TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11c, 64–73

A STORAGE TIME INFLUENCE ON MECHANICAL PARAMETERS OF TOMATO FRUIT SKIN

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Summary. Presented work introduces the results of comparative analysis concerning selected mechanical properties of greenhouse Admiro and Encore and soil-grown Surya and Polset tomato's cultivars skin, stored at 13˚C. A statistically significant effect of both: variety and storage time on the Young's modulus, critical stress and Poisson's ratio values was observed. The Young's modulus determined for greenhouse fruit's skin demonstrated considerably higher values than observed for the soil-grown varieties, in addition the highest values were set for an Encore while the lowest one for a Polset variety. The values of Young's modulus and critical stress decreased with the storage time growth while the Poisson's ratio remained in the range from 0.4 to 0.49. Poisson's ratio, established for greenhouse tomato's peel, took higher values than in the Encore variety case.

Key words: tomato skin, mechanical properties, Poisson's ratio, Young's modulus.

INTRODUCTION AND RESEARCH GOAL

The subject of numerous researches ongoing in various scientific centers covers determination of mechanical properties for fruits and vegetables. The literature data shows that the most important and most often defined mechanical parameters are: the Young's modulus, the Poisson's ratio, the critical stress and strain, the biological yield point, and the rupture point [Sitkei 1986]. However, only a few works takes up the challenge of making the fruits and vegetables cover a research matter.

The tomato fruit's skin has a layered structure, functions mainly as a protection for the pulp, and is a kind of a border against external destructive factors, [Barrett et al. 1998; Telis 2004; Bargel and Neinhuis 2005, De los Reyes, 2007]. Probably the differences in the skin layers construction occurring among the tomato varieties, also decide on its mechanical properties. Fruit stores as well as food-processing plants are interested in fruits with a skin resistant to damage during e.g. transport and storage. However, from the perspective of the individual consumer, tomato fruit should have skin soft and easy to remove. Miles et al. (1969) also considered skin as the most important part of the tomato fruit, responsible for its mechanical strength.

Received strength parameters may thus allow the analysis of their changes depending on the tomato's variety and the growing environment as well as determine an attempt to assess the current state of physiological fruit. It can be expected, that on the basis of mechanical parameters variability, the fruit's shelf-life during the entire period of storage will be possible to assess.

The aim of this study was to examine the variability of selected strength parameters of tomato's fruit skin for the soil-grown and greenhouse varieties, stored at 13˚C.

MATERIALS AND METHODS

Tomato fruits of two greenhouse varieties: Admiro and Encore cultivated at "Leonów" (Niemce near Lublin, Poland) as well as tomato fruits of two soil-grown varieties: Polset and Surya cultivated in Ostrówek near Lublin were investigated.

Examined fruit material was delivered directly after harvesting. Tomato fruits were in the initial ripening stage with green-orange colored skin. The harvested fruits were similar in size. Fruits with visible defects and skin damages were rejected, and the remaining material was stored in a controlled environment chamber at temperature 13 ºC. Tomatoes were removed from the controlled environment chamber and kept in a laboratory until fruit temperature became equal to ambient temperature (around 2 hours). After washing and drying the surface of the fruit, skin specimens were procured for tensile tests. The incision was made from the base of the tomato to the stalk. Longitudinal strips were sliced off from each fruit with a profiled, single-blade knife with a limiter. Parameters such as length, width and thickness were measured with the use of a caliper before the examination. The samples had the shape of a strip with the length of 30 mm ± 0.1 mm and the width of 10 mm ± 0.1 mm. The above values were measured with the use of a caliper. The thickness of each sample was measured under an optical microscope at 5 points in the central part of the strip on both sides with the accuracy of ± 0.05 mm. Prepared samples were placed in clamping grips of the tensile machine, which allows constant and measurable increase of the tensile force value which equalled 4.2 N min $^{-1}$. Powdered graphite markers were randomly sprayed on the sample surface. The experiment was conducted on the measuring position assigned for the determination of mechanical properties of biological material [Gładyszewska 2006]. The method of random markers was applied to determine Young's modulus, Poisson's ratio and critical surface tension of the skin. This method relies on the analysis of the image of and the distance between points on the surface of the sample subjected to uniaxial stretching tests [Gładyszewska 2007]. The images of the stretched sample with graphite markers randomly sprayed on the sample surface and the value of the tensile force corresponding to each image were downloaded to the computer. The signal from the tensometer was transmitted to the computer with the use of an analogue-to-digital converter. The random marking method has fewer limitations and produces fewer errors than other techniques for testing the mechanical properties of biological materials. Its main advantage is that the obtained results are independent of the effects observed along the specimen's edges which are close to the clamping grips of the testing machine. The ends of the samples prepared directly before measurement were placed in the clamping grips of the tensile testing machine. The fixed clamping grip was connected to the Megaton Electronic (AG&Co) KT-1400 tensometer with a force measurement range of 0 -100 N, and the moving grip was flexibly connected to a transmission device for stretching the specimen. Using a CCD camera equipped with a microscope lens, the specimen was observed at 240 x 320 pixel resolution under 5x magnification.

Each measurement was performed in 30 replications. Young's modulus E is defined as the ratio of stress over strain in the direction of the applied force (x-axis) (equation 1). Young's modulus for each sample was determined based on the value of the slope of a straight line approximating individual dependence $\varepsilon_x = f(\sigma)$, where ε_x is the relative elongation in the direction of the x-axis (-), and σ is the value of stress (MPa).:

$$E = \frac{\sigma}{\varepsilon_x}.$$

The critical surface tension of a stretched specimen was determined using Eq. (2), and Poisson's ratio v was computed based on dependence (3).:

$$\sigma = \frac{F}{S},$$

$$v = -\frac{\varepsilon_y}{\varepsilon_x},$$

where: F (N) is a force value corresponding to destruction of a sample, $S = a \cdot b$, a and b are thickness and width of a sample, respectively (mm), ε_x is a relative elongation in the direction of the applied tensile force (-), ε_y is a relative elongation in a perpendicular direction to the applied force (-).

The results were processed statistically using the Statistica 6 application.

RESULTS AND DISCUSSION

There is no possibility to determine unambiguously the physical features, characterizing the mechanical properties of tomato's fruit skin, without defining a thickness, for which these values were achieved. In the case of tomato fruits a visible, sharp boundary separating the skin from the flesh of the fruit is hard to define. The values should therefore be related to the average thickness of the samples accounting for 0.68 mm in case of greenhouse tomato fruit varieties and 0.77 mm for soil-grown ones [Ciupak 2010].

Changes in the average value of Young's modulus for the greenhouse (Admiro and Encore varieties) tomatoes' fruit skin, and skin of the Polset and Surya stored at 13 °C is presented on the figures 1 and 2 respectively.

The values of Young's modulus (Fig. 1a) determined for the greenhouse tomato fruit of Admiro variety on the harvesting day came to 4.15 MPa and after 14 days of storage reached 3.79 MPa, while in 21th day, its fall to a level of 3.04 MPa could be observed. On the final experimental day, the Young's modulus gained about 40 % lower values in comparison to the level from the first day of examination and accounted for 2.48 MPa.

a) b)

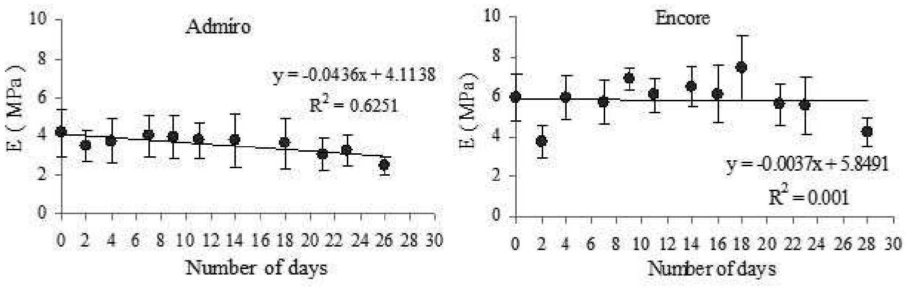

Fig. 1. The average values of Young's modulus for skin of greenhouse tomato fruit, Admiro (a) and Encore (b) varieties, stored at 13°C with a standard deviation

Figure 1b shows the changes of average Young's modulus values obtained for Encore tomato's fruit skin. During the four-week fruit storage, any clear upward trend or downward changes in the value of this parameter were not observed. On the harvesting day, Young's modulus average value came to 5.94 MPa. After two days of storage at 13 °C about 37 % decrease was noted, while on the fourth day increase to a value equal to that from the first day of research was registered. Gradual increase of the Young's modulus value during subsequent days was observed. On 18th day of storage, Young's modulus increased to 7.4 MPa while on the last day of testing (28th day of storage) 30 % decline of Young's modulus (to 4.19 MPa), in comparison with the first day values, was noticed (Fig. 1b).

Figure 2 illustrates the changes in Young's modulus values determined for tomato's skin of the soil-grown: Polset (Fig. 2a) and Surya (Fig. 2b) varieties, stored at 13 °C. In case of Polset variety of fruit only 14 days of measurements were possible to conduct. After this time, due to the progressive process of fruit softening and difficulties in the sample preparation, the studies were finished. The value of Young's modulus for Polset tomato skin came to 3.36 MPa on the harvesting day. This value slope to a level of 2.8 MPa was observed after 4 days of storage, while on the last day of measurement Young's modulus reached 2.31MPa, which was lower by over 30% from the initial rate (Fig. 2a).

Tomato fruits of Surya variety remain firm throughout the storage period and were tested for 4 weeks (Fig. 2b). On the harvesting day the average value of Young's modulus came to 3.99 MPa. After 4 days of storage, this value increased to 4.58 MPa, and then its clear downward trend with increasing storage time was observed. On the 14th day of storage the value of longitudinal modulus of elasticity fall to a level of 3.19 MPa was noticed, while on 21th day a clear decrease to the value of 2.25 MPa was noted. On the last testing day, the value of Young's modulus accounted only for 2.03 MPa

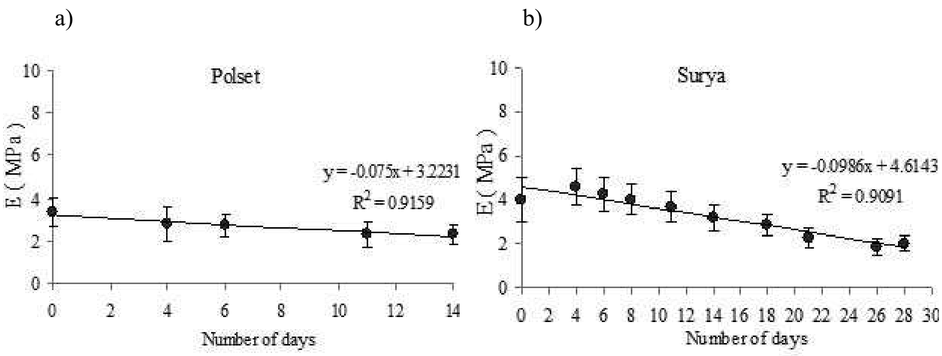

Fig. 2. The average values of Young's modulus determined for skin of soil-grown tomato fruit of Polset (a) and Surya (b) varieties, stored at 13°C with a standard deviation

The line graphs 3 and 4 (Fig. 3, Fig. 4) show the changes in the value of critical stress determined for tomato's skin for both greenhouse and soil-grown cultivars, stored at 13° C.

a) b)

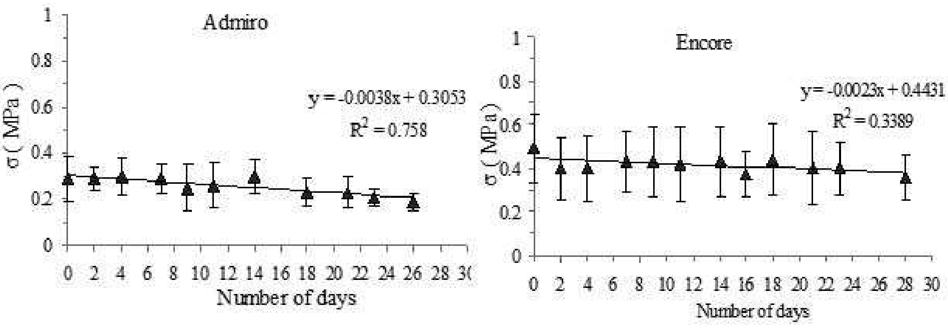

Fig. 3. The average values of critical stress determined for tomato's skin of greenhouse Admiro (a) and Encore (b) varieties, stored at 13°C with a standard deviation

Critical stress values calculated for the skin of the Admiro tomato during the harvesting day came to the 0.29 MPa and remained steady for over 14 storage days. On the last day of measurements, the parameter value decreased by over 30 % compared to the figure obtained in the first day of testing and reached 0.19 MPa (Fig. 3a). The average critical stress values at the date of harvesting for the Encore tomato fruits accounted for 0.49 MPa. Mentioned level was constant up to 23th day of fruit storage in a climate chamber. On the last day of the experiment, the critical stress values achieved 0.36 MPa (Fig. 3b).

The data on the figure 4 reflects the changes in critical stress values in addition to the skin of Polset and Surya varieties. On the first day of the experiment the values of the critical stress determined for Polset variety amounted to 0.29 MPa (Fig. 4a), while for the Surya variety came to 0.48 MPa (Fig. 4b).

a) b)

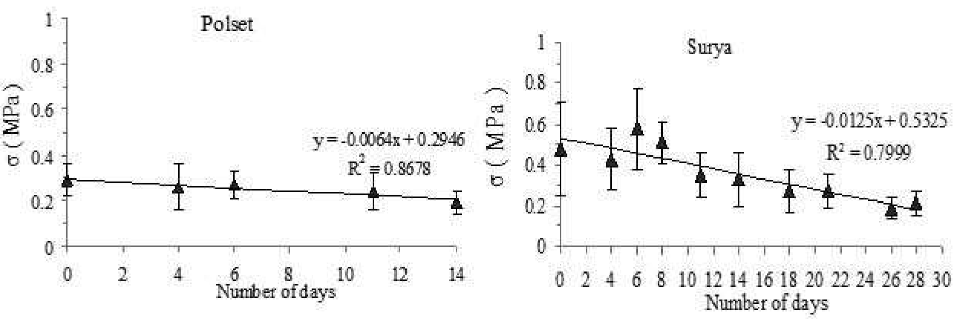

Fig. 4. The average values of critical stress determined for soil-grown tomato varieties: Polset (a) and Surya (b), stored at 13°C with a standard deviation

After four days of storage at a temperature of 13 ° C, the critical stress values for the Polset variety decreased slightly to 0.26 MPa. Similarly, for the Surya, the slight slope to a 0.43 MPa was observed. On the last, 14th day of Polset storage, the critical stress value determined for the skin, declined to the 0.19 MPa while in case of the Surya variety this figure remained at the level of 0.33 MPa. On the last 28th day of Surya fruits storage, a critical stress values amounted to 0.21 MPa and were approximately about 56 % lower than during the first testing day (Fig. 4b).

The figure 5 shows changes in the value of Poisson's ratio in addition to the skin of greenhouse tomato fruit of Admiro and Encore varieties stored at 13 °C. The value of the parameter, in the instance of Admiro tomato skin, decreased by 22 % from 0.73 on the harvesting day to 0.57 after 26 days of storage (Fig. 5a).

The value of Poisson's ratio according to the Encore tomato skin has changed within 28 days of storage (Fig. 5b). On the harvesting day the ratio accounted for 0.56, while on the last day of storage, fell to a level of 0.43.

a) b)

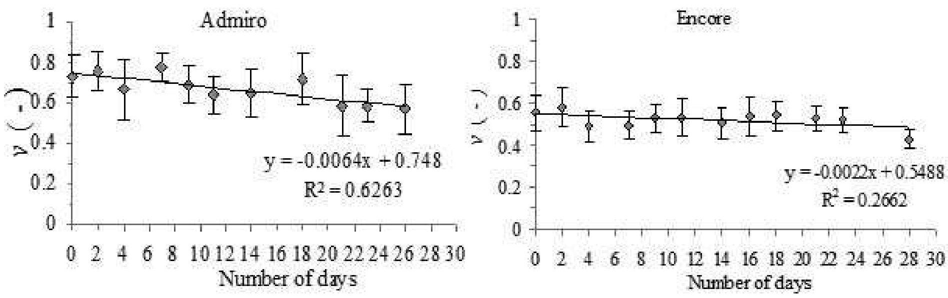

Fig. 5. The average values of the Poisson's ratio according to the skin of Admiro (a) and Encore (b) varieties, stored at 13°C with a standard deviation

Mean values of Poisson's ratio calculated for the skin of soil-grown tomato fruits of Surya and Polset varieties stored at 13 °C is given on the figures 6a and 6b respectively. The value of this parameter for a Polset variety ranged from 0.42 to 0.45 (Fig. 6a), while for Surya fruits the Poisson's ratio reached values between 0.4 - 0.49 (Fig. 6b).

a) b)

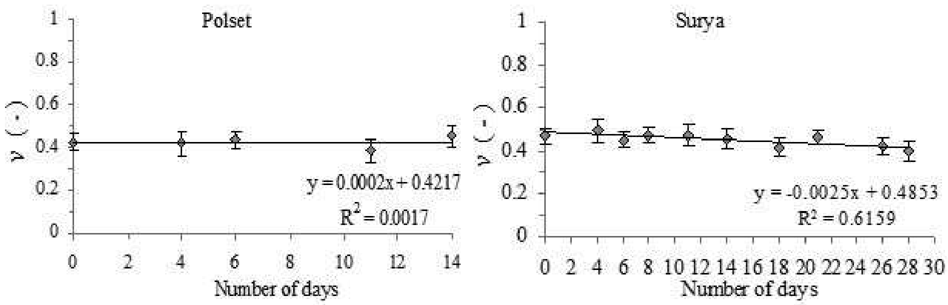

Fig. 6. The average values of the Poisson's ratio according to the skin of soil-grown tomato of Polset (a) and Surya (b) varieties, stored at 13°C with a standard deviation

Table 1 shows the Young's modulus, Poisson's ratio and critical stress values determined for the tomato skin of all tested cultivars, stored at 13˚C, set during the entire study period. The values are given at intervals so that the upper limit of the range corresponds to the value determined at the date of fruits harvesting while the lower is the value on the last day of storage. In the case of soil-grown tomato fruit varieties (Surya and Polset) the Poisson's ratio value changed within the ranges given in Table 1.

Table 1. The average value of the parameters determined during conducted research

Storage temperature **13°C**	Young's modulus E (MPa)	Poisson's ratio *ν* (-)	Critical stress σ (MPa)	Storage time (days)
Admiro	4,15 – 2,48	0,73 – 0,57	0,29 – 0,19	26
Encore	5,94 – 4,19	0,56 – 0,43	0,49 – 0,36	28
Polset	3,36 – 2,31	0,42 – 0,45	0,29 – 0,19	14
Surya	3,99 – 2,03	0,40 – 0,49	0,48 – 0,21	28

Young's modulus determined for the skin of Admiro and Encore greenhouse varieties was higher than determined for the soil-grown Polset and Surya cultivars. On the harvesting day, the skin of Encore variety achieved the highest value of this parameter while the lowest were noted for the Polset cultivar (Table 1). Young's modulus, Poisson's ratio and critical stress calculated for the tomato's skin of the Surya variety are significantly higher than defined for the Polset fruits. The data reflects the decrease of the longitudinal elasticity modulus and critical stress values for the soil-grown tomato's skin stored at 13 ˚C over the whole storage time. The Poisson's ratio changes in the range from 0.4 to 0.49 could be observed (Table 1).

As it can be seen on the figure 1b for the Encore variety fruits, the Young's modulus demonstrates not only high fluctuations but also a significant scatter of results around the mean value. Similarly, a high coefficient of variation (more than 20 %) for Admiro variety could be observed (Fig. 1a). The largest spread of the critical stress values around the mean was determined for the skin of Surya and Encore tomato varieties (Fig. 3b and Fig 4b). For the Encore variety, Young's modulus and critical stress values fluctuation and scatter have been reflected in studies in which unequal softening and surface dying process was observed.

According to the literature data, the value of Young's modulus of tomato fruit skin is strongly dependent on the variety and can cover a wide range of values from about $20 \cdot 10^{-3}$ MPa to 110 MPa and even 600 MPa for Beefsteak cultivar (Table 2).

Table 2. The Young's modulus values determined for the tomato fruit skin

Variety	Young's modulus E (MPa)	Literature position
Delicious Sunripe Oxheart	$25 \cdot 10^{-3}$ $21 \cdot 10^{-3}$ $17 \cdot 10^{-3}$	Hankinson and Rao 1979
[-]	5 – 50	Hamm et al 2008
[-] Beefsteak	10 – 110 600	Bargel and Neinhuis 2004a, 2005

Inbred 10 Sweet 100	43 27	Matas et al 2004
Espero	70	Andrews et al 2002a
Scout, Viceroy Rideau	80 - 82 75	Voisey and Lyall 1965

A comparison of the values obtained on the basis of studies with available literature data (Table 2) indicates that the average values of Young's modulus determined for the skin of all tested tomato cultivars are similar and, together with a standard deviation, includes the lower limit of the values given by Hamm et al. (2008) (Table 2). Hankinson and Rao (1979) obtained much lower quantities than designated in this study. So much diversity may be caused by differences in cellular structure and strength properties of the skin.

The values of Poisson's ratio determined on the basis of the studies are summarized in Table 1. According to Hamm et al. (2008) for this value for skin of the tomato accounts for 0.5. Among the obtained results a scatter of Poisson's ratio are also observed, however for greenhouse fruits the ratio variability was greater than for the soil-grown cultivars (Fig. 5, Fig. 6).

CONCLUSIONS

1. Statistically significant influence of both: fruits variety and storage time on the Young's modulus and critical stress values was defined.
2. Young's modulus determined for the skin of greenhouse Admiro and Encore varieties was higher than for the soil-grown Polset and Surya cultivars. The highest value was set for the skin of Encore while the lowest for Polset variety.
3. Surya variety is characterized by the higher values of Young's modulus, critical stress and Poisson's ratio than in case second (Polset) soil-grown cultivar.
4. The values of Young's modulus and critical stress determined for the skin of the soil-grown tomatoes decreased with the growth of the storage time, while Poisson's ratio run in the range of 0.40 - 0.49.
5. For greenhouse varieties greater dispersion of Young's modulus and Poisson's ratio values around the average was observed.
6. The further research are needed in order to evaluate a possible physiological state of fruits and their degree of maturity on the basis of changes in mechanical properties during the study period.

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WPŁYW CZASU PRZECHOWYWANIA NA PARAMETRY WYTRZYMAŁOŚCIOWE SKÓRKI OWOCÓW POMIDORA

Streszczenie. W pracy przedstawiono wyniki analizy porównawczej wybranych mechanicznych właściwości skórki owoców pomidora szklarniowego odmian Admiro i Encore oraz owoców pomidora gruntowego odmian Polset i Surya przechowywanych w temperaturze 13 ºC. Stwierdzono statystycznie istotny wpływ odmiany i czasu przechowywania na wartość modułu Younga, naprężenia krytycznego i współczynnika Poissona. Moduł Younga skórki owoców szklarniowych był wyższy niż skórki owoców gruntowych. Najwyższą wartość wyznaczono dla owoców odmiany Encore, zaś najniższą dla owoców odmiany Polset. Wartość modułu Younga, naprężenia krytycznego skórki owoców gruntowych obniżała się wraz z wydłużaniem czasu przechowywania, zaś współczynnik Poissona zawierał się w przedziale 0,4 – 0,49. Współczynnik Poissona wyznaczony dla skórki owoców pomidora szklarniowego odmiany Admiro charakteryzował się wyższą wartością niż w przypadku odmiany Encore.

Słowa kluczowe: mechaniczne właściwości, moduł Younga, współczynnik Poissona, skórka owocu pomidora.