

## The Numerical Simulation of Rebound Velocity Pendulum Method for Ripening Detection of Melon

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### Abstract

A robust numerical analysis was proposed for simulating the rebound velocity pendulum method for melon. For considered varieties (*Zard-Eyvanekey* and *Sousky-Sabz* varieties), the change in impact parameters (extracted from excitation by pendulum) was studied for five stages of ripening. With the melon ripeness, the rebound velocity, rebound height, relative rebound height, rebound angle, rebound energy and coefficient of restitution (velocity ratio) increased, while the absorbed energy decreased (from 37.6 to 27.9 mJ for *Zard-Eyvanekey* and from 38.5 to 27.9 mJ for *Sousky-Sabz*). The regression analysis showed a highly significant linear relationship (coefficient of determination,  $R^2$  more than 0.8059) between impact parameters and five stages of ripening. So the results of the analysis are feasible in ripening detection and hence in the classification of the melon maturity.

**Keywords:** Firmness, Impact analysis, Melon, Non-destructive method

### Introduction

There are several non-destructive, fast and objective quality measures that have been proposed and some of them are commercially available (De Ketelaere *et al.*, 2006). Some promising dynamic methods for fruit quality evaluation are based on measurement of fruit response to force vibration or impact (Lien *et al.*, 2009). The use of mass impact either by a light rigid mass or fruit falling has been widely applied in the detection of fruit maturity (Delwiche *et al.*, 1987). The material is either dropped freely onto a force transducer or hammered with an accelerating rigid mass. The impact responses are interpreted in either the frequency or the time domain. The impact indices show a strong correlation with the firmness of vegetables and fruits (García-Ramos *et al.*, 2003). There is a vertical impact sensor to measure the response of fruit to impacts. The sensor consisted of a small, semi-spherical mass with an accelerometer, which was dropped from different heights onto the fruit. Manual impact sensors, lateral impact

sensors are some other sensors used as mechanical measures (Khalifa *et al.*, 2011; Nourain, 2012). Researchers have shown interest in using impact techniques for predicting firmness of fruits. Previous studies have shown that impact techniques such as impacting of fruits on a load-cell (Lien *et al.*, 2009; Ragni *et al.*, 2010) and impacting the fruit with a small spherical impactor (Homer *et al.*, 2010; Yurtlu, 2012) can be used to evaluate the firmness of fruits successfully. García-Ramos *et al.* (2005) describe many ways of using impact sensors, such as hitting the fruit with some element that includes the sensor, putting the fruit over a load cell and letting a weight fall on it, or placing the fruit on a flat plate with a load cell located beneath it. Moreover, some of them reached a commercial use, as is the case of iFD (Intelligent Firmness Detector, Greffa, Netherlands), Aweta (Netherlands), and Sinclair iQ Firmness Tester (García-Ramos *et al.*, 2005).

Lien *et al.* (2009) used nondestructive impact technique to determine tomato ripeness. They reported that maximum impact force, impact time and fruit mass was highly related with Magness-Taylor force of the tomatoes dropped on a force sensor with a classification precision of 82.30% (Lien *et al.*, 2009). Mao *et al.* (2016) developed an

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acoustic device after investigating the influence of hitting ball and fruit tray on spectrum. They proposed three firmness indices to correlate with the firmness of watermelon. They found that significant correlation was between firmness and these indices using linear regressive model and nonlinear model of artificial neural network (ANN) (Mao *et al.*, 2016). In a study, the ripening of watermelon was examined using sound analysis by an impactor. The results showed that the intensity and location of impact effect had a significant effect on the sound signals. There was no significant difference between the biomechanical properties of the peel of the unripe, ripe, and over ripe fruits, and it is therefore expected that the observed difference in the sound properties of the watermelons is more due to the difference in the properties of the flesh than the peel (Saadatinia *et al.*, 2014). Khoshnam *et al.* (2017) examined the effect of acoustic system variables on sound signals of melon varieties. They concluded that the impactor ball, pendulum angle, sound level meter position and variety type factors did not show significant effect on resonance frequency but they had a significant effect on FFT magnitude and sound pressure meter (Khoshnam *et al.*, 2017).

Rebound technique has been used with some success to qualify firmness of fresh product after an impact with surface (Gan-MorGalili, 2000). Ragni *et al.* (2010) developed an impact measuring device for prediction of firmness online in kiwifruit pack house (Ragni *et al.*, 2010). Lien and Ting

(2014) in guaya predicted maturity by using an automated sorting machine by analyzing the impact response of dropped fruit (LienTing, 2014).

The objective of the present study is to study the impact of parameters change such as rebound velocity, rebound height, relative rebound height, rebound angle, absorbed energy, rebound energy and coefficient of restitution (velocity ratio) after impact in during of melon ripening (*Zard-Eyvanekey* and *Sousky-Sabz* varieties) and investigation some best linear and single regressions between the impact variables and stage period of ripening. The ultimate goal of this study was to investigate the feasibility of non-destructive maturity sorting of melon by impact rebound response technique without affecting the fruit quality.

## Materials and Methods

### Sampling of melon

This research was conducted on *Zard-Eyvanekey* and *Sousky-Sabz* variety (export varieties) obtained from a plantation in Garmsar township (35° 13' 20" N, 52° 20' 26" E). They were carefully picked by hand during the summer and autumn in the early morning from the area of Davarabad, Garmsar, Iran. Fruits were selected according to color, size and lack of blemishes in order to obtain homogeneous samples. They were selected at five different stages of ripening. Before each test series, the melon was transferred to department laboratory at 18 to 22°C temperature for 24 hours. They were selected at five different stages of ripening (Table 1).

**Table 1-** Date of harvesting and tests series

| Stage | Operation             | Date           | Description     |
|-------|-----------------------|----------------|-----------------|
| 1     | First series of test  | Mid-August     | Immature        |
| 2     | Second series of test | Late-August    | Early ripening  |
| 3     | Third series of test  | Mid-September  | Moderately ripe |
| 4     | Forth series of test  | Late-September | Ripe            |
| 5     | Fifth series of test  | Mid-October    | Over ripe       |

### Excitation method

A pendulum is defined as a mass, or ball, connected to a rod or rope. The equilibrium position of the pendulum is the position when

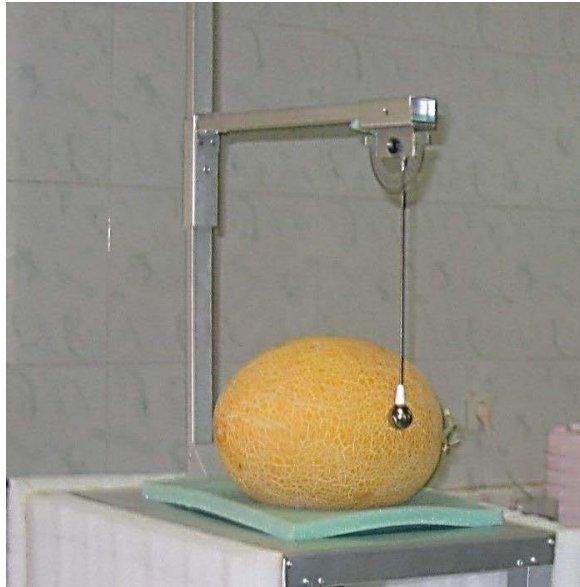
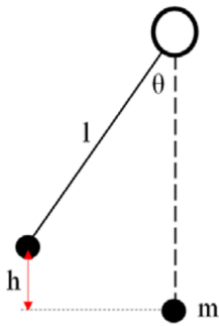
the mass is hanging directly downward. At any given moment, the velocity of the pendulum bob will be perpendicular to the rope. The pendulum's trajectory describes an arc of a

circle, where the rope is a radius of the circle and the bob's velocity is a line tangent to the circle. The mechanical energy of the pendulum is a conserved quantity. The potential energy of the pendulum,  $mgh$ , increases with the height of the ball; therefore, the potential energy is minimized at the equilibrium point and is maximized at  $\theta = \pm \theta_{\max}$ . Conversely, the kinetic energy and velocity of the pendulum are maximized at the equilibrium point and minimized when  $\theta = \pm \theta_{\max}$ . In the following

$$(mgh + \frac{1}{2}mv^2)_1 = (mgh + \frac{1}{2}mv^2)_2 \Rightarrow 0 + \frac{1}{2}mv^2 = mgh + 0 \Rightarrow v = \sqrt{2gh} \quad (1)$$

discussion,  $v$  signifies velocity,  $U$  signifies potential energy, and  $KE$  signifies kinetic energy.

The total mechanical energy is equal to the kinetic energy at the equilibrium point where  $U=0$  (point 1). The total mechanical energy is also equal to the total potential energy at  $\pm \theta_{\max}$  where  $KE=0$  (point 2). Putting these equalities together, we get From the figure 1, we see that,  $h = l - l \cos(\theta_{\max})$ .



**Fig.1.** (Right) General view of experimental setup (Left) schematic representation of the pendulum model, assumes massless rod

If we plug that value into the equation (1), we can solve for  $v$ :

$$v = \sqrt{2gl(1 - \cos \theta)} \quad (2)$$

This relationship shows the velocity at impact pendulum. Where  $v$ = impact velocity,  $g$ = gravitational acceleration,  $l$ = length of pendulum rod and  $\theta$ =impact angle. It is clear that the longer the rod and the greater the angle, the faster the pendulum ball will move. Knowing the rebound velocity ( $v'$ ) from the energy conservation law we determine the rebound height ( $h'$ ):

$$h' = \frac{v'^2}{2g} = l(1 - \cos \theta') \quad (3)$$

The relative rebound height ( $h_{rel}$ ) is the rebound height ( $h'$ ) divided by the impact height ( $h$ ) and is defined as:

$$h_{rel} = \frac{h'}{h} \quad (4)$$

Knowing the rebound velocity ( $v'$ ) by the equation (1) we determine the rebound angle ( $\theta'$ ):

$$\theta' = \text{Arccos}(1 - \frac{v'^2}{2gl}) \quad (5)$$

The kinetic energy of the pendulum is calculated as following equation:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}m(\sqrt{2gl(1-\cos\theta)})^2 \quad (6)$$

$$= mgl(1-\cos\theta) = mgh$$

Where  $E$  = total energy or energy of impact (J)  
Absorbed energy is calculated by subtracting rebound energy of the impact energy. The value of the absorbed energy during the impact can be determined by the formula:

$$E_{abs} = E - E' = mg(h - h') \quad (7)$$

Where  $E_{abs}$  = energy absorbed by the sample (J)

The value of the rebound energy of the pendulum arm can be determined by the formula:

$$E' = E\left(\frac{h'}{h}\right) \quad (8)$$

The coefficient of restitution ( $e$ ) determines the amount of kinetic energy retained by the body during the impact and it describes the rebound characteristics were calculated from:

$$e = \frac{v'}{v} = \left(\frac{h'}{h}\right)^{1/2} \quad (9)$$

The coefficient is usually defined as the ratio of final to initial relative velocity components of the striking bodies in the direction normal to the contact surfaces (Amer Eissa, 2004).

The setup is comprised of a melon sample, melon-bed and an impactor (pendulum). During the test, the fruit (melon) was placed on soft foam support in order to create free support conditions and not to disturb the vibration pattern. The rebound velocity of all individual fruit was measured on the three positions along the equator approximately 120° between them. The impact needs a sufficient stroke, mass, velocity, and right angle. The combination of this causes problems to miniaturize the little impactor. The impactor consists of a steel ball of diameter, 26 mm and a 256 mm long copper rod. The weight of the impactor was 72.13 g.

Preliminary tests were performed in order to identify a proper peripheral velocity of the pendulum. Several different velocities of the

ball pendulum, from 15 to 75 degrees, were attempted. It was concluded that impact parameters were affected by the impacted velocity of the pendulum in this range of angles. In addition, within the tested range of angles, repeated hits of the pendulum did not cause any damage to the melon peel and flesh. Because the impactor was designed also considering the fruit elasticity threshold, low impact forces were composed during the impact on the fruit surface, therefore, mechanical damage did not occur on the fruit surface. For this reason, measurements by means of the impactor were named as “nondestructive measurement”. As a result of the preliminary tests, an angle of 45 degrees was selected for the impact device for all further tests.

#### Finite element modeling

Finite element models of fruit were first created using Abaqus version 6.14-5. For the FE model, the melon was considered as an elastic body with a seed cavity. The nonlinear visco-elastic texture of the melon was therefore simplified as linear elastic texture. For the melon model the structural element C3D8I was used for rind and flesh. The element is defined by 20 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. C3D8I is well suited to modeling of irregular meshes. The melon fruit can be considered a multibody system, which consists of epicarp, mesocarp and endocarp tissues, during modeling. The material properties of different types of tissues in the melon were taken from a previous study that used finite element analysis (Namjoo *et al.*, 2016). The melon is considered to be homogeneous and no boundary constraints have been applied. The first step in the finite element analysis is the construction of the geometrical model of the melon. This construction is a highly complicated task not only for melons, but also for most of the agricultural objects. Fig. 2 shows finite element model before and after impact on melon skin by pendulum. The colorful area indicates the contact between ball pendulum with the model melon. Analysis of variance

(ANOVA) was applied to the data. Means corresponding to the different stages of

evolution were compared using Duncan's multiple range tests ( $p < 0.05$ ).

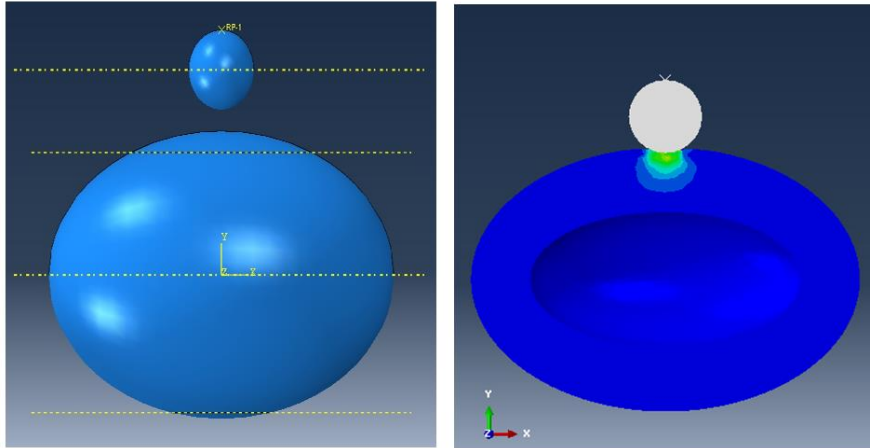


Fig.2. Simulation of ball pendulum and melon before (a) and after (b) impact in Abaqus

**Results and Discussion**

Figure 3 and 4 show the impact velocity variations on *Sousky-Sabz* and *Zard-Eyvanekey* variety, respectively. These Figures were prepared by using the analysis of Abaqus version 6.14-5 software. It is obviously that the rebound velocity values differ relating to

harvesting stage for both varieties. The rebound velocity was high in over ripe stage and decreased by ripening reduction (over ripe to immature) for both varieties. This values extracted and used for others impact parameters.

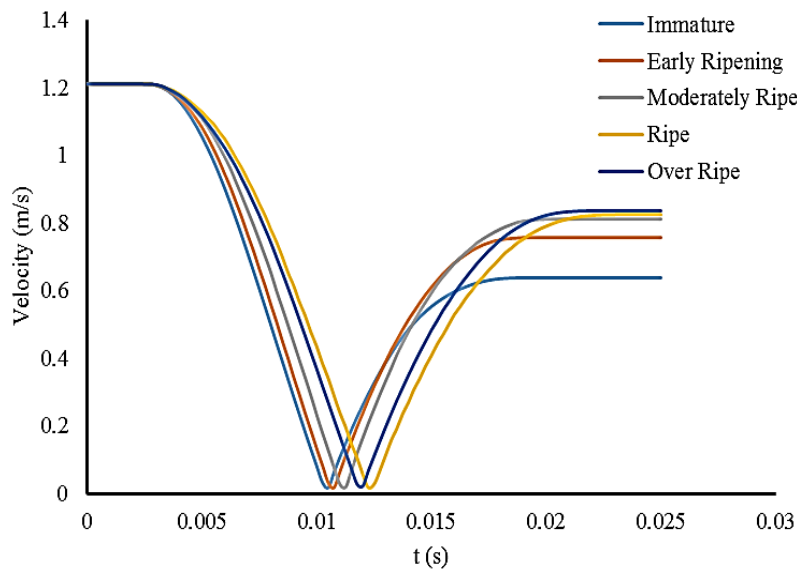


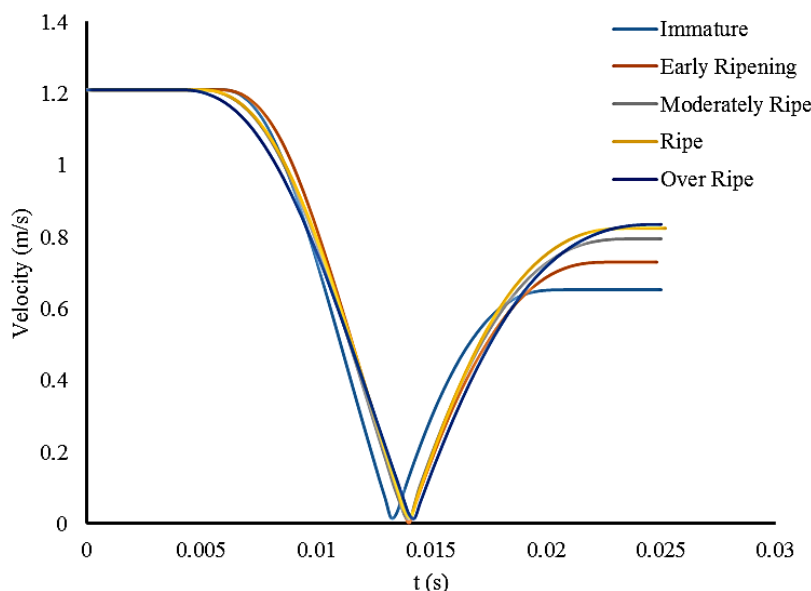
Fig.3. Impact velocity variations on *Sousky-Sabz* variety

Several variables of the impactor on fruit such as rebound velocity, rebound height, rebound angle, absorbed energy, rebound energy and coefficient of restitution (velocity ratio) versus stage of ripening can be obtained.

The impactor was held by hand and adjusted on 45 degrees. It saved potential energy and after releasing, its saved potential energy was modified to kinetic energy during the release and impacted the fruit at a velocity of 1.21

$\text{m s}^{-1}$ . By substituting values  $g=9.8 \text{ m s}^{-2}$ ,  $l=256 \text{ mm}$ ,  $\theta=45^\circ$  and  $m=72.13 \text{ g}$  into Eq. 1 and 5, values were obtained as  $v=1.21 \text{ m s}^{-1}$  and  $E=52.8 \text{ mJ}$ . Indeed, other impact

parameters by substituting rebound velocity (from Fig. 2 and 3) on the Eq. 2, 3, 4, 6, 7 and 8 were obtained.



**Fig.4.** Impact velocity variations on *Zard-Eyvanekey* variety

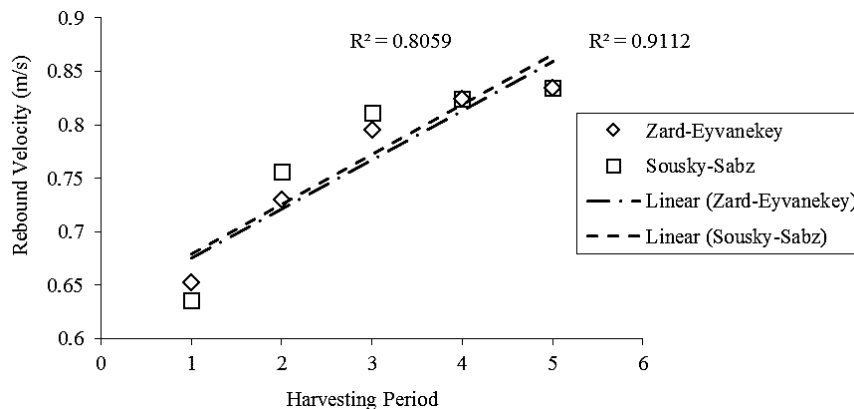
Melon fruits are made of viscoelastic materials and, for this reason; the impact caused to them is a complicated phenomenon. The mean values are shown in Table 2 on the impact characteristic parameters for each variety and degrees of ripeness. The rebound velocity of impactor ( $v'$ ) on samples increased during the growing season slowly as the rebound velocity values of *Zard-Eyvanekey* from  $0.653$  to  $0.835 \text{ m s}^{-1}$  (about 27.9%) and the rebound velocity values of *Sousky-Sabz*

from  $0.636$  to  $0.835 \text{ m s}^{-1}$  (about 31.3%) increase (Fig. 3). However, the increasing rates were different during the harvesting stages in both varieties: faster rate in the initial stages and lower in the final stages. The average of the rebound velocity in the fourth harvest (ripened) impactor on both varieties estimated  $0.824 \text{ m s}^{-1}$  (Fig. 4). This phenomenon could be due to the texture of the peel and flesh fruit which had more elasticity and springiness than another maturity stages.

**Table 2-** Changes of impact parameters of melon during harvesting ( $l= 256 \text{ mm}$ ,  $m= 72.13 \text{ g}$ ,  $\theta= 45^\circ$ ,  $h=75 \text{ mm}$ ,  $E= 52.8 \text{ mJ}$  and  $v= 1.21 \text{ m s}^{-1}$ )

| Variety               | Maturity stage | $v'$ ( $\text{m s}^{-1}$ ) | $h'$ (mm)          | $h_{\text{rel}}$   | $\theta'$ ( $^\circ$ ) | $E_{\text{abs}}$ (mJ) | $E'$ (mJ)          | $e$                |
|-----------------------|----------------|----------------------------|--------------------|--------------------|------------------------|-----------------------|--------------------|--------------------|
| <i>Zard-Eyvanekey</i> | First          | 0.653 <sup>d</sup>         | 21.8 <sup>d</sup>  | 0.29 <sup>d</sup>  | 23.8 <sup>d</sup>      | 37.6 <sup>a</sup>     | 15.3 <sup>d</sup>  | 0.54 <sup>d</sup>  |
|                       | Second         | 0.730 <sup>c</sup>         | 27.2 <sup>c</sup>  | 0.36 <sup>c</sup>  | 26.6 <sup>c</sup>      | 33.8 <sup>b</sup>     | 19.1 <sup>c</sup>  | 0.60 <sup>c</sup>  |
|                       | Third          | 0.795 <sup>b</sup>         | 32.2 <sup>b</sup>  | 0.43 <sup>b</sup>  | 29.1 <sup>b</sup>      | 30.3 <sup>c</sup>     | 22.7 <sup>b</sup>  | 0.66 <sup>b</sup>  |
|                       | Fourth         | 0.824 <sup>ab</sup>        | 34.6 <sup>ab</sup> | 0.46 <sup>ab</sup> | 30.2 <sup>ab</sup>     | 28.6 <sup>cd</sup>    | 24.4 <sup>ab</sup> | 0.68 <sup>ab</sup> |
|                       | Fifth          | 0.835 <sup>a</sup>         | 35.6 <sup>a</sup>  | 0.47 <sup>a</sup>  | 30.6 <sup>a</sup>      | 27.9 <sup>d</sup>     | 25.1 <sup>a</sup>  | 0.69 <sup>a</sup>  |
| <i>Sousky-Sabz</i>    | First          | 0.636 <sup>d</sup>         | 20.6 <sup>d</sup>  | 0.27 <sup>d</sup>  | 23.2 <sup>d</sup>      | 38.5 <sup>a</sup>     | 14.5 <sup>d</sup>  | 0.53 <sup>d</sup>  |
|                       | Second         | 0.756 <sup>c</sup>         | 29.1 <sup>c</sup>  | 0.39 <sup>c</sup>  | 27.6 <sup>c</sup>      | 32.4 <sup>b</sup>     | 20.5 <sup>c</sup>  | 0.62 <sup>c</sup>  |
|                       | Third          | 0.811 <sup>b</sup>         | 33.5 <sup>b</sup>  | 0.45 <sup>b</sup>  | 29.7 <sup>b</sup>      | 29.3 <sup>c</sup>     | 23.6 <sup>b</sup>  | 0.67 <sup>b</sup>  |
|                       | Fourth         | 0.824 <sup>ab</sup>        | 34.6 <sup>ab</sup> | 0.46 <sup>ab</sup> | 30.2 <sup>ab</sup>     | 28.6 <sup>cd</sup>    | 24.4 <sup>ab</sup> | 0.68 <sup>ab</sup> |
|                       | Fifth          | 0.835 <sup>a</sup>         | 35.6 <sup>a</sup>  | 0.47 <sup>a</sup>  | 30.6 <sup>a</sup>      | 27.9 <sup>d</sup>     | 25.1 <sup>a</sup>  | 0.69 <sup>a</sup>  |

Means in the same column followed by different letters are significantly different according to Duncan's test ( $p<0.05$ ).



**Fig.5.** Rebound velocity of melon varieties trend over five test series

The rebound height of impactor on melons increased over the period of ripening (Fig. 5). At initial stages of growth, the change was so noticeable and then was gradually decreased. The rebound height of impactor on Zard-Eyvanekey from 21.8 to 35.6 mm and for Sousky-Sabz from 20.6 to 35.6 mm increase. This value was same (34.6 mm) for both varieties in full ripening.

The rebound angle values of the two cultivars increased over the period of development and ripening. This parameter increased from 23.8 to 30.6° for Zard-Eyvanekey and from 23.2 to 30.6° for Sousky-Sabz cultivar from 1<sup>st</sup> to 5<sup>th</sup> stage of ripening. The average of rebound angle values in the ripened stage estimated 30.2° for both varieties.

The absorbed energy values by impactor had shown a decreasing trend. This value, Zard-Eyvanekey, was 37.6 mJ in first stage and 27.9 mJ in fifth stage (reduction 25.8%), whereas these values were 38.5 mJ and 27.9 mJ (reduction 27.5%) for Sousky-Sabz. The absorbed energy value was 28.6 mJ for both varieties in full ripening.

Idah *et al.* (2007) studied the impact damage assessment of fresh tomato fruits to ascertain the effects of drop height, impact surfaces, maturity and size of fruits on bruise area and impact energy. They found that the impact energy on the fruit was greatly influenced by the drop height and the mass of fruits. The bigger and fully ripe fruits

generally absorbed more energy than the smaller ones (Idah *et al.*, 2007).

So the ripe and over-ripe melon samples of maturity stages were able to absorb some of impact energy less than another maturity stages, which cause to increase the coefficient of restitution and that reflect on the ripening detection of melon.

Because of the sum of absorbed energy and rebound energy is constant (Eq. 7) the value of the rebound energy of the two varieties increased over the period of development and ripening. The rebound energy value, Zard-Eyvanekey, was 15.3 mJ in first test series and 25.1 mJ in fifth test series, whereas these values were 14.5 mJ and 25.1 mJ for Sousky-Sabz. This value was 24.4 mJ for both varieties at ripe stage.

The coefficient of restitution ( $e$ ) followed upward trends throughout ripening in both varieties as expected (because it calculated from velocity rebound and velocity impact or rebound height and impact height). This value for Zard-Eyvanekey variety was initially at 0.54 and reached the value of 0.69, these values were 0.53 and 0.69 in Sousky-Sabz variety, respectively. The coefficient of restitution in the fourth harvest (ripened), Zard-Eyvanekey and Sousky-Sabz determined 0.68. The coefficient of restitution for the one-dimensional impact between the two bodies, in pure translation movement, is defined as the relative velocity ratio (with changed sign) between the two bodies, at the beginning and end of the collision. This is a measure of

impact energy lost due to internal sources: frictions in the contact area.  
 elastic waves, plastic deformations and

**Table 3-** Relation between main impact parameters to five stages of ripening for melon varieties (x= harvest period)

| Variety        | Impact parameters          | Equation                   | R <sup>2</sup> |
|----------------|----------------------------|----------------------------|----------------|
| Zard-Eyvanekey | Rebound velocity           | $v' = 0.0458x + 0.63$      | 0.9112         |
|                | Rebound height             | $h' = 3.5x + 19.78$        | 0.9277         |
|                | Relative rebound height    | $h_{rel} = 0.02x + 0.108$  | 0.9346         |
|                | Rebound angle              | $\theta' = 1.72x + 22.9$   | 0.9133         |
|                | Absorbed energy            | $E_{abs} = -2.46x + 39.02$ | 0.9280         |
|                | Rebound energy             | $E' = 2.49x + 13.85$       | 0.9275         |
|                | Coefficient of restitution | $e = 0.038x + 0.52$        | 0.9070         |
| Sousky-Sabz    | Rebound velocity           | $v' = 0.0466x + 0.63$      | 0.8059         |
|                | Rebound height             | $h' = 3.55x + 20.03$       | 0.8311         |
|                | Relative rebound height    | $h_{rel} = 0.021x + 0.107$ | 0.8167         |
|                | Rebound angle              | $\theta' = 1.74x + 23.04$  | 0.8106         |
|                | Absorbed energy            | $E_{abs} = -2.5x + 38.84$  | 0.8235         |
|                | Rebound energy             | $E' = 2.51x + 14.09$       | 0.8322         |
|                | Coefficient of restitution | $e = 0.038x + 0.524$       | 0.8261         |

Kafashan *et al.* (2008) found that averages of restitution coefficients for lateral sides, blossom side and stem side on 'Jonagold' apples were calculated 0.524, 0.596 and 0.507, respectively. The results showed that the maximum and minimum restitution coefficients were found on the blossom sides and stem sides of apple fruits, respectively (Kafashan *et al.*, 2008). Table 3 shows correlation coefficients (R<sup>2</sup>) nondestructive impact parameters and stage of ripening. The results of this table indicate a highly significant linear relationship between impact parameters and five stages of ripening. There is a better coefficients of correlation for *Zard-Eyvanekey* variety.

### Conclusions

Over ripe melons had a maximum rebound velocity, rebound height, relative rebound height, rebound angle, rebound energy and coefficient of restitution (velocity ratio) and minimum absorbed energy, whereas an immature melon shows opposite results. Both varieties had increasingly trends in the impact parameters attributes rebound velocity, rebound height, relative rebound height, rebound angle, rebound energy and coefficient of restitution (velocity ratio) and percentage of absorbed energy of the two varieties decreased over the period of ripening. The regression analysis showed a highly significant linear relationship between impact parameters and five stages of ripening.

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## شبیه‌سازی عددی روش سرعت بازگشت آونگ جهت تشخیص رسیدگی خربزه

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### چکیده

در این تحقیق جهت شبیه‌سازی روش سرعت بازگشت آونگ روی خربزه، تجزیه و تحلیل عددی نیرومندی پیشنهاد شد. تغییر پارامترهای ضربه روی دو رقم خربزه (زرد ایوانکی و سوسکی سبز) و در پنج مرحله رسیدگی بررسی شد. نتایج نشان داد که سرعت بازگشت، ارتفاع بازگشت، ارتفاع نسبی بازگشت، زاویه بازگشت، انرژی بازگشت و ضریب پس‌جهش (نسبت سرعت) با رسیدگی خربزه افزایش و انرژی جذب شده کاهش یافت. تجزیه و تحلیل رگرسیون رابطه خطی با معنی‌داری بالایی بین پارامترهای ضربه و پنج مرحله رسیدگی را نشان داد. نتایج تجزیه و تحلیل در تشخیص رسیدگی و از این رو در طبقه‌بندی بلوغ خربزه امکان‌پذیر است.

**واژه‌های کلیدی:** تجزیه و تحلیل ضربه، خربزه، روش غیر مخرب، سفتی

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