COMPARISON OF DIFFERENT NON-DESTRUCTIVE MEASUREMENT METHODS

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Abstract

The postharvest changes of tomato samples (stored at 23.5°C and 8°C) were measured by a precision penetrometer (flat-plate compression), impact and acoustic firmness measurement during the 11 days storage period. The characteristic softening process was observed successfully by all the three methods. From the 1st day significant difference was found between the different storage conditions in case of F_{max}, slope of the force-deformation curve and the impact firmness coefficient. Concerning the firmness results, the highest correlation was found between the parameters measured by the SMS penetrometer (slope of the force-deformation curve (R^2=0,684, R^2=0,442) and F_{max} [R^2=0,645, R^2=0,448]) and the impact firmness coefficient, in case of both treatments. Interesting phenomena were observed, when plotting the firmness changes versus mass loss. No significant difference was found between the treatments in case of all the measured firmness parameters. This suggests that the firmness changes only depend on the mass loss changes. The percental firmness changes measured by the three different measuring methods (four firmness parameters) showed almost identically the same way and level of changes independently from measuring method and temperature treatment.

Keywords: acoustic, impact, non-destructive firmness

Introduction

The quality of the tomato texture influenced by flesh firmness, the ratio between pericarp and locular tissue and skin toughness (Kader, 1978). After harvest, tomatoes continue the ripening process and it can overripe. Quality loss and reduced shelf life could be the end result (Geeson et al, 1985). The firmness changes highly correlated with the surface, appearance and the characteristic of the tomato, witch is related to the colour and the shape (Yang et al, 1988).

Firmness of the fruit can be determined by destructive and non-destructive methods (Ali, 1998). Usually a penetrometer is used in order to measure fruit firmness destructively. A probe with flat or convex tip is driven into the fruit flesh and the maxmum force is recorded. Many precision penetrometers were developed such as Stable Micro System (SMS), Instron. Previous studies have compared the measuring results of different types of penetrometers (Abbot et al, 1976; Bongers, 1992) and investigated different experiemental designs to the firmness detection (Harker et. al, 1996).

There are many studies using acoustic measurements for food firmness evalution, as well (for eg. Arimi et al, 2010; Chen et al, 2005; Sanz et al, 2007, Shin-ichiro et al., 2013). Acoustic methods are based on the excitation of the sample by a hit inducing a specific resonant signal, which is related to sample's mechanical features (Zsomné Muha, 2008). In 1968 Abbot et al. noticed that the peak of the frequency curve depends not just on the texture of the fruit, but also on its shape and mass. Considering this they published the following formula to measure firmness: $S=f^2*m$ (S – acoustic stiffness coefficient, f – second resonance frequency, m – sample mass). Cook (1972) described this factor with another equation: $S=f^2*m^{2/3}*\rho^{1/3}$ (S – acoustic stiffness coefficient, f – first resonance frequency, m – sample mass, ρ – sample density). Gómez in 2005 concluded the acoustic stiffness coefficient and the elasticity modulus offers a more precise image of the post-harvest tomato changes than the Magness-Taylor method.

The impact firmess measuring method is widely used for the determination of fruit firmness (P. Chen et al, 1996). This method is based on the observation, that the mechanical properties of the excited sample are related to the force or acceleration sensor's signal change. This response depends on the impacting velocity, mass, radius of curve, elastic modulus and the Poisson's ratio of the spherical impactor head.

There are many publications that studies the correlation between Magness-Taylor's firmness and the impact firmness (Burgos et al, 2002, Ortiz-Canavare et al, 2001).

The objective of this study was to follow the effect of the two different storage conditons to the stiffness of tomatos. Further aim was to compare the results of three different non-destructive firmness measurements.

Materials and Methods

100 pieces of freshly harvested tomato samples (*Lycopersicon esculentum L. cv. Pitenza*) were collected from an experienced grower in mature pink and/or light red (4-5) maturity stage (according to the USDA color chart from 0 to 6). The tomatoes were separated randomly into two groups and stored at 23.5°C (±1°C) and at 8°C (±1°C) for 11 days. The temperature was measured with Voltcraft DL-121TH USB Temperature & Humidity Data Logger.

The firmness was measured by Stable Micro System (SMS) TA-XT2 Texture Analyzer equipped with a flat compresson plate. In order to provide a non-destructive measurement setup, the penetration depth was set only to 0.2 mm. The speed of the probe was set to 0.1 mm/s. The force and the deformation data were stored by the Texture Expert 1.22. The maximum force (F_{max}) and the slope between the initial part and the F_{max} of the force-derformation curve were recorded.

During the acoustic response measurement the samples were placed on a soft elastic support. The tomato was hit on its equator marked location with a wooden stick by hand. The generated sound response was recieved by a sensitive microphone located under the soft sample support. The raw data (sound responses) were transformed with the Fast Fourier Transformation. The characteristic frequency (the highest peak) of the curve was used to evaluate the acoustic stiffness coefficient: $S=f^2*m*10^{-6}$ [N/mm], where f is the characteristic frequency [Hz] and m is the mass [g]. The acoustic response technique gives information from the global stiffness of the sample (Zsom-Muha and Felöldi, 2007).

The impact measuring system contained a piezo-electronic force sensor equipped impact hammer (impactor), a signal converter and a computer. The first step of the measurement was to impact the sample with an aproximetly 150 g, 22 cm long PCB Piezotronics 086c03 impactor. The converted signal was stored on the computer by the program „Impact" developed by Szent István University, Faculty of Food Science, Department of Physics and Control. The program records the force-time curve and determines the time to reach the curve maximum peak and the maximum voltage value of the force sensor. In order to define the impact firmness coefficient, the $D=1/\Delta T^2$ [$1/ms^2$] formula (Felföldi és Fekete, 2000) was used (where ΔT – the time needed to reach the highest peak of the force-time curve [ms]). All samples were measured 3 times around the equator and the average of this 3 measurement was used to characterize the surface firmness of the tomato.

Data were converted by means of routines in MS-Excel and were analyzed using the SPSS for Windows ver. 14. Statistical analysis was performed at 95 % significance level (in figures marked with 95 % CI)

Results and discussion

Fig. 1 shows the changes of the maximum force values (measured by SMS precision penetrometer) during the shelf-life. The F_{max} values decreased during the storage period. At the beginning, the changes were fast and after the 7th day with lower intensity. From day 1, significant difference was found between the F_{max} values of the two groups. In case of room temperature stored samples from day 1, in case of cold stored samples from day 2 singificant difference was found compared to the initial values. The changes of the slope of the force-deformation curve during storage can be seen in Fig. 2 with great similarity to the changed observed in case of F_{max}. From day 2, significant difference was found between the two treatmens, too.

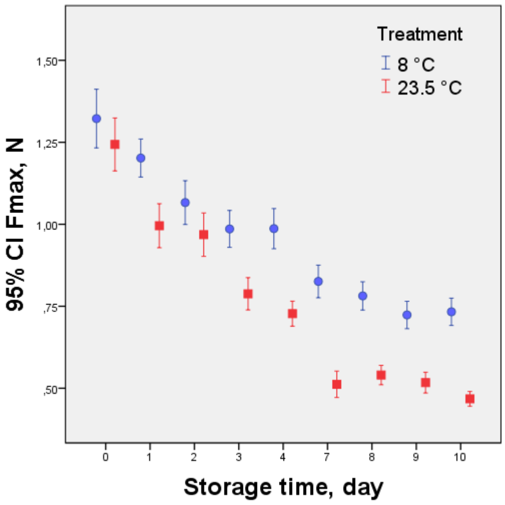

Fig. 1: The changes of the Fmax values during the storage period

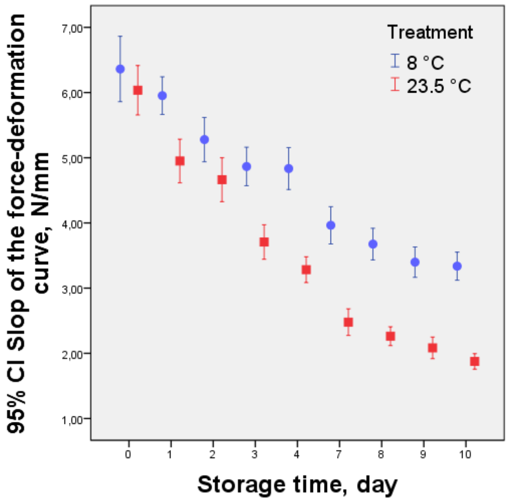

Fig. 2: The changes of the slope of the force-deformation curve during the storage period

It is noticeable that the standard deviation of the groups decreased during the measurement remarkably. According to our expectations, at the lower temperature stored samples had higher force values (0.7 N), expecially at the end of the measurements, than the room temperature stored ones (0.5 N). The reduction of the F_{max} values and the slope of the force-deformation curve from day 1 to the last day was about 60 % and 70 % in case of 23.5 °C and 40 % and 45 % in case of 8 °C, respectively.

According to the results shown in Fig. 3, significant difference was found in case of both temperature treatments between the initial values and the values of day 2 or 3. The acoustic stiffness results showed no significant difference between the two temperature treatments during the entire storage period due to the high standard deviations. The acoustic stiffness coefficient decreased to around 18 N/mm in case of cold stored samples and to around 13 N/mm in case of room temperature stored samples.

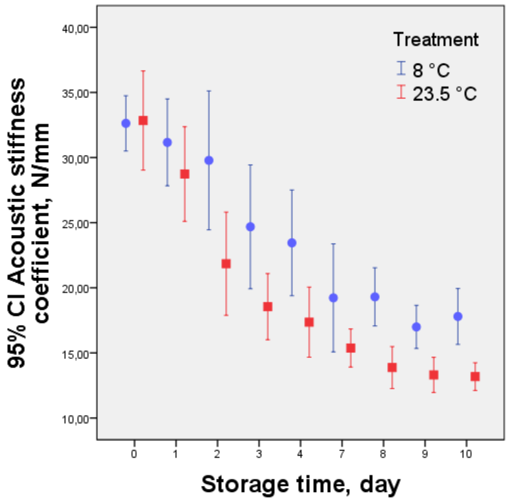

Fig. 3: The changes of the acoustic stiffness coefficient during the storage

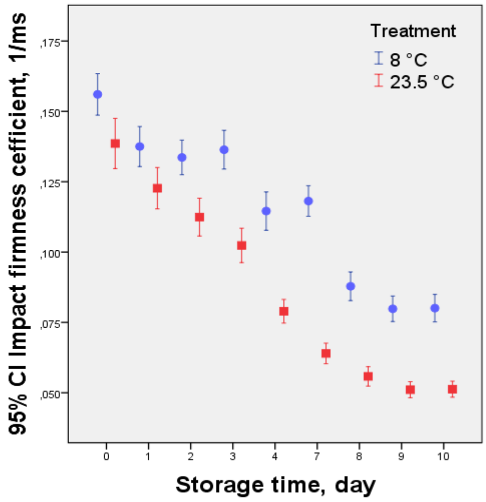

Fig. 4: The changes of the impact firmness coefficient during the storage

There was significant difference between day 1-2 and the initial impact firmness coefficient (Fig. 4). From the 1st day significant difference was found between the different storage conditions. After the 8 day long storage, the impact stiffness coefficient values didn't change significantliy. The final impact stiffness coefficient values were 0.05 $1/ms^2$ in case of cold stored sample (about 48% of decrease), and 0.08 $1/ms^2$ in case of room temperature stored tomatoes (about 68% of decrease).

Comparing the resulted firmness values obtainined by the three different non-destructive methods (Table 1), no strong correlation was found between the results oh the measuring methods. The highest correlation was found between the parameters measured by the SMS penetrometer (slope of the force-deformation curve (R^2=0,684, R^2=0,442) and Fmax [R^2=0,645, R^2=0,448]) and the impact firmness coefficient, in case of both treatments. It can be concluded from the data that the penetrometer measurement (SMS), with the applied setup (0.2 mm penetration depth), is in a closer relationship with the surface firmness of the tomato.

Table 1: Comparing the three firmness measurement factors

	Room temperature		Cold temperature	
	Acoustic stiffness coefficient	Impact firmness coefficient	Acoustic stiffness coefficient	Impact firmness coefficient
F_{max}	R^2=0,244	R^2=0,645	R^2=0,099	R^2=0,448

Slope of force-deformation curve	R^2=0,285	R^2=0,684	R^2=0,414	R^2=0,442
Acoustic stiffness coefficient		R^2=0,238		R^2=0,122

Interesting phenomena were observed, when plotting the firmness changes versus mass loss. No significant difference was found between the treatments in case of all the measured firmness parameters. The Fig. 5 suggests that the firmness changes only depend on the mass loss changes. The observed significant difference between the temperature treatments originated from the lower level of mass loss. The mass loss dependent firmness change can be estimated by an exponential function. In order to compare the results of the different firmess measurements, the observed changes of the samples were calculated as the percentage of the initial value. The percental firmness changes measured by the three different measuring methods (four firmness parameters) (Fig. 6) showed almost identically the same way and level of changes independently from measuring method and temperature treatment. The equations for the average daily value fitted exponential curves are listed in the Table 2.

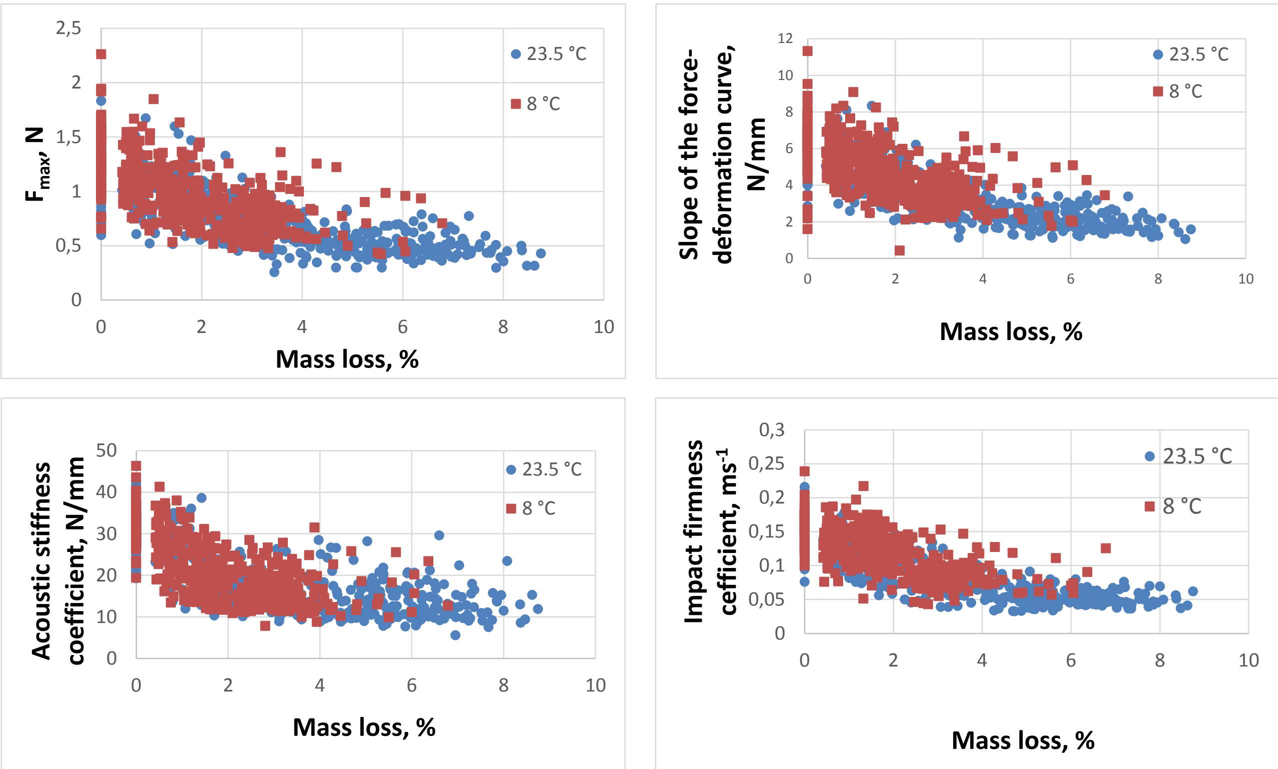

Fig. 5: The changes of the different firmness value vs mass loss

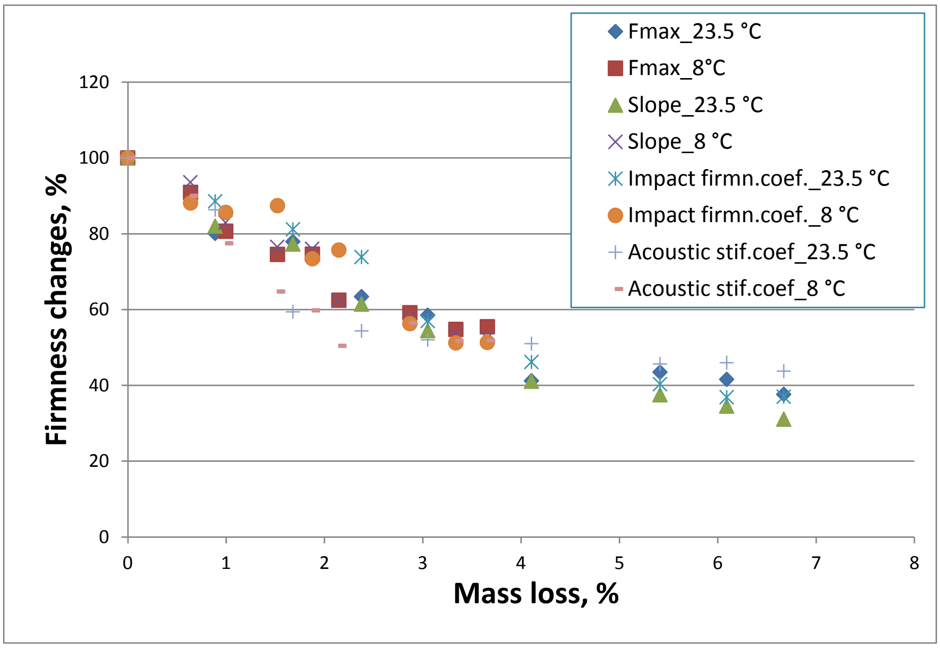

Fig. 6: The percental firmness changes measured by the three different measuring methods vs. mass loss

Table 2: The equations for the average daily value fitted exponential curves

	Exponential equation (23.5 °C)	Exponential equation (8 °C)
F_{max}	$y=72{,}94*e^{-x/3{,}414}+27{,}16$	$y=69{,}83*e^{-x/3{,}215}+31{,}13$
Slope	$y=87{,}14*e^{-x/4{,}093}+13{,}59$	$y=101{,}83*e^{-x/5{,}254}$
Acoustic stiffness coefficient	$y=100{,}35*e^{-x/5{,}776}+2{,}075$	$y=102{,}82*e^{-x/5{,}467}$
Impact firmness coefficient	$y=59{,}01*e^{-x/1{,}663}+43{,}34$	$y=59{,}25*e^{-x/1{,}559}+43{,}93$

Conclusion

All the three firmness measuring method was found to be suitable for monitoring the postharvest changes of tomatoes. Significant difference was found in case of both temperature treatments between the initial values and the values of day 1 or 3. From the 1st day significant difference was found between the different storage conditions in case of the in case of F_{max}, slope of the force-deformation curve and the impact firmness coefficient. No strong correlation was found between the results of the three measuring methods. The highest correlation was found between the parameters measured by the SMS penetrometer (slope of the force-deformation curve and Fmax and the impact firmness coefficient, in case of both treatments. When plotting the firmness changes versus mass loss, no significant difference was found between the treatments in case of all the measured firmness parameters. The percental firmness changes measured by the three different measuring methods (four firmness parameters) showed almost identically the same way and level of changes independently from measuring method and temperature treatment.

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