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CHANGES IN THE MECHANICAL PROPERTIES OF THE GREENHOUSE TOMATO FRUIT SKINS DURING STORAGE

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K e y w o r d s: tomato skin, storage period, Young's modulus, Poisson's ratio.

A b s t r a c t

This study investigates the effect of the period of storage of greenhouse tomato (*Lycopersicon Esculentum* Mill) c.v. Admiro on changes in the selected mechanical properties of tomato skin. Changes in the value of Young's modulus and Poisson's ratio were determined in tomato fruit harvested from the maternal plant at the initial phase of skin ripeness, stored in a controlled environment chamber with limited light access at a temperature of 14ºC. A decrease in the value of Young's modulus and Poisson's ratio was observed.

ZMIANY MECHANICZNYCH WŁAŚCIWOŚCI SKÓRKI OWOCÓW POMIDORA SZKLARNIOWEGO PODCZAS PRZECHOWYWANIA

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S ł o w a k l u c z o w e: skórka owoców pomidora, czas przechowywania, moduł Younga, współczynnik Poissona.

A b s t r a k t

W pracy przedstawiono wyniki badań nad wpływem czasu przechowywania owoców pomidora szklarniowego (*Lycopersicon Esculentum* Mill) odmiany Admiro na zmianę wybranych mechanicznych właściwości skórki. Zbadano zmienność modułu sprężystości podłużnej oraz współczynnika Poissona podczas przechowywania owoców pomidora zebranych bezpośrednio z rośliny macierzystej w początkowym stadium dojrzałości skórki, a następnie przechowywanych w komorze klimatycznej z ograniczonym dostępem światła w temperaturze 14ºC. Zaobserwowano zmniejszenie wartości modułu Younga, a także współczynnika Poissona.

Introduction and objective of the study

Plant production (including fruit and vegetable growing) is oriented towards individual consumers and the processing industry. For specific target groups to be identified, qualitative standards have to be met as regards the product's safety, nutritional value, storage and processing requirements. During collection, packaging, transport and even storage, tomato fruits are often subjected to breaking load and breaking stress. Surface damage directly lowers the product's commercial value. Physiological changes during the ripening process also contribute to the fruit's susceptibility to damage (GONLEY, EGAN 1978, HANKINSON, RAO 1979, MOSHENIN 1970, RAMANA 1991). The mechanical properties of tomato skins which are directly exposed to external damaging factors are, therefore, an important consideration. The basic physical indicators which describe the mechanical properties of the investigated plant material are Young's modulus E and Poisson's ratio ν (DOBRZAŃSKI 1998, GŁADYSZEWSKA 2007, MOSHENIN 1970). Strength tests of tomato skins are also carried out with the use of rheological methods supporting the development of mathematical models (PETRACEK, BUKOVAC 1995, THOMPSON 2001). BARGEL and NEINHUIS (2005) performed a detailed study investigating the relationship between the biochemical properties of tomato skins and the process of fruit growth and ripening. They carried out a combined analysis of SEM (scanning electron microscopy) images and uniaxial tensile tests. KABAS et al. (2008) determined Poisson's ratio by measuring the transverse and longitudinal strain of a tomato during compression between two plates.

Published sources quote the values of Young's modulus E obtained from uniaxial tensile tests of tomato skins (HAMAN, BURGES 1986, HERSHKO et al. 1994, MATAS et al. 2005, RAJABIPOUR et al. 2004, VOISEY, LYALL 1986, WIDEMANN, NEINHUIS 1998). The value of Young's modulus is determined with the use of popular measuring devices such as Instron testing machines. Poisson's ratio ν may be very difficult or impossible to determine as transverse strain cannot be measured with the use of a standard strength testing device.

The objective of this study was to determine the basic mechanical properties of tomato skins, i.e. Young's modulus and Poisson's ratio, during uniaxial tensile tests, subject to the period of fruit storage.

Method

Greenhouse tomato fruits (*Lycopersicon Esculentum* Mill) cv. Admiro grown by the Kwietniewski Gardening Production Company in Chodel, Lublin Province, were subjected to laboratory analyses in September 2007. Tomato fruits were harvested directly from the maternal plant at the initial ripening stage (orange skin color) and stored in a controlled environment chamber with limited light access at a temperature of 14°C. The applied storage temperature is consistent with Polish Standard requirements (1993) and the recommendations of the Main Inspectorate of Plant Health and Seed Production (Państwowa Inspekcja Ochrony Roślin i Nasiennictwa).

The mechanical properties of thin-layer biological materials such as tomato fruit skins were investigated by image analysis and an analysis of the mutual position of markers randomly applied to the studied material (GŁADYSZEWSKA 2007). Young's modulus and Poisson's ratio are computed with the use of a tensometric platform and specialist software. This method supports skin peeling tests and strain observations. By applying the random marking method in strength tests, the authors were able to disregard boundary conditions which made the produced results independent from material strain in the area of critical cross-sections (GŁADYSZEWSKA 2006).

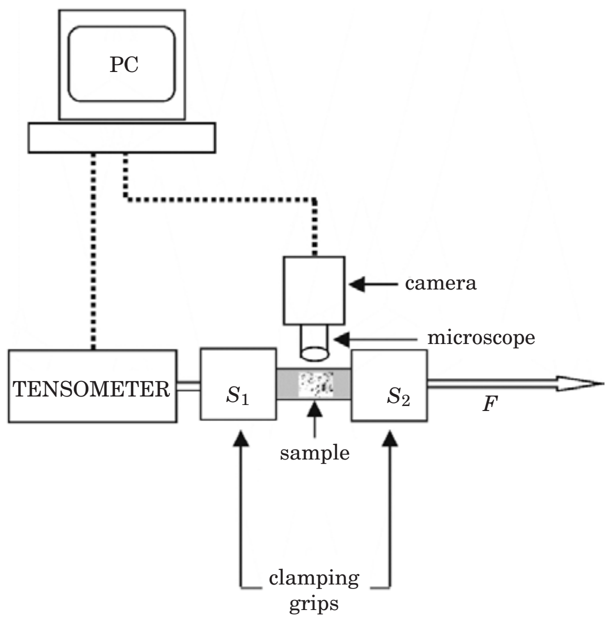

Fig. 1. Specimen mounted in clamps. S_1 and S_2 – clamping grips, F – force

Graphite markers were randomly sprayed on the surface of the specimen. The direction of force F ensured that the specimen was stretched precisely in its plane. The applied markers did not affect the specimen's properties and they did not come into contact, therefore, the studied material's natural mechanical properties were preserved. The specimen was placed in clamping grips S_1 and S_2. Grip S_1 was connected to a Megaton Electronic AG&Co. KT-1400 tensometer with a force measurement range of 0-100 N. S_2 was a moving grip. After the strength test began, the specimen image generated by a camera equipped with a microscope lens was transmitted to computer memory with information on the current value of the tensile force corresponding to the given image. With the use of a microscope lens, the specimen was viewed at 240×320 pixel resolution and 5× magnification. The signal from the tensometer was transferred by an analogue-to-digital converter to computer memory, and the observed image – to video input. The tensile strength value was later correlated with specimen strain.

The first measurements were performed directly after harvest, and follow-up measurements were carried out as scheduled. Measurements were taken every 2–3 days for 26 days. Tomatoes were removed from the controlled environment chamber and kept in a laboratory until fruit temperature became equal to ambient temperature. The surface of tomatoes was washed and a specially profiled knife was used to cut 30 mm long and 9–13 mm wide skin strips. The incision was made from the base of the tomato to the stalk. A third dimension (thickness) had to be specified as part of the applied method. Skin thickness was measured at 10 points with the use of an optical microscope. The specimen prepared in this way was placed in clamping grips S_1 and S_2. Prior to measurement, powdered graphite markers were applied to the specimen with a special brush.

The image of the skin surface with the marked points was transferred from the camera to a computer analyzing the changes between the points during a tensile strength test. The cosine of the angle between the grid axis and the image edge, and the force exerted on a given specimen were determined. The relative distance shift between selected points before and after strain and the value of angle cosines were used to determine stress values. The value of Young's modulus E for each of the 30 specimens was determined based on the tangent of the inclination angle of a straight line describing a single dependence: $\varepsilon_x = f(\sigma)$, (Fig. 2 and Fig. 3), where:

$$\sigma = \frac{F}{S} \tag{1}$$

σ – stress value [MPa],
F – value of force exerted on the specimen [N],
S – cross-sectional area of the specimen [mm^2].

The value of Poisson's ratio ν was calculated based on the following formula:

$$\nu = \frac{\varepsilon_y}{\varepsilon_x} \tag{2}$$

where:

ε_x – strain in the direction of the x-axis,

ε_y – strain in the direction of the y-axis.

The process of data collection during measurement and the calculations applied to determine the required parameters were controlled by the Videoo software (GŁADYSZEWSKA, CHOCYK 2005).

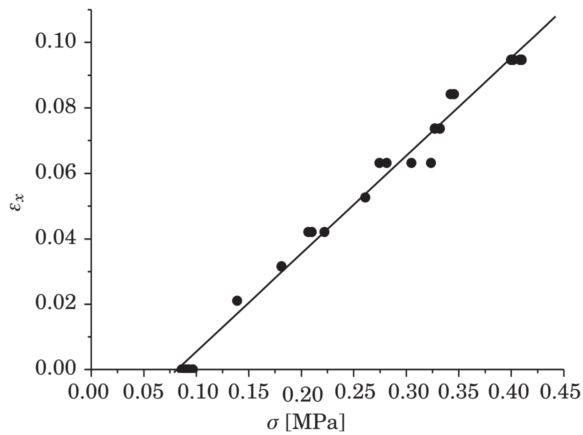

Fig. 2. Example of a dependence ε_x (σ) for the stretched specimen

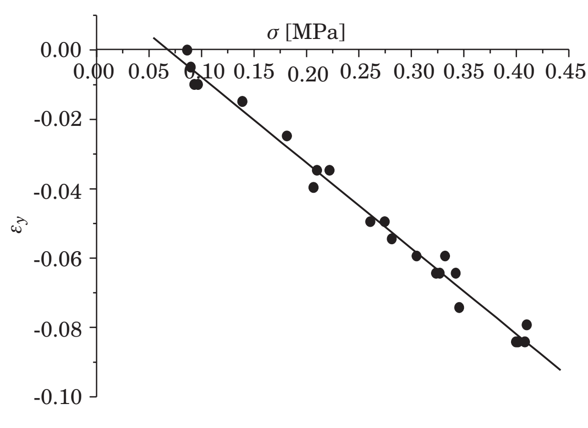

Fig. 3. Example of a dependence ε_y (σ) for the stretched specimen

Results and discussion

Figure 4 presents the dependence of an average values of Young's modulus E determined for tomato fruit skin samples on every day of the storage period. A decrease in the value of the elasticity modulus E of tomato skins was observed during the analyses from about 4.5 MPa on harvest day down to about 2.35 MPa after 26 days of storage at a temperature of 14°C. The obtained values of Young's modulus can be considered as rather low in comparison with other values reported in the literature. Hankinson and Rao have found for different tomato cultivars Young's modulus varying from 17.16 up to 24.67 MPa (HANKINSON, RAO 1979). BARGEL, NEINHUIS collected results revealing much higher spread of Young's modulus, from 14.1 even up to 600 MPa for different tomato cultivars (BARGEL, NEINHUIS 2004). Matas et al. have performed experiments for different relative humidities of tomato peels. A clear increase of Young's modulus has been found with a decrease of the relative humidity (MATAS et al. 2005). In our storage experiment Young's modulus decreases with the time of storage therefore this effect cannot be connected with eventual decrease of relative humidity. Moreover, such low values of Young's modulus as observed in our work has also been reported by Matas et al. when tensile force ranged from 0.1 N up to 0.2 N (MATAS et al. 2004).

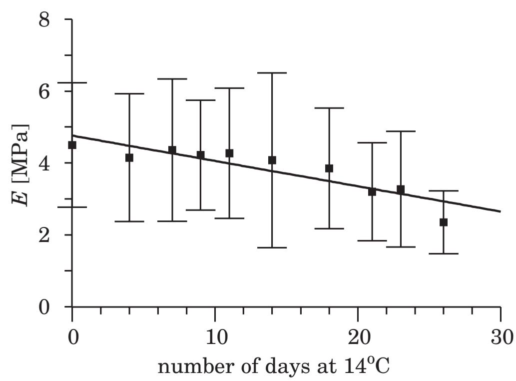

Fig. 4. Average values of Young's modulus E determined for tomato fruit skin samples on every day of the storage period

The values of Poisson's ratio ν determined for individual skin samples varied widely due to the specific properties of the investigated material. For average values (calculated from 30 repetitions), a drop in Poisson's ratio ν was noted over storage time from around 0.74 on harvest day to 0.55 after 26 days of storage at 14°C (see Fig. 5). One could be surprised by these large Poisson's ratio values, however quite similar values (up to 0.72) have already been reported by Thompson (THOMPSON 2001). Moreover it is necessary to stress that "0.5 limit" for Poisson's ratio is valid only for isotropic 3D materials, whereas tomato peel structure is not isotropic at all and the tested samples should be considered rather as 2D than 3D samples.

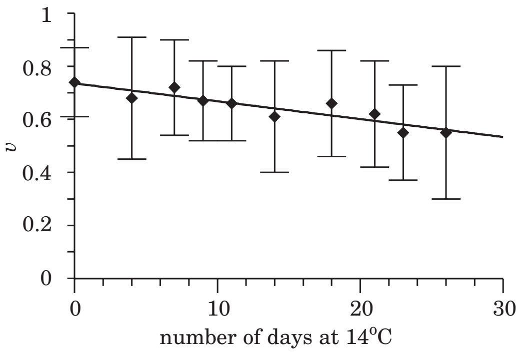

Fig. 5. Average values of Poisson's ratio ν determined for tomato fruit skin samples on every day of the storage period

Conclusions

Significant changes in the analyzed parameters were observed during long-term storage of tomatoes as the anticipated consequence of ripening progress and biochemical changes occurring in the fruit.

The following conclusions can be drawn from the conducted study:

1. The value of Young's modulus for tomato fruit skins (Admiro) stored at a temperature of 14°C decreased from 4.5 MPa to 2.35 MPa on day 26 of the experiment.

2. Poisson's ratio ν was also characterized by a decreasing trend from 0.74 to 0.55 on the last measurement day.

3. The values of Young's modulus E and Poisson's ratio ν varied widely due to the specific properties of the investigated plant material, i.e. tomato fruit skins.

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