TEKA Kom. Mot. Energ. Roln. – OL PAN, 2010, 10, 59–65

THE INFLUENCE OF THE STORAGE TIME ON SELECTED MECHANICAL PROPERTIES OF APPLE SKIN

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Summary. In the article the research results of the storage time influence on the change of selected mechanical properties of Topaz variety apple skin were presented. The changeability of Poisson's ratio, Young's modulus and critical stress during two-month apple storage were studied. The increase of Young's modulus and critical stress parallel to the stabilization of Poisson's ratio at the level of 0,44-0,67 was observed.

Key words: apple skin, Young's modulus, Poisson's ratio, critical stress

INTRODUCTION

The area size, over which at present fruit and vegetables are planted, forces mechanical harvest. It is dictated by economical reasons resulting from the lack of suitable workforce and a short harvest period. However, this causes a damage in the harvested agricultural produce. To determine the kind of physical phenomena and, consequently, the cause of the occuring damage, physical properties of fruit and vegetables should be analysed. It can be achieved by the determination of the material's constant such as Young's modulus and Poisson's ratio.

There is extensive literature concerning the researches of mechanical properties of plant materials. Because of the metamorphic nature of cellular structure of such materials and also its anisotrophy and heterogeneity it is difficult to directly determine the Poisson's ratio of plant materials. Hence a lot of indirect methods are practised. Two main ways of the determination of Poisson's ratio of plant materials can be singled out. The first consists in axial compression or tension of sample or whole fruit and strain measuring in the direction of force action as well as strain in the perpendicular direction to the acting load. This allows to determine Poisson's ratio by the definition.:

$$\nu = -\frac{\varepsilon_y}{\varepsilon_x}, \qquad (1)$$

where: ε_x – strain in the direction of tensile force
ε_y – strain in the perpendicular direction to the acting force

The second way consists in Poisson's ratio's calculation by means of the determination of any of the two material's constants defning the mechanical properties of a given material such as: bulk modulus K, shear modulus G, Young's modulus E.

The first method found application in Anazodo and Chikwendu research [Anazodo 1983], who determined Poisson's ratio of corn cob on the basis of radial compression test between two flat parallel surfaces, assuming that body deformation is symmetrically relative to horizontal and vertical axes. Chappell and Hamann [Chappell 1968] defined the temporal relation of Poisson's ratio for apple flesh through the application of uniaxial compressing loading on a cylindrical sample. The value of the applied force as well as the axial and lateral deformation were recorded on oscillograph.

Similar measurements of Poisson's ratio were carried out by Hammerle and McClure [Hammerle 1971] testing sweet potato flesh and using photomicrometer in their experiments. Burubai [Burubai 2008] determined Poisson's ratio for African nutmeg. During the compression of samples he made measurements of radial and axial strain by means of digital calliper.

The second method was used by White and Mohsenina [White 1967], who defined Poisson's ratio in an indirect way, determining in two independent experiments Young's modulus E and bulk modulus K as well as making use of the equation:

$$\nu = \frac{1}{2} \cdot \left(1 - \frac{E}{3K}\right). \tag{2}$$

A similar method was applied by Finney and Hall [Finney 1967] studying potato tubers. Another way of determining Poisson's ratio was presented by Hughens and Segerlind [Hughens 1972]. They carried out an axial compression of cylindrical samples by the same dimensions, moreover one of them was compressed unconstrained, while the other in the cylinder preventing radial strains. On the assumption that the material of both samples is identical they received functions describing behaviour of material in uniaxial stress state and uniaxial strain state. These equations enabled the determination of Poisson's ratio. The method found an extensive application. It was used by DeBaerdemaeker [DeBaerdemaeker 1976] in research of apple flesh and by Gołacki and Stropek to determine the changeable in time Poisson's ratio for carrot [Gołacki 2004], potato [Gołacki 2003] and apple [Gołacki 2001].

Another approach was presented by Gyasi, Fridley and Chen [Gyasi 1981]. They defined in an indirect way the change of Poisson's ratio value in time for flesh and skin of lemon as well as orange by means of the formula:

$$\nu = \frac{1}{2} \cdot \left(1 - \frac{G_r(t)}{3K}\right), \tag{3}$$

previously determining bulk modulus K and function $G_r(t)$, which describes the phenomenon of stress relaxation occurring in the test of uniaxial unconstrained sample compression.

The above-presented measurement methods concerned fruit flesh, however, a lot of research showed that the resistance especially to cracking and puncture to a considerable degree depends on the physical properties of the skin itself. Consequently, the researchers' interest focused on the mechanical properties of tomato skin [Matas 2005, Gładyszewska 2009] and apple skin [Clevenger 1968]. Also the strength tests of seed cuticle leguminous plants were carried out [Dobrzański 1998, Gładyszewska 2007].

Hence the aim of the research presented in this article was the determination of variability of Poisson's ratio, Young's modulus and critical stress of Topaz variety apple skin subjected to uniaxial tension during its 70 days of storage.

MATERIAL AND RESEARCH METHOD

The subject of the research was Topaz variety apple skin. The measurements were carried out from November 2008 to January 2009 at intervals not bigger than 10 days. In each measurement series 40 repetitions were performed. Apples for the experiment were selected randomly out of these whose skin was coloured red and did not have any visible, external damage. The apples were kept in a storage house and one day before the measurements they were placed in the room temperature (20°C) for thermal stabilisation of fruit. The samples had a rectangular shape and were cut out longitudinally from the coloured part of apples, so that the flesh layer on the skin was the thinnest possible. To get the skin sample the knife with the limiter was used, providing the repeatability of the sample thickness. The remains of the flesh were not removed on account of the high probability of skin damage and thus the possibility of obtaining faulty findings. Next, the measurement of skin thickness was performed by microscope with the accuracy of ±0,01 mm in 5 different points and the average value for a given sample was calculated. The width of the sample was also measured by means of calliper with accuracy of ±0,02 mm. To eliminate the effect of skin drying each test was carried out immediately after the sample's preparation. After each measurement force *F* was recorded, by which tearing of the sample subjected to tension occurred. Knowing cross section surface area of sample *S*, critical stress can be calculated from the formula:

$$\sigma = \frac{F}{S}, \tag{4}$$

where : F[N] force causing sample damage, $S = a \cdot b$, a and b denote thickness and width of the sample, respectively.

With the aim of determining Young's modulus and Poisson's ratio the method of randomly distributed markers was used based on image analysis and distance analysis of points placed on apple skin surface subjected to uniaxial tension [Gładyszewska 2007]. Knowing the strain ε_x for different stress values σ we can define Young's modulus:

$$\nu = -\frac{\varepsilon_y}{\varepsilon_x}, \tag{5}$$

$$E = \frac{\sigma}{\varepsilon_x}. \tag{6}$$

WATER CONTENT MEASUREMENT

To measure the water content in the apples' flesh the oven dry method was applied. The research consisted in establishing the difference in sample mass before and after drying at the temperature of 70°C. The ground apple flesh was placed in small containers and weighed on a WAS 160/C/2 analytical scale to an accuracy of ±0,01g, next it was dried in a dryer for 72 hours till the establishment of constant mass of the sample. After the drying the sample was weighed again. The absolute humidity was calculated according to the formula:

$$w = \frac{(m - m_1)}{m_1} \cdot 100[\%], \tag{7}$$

where: w – absolute humidity of apple flesh [%],
m – mass of fresh sample [g],
m_1 – mass of sample after drying [g].

To determine the water content the average value from 20 samples was assumed. The average values of apple flesh absolute humidity during all the period research did not show statistically significant differences and amounted from 84% to 85,9%.

MEASURING STAND

The measurements were carried out on the stand for mechanical properties research of thin-film biomaterials [Gładyszewska 2006]. The sample, prepared directly before measurement, was clamped in the strength machine. One of the clamps was attached permanently to KT 1400 extensometer of Megaton Electronic AG&CO with the range of the measured force 0-100N and the other moveable was connected with a pull rod through transmission with tank, to which water was supplied at a given flow velocity. Thus the constant velocity of increasing loading force of the sample during the experiment was regulated. The stand was also fitted with a CCD camcorder with microscopic lens, which enabled the observation of the tensed sample with the resolution of 240x320 pixels of 5 times magnification. The picture from the camcorder was transferred to the computer memory together with the information about tensile force value. It enabled later connection of the tensile force value with the corresponding sample strain. Markers in the form of graphite powder were placed on the skin at random. When some water was supplied to the tank through transmission and the pull rod, the process of sample tension up to its tearing apart was carried out.

The method of randomly distributed markers allows to avoid a lot of limitations and errors typical for other mechanical properties research methods of biological materials. Its most important advantage is the independence of the obtained results from the effects occurring in the sample boundary area, that is close to strength machine clamps[Gładyszewska 2007]. This method enables to carryout measurements in a well-defined selected place of the tested sample skin, e.g. where there is the necessity of cutting out a sample with a constant cross section in the middle part.

RESULTS AND DISCUSSION

The carried out tests of Topaz variety apple skin tearing and application of the method of randomly distributed markers enabled to determine Poisson's ratio, Young's modulus and critical stress of the tested samples in over two-month storage time. Figure 1 presents the changes of Poisson's ratio in time. The average Poisson's ratio values amount to (0,44-0,67). Such a large distribution of results is caused by non-homogenity of the material.

Figure 2 shows variability of Young's modulus during two-month storage of the apples. The average values of Young's modulus during the first month remain without any changes stabilising on the level amounting to 8-9 MPa, while after this period an increase occurs up till 11-12 MPa and the constant value remains again to the end of the research. Despite the balanced value of the tested apple's flesh water content (84%-85,5%), during storage time the skin, as an external cover of fruit, undergoes physical changes causing its bigger capability of load carrying visible in the increase of Young's modulus value .

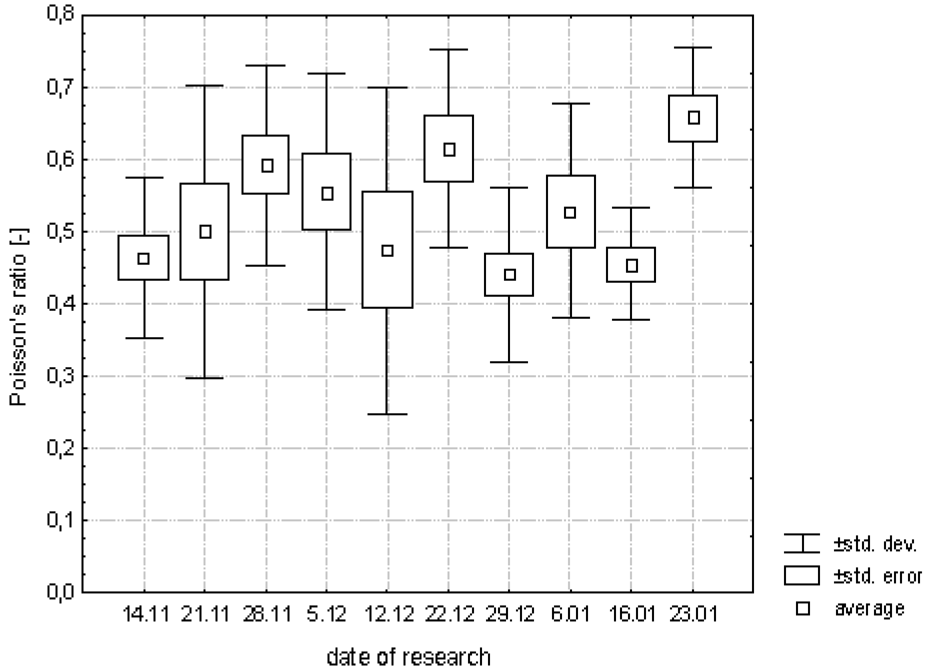

Fig. 1. The influence of apple storage time on Poisson's ratio of skin

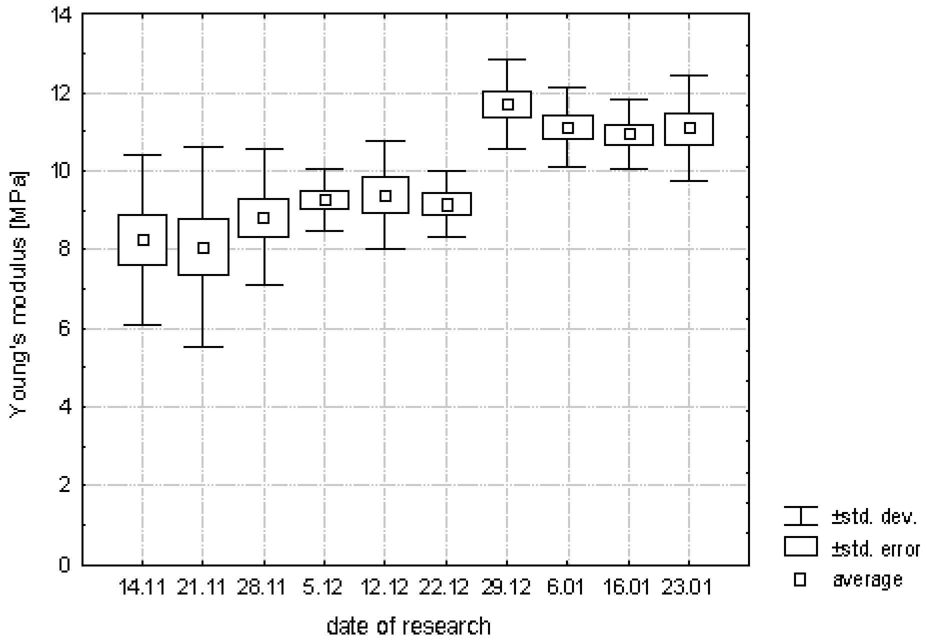

Fig. 2. The influence of apple storage time on Young's modulus of skin

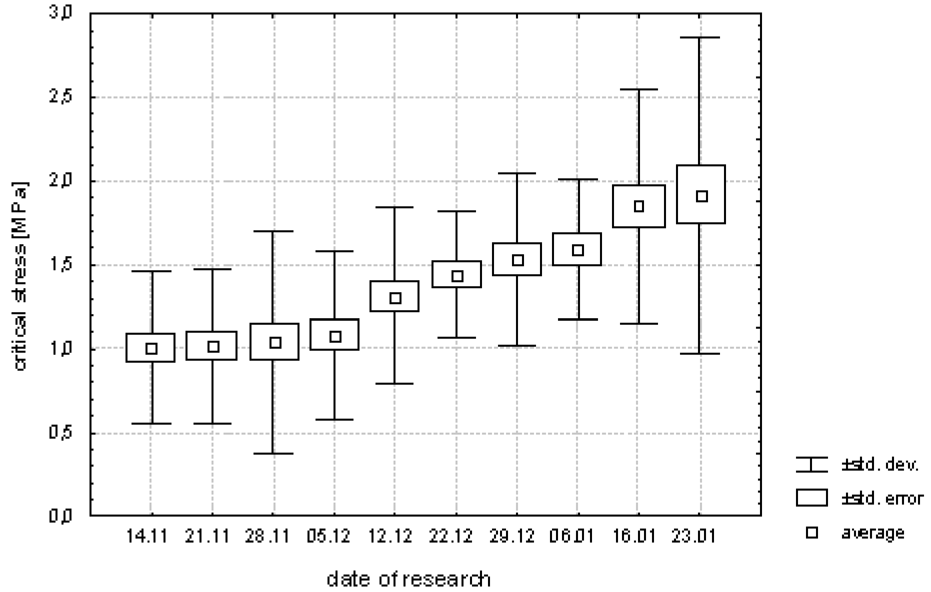

Fig. 3. The influence of apple storage time on critical stress of skin

In the case of the relationship between the critical stress and date of research presented in Figure 3, there is a visibly increasing trend from 1 to 1,9 MPa in over two-month storage time. But on account of big values of standard deviation in the consecutive measurements a statistically significant difference can not be found between the average values of critical stress within the research period.

CONCLUSIONS

The carried out research and the analysis of the obtained results allows to express the following conclusions:

1. Poisson's ratio value of Topaz variety apple skin in the studied period fluctuated in the range of 0,44-0,67.
2. Young's modulus value of apple skin remained constant in the range of 8-9 MPa in the first month of research, and then increased to 11-12 MPa value, staying on the constant level.
3. There is a visible increasing tendency of the critical stress values of apple skin from 1 to 1,9 MPa.

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WPŁYW CZASU PRZECHOWYWANIA NA WYBRANE WŁAŚCIWOŚCI MECHANICZNE SKÓRKI JABŁKA

Streszczenie. W pracy przedstawiono wyniki badań nad wpływem czasu przechowywania jabłek odmiany Topaz na zmianę wybranych mechanicznych właściwości skórki jabłka. Zbadano zmienność modułu Younga, współczynnika Poissona oraz naprężenia krytycznego w trakcie dwumiesięcznego przechowywania jabłek. Zaobserwowano zwiększenie wartości modułu Younga oraz naprężenia krytycznego przy jednoczesnym ustabilizowaniu się współczynnika Poissona na poziomie 0.44 - 0,67.

Słowa kluczowe: skórka jabłka, współczynnik Poissona, moduł Younga, naprężenie krytyczne