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ELASTIC HYSTERESIS DETERMINATION FOR THE SKIN OF TOMATO FRUIT DURING UNIAXIAL TENSION TEST

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Summary. The presented work covers the problem of hysteresis loop characteristic determination during uniaxial stretching of the tomato fruit skin cv. *Admiro* stored in a controlled environment chamber at 21°C in the cycle load-unload process. The force and strain, as well as the absorbed energy, degree of elasticity and hysteresis losses were determined with the use of the random markers method. The absorbed energy values for the skin of fresh fruits ranged from $2.1 \cdot 10^{-3}$ mJ to $18.6 \cdot 10^{-3}$ mJ, while the hysteresis losses fall between 12.3 % and 54.2 %, depending on tensile force value. The absorbed energy and hysteresis losses were defined for the stored fruit stabilized at the level of $20.3 \cdot 10^{-3}$ mJ and 50.8%, respectively. The degree of elasticity ranged between 40% and 71 %.

Key words: tomato skin, absorbed energy, degree of elasticity, hysteresis losses.

INTRODUCTION

The knowledge of mechanical properties of plant origin materials (vegetables and fruit), is of major importance when it comes to the storage, transport and converting processes as well as the machines and devices design [Thiagu 1993].

Fruit and vegetables damage, which may occur at each stage of the production and processing, is considered the fundamental problem in the area of nowadays crop production [Machado 1999; Dobrzański 2008]. Therefore, the maintenance of high quality products, which also means material damage minimising, plays a significant role in nowadays production, mainly because loads and stresses that cause mechanical defects considerably reduce their nutritional and trade value [Desmet 2004; Van Zeebroeck 2005; Singh 2006; Van Linden 2006].

Mohsenin (1986), among the parameters that characterise the crop material in the respect of its mechanical capacity, mentions ultimate compressive strength, tensile and shear strength, stress relaxation, Young's modulus, Poisson's ratio and elastic hysteresis. It needs to be emphasized [Stopa 2010], that a correct determination of the mentioned quantities is highly dependent on both the crop material type and the applied test method.

In the opinion of Chaib's (2007), rheological measurements and hysteresis characteristics are an important source of knowledge on the mechanical properties of the whole fruits as well as their structural elements (e.g. skin, pericarp tissue).

The skin of fruit e.g. tomato functions mainly as the protection of the soft internal tissue against external factors, affects the product's integrity and growth process [Andrews 2002; Bargel 2005] and determines its mechanical properties – elasticity, resistance and load response. Due to the above-mentioned, determination of mechanical properties of coat layers seems to be of the utmost importance considering the end product quality and safety, its storage, processing and the structural design of machines and devices used in food processing systems [Thiagu 1993].

Elastic hysteresis is a measure of energy dissipation, which is caused by the internal friction and material structure destruction. What is more, it allows to describe both the structure and its changes during deformation [Bohdziewicz 2003; Łysiak 2006]. The energy dissipation may be also developed by the mechanical vulnerability such as cracking or disintegration [Dobraszczyk 1994; Fossdal 2005].

Recent year's data indicate the growing popularity of rheological investigation applications, connected with determination of hysteresis loop with reference to the crop materials. Gindl (2006) in the cycling stretching test applied repeated loading and unloading with recuperated cellulose fibre. Spatz (1999) used the stretching test during the rheological examination of the *sklerenchym tissue. Hysteresis loop was also determined in the* compression tests with respect to the apples [Holt 1983; Blahovec 1997], pears [Blahovec 2002], potato bulbs [Holt 1983], sugar beet roots [Bzowska-Bakalarz 1994] and wheat grain [Łysiak 2006]. The rheological properties of the isolated tomato skin were defined by Petracek (1995) and Edelmann (2005).

The determination of hysteresis loop characteristics is usually connected with load and unload energy, absorbed energy value and hysteresis losses [Holt 1983; Bzowska-Bakalarz 1994; Doherty 1998; Blahovec 2002; Malkin 2006; Bohdziewicz 2007]. The elasticity of the fruit tissue might be characterised by the value of elasticity modulus (degree of elasticity) expressing the participation of accumulated elastic strain energy in the general deformation force balance [Bohdziewicz 2007].

On account of the shortage of data concerning the hysteresis loop losses for the skin of the soft fruits, the authors of the present article decided to conduct the research focusing on the determination of the absorbed energy, degree of elasticity and loses of hysteresis loop for the skin of the tomato put through the tension in the process of loading and unloading.

MATERIALS AND METHODS

Laboratory tests were carried out on tomato fruits (*Lycopersicon esculentum* Mill) cv. *Admiro*, ripe and similar in size, supplied by the Leonów Greenhouse Gardening Company in Niemce near Lublin.

The experiment was conducted on the measuring stand assigned for the determination of mechanical properties of biological materials [Gładyszewska 2006].

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 thickness of each sample was measured under an optical microscope with the accuracy of ± 0.05 mm.

The prepared samples were placed in clamping grips of the tensile machine, which allows constant and measurable increase of the tensile force value. Powdered graphite markers were randomly sprayed on the sample surface. The strips were at first stretched, up to the chosen force value (increment in the force during uniaxal tension was equal to 1.4 N·min^{-1}). Then the sample was unloaded by decreasing the tensile force to zero. The force value as well as the sample tensile strain was determined on the grounds of the method of random markers [Gładyszewska 2007].

The obtained relations of force-tensile strain, derived from 15 repetitions were used to determine the average value of absorbed energy W_a [mJ], which relates to the area between the load and unload curves (Fig. 1). Degree of elasticity t_{sp} and the hysteresis loss degree S_h were determined according to the relations 2 and 3, respectively.

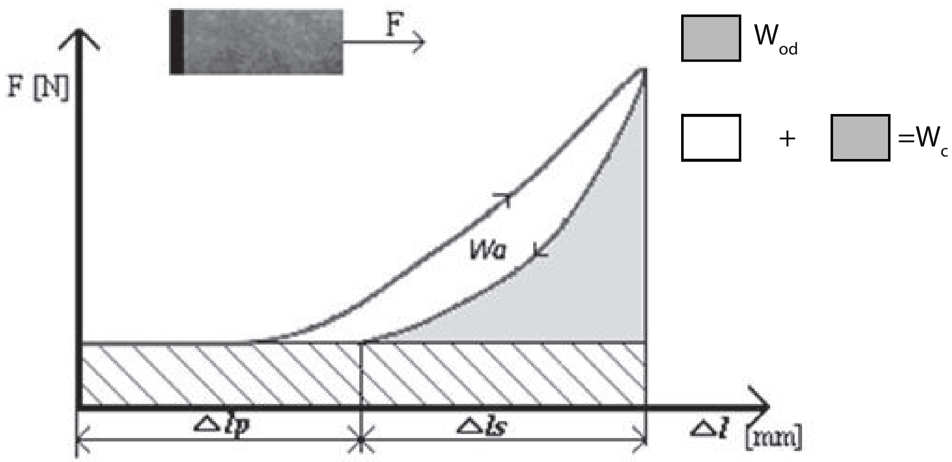

Fig. 1. Load curve for tomato fruit skin with marked parameters: W_c, W_a, Δl_p i , Δl_s

$$W_a = W_c - W_d, \tag{1}$$

$$t_{sp} = \frac{\Delta l_s}{\left(\Delta l_s + \Delta l_p\right)} \cdot 100\%, \tag{2}$$

$$S_h = \frac{W_a}{W_c} \cdot 100\%, \tag{3}$$

where: W_c – total energy [mJ], W_{od} – unload energy [mJ], Δl_s – elastic strain [mm], Δl_p – plastic strain [mm].

RESULTS AND DISCUSSION

Figure 2 presents the exemplary characteristic of the load-unload test for the tomato skin sample. Along with the tensile force increase, strain growth could be observed. The specimen, which was cut from the fruit directly after harvesting, could be loaded and unloaded several times. The first loading of the examined sample was conducted until the tensile force reached 1.7 N. Then, the sample was completely unloaded, after which the specimen was subjected to a load of 2.3 N. The sample damage was observed in the presence of tensile force of 3.5 N (Fig.2).

Table 1 shows the absorbed energy values W_a, material degree of elasticity $\boldsymbol{t_{sp}}$, and hysteresis losses S_h, for the first (I) and second (II) load (Fig. 1).

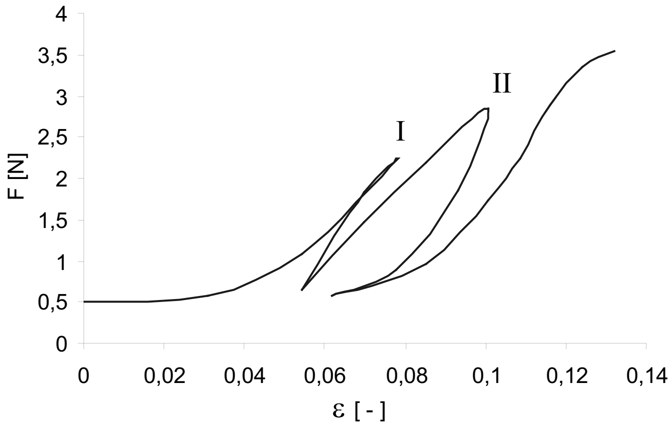

Fig. 2. Force – relative strain relation F(ε) during the cyclic load-unload test for tomato skin sample, harvested directly from the plant

Table 1. Average values of absorber energy W_a, degree of elasticity t_{sp} and hysteresis losses for the fresh tomato fruits during load I and II

	Load I	Load II
Force [N]	1.7	2.3
W_a [mJ]	$2.1 \cdot 10^{-3}$	$18.6 \cdot 10^{-3}$
t_{sp} [%]	40	71
S_h [%]	12.3	54.2

In case of the first load (I), the amount of absorbed energy was 8 times lower than during the second one (load of 2.3 N). For the second load (II) over fourfold increase in hysteresis losses degree was observed compared to load I. The degree of elasticity value, determined during the first load-unload cycle stayed in the region of 40 % while through the second one reached 71% (Tab.1).

It was possible to load only once (one load and one unload) the samples that were cut from the stored fruits and kept at the temperature of 21°C in the controlled environment chamber for 2 days. The research showed that the time and storage conditions of the tomato fruit as well as its ripening process had a huge impact on the skin structure and mechanical properties [Ciupak 2010].

Figure 3 presents the sample graph of the tensile force in the function of specimen relative strain F(ε), which was determined in the load-unload cycle. The value of the tensile force was not higher than 3 N for all the examined cases, which allows to load the sample completely and to avoid sudden rupture at the same time. The obtained hysteresis loops were used in the average absorbed energy values W_a, degree of elasticity t_{sp} and hysteresis losses S_h determination. The parameters were calculated on the basis of 15 repetitions and presented in Table 2.

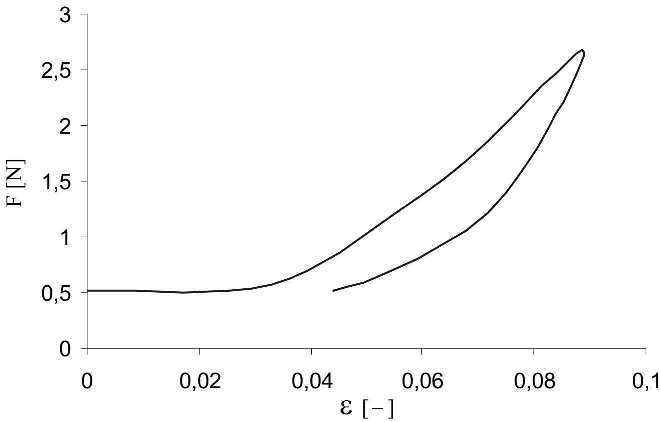

Fig. 3. Sample graph of the tensile force in the function of relative strain F(ε)

For the examined tomato skin the 50 % hysteresis loss could be observed (Tab.2). The skin of the fruits stored in an environment chamber and samples from tomatoes harvested directly from the plant (I load) were comparable with respect to degree of elasticity t_{sp}, which reached the level of 40 % (Tab. 1 and Tab. 2).

Table 2. Average values of absorbed energy W_a, degree of elasticity t_{sp} and hysteresis losses S_h determined for stored tomato fruits

W_a [mJ]	$20.3 \cdot 10^{-3}$
t_{sp} [%]	41
S_h [%]	50.8

It might be expected that with the material and skin cells damage growth during uniaxal tension test, the values of absorbed energy and hysteresis losses would increase while on the other hand the decrease in degree of elasticity value should be observed. Blahovec (2002) obtained similar results during compression tests with respect to pears.

On account of the lack of information concerning determination of absorbed energy, degree of elasticity and hysteresis losses for the skin of the tomato, the received results cannot be compared with other outcomes. Admittedly, Pertacek (1995) established rheological characteristics of isolated tomato skin, while Edelmann (2005) described the cuticle participation in rheological tomato skin properties, but the numerical values of the determined parameters were not provided.

It might be observed, that the absorbed energy values (Tab. 1, Tab. 2) are significantly lower than the energy obtained during e.g. apple compression test, contained in the 0,1 J to 0.4 J range [Blahovec 1997] and pears ($3.6 \cdot 10^{-3}$ J to 0.3 mJ) [Blahovec 2002]. The absorbed energy value during the cycle load of wheat grain and its increase with the humidity escalation was determined by Łysiak (2006) at the level of 2.5 mJ – 23 mJ.

The degree of elasticity for tomato skin, determined on the level of 40 % < t_s < 71 % (Tab. 1 i Tab. 2), might be compared with the data obtained during tests on the pears – 28.3 % < t_{sp} < 75.9 % [Blahovec et al. 2002] and sugar beet roots – 64 % < t_{sp} < 88 % [Bzowska-Bakalarz 1994].

The calculated hysteresis losses for tomato skin S_h ranged from 12.3 % to 54.2 %. Blahovec (2002) presented similarly wide range for that parameter, establishing it between 35 % - 85 % for pears. Hoolt (1983) determined the hysteresis losses for the potato at the level of 75 % and for apples at 30 %. Bzowska-Bakalarz (1994) conducted investigation on hysteresis losses in the first load-unload cycle with reference to fresh and withered sugar beet roots. The outcome of this study showed that the hysteresis losses value ranged from 34 % to 62 % and was about 35 % higher for fresh roots than the one determined for the withered roots.

CONCLUSIONS

1. Absorbed energy values for the skin of tomato harvested directly from the plant ranged from $2.1 \cdot 10^{-3}$ mJ to $18.6 \cdot 10^{-3}$ mJ while the degree of elasticity and hysteresis losses – 40% to 71% and 12.3 % to 54.2 % respectively, depending on tensile force value.
2. Absorbed energy, hysteresis losses and degree of elasticity defined for stored fruits was stabilized at the level of $20.3 \cdot 10^{-3}$ mJ, 41 % and 50.8 %, respectively.
3. The outcome of this study shows that the random markers method might be applied for elastic hysteresis determination with reference to soft fruits. It should be pointed out that the presented research provided a preliminary characteristic in the field of mechanical properties of soft fruit and its continuation is required.

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WYZNACZANIE HISTEREZY ODKSZTAŁCEŃ SKÓRKI OWOCÓW POMIDORA W TESCIE JEDNOOSIOWEGO ROZCIĄGANIA

Streszczenie. W pracy przedstawiono charakterystykę pętli histerezy skórki owoców pomidora odmiany Admiro przechowywanych w komorze klimatycznej w temperaturze 21 ºC, otrzymaną podczas rozciągania próbki w procesie obciążenie-odciążenie. W oparciu o metodę losowych znaczników wyznaczono wartości siły i odkształcenia próbki, a następnie wartość energii zaabsorbowanej, stopnia sprężystości materiału oraz strat histerezy. W zależności od siły obciążającej wartość energii zaabsorbowanej dla skórki owoców świeżych zawierała się w przedziale $2,1 \cdot 10^{-3}$ mJ do $18,6 \cdot 10^{-3}$ mJ, a straty histerezy od 12,3 % do 54,2 %. Dla owoców przechowywanych energia zaabsorbowana wynosiła $20,3 \cdot 10^{-3}$ mJ, zaś starty histerezy 50,8 %. Stopień sprężystości badanego materiału zawierał się w przedziale od 40 % do 71 %.

Słowa kluczowe: skórka pomidora, energia zaabsorbowana, stopień sprężystości, strata histerezy.