Determination of Mechanical Properties of Greengage Plum Prunus Angeleno

Ispitivanje mehaničkih osoba Prunus Angeleno

Sorte šljive Prunus Angeleno

ABSTRACT

Paper dealt with the determination of mechanical properties of greengage plum fruit of variety Prunus Angeleno. The Angeleno plum is a common late season variety which almost becomes the only choice for consumers in autumn (as the northern hemisphere season ends) and spring (as the southern hemisphere season ends). This is a dark red plum with a pale yellow flesh and small stone. The flesh is dense and crunchy, without much juice, but sweet with well-balanced flavour due to the long growing time. It will not soften, as main-stream plum varieties will, and is a totally different experience to the soft succulent Victoria plum. Angeleno is popular with growers due to ease of storage and transport, and it’s late-season slot in their production calendar. Origin of Angeleno is USA, released in 1995. Angeleno is also known a Suplumsix, a Sunworld variety.

The compress test was realized by means of test stand Andilog Stentor 1000. The compress load curves of the stress on the strain were evaluated of the lateral and longitudinal directions by two methods. The moduli of elasticity were determined and the stress and the strain in the rupture point and the bioyield point were evaluated. The modulas of elasticity in the lateral loading achieved the value about 1 MPa and the stress was in the bioyield point was 0.3 MPa. The strain in the bioyield point was 0.3 mm/mm. The stress in the rupture point was 0.3 MPa and the strain in the rupture point was 0.5 mm/mm. The modulas of elasticity in the longitudinal loading achieved the value about 2 MPa and the stress in the bioyield point was 0.6 MPa. The strain in the bioyield point was 0.3 mm/mm. The stress in the rupture point was 0.5 MPa and the strain in the rupture point was 0.5 mm/mm.

Key words: plum, compress test, modulus of elasticity.

REZIME

Ovaj rad bavi se ispitivanjem mehaničkih osobina sorte šljive sa belim mesom Angeleno. Angeleno šljiva je kasnostasna sorta koja gotovo postaje jedini izbor za potrošače u jesen (severna hemisfera) i proljeće (južna hemisfera). Ovo je šljiva tamo crvene boje sa bledo žutim mesom i malom košćicom. Meso je gusto i hrkavo, bez mnogo sok, ali slatko sa dobro izbalansiranim ukusom zbog dugog vremena razvoja. Ne omekšava, kao većina sorti šljiva i potpuno je drugačija od meke sočne sorte šljive Victoria. Angeleno je popularan kod uzgajivača zbog lakoće skladištenja i transporta, a kasno nastupa u proizvodnom kalendaru. Poreklo Angeleno šljive je iz SAD. Angeleno je takođe poznat kao Suplumsix, Sunworld sorta. Test kompresije je izveden pomoću uređaja Andilog Stentor 1000. Krive napona i relativne deformacije određene su za dva pravca ploda, uzdužni i bočni. Određen je modul elastičnosti, napon i deformacija u tački razaranja i bioyield tačka. Modul elastičnosti u bočno opterećenje dostiže vrednost oko 1 MPa, a napon u bioyield tački je bio 0.3 MPa. Relativna deformacija u bioyield tački bila je 0.3 mm/mm. Napon u tački razaranja bio je 0.5 MPa, a relativna deformacija bila je 0.5 mm/mm. Modul elastičnosti pri uzdužnom opterećenju postiže vrednost oko 2 MPa, a napon u bioyield tački je bio 0.6 MPa. Relativna deformacija u bioyield tački bila je 0.3 mm/mm. Napon u tački razaranja bio je 0.5 MPa, a relativna deformacija bila je 0.5 mm/mm.

Ključne reči: šljiva, test kompresije, modul elastičnosti.

INTRODUCTION

Mechanical damages such as bruising, collision and impact during food processing stages diminish quality and quantity of productions as well as efficiency of operations. Studying mechanical characteristics of food materials will help to enhance current industrial practices. Mechanical properties of fruits and vegetables describe how these materials behave under loading in real industrial operations. Optimizing and designing more efficient equipments require accurate and precise information of tissue behaviours.

Mirzaie et al. (2009) presented some physical properties of three apricot varieties (Nasiry Rajabali, and Ghamavi) fruits. These properties are necessary for the design of equipment for harvesting, processing, transporting, separating, packing and storage processes. Technological properties such as physical characteristics (linear dimensions, mass, volume, and so on), elasticity modulus, and hydrodynamic characteristics (terminal velocity, drag force, and so on) were determined. Babić et al. (2009) interested in the realization of two mathematical models for apricot halves surface predicting, based upon fruit dimensions estimation. The ellipsoid was adopted as shape resemble to apricot fruit shape. The new rearranged ellipsoid model was assembled. The apricot halves surface area variety Novosadska roda was predicted by measure only one fruit’s dimension, the height. Severa (2008) interested in global shape of the peaches of the Red Haven variety. The knowledge of the parameters (curvature etc.) is very useful e.g. for the evaluation of the results of the strength tests. Compression tests have been also performed - the whole peaches have been compressed between two plates at the constant cross-head velocity 20 mm/min. The force – displacement curves are characterised by certain monotonic increase and the point called bioyield, where force exhibits a drop. The bioyield significantly decreases with the date of the harvesting. The same result is approximatively valid for apparent modulus of elasticity. Shirmohammadi, M. et al. (2011) realized empirical investigation on mechanical properties of pumpkin peel. The compression test has been conducted on Jap variety of pumpkin. Additionally, stress strain curve, bioyield and toughness of pumpkin skin have been calculated. The required energy for

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reaching bioyield point was 493.75, 507.71 and 451.71 N.mm for 1.25, 10 and 20 mm/min loading speed respectively. Average value of force in bioyield point for pumpkin peel was 310N.

The aim of the study is determination of mechanical properties of Angeleno plum fruit at the compress test and determination of moduli of elasticity and stress and strain in the bioyield point and in the rupture point in the lateral and longitudinal direction.

MATERIAL AND METHOD

The Angeleno plum is a common late season variety which almost becomes the only choice for consumers in autumn (as the northern hemisphere season ends) and spring (as the southern hemisphere season ends). This is a dark red plum with a pale yellow flesh and small stone. The flesh is dense and crunchy, without much juice, but sweet with well-balanced flavour due to the long growing time. It will not soften, as main-steam plum varieties will, and is a totally different experience to the soft succulent Victoria plum. Angeleno is popular with growers due to ease of storage and transport, and it’s late-season slot in their production calendar. Origin of Angeleno is USA, released in 1995. Angeleno is also known as Suplumsix, a Sunworld variety.

A testing machine (Andilog Stentor 1000) was employed compression tests. The sample was placed between two parallel plates (Figure 1) and was cracking. Compression force was exerted just along the thickness of the sample in the lateral and longitudinal directions. The experiments were carried out at loading rate 20 mm/min (Maghsoudi et al., 2012). The force F(N) and the compression D1(m) were transformed by means of software Microsoft Office Excel 2003 on the stress σ (MPa) and the strain ε (mm.mm⁻¹). The stresses σ (MPa) were determined from the equation:

\[
\sigma = \frac{F}{S}
\]

(1)

where F(N) is force and S(mm²) is an initial cross section of the sample. The strains ε (mm.mm⁻¹) were determined as a change in the specimen’s diameter from the equation:

\[
\varepsilon = \frac{\Delta l}{L_0}
\]

(2)

where Δl (mm) is the compression between plates and L₀ is initial diameter of the sample. Modulus of elasticity E (MPa) in the linear part of the stress – strain curve is defined as the stress change divided by change in strain within the linear region of the stress/strain curves:

\[
E = \frac{\sigma}{\varepsilon}
\]

(3)

Modulus values were calculated as the slope of the linear part of the stress – strain curve on the base of regression method.

The second method of the determination of apparent modulus of elasticity was realized on the base of the Hertz equations for contact stresses used in solid mechanics (ASAE, 2004):

\[
E_s = \frac{0.338 F(1-\mu^2)}{D_1^2} \left[ K_U \left( \frac{1}{R_U} + \frac{1}{R_L} \right)^3 + K_L \left( \frac{1}{R_L} + \frac{1}{R_U} \right)^3 \right]^{\frac{1}{3}}
\]

(4)

where, E_s (Pa) is apparent modulus of elasticity, D₁ (m) is compression, μ (-) represents Poisson’s ratio, F (N) is force, R_U, R_L (m) are minimum and maximum radii of curvature of the convex surface of the compression tool and the specimen at the point of contact with the upper plate, R_U, R_L (m) are minimum and maximum radii of curvature of the convex surface of the the compression tool and the specimen at the point of contact with the lower plate. The constants K_U and K_L are dimensionless parameters related to geometrical characteristics of the bodies in contact with each other and can obtain them from the Table 1 on the base of determination of contact angle θ. The cosθ is determined from the equation:

\[
\cos \theta = \left( \frac{1}{R_U} - \frac{1}{R_U} + \frac{1}{R_L} - \frac{1}{R_L} \right) \left( \frac{1}{R_U} + \frac{1}{R_U} + \frac{1}{R_L} + \frac{1}{R_L} \right)
\]

(5)

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Table 1. Values of constant K (-) for various values of contact angle θ (°) (Adapted from Kozma and Cunningham, 1962) (ASAE, 2004)

Bioyield point is defined as the point at which an increase in deformation is observed with the decrease or no change of force. Rupture point is a point on the stress – strain or force – deformation curve at which the axially loaded specimen ruptures under the load. Rupture point corresponds to the failure in the macrostructure of the specimen while bioyield point corresponds to a failure in the microstructure of the sample (Sahin, Sumnu, 2006). The both point were determined from the stress – strain curves.

RESULTS AND DISCUSSION

The longitudinal diameter of the plum fruit was 37 mm and the lateral diameter was 41 mm.

The stresses and strains were calculated from the equations (1) and (2). The moduli of elasticity were determined and the stress and the strain in the rupture point and the bioyield point were evaluated. Modulus values were calculated as the slope of the linear part of the stress – strain curve on the base of regres-
sion method. The modulus of elasticity in the lateral loading achieved the value about 1 MPa (Figure 3) and the stress in the biøyield point was 0.3 MPa. The strain in the biøyield point was 0.3 mm/mm. The stress in the rupture point was 0.3 MPa and the strain in the rupture point was 0.5 mm/mm (Figure 2). The modulus of elasticity in the longitudinal loading achieved the value about 2 MPa (Figure 5) and the stress in the biøyield point was 0.6 MPa. The strain in the biøyield point was 0.3 mm/mm. The stress in the rupture point was 0.5 MPa and the strain in the rupture point was 0.5 mm/mm (Figure 4).

Apparent moduli of elasticity $E_a$ in the lateral loading were calculated from the equation (4) for all range deformations $\varepsilon$ from 0.00 mm/mm to 0.30 mm/mm i. e. for all range compressions $D_c$ from 0 mm to 20 mm and for all range forces $F$ from 0 N to 82 N.

![Compress diagram - lateral loading](image1)

**Fig. 2. Compress stress – strain curve of plum fruit Prunus Angeleno in the lateral loading**

![Determination of modulus of elasticity - lateral loading](image2)

**Fig. 3. Determination of modulus of elasticity of plum fruit Prunus Angeleno in the lateral loading**

![Compression diagram - longitudinal loading](image3)

**Fig. 4. Compress stress – strain curve of plum fruit Prunus Angeleno in the longitudinal loading**

![Determination of modulus of elasticity - longitudinal loading](image4)

**Fig. 5. Determination of modulus of elasticity of plum fruit Prunus Angeleno in the longitudinal loading**

Poisson’s ratio $\mu$ was assumed 0.35 (Stroshine, 2000). The radius of curvature of the convex surface of the compression tool $R_{c'}$, which was a flat plate was infinity great ($1/R_{c'}=0$) and the radius of curvature of the convex surface of plum fruit $R_c$ at the point of contact with the upper plate was 18.5 mm. The radius of curvature of the convex surface of the compression tool $R_{c'}$, which was also a flat plate was infinity great ($1/R_{c'}=0$) and the radius of curvature of the convex surface of plum fruit $R_c$ at the point of contact with the lower plate was 20.5 mm. The constants $K_c$ and $K_{c'}$ were equal and the constant $K$ was determined by the determination of the contact angle $\theta$ by the equation (5) from the Table 1. The calculated value of cos$\theta$ was 0.0513. The value of constant $K$ was 1.349. The values of the apparent moduli of elasticity in lateral loading are presented in the Fig. 6. The moduli of elasticity were in the selected level in the range from 1 to 2 MPa and were not constant, but were depended on the deformation.

![Dependence of apparent modulus of elasticity on deformation - lateral loading](image5)

**Fig. 6. Dependence of apparent moduli of elasticity on the deformation of plum fruit Prunus Angeleno in the lateral loading**

Apparent moduli of elasticity $E_a$ in the longitudinal loading were calculated also from the equation (4) for all range deformations $\varepsilon$ from 0.00 mm/mm to 0.30 mm/mm i. e. for all range compressions $D_c$ from 0 mm to 12 mm and for all range forces $F$ from 0 N to 200 N. The values of cos$\theta$ and constant $K$ were the same as for lateral loading. The values of the apparent moduli of elasticity in the longitudinal loading are presented in the Fig. 7. The moduli of elasticity were in the selected level in the range...
from 2.5 to 5 MPa and were not constant, but also were depended on the deformation.

Fig. 7. Dependence of apparent moduli of elasticity on the deformation of plum fruit Prunus Angeleno in the lateral loading

The value of the $E$ depends on the deformation at which it is calculated. This is indication that severeral of the assumptions on which the Hertz equations are based were not completely satisfied. For example, the plum fruit is not an elastic solid. The values of the moduli of elasticity which were determined from the first and second method were consistent. Mirzaee et al. (2009) presented the mean values of elasticity modulus of three different apricot fruits which were established between 0.32 – 0.53 MPa and were determined at 79.61% (Nasiry), 84.17% (Rajabali) and 79.84% (Ghavami) moisture content. Plocharski and Konopacka (2003) were found that fruit of the Dabrowicka, Amerf and Valjevka varieties should have – at the consumption, stage of maturity – an apparent modulus of elasticity ranging from 0.100 to 0.250 MPa (optimum at 0.150 MPa), when measured usinga 6 mm probe and when recalculated using a 4 mm probe, respectively 0.071–0.217 MPa (optimum at 0.120 MPa). Infante et al. (2011) presented the compression strength measured on-tree and postharvest of ‘Angeleno’ and ‘Autumn beat’ plums. The compression forces were in the range from 18 N to 23 N.

CONCLUSION

The compress test was realized by means of test stand Andilog Stentor 1000 on the Angeleno plum fruit. The compress load curves of the stress on the strain were evaluated of the lateral and longitudinal directions. The moduli of elasticity were determined and the stress and the strain in the rupture point and the biopsyel point were evaluated.

The modulus of elasticity in the lateral loading achieved the value about 1 MPa and the stress in the biopsyel point was 0.3 MPa. The strain in the biopsyel point was 0.3 mm/mm. The stress in the rupture point was 0.3 MPa and the strain in the rupture point was 0.5 mm/mm. The modulus of elasticity in the longitudinal loading achieved the value about 2 MPa and the stress in the biopsyel point was 0.6 MPa. The strain in the biopsyel point was 0.3 mm/mm. The stress in the rupture point was 0.5 MPa and the strain in the rupture point was 0.5 mm/mm.

The apparent modulus of elasticity was also realized on the base of the Hertz equations for contact stresses used in solid mechanics. The apparent moduli of elasticity in the lateral loading were in the range from 1 to 2 MPa. The apparent moduli of elasticity in longitudinal loading were in the range from 2.5 to 5 MPa. The moduli were not constant but were depended on the deformation. The values of the moduli of elasticity which were determined from the first and second method were consistent.

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