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CHANGES OF MECHANICAL PROPERTIES OF KUMQUAT (*CITRUS JAPONICA* THUNB.) AND CAPE GOOSEBERRY (*PHYSALIS PERUVIANA* L.) FRUITS DURING STORAGE

Jerzy Bohdziewicz*, Gabriel Czachor

Department of Agricultural Engineering, Wroclaw University of Environmental and Life Sciences
* *Corresponding author: e-mail: jerzy.bohdziewicz@up.wroc.pl*

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ABSTRACT

The selected physical properties as well as mechanical proprieties of kumquat and cape gooseberry fruit kept in the temperature of 12ºC for 3 days, 8ºC for 6 days and 4ºC for 9 days were studied. The mass and size of fruit in three perpendicular directions were determined and density and moisture of tested material were calculated. Compressive tests of whole fruit were conducted for two directions of load application in order to determine the unit work W_P an apparent coefficient of elasticity, stress σ and strain ε. The growth of inputs of the deformation work with expansion of the storage time was confirmed with regard to kumquat fruit which is related to the decrease of their conventional density. The decrease of the stress and elasticity values coefficient of cape gooseberry fruit with higher temperatures of storing expressed with the change of the slope angle of curves of the relation of stress-deformation was proved.

Introduction

Irregularity, seasonality of deliveries and the limited range of distribution have the influence on the marginal economic meaning of tropical plants fruit in Poland. However, the global economy processes in reference to consumers' market can cause changes in this range. The observed climate changes in the world scale are causes for moving the tillage zones from the tropical areas to the northern direction. For example fruits of kumquat (*Citrus japonica* Thunb.) which originate in China and South American cape gooseberry fruit (*Physalis peruviana* L.) which are grown in the south countries of Europe, and then are delivered to the Polish market.

The quality standards of fruit admitted for trade in the European Union countries relate, first of all, to organoleptic properties such as selected physical properties, packaging procedures to suitable quality of the products and assurance of consumers' health safety. There is no information on the changes of mechanical properties of kumquat and cape gooseberry fruit during storage.

Exact requirements are related to moisture and suitable conditions of atmosphere with regard to considerable distances of transportation of the fruit. The fruit can even be kept several weeks in such conditions.

However, since the moment of purchase, the conditions of storage change the texture of fruit which deteriorates with time. The physiological activity and composition of chemical substances of tissues also change. In reference to kumquat fruit the recommended limitation of the storage time is one week.

Investigations of Babitha and Kiranmayi (2014) showed the increase of the pH coefficient and moisture values of tomato fruit after 24 days of storage in the room temperature and after chilling both in normal conditions and in the modified atmosphere.

In the available literature we can find information related to the influence of time and the temperature of storage on changes of firmness and puncture force of different fruit within the standard test TPA. For example, pear fruit (Eissa et al., 2012) and tomato (Abaloushi et al., 2012) stored in the temperatures of 5, 15 and 25ºC by the period of 4 weeks were tested. The increase of firmness and the puncture force after one week of storage was proved in both fruit, independently to temperature of storage and the degree of fruit's maturity. Gradual decrease of the value of these texture properties was proved in the following weeks.

Sirisomboon and Lapchareonsuk (2012) conducted investigations on pomelo fruits stored by 4 months. In this case it was proved that the firmness of the fruit tissues had reduced in the course of storage time, however the degree of elasticity imperceptibly increased after 30 days of storage and then reduced its value gradually. Physical features such as mass and volume changed only imperceptibly.

Liliantabar et al. (2012) carried out the compressive test between two rigid plates of whole kumquat fruits. It was proved that the average density is near 1200 $kg \cdot m^{-3}$ as well as average value of the module of elasticity was 52.1 MPa and the maximum break force was 24.1 N. Liliantabar and Lorestani (2014) determined the equations of correlation among the sizes of kumquat fruit Nagami var. and its mass.

Physical proprieties and usefulness of cape gooseberry for consumption and medical usage were described by Puente et al., (2010). This fruit is a juicy oval shaped berry. The maximum puncture force is 9.75 N and the force of the flesh penetration is about 2.73 N.

Llanos et al., (2013) also performed investigations of the mechanical properties of cape gooseberry fruit. These investigations were conducted with the use of the texture analyzer TPA, near the loads in the axial and radial direction. Mechanical proprieties were appointed on the basis of the course of the real stress (σ) versus the Hencky strain (εH) squeezing fruit between rigid plates. The average value of stress σ for the axial direction was 6 kPa with the 0.83 value of deformation (εH). Respectively for the radial direction σ is about 3 kPa with 0.41 value of εH.

Methodology

The objective of the research was determination of physical and mechanical properties of kumquat and cape gooseberries fruits which take place during storage in different temperatures and in various time intervals.

The fruit after purchase at the wholesalers were sorted with regard to shape and sizes at 4 groups. The first of them was kept by 24 hours in the room temperature of 20ºC. The second group was placed in the temperature of 12ºC by 3 days, the next group in the temperature of 8ºC by 6 days and last group in the temperature of 4ºC by 9 days. The strength compression test was conducted to the delimitation of mechanical features of fruit in two mutually perpendicular directions of load application with 10 iterations in both directions. Also the conventional density and the moisture of the studied material were determined.

For investigations the Instron machine type 5566 with measurement head 2525-806 in range to 1 kN was used. The strength test was realized in the parallel direction to fruit longitude axis and in the direction perpendicular to it. The speed of deformation during compressive test was $3 \cdot 10^{-5}$ m·sec^{-1}.

The expenditures of the unit work W_P of deformation of squeezing fruit were measured. For calculations the following equation was used:

$$W_p = \frac{W}{m} \ (\mathrm{J \cdot kg^{-1}}) \tag{1}$$

where:
- W – work of deformation,
- m – fruit mass.

The value of the apparent coefficient of elasticity E_C was accepted as the measure of the material resistance to the load squeezing considered as the coefficient defining the $\sigma - \varepsilon$ relation (Bohdziewicz and Czachor, 2010). The measurement method of spherically shaped objects was developed earlier for calculations of values of this coefficient (Bohdziewicz, 2008). The calculations formula has the following form:

$$E_C = \frac{\xi \cdot \int_0^{\lambda} F_{(\lambda)} \cdot \mathrm{d}\lambda}{\varepsilon^2} \ (\mathrm{MPa}) \tag{2}$$

where:
- $F_{(\lambda)}$ – force,
- ξ – coefficient taking into account the sizes of fruit,
- ε – relative deformation in direction of the load,
- $\mathrm{d}\lambda$ – displacement.

Results and discussion

80 pieces of kumquat and cape gooseberry fruit were tested -10 pieces in each compressive test. The results of calculations of the average values of coefficients and ratios characterizing the mechanical properties of the stored fruit in the break point of the sample were presented in tables 1 and 2.

The change of average values of kumquat fruit's density in the storage time is visible from the comparison of the records of physical features values in both tables, even after lowering the temperature. These fruits have thin penetrable external skin in distinction to waxy skin of cape gooseberry which makes transpiration of moisture difficult. In consequence the average values of the coefficient W_p as expenditures of the deformation work in relation to the mass increased. Variability of the values of mechanical properties with the load in both directions as a consequence of various shape of fruit. The kumquat fruits had from 1.1 to 1.2 time larger diameter in the axial direction than in the radial one, but the opposite relation report to the cape gooseberry fruit.

Table 1.
Average values and standard deviation (SD) of selected physical features and mechanical properties in the break point of sample, compressive test of whole kumquat fruit kept in different temperatures and time

Test conditions	Physical features			Mechanical properties			
	Mass (g)	Moisture (%)	Density (kg·m^{-3})	W_p (J·kg^{-1})	E_c (MPa)	σ (MPa)	ε (-)
Axial 20°	6.2 (0.7)	86 (2)	1210 (72)	49.6 (5.1)	0.42 (0.04)	0.22 (0.02)	0.53 (0.02)
Radial 20°	6.6 (1.3)	84 (3)	1245 (75)	28.6 (9.9)	0.34 (0.05)	0.16 (0.03)	0.46 (0.05)
Axial 12°	6.1 (1.1)	85 (1)	1245 (156)	48.1 (8.2)	0.46 (0.09)	0.23 (0.05)	0.51 (0.02)
Radial 12°	6.3 (0.6)	85 (2)	1151 (85)	27.1 (5.3)	0.33 (0.04)	0.14 (0.02)	0.43 (0.02)
Axial 8°	5.9 (0.5)	86 (2)	1139 (60)	52.8 (14)	0.46 (0.07)	0.23 (0.05)	0.51 (0.05)
Radial 8°	6.5 (1.1)	85 (2)	1045 (100)	33.5 (9.5)	0.33 (0.05)	0.15 (0.03)	0.45 (0.06)
Axial 4°	6.0 (1.1)	83 (2)	1010 (94)	68.9 (17.4)	0.47 (0.06)	0.25 (0.03)	0.54 (0.040
Radial 4°	6.3 (0.8)	84 (2)	1045 (79)	33.1 (7.8)	0.33 (0.05)	0.15 (0.03)	0.44 (0.03)

Table 2.
Average values and standard deviation (SD) of selected physical features and mechanical properties in the break point of sample, compressive test of whole cape gooseberry fruit kept in different temperatures and time

Test conditions	Physical features			Mechanical properties			
	Mass (g)	Moisture (%)	Density (kg·m^{-3})	W_p (J·kg^{-1})	E_c (MPa)	σ (MPa)	ε (-)
Axial 20°	4.3 (0.4)	84 (3)	1253 (45)	10.3 (3.3)	0.13 (0.02)	0.05 (0.01)	0.36 (0.07)
Radial 20°	4.1 (0.5)	84 (2)	1287 (85)	10.5 (1.2)	0.22 (0.02)	0.08 (0.01)	0.35 (0.02)
Axial 8°	4.1 (0.4)	84 (2)	1204 (73)	9.7 (1.9)	0.13 (0.02)	0.05 (0.01)	0.41 (0.05)
Radial 8°	4.1 (0.5)	84 (2)	1287 (86)	10.4 (1.2)	0.22 (0.02)	0.08 (0.04)	0.35 (0.02)
Axial 4°	4.4(0.8)	84 (2)	1208 (55)	9.5 (3.4)	0.14 (0.02)	0.05 (0.01)	0.39 (0.06)
Radial 4°	4.5 (0.4)	83 (1)	1204 (41)	10.1 (1.8)	0.21 (0.03)	0.08 (0.01)	0.36 (0.03)

Values of the elasticity coefficient of kumquat fruit are about 0.4 MPa which classifies these as soft fruit. However, according to investigations of Liliantabar et al., (2012) the average value of this coefficient is close to 50 MPa. Similarly, the investigations of Llanos et al., (2013) prove that the value of the stress σ is above ten times higher than in case of cape gooseberry fruit. In both cases this proves the lack of possibility of objective verification of results obtained by different methods, which was also confirmed by Li et al., (2013).

The dynamics of the value changes of individual mechanical features in the course of deformation of fruit during the compression test was qualified on the basis of curves presented in figures 1 to 6.

The change of the coefficient value E_C with the increase of deformation in relation to temperature is noticeable in both figures. This coefficient is the measure of mechanical resistance of squeezed fruit, the largest susceptibility on damages is in room temperature.

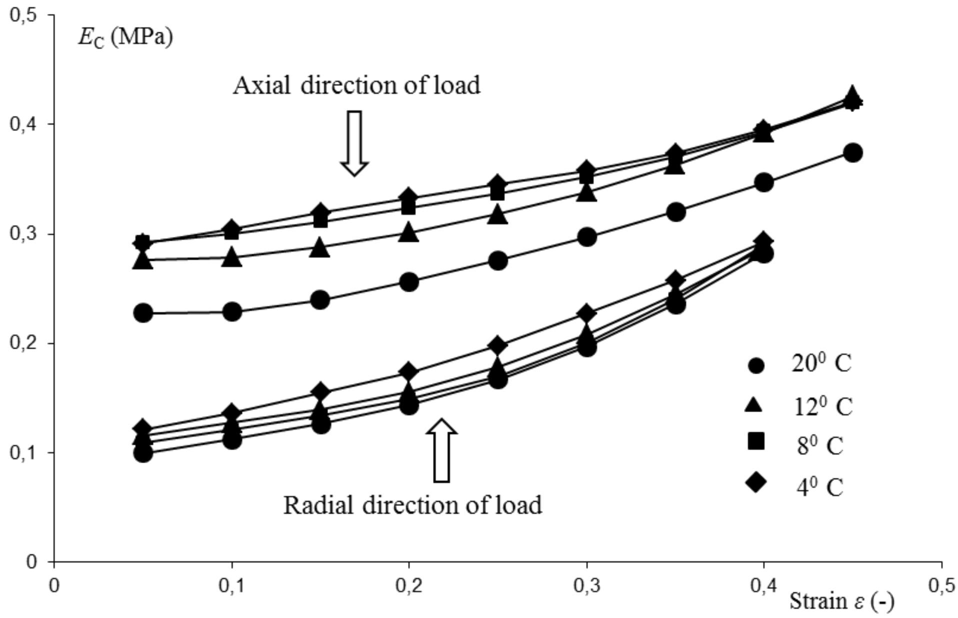

Figure 1. Compilation of average values of coefficient of elasticity E_C versus strain ε for both load directions; strength test of kumquat fruit

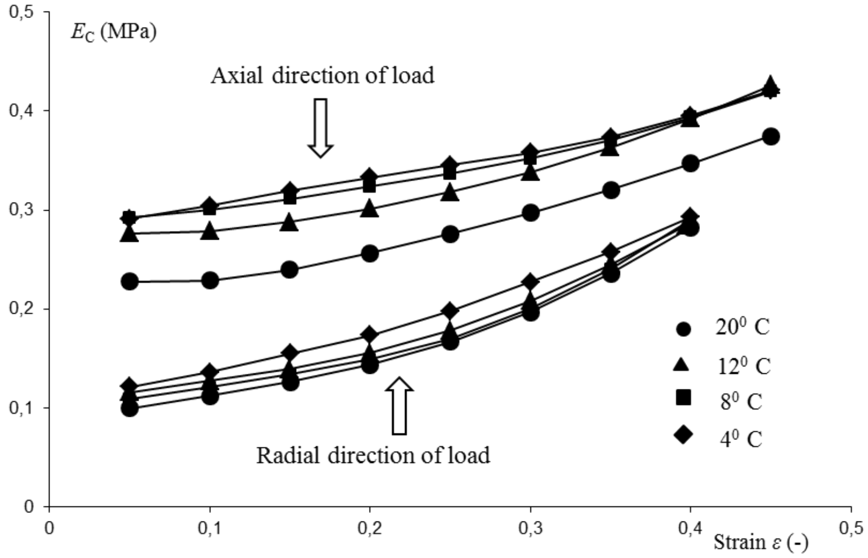

Figure 2. Compilation of average values of coefficient of elasticity E_C versus strain ε for both load directions; strength test of cape gooseberry fruit

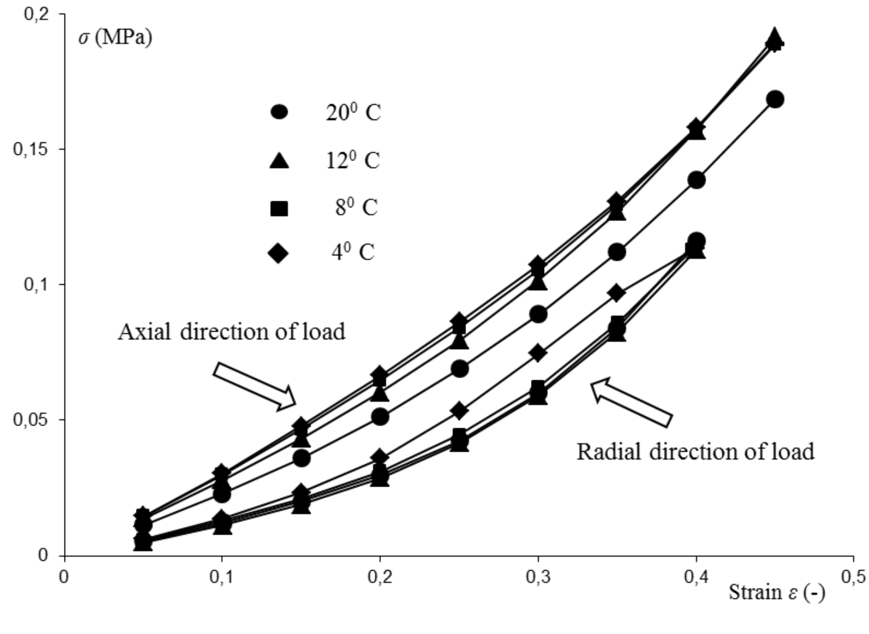

Figure 3. Compilation of average values of stress σ versus strain ε for both load directions; strength test of kumquat fruit

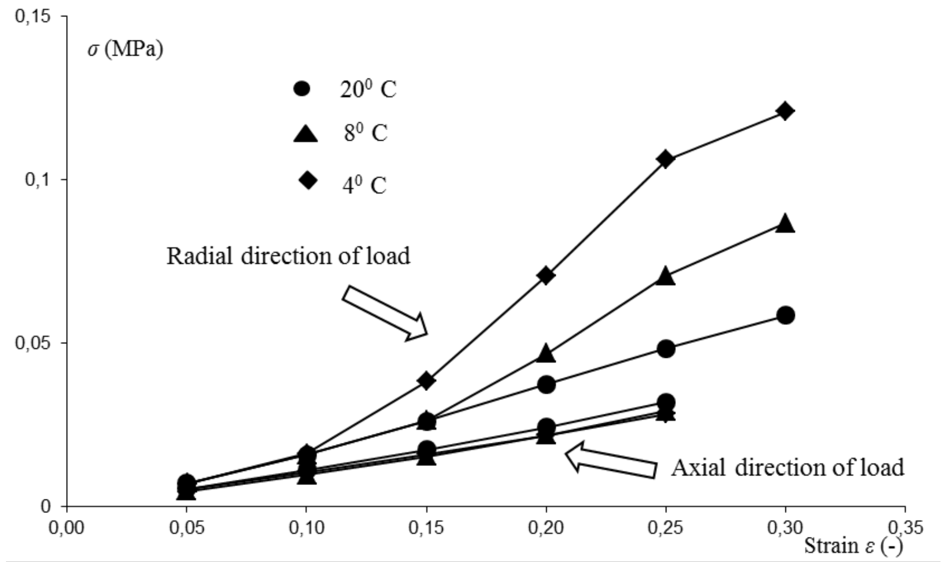

Figure 4. Compilation of average values of stress σ versus strain ε for both load directions; strength test of cape gooseberry fruit

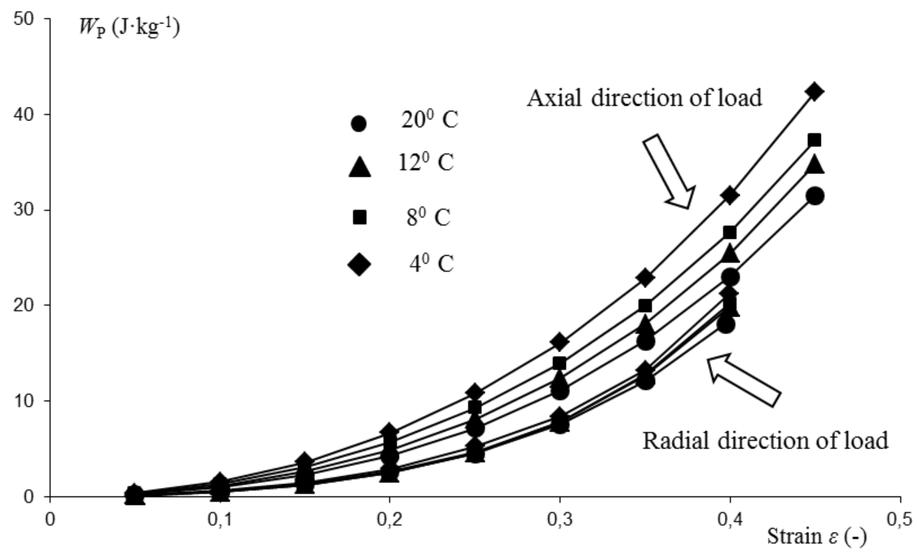

Figure 5. Compilation of average values of unit work W_p versus strain ε for both load directions; strength test of kumquat fruit

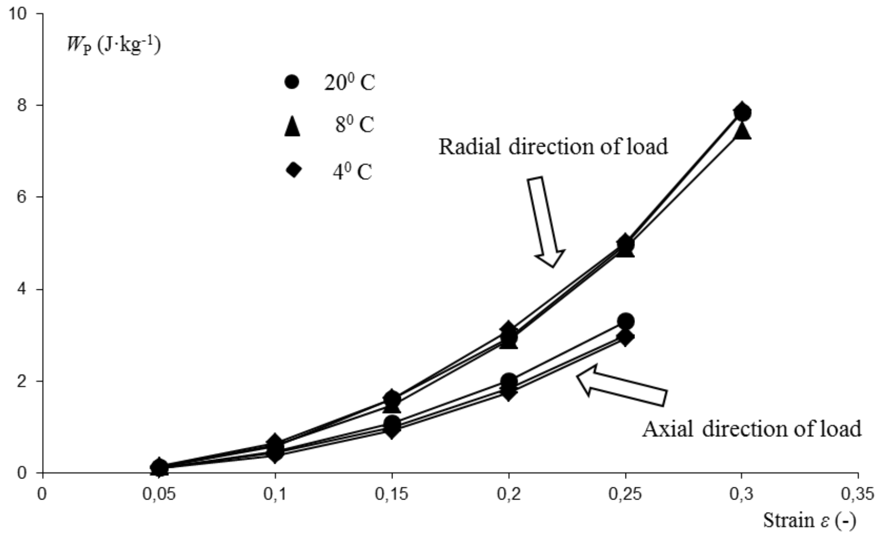

Figure 6. Compilation of average values of unit work W_p versus strain ε for both load directions; strength test of cape gooseberry fruit

The stress-strain relations presented in figures 3 and 4 have similarly courses independently to the temperature. The differentiation of the stress σ value for the cape gooseberry fruit in radial direction of load requires explanations. This is the consequence of decrease of $\sigma - \varepsilon$ curve slope in the final phase of deformation. First of all, this concerns the fruit stored in the higher temperature and results from dislocation of the break point in relation to the yield point position in the diagram graph.

The growth of the unit work expenditures is the consequence of density change of kumquat fruits during storage. As it follows from figure 5 the dynamics of the coefficient W_p value changes as the function of deformation in axial direction load is equal in the whole course of the compression independently to the temperature. These relations are not observed with regard to cape gooseberry fruit, see figure 5.

Equations taken down in tables 3 and 4 describe the dynamics of changes of individual mechanical features depending on the deformation.

In table 3 we can notice the essential differentiation values of the equation coefficients of kumquat fruit both depending on the temperature and the direction of load application. The influence of direction of load application is perceptible in reference to cape gooseberry (table 4), however the influence of the storage temperature is perceptible only for the radial direction.

Table 3.
Changes of the coefficient W_p average values as well as coefficient of E_C and stress σ during the compressive test of the kumquat fruits

Relations	Test conditions	Regression equation	R^2
$W_p = f(\varepsilon)$	Axial 20ºC	$y = 167.04x^{2.2269}$	0.9975
	Axial 4ºC	$y = 220.38x^{2.1508}$	0.9994
$E_C = f(\varepsilon)$	Axial 20ºC	y = 0.3817x + 0.1898	0.9628
	Axial 4ºC	y = 0.3084x + 0.2177	0.9855
$\sigma = f(\varepsilon)$	Axial 20ºC	y = 0.3898x – 0.0196	0.9767
	Axial 4ºC	y = 0.4295x – 0.016	0.9888
$W_p = f(\varepsilon)$	Radial 20ºC	$y = 140.15x^{2.4108}$	0.9947
	Radial 4ºC	$y = 154.99x^{2.3883}$	0.995
$E_C = f(\varepsilon)$	Radial 20ºC	y = 0.5081x + 0.056	0.9463
	Radial 4ºC	y = 0.487x + 0.085	0.9901
$\sigma = f(\varepsilon)$	Radial 20ºC	y = 0.2967x – 0.022	0.9308
	Radial 4ºC	y = 0.3193x – 0.019	0.9735

Table 4.
Change of the coefficient W_p average values as well as coefficient of E_C and stress σ during the compressive test of the cape gooseberry fruits

Relations	Test conditions	Regression equation	R^2
$W_p = f(\varepsilon)$	Axial 20ºC	$y = 58.289x^{2.0904}$	0.9998
	Axial 4ºC	$y = 54.279x^{2.1322}$	0.9994
$E_C = f(\varepsilon)$	Axial 20ºC	y = 0.0965x + 0.1021	0.9871
	Axial 4ºC	y = 0.1229x + 0.085	0.9767
$\sigma = f(\varepsilon)$	Axial 20ºC	y = 0.1317x – 0.002	0.9967
	Axial 4ºC	y = 0.1226x – 0.002	0.9936
$W_p = f(\varepsilon)$	Radial 20ºC	$y = 110.08x^{2.2158}$	0.9998
	Radial 4ºC	$y = 109{,}66x^{2.2531}$	0.9998
$E_C = f(\varepsilon)$	Radial 20ºC	y = 0.2243x + 0.135	0.9259
	Radial 4ºC	y = 0.3982x + 0.122	0.9893
$\sigma = f(\varepsilon)$	Radial 20ºC	y = 0.209x – 0.004	0.9987
	Radial 4ºC	y = 0.3306x – 0.011	0.9706

Conclusions

1. Considerable differences occur in behavior of kumquat and cape gooseberry fruit during the compressive test despite external similarity. The growth of expenditures of the unit work of deformation as a consequence of decrease of the several density values was affirmed after one week storage of kumquat fruits. Other mechanical features did not

change. In the same time the mechanical properties of cape gooseberries fruit practically do not undergo any changes.
2. The decrease of the temperature during storage results in the increase of slope curves that characterize course changes of individual mechanical features in the final phase of deformation. This has an influence on interpretation of results of strength tests.

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ZMIANY WŁAŚCIWOŚCI MECHANICZNYCH OWOCÓW KUMKWATA (*CITRUS JAPONICA* THUNB.) I MIECHUNKI (*PHYSALIS PERUVIANA* L.) PODCZAS PRZECHOWYWANIA

Streszczenie. Badano cechy fizyczne oraz właściwości mechaniczne owoców kumkwata i miechunki, przechowywanych w temperaturze 12ºC przez 3 dni, 8ºC przez 6 dni oraz 4ºC przez 9 dni. Wyznaczono masę i rozmiary owoców w trzech wzajemnie prostopadłych kierunkach, obliczano gęstość i wilgotność. Przeprowadzono testy ściskania dla dwóch kierunków przyłożenia obciążenia do wyznaczenia jednostkowej pracy W_P, pozornego współczynnika sprężystości E_C, naprężenia σ oraz odkształcenia ε. W odniesieniu do owoców kumkwata stwierdzono wzrost nakładów pracy odkształcenia przy wydłużeniu czasu składowania, co wiąże się ze spadkiem umownej gęstości owoców. Stwierdzono obniżenie wartości naprężenia i współczynnika sprężystości owoców miechunki przy wyższych temperaturach składowania jako skutek zmiany kąta nachylenia krzywej zależności od przebiegu odkształcenia.

Słowa kluczowe: właściwości mechaniczne, kumkwat, miechunka, przechowywanie