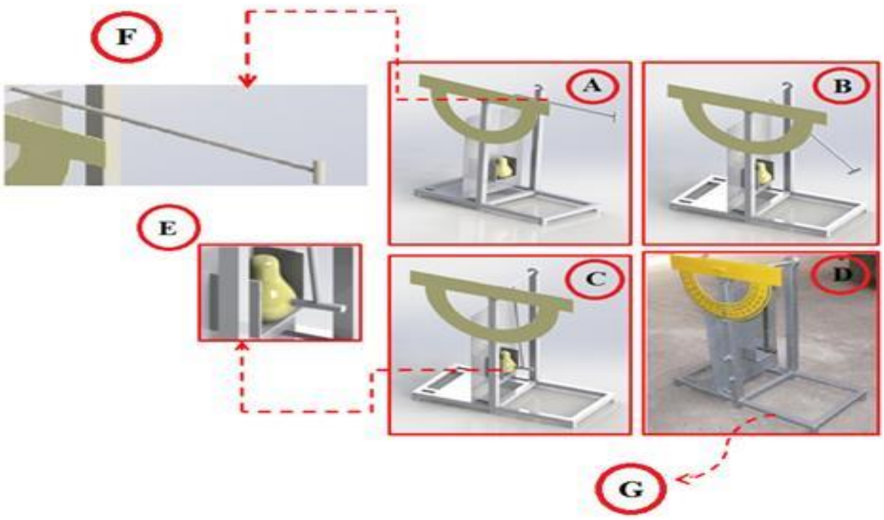

Fig. 2. Schematic of the impact device

Impact test

At first, the pendulum device and the required weights were made at the laboratory of the Gorgan Biosystem Mechanics Group (Fig. 2). Then the fruits were placed in the desired space and the arm of the machine has been raised to the desired angle (90 degrees) and in the controlled state, the arm was dropped and the pear was 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 was ignored.

Imaging via 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 5, 10, and 15 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 Compute Tomography (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 rotates to create the image. Also, the pitch was locked for the test; i.e., pitch 1. images were recorded at 80 kV and 120 mAh current, and 1 mm slices were used to create a full image. 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 B31 smooth 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.

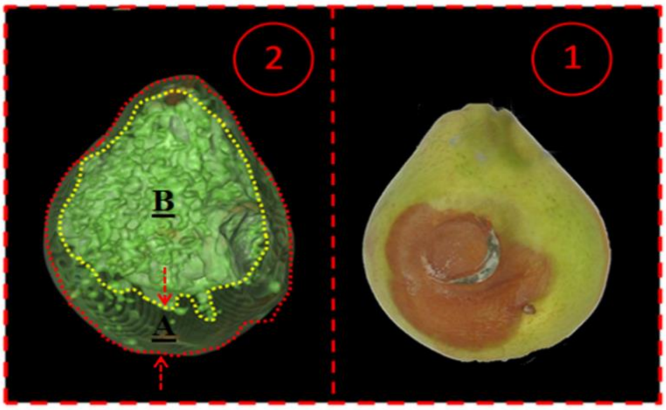

Fig. 3. Two-dimensional pears view before and after image processing

Measurement of biochemical properties

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 80% methanol (for a 1:10 ratio) in a cold mortar. The homogenized mixture was placed on a shaker device in a dark room for 24 h 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 described by Bandet et al. (1997). At first, 2 mL of DPPH with a concentration of 0.1 millimoles (4 mg of DPPH in 100 mL of methanol) was mixed in the tube and 2 mL of the prepared methanolic solution was added to it, following which the 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 (1) substitutions were converted to neutralization percentages (Li et al., 2012).

$$\mathrm{DPPH} = \frac{Ac - As}{Ac} \times 100 \qquad (1)$$

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 5 mL 80% methanol) was mixed with 100 µL of F-C and 1.16 mL of distilled water following which 300 µL of 1 M 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, at 40 °C in a dark room for 30 min. 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 mg gallic acid per gram (Jaramillo-Flores et al., 2003).

Vitamin C

The amount of 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 color that lasted for about 15 s. The vitamin C amount is expressed in mg per 100 g of the sample weight. The amount of vitamin C was obtained by the equation 2 (Jaramillo-Flores et al., 2003).

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

Firmness

To measure the hardness of the fruit flesh, a barometer device or penetrometer (Model EFFEGI, Italy) was used to measure the hardness of the pear specimens without having their skin peeled through the exertion of pressure in g. 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 hardness was read from the barometer gauge and recorded.

Method of testing and statistical analysis

Samples were stored at 5, 10, and 15 days after static and dynamic quasi-loading. Then a CT scan was performed to determine the amount of bruising. Then the chemical properties of antioxidants, phenol, vitamin C and its firmness were measured. All experiments were performed in three replications and the results were analyzed using a factorial experiment in a complete randomized design with SAS statistical software.

Results

The results of the variance analysis of the effect of loading forces and storage period on the percentage of pear bruise are shown in Table 1. According to the results obtained in this Table, it can be concluded that all parameters (wide edge pressure and thin edge and dynamic impact) had significant effects on the bruise and in all cases, except for their interaction, they have a significant level of 5%.

Wide-Edge Compression

According to the results of this experiment in three different loading forces, with increasing storage period, the percentage of pear bruise increased. According to Fig. 4, the highest and lowest amounts of bruise were observed at 45.138 and 0.094%, respectively, during the 15-day and 5-day storage period. The highest and lowest amounts of phenolic content was 28.8603 mg/100g in 70 N loading force- 5-day storage period and 13.1197 mg/100g in 130N loading force- 15-day storage period, respectively. Also, in the study of the storage period of 5 and 15 days, the amount of bruise increased by 72% and the phenol content decreased by 30%.

With increasing storage period, the vitamin C content in pears under the loading force of the wide edge compression is reduced (Figure 5). The highest and lowest amounts of vitamin C were 7.7 mg/100ml in 5-days storage and 5.7667 mg/100ml in 15-day storage period, respectively. Also, in the study of the storage period of 5 and 15 days, the amount of bruise increased by 72% and the vitamin C decreased by 16%.

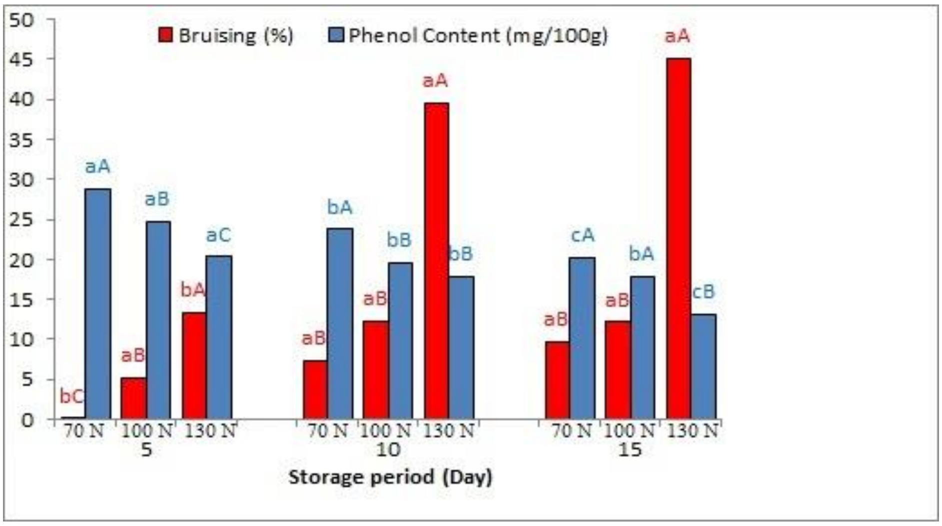

Fig. 4. Percentage of bruising and phenolic content as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N"

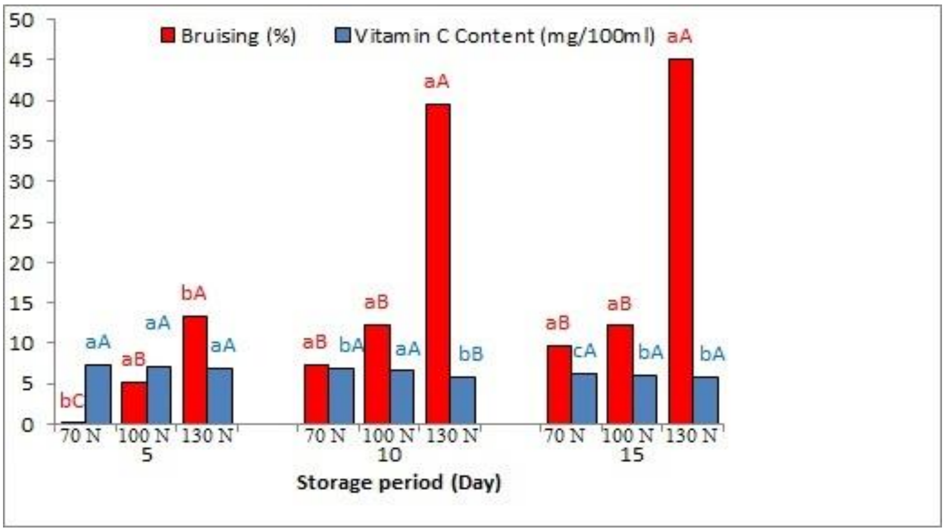

Fig. 5. Percentage of bruising and vitamin C content as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

Thin-Edge Compression

In section of the thin edge compression according to the results obtained in Figure 6, and in the constant loading force, with increasing storage period, the percentage of pear bruising was increased. In a constant storage period, with increasing loading force, the percentage of bruising was also increased. In this case the highest and lowest bruising percentages (19.880 and 0.007%) were observed during the storage period of 15 days and 5 days, respectively. The highest and lowest amounts of antioxidants were 51.5% in 15 N loading force and 5-day storage period and 37.5667% in 20 N loading force and 15-day storage period, respectively. Also, in the study of the storage period from 5 to 15 days, the amount of bruise increased by 98% and the antioxidants decreased by 17%.

By increasing the loading force from 15 to 20 N, the amount of firmness of the fruit was decreased (Fig. 7). The highest and lowest amounts of firmness were 11.0333 g in 15 N load force and 5-day storage period and 5.8 g in 20 N load force and 15-day storage period, respectively. Also, in the study of the storage period of 5 and 15 days, the amount of bruise was increased by 98% and the firmness was decreased by 36%.

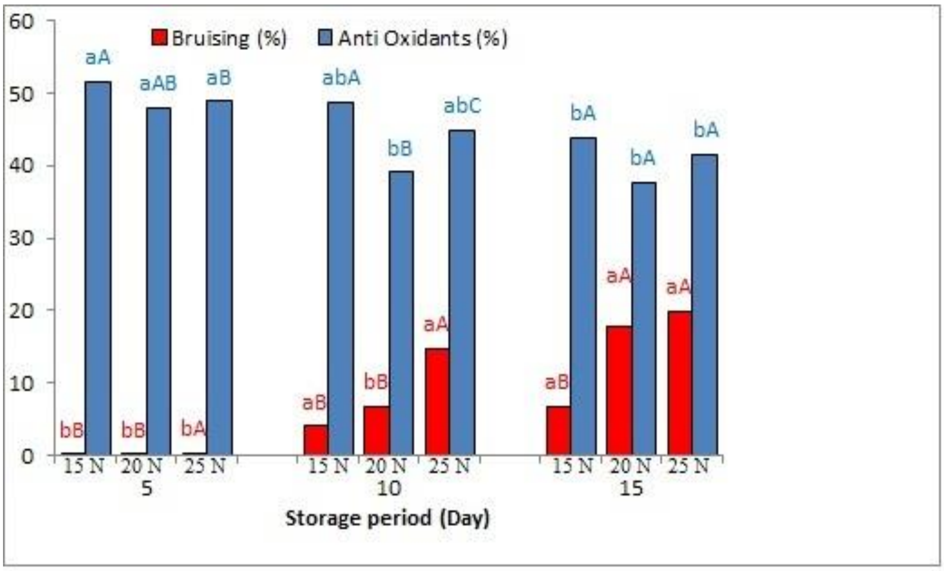

Fig. 6. Percentage of bruising and antioxidant content as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

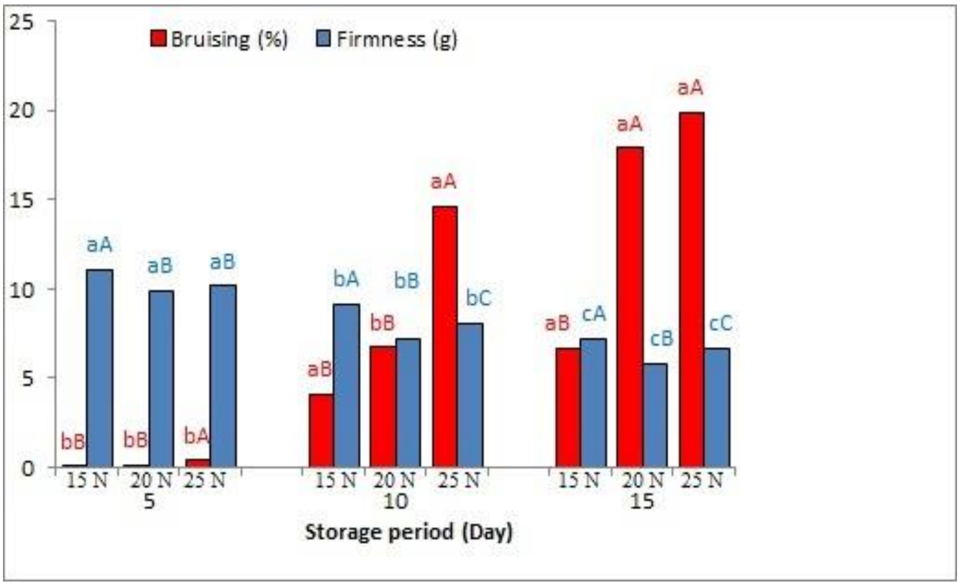

Fig. 7. Percentage of bruising and firmness as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

Dynamic Impact

According to the results obtained in a constant pendulum weight in Figure 8, with increasing storage period, the percentage of pear bruising was increased. Also, in a constant storage period, with increasing pendulum weight, the percentage of bruising was increased. The highest and lowest amounts of bruising was 47.36 and 0.21%in the 15-days and 5-days storage period respectively, and the impact mode with weights of 400 and 300 g. The highest and lowest amounts of phenol content were 28.8603 mg/100g in 300 g pendulum weight and 5-day storage period and 13.1197 mg/100g in 400 g pendulum weight and 15-day storage period, respectively. Also, in the study of the storage period of 5 and 15 days, the amount of bruise was increased by 92% and the phenolic content decreased by 30%.

With increasing pendulum weight and storage periods, the percentage of antioxidant content was decreased (Fig. 9). The highest and lowest amounts of antioxidant were 48.541% in 300 g pendulum weight and 5-days storage period and 25.015% in 400 g pendulum weight and 15-day storage period, respectively. Also, in the study of the storage period of 5 and 15 days, the amount of bruise increased by 92% and the phenolic content decreased by 17%.

In constant pendulum weight, the amount of fruit firmness decreased by increasing storage period (Fig. 10). The highest and lowest firmness values were 9.2 g in 300 g pendulum weight and 5-days storage period and 2.4333 g in 400 g pendulum weight and 15-day storage period. Also, in the study of the storage period of 5 and 15 days, the percentage of bruise was increased by 92% and the firmness decreased by 36%.

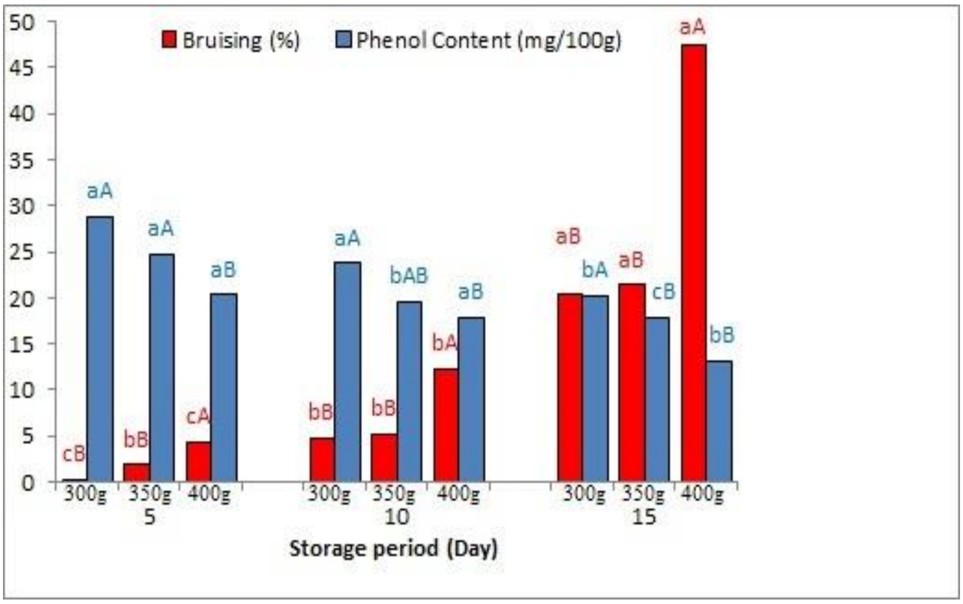

Fig. 8. Percentage of bruising and phenolic content as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

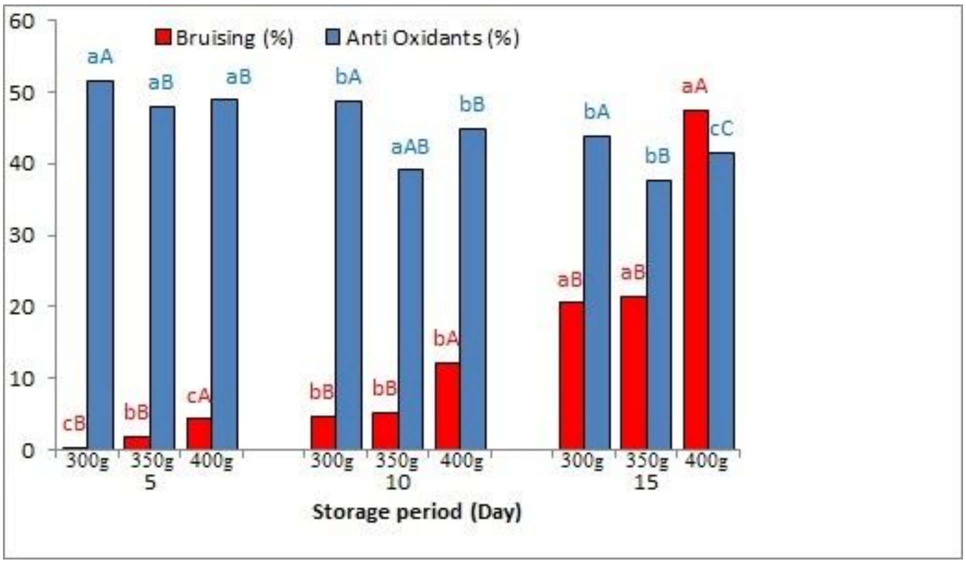

Fig. 9. Percentage of bruising and antioxidant content as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

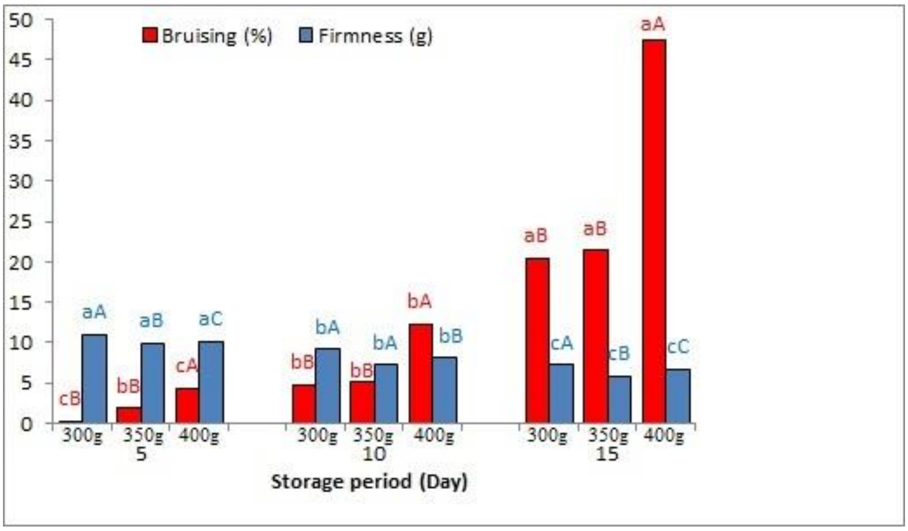

Fig. 10. Percentage of bruising and firmness as function of "storage period 5, 10 and 15 days" and "loading force 70, 100 and 130 N".

Table 1. Analysis of variance of pear bruise under the effect of loading force and storage period

Static loading					
Parameters	df	Mean square		F value	
		Wide edge pressure	Thin edge pressure	Wide edge pressure	Thin edge pressure
Storage period	2	670.900	482.74	14.370**	34.81**
Loading force	2	1898.86	146.48	40.67**	10.56**
Storage period×Loading force	4	156.95	447.93	3.36*	3.46*
Error	18	46.68	13.86		
Dynamic loading					
Parameters	df	Mean square		F value	
Storage period	2	1936.44		11.78**	
Loading force	2	456.009		8.65**	
Storage period×Loading force	4	152.97		1.65*	
Error	18	48.75			

Discussion

Wide-Edge Compression

Wide edge compression due to the pressure on the fruit tissues and the shear and flexural stresses in that area reduced the firmness of the fruit during storage, resulted in increase in the bruise percentage. Following the increase in bruising, the cellular structure of the fruit deteriorated faster. Ignoring the beneficial effects of free radicals and protecting cells from oxidative damage, the amount of phenolic content of the fruit decreased (Ghasemnezhad et al., 2010; Wu et al., 2016; Li et al., 2017). As a result, by increasing the amount of bruise, the amount of phenolic content decreased in the pear fruits.

Decrease in the content of vitamin C is because of the loss of water in the fruit tissue. Following the loss of water in the fruit, vitamin C in the fruit would be oxidized and reduced. These results are similar to those obtained by on kiwi fruit (Tavarini et al., 2008; Amodio et al., 2007). Finally, considering the effect of wide edge compression on the amount of vitamin C, it can be concluded that increasing the amount of bruise in the fruit, resulted in the decrease in the amount of vitamin C.

Thin-Edge Compression

Investigating the effects of thin edge compression on pear bruises showed that the results are similar to the wide-edge compression due to the pressure on the cells of the desired location from the fruit and the shear and flexural stresses in that area, which decreased the firmness of the fruit during storage and increased the percentage of the bruise on the fruits. In other words, increasing the amount of applied pressure led to an increase in the amount of bruising (Li et al., 2017).

Then, in evaluating the qualitative properties of pear, by increasing the loading force from 15 to 20 N, the percentage of antioxidants in the fruit decreased, while it was increased by 25 N. But in all cases, it caused reduction in the percentage of antioxidants by longer storage periods. The reason for decreasing the amount of antioxidant content can be due to the tension caused to the product due to the loading force, which caused the formation of a bruise in the fruit (Torres et al., 2010). Therefore, the amount of the antioxidant is often decreased by increasing the amount of bruising, and there was an inverse relationship between the amount of antioxidant and the percentage of the bruise.

In the next section of the experiment, it was observed that by increasing the amount of bruising decreased the fruit firmness. In this way, the pressure on the fruit cells caused the shear and flexural stresses and, as a result, decreased the firmness of the fruit during storage. In a similar experiment on kiwi fruit, fruit tissue was found to be an important factor for bruising (Ahmadi, 1982; Li et al., 2017).

Dynamic Impact

The observed results in terms of fruit bruising may be due to the physical damage to the fruit tissue and contact between the oxidizing enzymes of cytoplasmosis and polyphenol oxidase (PPO) and peroxidase (POD) and phenolic content, so that in the presence of oxygen, Enzyme oxidation in damaged cells converts phenolic materials into quinones and causes brown pigmentation in the damaged part of the fruit. Therefore, by increasing the amount of force applied, the activity of enzymes related to oxidation of phenolic compounds would be increased leading to elevation in the percentage of bruising on the fruits (Hussein et al., 2018). In a similar study that was conducted to investigate the resistance of pear damage in the course of impact, it was reported that in low loadings, the amount of bruising was not visible and by increasing the loads, a higher level of bruising could be observable (Komarnicki et al., 2016).

Finally, according to the observed results, including the amount of bruise and phenolic content of fruit, it can be concluded that there is an inverse relationship between the amount of bruising and the amount of phenolic content in the pear fruits.

The reason for these observations made in the fruit firmness measurement section is the use of different stresses on the fruit, which reduced the stiffness of the fruit during storage. On the other hand, in studies on feijoa, it was observed that mature and soft fruits are more susceptible to mechanical damage and there is an inverse relation between fruit firmness and storage period (Li et al., 2017, Castellanos et al., 2016, Ahmadi, 1982).

In the present study, percentage of bruising was investigated following application of different external loads on the chemical properties of antioxidants, phenol, vitamin C and firmness. According to the observations, it was concluded that different storage periods and different loading forces influenced the bruise percentage and also the chemical properties of pear fruits. More precisely, by increasing the amount of loading force and storage periods, an increase in the percentage of bruising was observed, which resulted in decrease in all of the studied chemical properties. Increase in the percentage of the bruise due to loading force of the thin edge, the wide edge, and the impact, negatively influenced the chemical properties. Therefore, an inverse relationship was detected between the percentage of bruising and the chemical properties of the pear fruits. Consequently, the highest amount of qualitative properties was related to the least amount of loading force and 5 day storage period.

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