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TENSILE STRESS AND PENETRATION TEST OF THE *RED HAVEN* PEACHES SKIN

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Abstract

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Skin protects fruits against changing external factors such as varying temperature, moisture, etc. The knowledge of its mechanical properties is thus of critical importance. The paper is focused on determination of selected mechanical characteristics of *Red Haven* peach skin. Such destructive experiments (tensile stress and penetration test) were performed, where fruit skin integrity was radically violated. In a peach, a part of the skin is subject to external mechanical action and resulting deformation is measured and it can be viewed as a function of parameters describing both the action and considered sample of the skin or vice versa. Several basic physical quantities such as Young's modulus of elasticity, stress in failure, toughness, and maximal penetration pressure were determined. These quantities, depending e.g. on date of harvest and describing quality and maturity of peaches, were quantified and evaluated. The results obtained within this research can be used e.g. for creation of detailed mathematical model.

peach skin, tensile stress, Young's modulus of elasticity, penetration

Physical properties of fruits are the most important for industrial processing of fleshy crop. There are many different methods to study features of the fruits. Some features are proportions, mass, color and shape of surface. These are called external factors. On the other hand, firmness, sugar and acid content which are called internal factors (Severa, 2008a). Knowledge of these features is needed for example for optimization of storage conditions, for determining convenient date of harvest etc. One of the most important internal factors is firmness, which is closely linked with quality and ripeness.

The peach skin represents a protecting shell, preventing the mechanical damage of the fruits' pulp. Moreover, it protects the fruits from a variety of pests, or fungi. For these reasons, the surface properties of fruits skin are very important and deserve to be studied. Some properties can be quantified by use of classical continuum mechanics (definitions of relevant terms are part of this article). Toughness of the skin is a relevant factor influencing firmness. Skin plays very important role in protection of fruit. The fruits' flesh would quickly deteriorate by fungi, pests and rot without the skin protection.

The most common method for assessing the flesh fruit firmness is the puncture test. The maximal penetration force is measured that is required to let a cylindrical probe penetrate in the fruit flesh up to a predetermined depth. It is often performed manually (Harker *et al.*, 2002; Hoehn *et al.*, 2003). Sophisticated devices allow a motorized penetration of the probe into the fruit, at a defined speed and to record the complete force versus displacement curve. Mehinagic *et al.* (2003) proposed to extract various texture parameters from the force-deformation curves. Other authors (Duprat *et al.*, 1995) tried to summarize the texture parameters with a small set of numerical values calculated from the penetrometric curve. The authors considered the entire force-displacement curve as an indicator of both flesh and skin properties. The rate of loading plays an important role in this kind of experiment, as it was documented for peaches as well as other biological materials (Severa, 2008b; Nedomová *et al.*, 2009a).

Studying fruits' surface properties by tensile stress test is a well known method used e.g. in (Rajabipour, 2004). There are two basic ways of fixing fruit's skin during the test. The first, loop method, works with

I: *Mean precipitation in the year 2008 compared with the long-term normal 1961–1990 for South Moravia (ČHMÚ, 2009)*

Month	1	2	3	4	5	6	7	8
Mean precipitation amount (mm)	20	12	41	35	57	55	74	52
Long-term normal 1961–1990 (mm)	30	30	29	38	65	75	64	61
Mean precipitation amount as percentage of the long-term normal	67	41	145	94	88	74	116	86

II: *Mean air temperature in the year 2008 compared with the long-term normal 1961–1990 for South Moravia (ČHMÚ, 2009)*

Month	1	2	3	4	5	6	7	8
Monthly mean air temperature (°C)	1.5	2.6	4.1	9.4	14.8	18.8	19.5	19.1
Long-term normal 1961–1990 (°C)	–2.6	–0.6	3.4	8.6	13.5	16.6	18.1	17.6
Deviation from long-term normal (°C)	4.1	3.2	0.7	0.8	1.3	2.2	1.4	1.5

III: *Data from Hydrometeorological station Velké Pavlovice in South Moravia (ČHMÚ, 2009)*

Month	1	2	3	4	5	6	7	8
Mean air temperature (°C)	2.1	3.2	5.1	10.5	15.8	19.8	20.3	20.1
Total precipitation (mm)	17.3	11.5	34.7	24.0	63.8	44.9	50.4	34.9
Sunshine duration (h)	60	113	156	193	260	266	226	246

cylindrical excision of skin, which is put on two hooks. Stress-strain dependence can be measured by splaying out the hooks. This method is rather difficult due to complicated preparation of specimens and it is not very practical. The second, conventional grip method, uses rectangular excision of fruit's skin which is stretched out. This method is easier to prepare. In presented research, only the second approach was used.

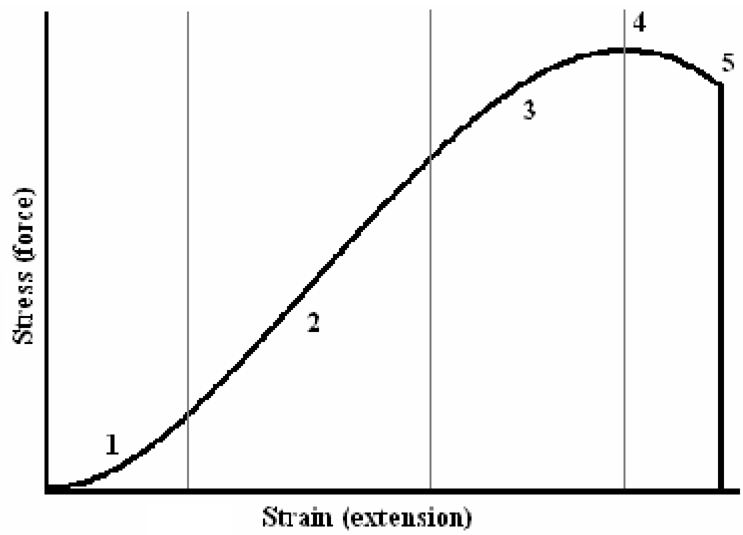
This study is focused on determination of peach skin properties. The peaches of *Red Heaven* variety, grown in the orchards of Mendel university in region of Lednice, southern Moravia, the Czech Republic, were tested. The peach samples studied within this research were concurrently used in experiments described in Čermák (2009) and Severa (2008c).

MATERIAL AND METHODS

Peach samples

The peach fruits of *Red Haven* variety, harvested in the orchards of the Department of Postharwest technologies, Lednice, Mendel University, Czech Republic were not affected by any mechanical way in order to keep their original character. The fresh fruits were tested, thus influencing of their skin by longer storing was eliminated.

The fruits were harvested in the year of 2008, which was extreme (above-normal) concerning temperature and an ordinary in rainfall (ČHMÚ, 2009). This fact is indeed affecting the skin's properties. The statistics confirming before-mentioned statement are listed in Table I, Table II and Table III.



1: *Relationship between stress and strain (or force and extension) in case of a general material*

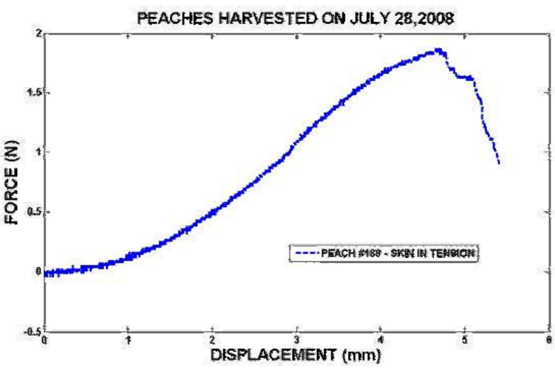
Theory of tensile stress

Results of tensile stress measurements were processed in terms of classical mechanical theory of continuum (Roylance, 2001), which uses relationship between stress and strain. A typical dependence course is shown in Fig. 1. Force-deformation Curve of organic meterials was studied by (Mohsenin, 1978).

Let us briefly recall the most important features of the curve expressing the dependence of tensile strength on extension of a general material sample. The curve can, in general case, be divided into four regions. We call the first area the root part (area 1 in Fig. 1). In the case of flexible materials, this part is often missing (Roylance, 2001), while in the case of organic materials, which have more complicated inner structure, this region occurs. Second area (area 2 in Fig. 1) is called linear elastic region. In this area, the material is deformed elastically, which means the curve is linear. We can easily find Young's modulus of elasticity *E* from slope *k* (slope of the force-extension curve) and material proportions *S*–section surface, l_0–initial length.

$$E = kl_0/S. \quad (1)$$

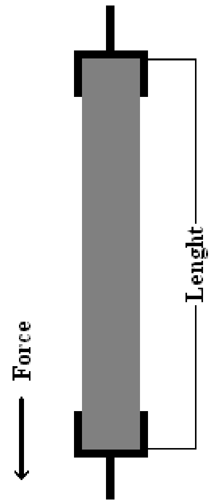
Third area (area 3 in Fig. 1) is called strain hardening region, in which the body is deformed inelastically and irreversibly. The point of maximal force is called ultimate tensile strength (point 4 in Fig. 1). Area following the ultimate strength point is called necking region, in which the material is necked and the force declines. This area is presented in the case of some metals and plastics. The area is very small or absent in organic materials (Rajabipour, 2004), such as peach skin, in contrast to the previous examples. The curve ends in breaking strength or rupture point (point 5 in Fig. 1) and the material breaks. In case of peach skin, the rupture point and maximum force point coincide. Typical stress-strain curve of a peach skin is shown in Fig. 2. Graph, contained in the figure, is based on data we work with in this article.



2: *Example of displacement-force diagram for peach skin*

Tensile stress of peach skin

Two groups of samples with different dates of harvest (28. 7. 2008, 4. 8. 2008) were studied. The first group was represented by four skins from different peaches, the second by six skins from four different peaches. All the peaches, used to provide skin samples, were ready for consummation and of comparable maturity. Skins of following dimensions: 14 mm (width), 20 mm (length), 0.9 mm (thickness from the surface to the flesh) were separated by scalpel. The skin was attached to the measuring device as shown in Fig. 3.



3: *Schematic of tensile test experiment and attached peach skin*

Young's modulus of elasticity

Young's modulus of elasticity can be easily obtained from the linear part of the curve in Fig. 1. Slope of linear part of the curve substituted into equation (1) determines Young's modulus of elasticity.

Stress in failure

Stress in failure *p* is maximal force F_{max} per area of normal section *S*. It can be calculated as

$$p = F_{max}/S, \quad (2)$$

where *S* is width multiplied by thickness.

Toughness

Toughness is energy density ρ_E at the break point. Mechanical energy before break of the peach skin is area under curve in Fig. 1. It can be calculated as a length integral of the force

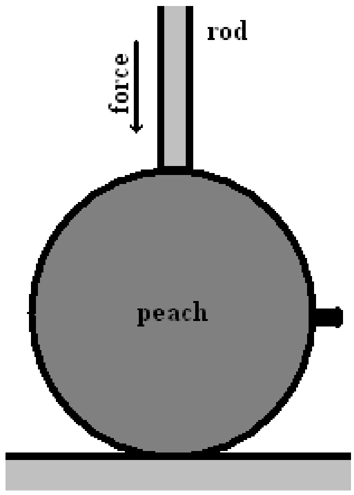
$$E_M = \int F dl. \quad (3)$$

Than toughness is this energy per volume of the skin. Measured dependence force-extension is fit by a polynomial of *n-th* degree. Energy needed to rupture the skin is simply calculated as the definite integral of the above mentioned polynomial.

Penetration test

For this test was used six samples, which were harwested 28. 7. 2008 and next six samples, which were harwested, 4. 8. 2008. Penetration tests were carried out in a similar way as described in Wu and Abbott (2002) who performed a mathematical analysis of the penetrometric curves for characterizing fruit variability and built a mathematical model representing the relaxation forces as a logarithmic function. In this way, they obtained a high correlation between firmness and the relaxation force at specific relaxation time. This result predicted skin hardness of fruit from penetrometric measurements.

In this research, penetration test is an experiment in which a cylindrical rod sinks into a whole peach at a constant speed as is shown in Fig. 4. Speed of rod movement was set to 20 mm/min. The cylindrical rod had diameter of 4 mm.



4: *Schematic of the pentration test*

Typical curve of force-displacement dependence is shown in Fig. 5. Graph, contained in the figure, is based on data we work with in this article.

Beginning of the curve is similar as in the case of displacement-force diagram in Fig 2. Maximum of the force stands for a point, where peach's skin is punctured by the rod; then magnitude of force decreases. Force increases again in the last part of the curve. Increase is approximately linear and describes deformation of peach's flesh by the rod. The test were set up so that the experiment ends when displacement reaches 15mm. Maximal penetration pressure p_p is a maximal force divided by cross area of the cylindrical rod.

Measuring devices

The measurement was carried out using Universal Testing Machine (TIRATEST 27025, Germany). The device has three main components: a stationary platform, a moving one and a data acquisition system. The measured data were already partially analysed by a computer programme, which is part of the apparatus TIRATEST, and then they were exported and further analysed in Microsoft Excel.

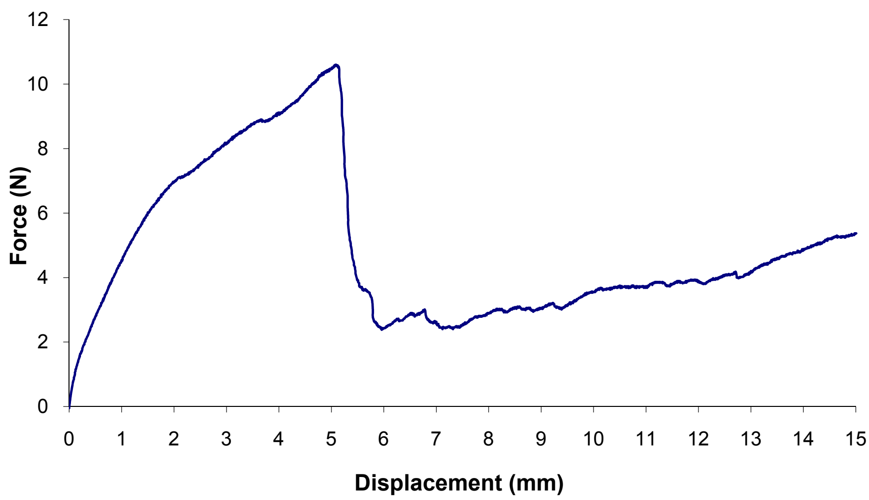
Methods of data evaluation

Standard statistical methods were applied to the data. is arithmetic mean, X_i is *i-th* measured value and n is number of all measurements. Mean quadratic deviation is given by

$$\delta X = [\Sigma(X_i - \overline{X})^2/(n^2-n)]^{1/2}. \quad (4)$$

RESULTS AND DISCUSSION

Measuring physical properties of organic materials produces large variations of the individual measurement values. For this reason, the deviation of a measured quantity, representing the whole set of peaches, is determined as in equation (4) and not by accounting for individual deviations.



5: *Penetrometric force-displacement dependence*

Young's modulus of elasticity, stress in failure and toughnes of each peach skin sample is shown in Table IV. Samples 1–4 were harvested 28. 7. 2008. and samples 5–8 (the suffix a and b indicates that peach skin samples e.g. 6a and 6b are from the same peach) were harvested 4. 8. 2008. Maximal penetration pressure is shown in Table V. In this case samples 1–6 were harvested 28. 7. 2008. and samples 6–12 were harvested 4. 8. 2008.

In case of this research, Young's modulus of elasticity (determined from linear part of the curve depicting the relationship force-extension) of a peach skin was calculated as $E = 1.08 \pm 0.12$ MPa. The stress in failure of a peach skin was determined as $p = 0.16 \pm 0.02$ MPa. Relative deviation of stress in failure is slightly larger than in the case of Young's modulus of elasticity. Relative deviation of the stress in failure value can also be evaluated when not considering the initial length, which may play an important role. The largest relative quadratic deviation was found in case of toughness. Energy per volume needed to break a peach skin is $\rho_E = 23 \pm 6$ kPa. Maximal penetration pressure is $p_p = 340 \pm 50$ kPa. Value of the maximal pressure is similar to the value of stress in failure. This value may also be influenced by shape of the tested object. General procedure for evaluating influence of samples shape on its strength properties is described in Nedomová *et al.* (2009b).

Very large relative deviation, reaching 26%, is typical for our results. This is not unusual for the measurements of physical properties of organic materials. One may expect that the accuracy can be increased by increasing the number of samples, which is time and financially costly.

The further development of the penetrometric method of the fruit firmness and skin properties evaluation requires other data on relationship between the penetrometric experiments and textural characteristics of the fruits. Influence of other parameters such as stage of maturity or variety should be studied in deeper details.

Results of this work and similar ones should bring better methods of storage and transit peaches. Optimal date for harvest or storage conditions can be found from knowledge of relation between properties of peach skin and maturity. This research shows that pressure larger than cca. 100 kPa can permanently affect peach skin and thus it can destroy this protective layer of a ripe peach.

IV: *Table of Young's modulus of elasticity (Y.m.), stress in failure (s.f.) and toughnes (t.) for each sample*

sample	1	2	3	4	5a	5b	6a	6b	7	8
Y.m. (MPa)	1.56	0.83	0.74	0.39	1.27	1.26	1.16	1.18	1.58	0.85
s.f. (kPa)	201	138	122	108	120	143	133	288	282	98
t. (kPa)	32.3	23.1	14.1	17.1	6.0	10.4	10.4	59.4	53.0	6.2

V: *Table of maximal penetration pressure (kPa) for each measured sample*

1	2	3	4	5	6	7	8	9	10	11	12
318	199	414	177	572	156	232	225	346	319	186	210

SUMMARY

The paper is focused on the problematic of determination and evaluation of skin strength of the Red Haven peaches in different stages of their maturity. Higher values of Young's modulus of elasticity, stress in failure, toughness, and maximal penetration pressure lead to the greater protection against influence of external conditions and generally, better fruit quality. The results clearly show that experimental data are characterized by rather high values of quadratic deviations. This results from the fact, that values measured for individual samples vary in a great extent. Thus it is more advantageous to perform a bigger series of experiments in comparison with evaluation a limited numbers of experiments with high precision. The future research may lead to a better definition of the influence of fruit picking maturity on of these variables. Except above described destructive methods, there are other suitable experimental procedures of non-destructive nature (such as acoustic response to impact loading). The results of both approaches can be successfully compared and correlated. The similar experiments have already been performed with whole fruits and the results of presented work well complete these previous findings and can be used e.g. for creating of suitable mathematical model.

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