STATIC LOW-LEVEL PEAR BRUISING IN A GROUP OF VARIETIES

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Stress-induced enzymatic browning is one the most important limiting factors in producing quality soft fruits (apples, cherries, pears etc.) and soft vegetables (e.g. potato tubers). The bruise extent is expressed by bruise volume depending on the total work of loading and/or the energy absorbed during loading. The pears of 16 varieties were tested in loading – unloading compression tests between two flat rigid plates to determine variety sensitivity to bruising. The bruises were cut and their volume was determined from the observed cross sections. The tests showed that the usual parameters used for evaluation of bruise sensitivity (*BRC*, *BS*) had limited ability to describe the variety differences as well as the special properties at low level bruising. The suitable mechanical parameters for this purpose were found to be: degree of elasticity and hysteresis losses applied to the characteristic low level deformation states (BV = 0 and BV = 0.5 cm^3). Some parameters of bruising were determined also from fruit shape and mass. The results served to classify 12 tested varieties.

pears; bruising; compression; impact; bruise volume; absorbed energy; hysteresis losses; degree of elasticity; quality

INTRODUCTION

Fruit bruising is one of the most important factors limiting the mechanisation and automation in harvesting, sorting and transport of soft fruits and vegetables, including potatoes. Dark spots appearing near the product surface are due to previous forceful mechanical contacts of the products with other bodies. Force loading of the round fruit can be quite variable (Johnson, 1987), ranging from static to dynamic. Bruise extent is usually described in terms of bruise volume (Blahovec et al., 1991), which closely related to product quality. Schoorl and Holt (1986) estimated that one 10 cm^3-bruise spot on an apple surface promotes 50-percent reduction in storage time. Studman (1995) lists fourteen factors affecting bruising of apples, but the role of some of them is slightly controversial. The most important bruise factor in every case is the loading extent, which is usually expressed in the terms of loading energy or absorbed energy (Holt, Schoorl, 1977).

Holt and Schoorl (1977) originally described the relation between bruise volume and the absorbed energy as a simple linear function where the constant term (intercept) is equal to zero and the slope is termed as the Bruise Resistance Coefficient (*BRC*). Other factors affecting the apple bruising may be reflected in *BRC*. This very fruitful, but yet controversial idea, was used by Holt and Schoorl (1983, 1984) and others, e.g., Brusewitz and Bartsch (1989) and Kamp and Nissen (1990). *BRC* is a term that increases when fruit susceptibility to bruising increases, or when bruise volume increases. The proportional character of the relation between the bruise volume and the absorbed energy does not enable the undamaging level of loading to be defined. Similarly to *BRC,* the Bruise Sensitivity (*BS*) is defined as a ratio of bruise volume and loading energy (Kamp, Nissen, 1990). Hyde and his students (e.g. Bajema, Hyde, 1998; Mathew, Hyde, 1997) used the reciprocal value of the *BRC*, so-called bruise resistance (BR), which was defined as the ratio of bruising energy to the resulting bruise volume. By this definition grater bruise resistance means the commodity is less easily bruised.

It was shown that for static bruising the obtained *BRC* and *BS* values are not constant – the bruise volume increases non-linearly with increasing of both energies – loading and absorbed (apples – Blahovec et al., 1997, cherries – Blahovec et al., 1996, pears – Blahovec et al., 2002). For fruits of the higher quality, the conditions corresponding to no and/or very little bruise damage are the things of the most importance. The evaluation of this area by two separate *BRC* (*BS*) values was proposed (Blahovec, 1999).

In a previous paper (Blahovec et al., 2002) it was shown that pear bruising sensitivity could be expressed by characteristic hysteresis losses and/or degree of elasticity rather than by load and/or absorbed energy.

In this paper the relations between bruise volume, the absorbed energy, the loading energy, the degree of elasticity (*DE*) and the hysteresis losses (*HL*) were studied using a group of pear varieties and quasi-static loading up to definite load with the aim to obtain more information about bruising at different loading extents.

MATERIALS AND METHODS

The pears of the group varieties were harvested in the orchard of the Research Institute for Pomology Ltd. at Holovousy in North-Eastern Bohemia at a stage of har-

Table 1. Main characteristics of the tested fruits

Variety	Test dates		Fruit mass m (g)		Fruit index h/d_{max}		m/d_{max}^2 (g.mm^{-2})	
	loading	spot analysis	MV	CV (%)	MV	CV (%)	MV	CV (%)
Astra	23/01/03	24/01/03	171.0	16.0	1.31	7.83	0.0380	5.93
Bohemica	04/12/02	06/12/02	170.5	12.7	1.21	4.98	0.0373	6.07
Boscova	27/09/02	01/10/02	198.5	17.3	1.34	4.37	0.0392	7.59
Decora	27/09/02	01/10/02	175.5	13.7	1.14	7.48	0.0363	6.09
Delta	09/12/02	10/12/02	237.1	17.8	1.21	7.03	0.0404	8.17
Dicolor	27/09/02	28/09/02	154.7	12.7	1.14	7.02	0.0339	6.14
Dita	24/01/03	27/01/03	234.7	19.4	1.17	6.46	0.0392	10.84
Elektra	03/12/02	05/12/02	208.1	15.7	1.51	6.18	0.0452	7.16
Erika	24/01/03	27/01/03	248.8	14.5	1.31	5.97	0.0430	7.70
Jana	04/12/02	06/12/02	245.5	22.3	1.03	5.24	0.0394	9.26
Konference	27/09/03	01/10/03	170.3	15.3	1.54	7.42	0.0409	8.42
Lada	26/09/02	27/09/03	260.7	19.2	1.58	6.04	0.0426	8.40
Lucasova	03/12/02	05/12/02	269.4	16.7	1.14	6.28	0.0429	6.46
Omega	24/01/03	27/01/03	226.8	12.7	1.30	4.62	0.0419	6.68
Vilu	26/09/02	30/09/02	360.0	12.7	1.50	5.32	0.0475	6.02
Vonka	26/09/02	30/09/02	191.0	22.9	1.17	6.25	0.0361	7.44

h – lengh of fruit, d_{max} – maximum fruit diameter, MV – mean value, CV – coefficient of variation

vesting maturity. Testing dates details are given in Table 1. Every test was conducted on forty defect-free fruits that were divided into four ten-fruit groups. The fruits were than compressed individually between two plates at a constant deformation rate of 0.167 mm.s^{-1}. The fruits' axis was oriented to be parallel with the compression plates. After reaching the desired force (20, 40, 60, and 80 N for fruits included in the separate groups – in some cases with very hard fruits, e.g. 'Decora', 'Dicolor', 'Bohemica', 'Astra', 'Dita', 'Erika', and 'Omega', the desired forces were higher up to 450 N in case of 'Omega') the fruit was unloaded at the opposite deformation rate. All the loading-unloading tests were performed in a Universal Testing Machine (UTM) Instron[TM] (model 4464) at usual laboratory conditions (temperature 20–22 °C). The UTM software was used to evaluate of the loading curves. The following parameters were obtained (Fig. 1, Blahovec et al., 1996, 1997): loading energy (W_L), unloading energy (W_U), absorbed energy ($W_A = W_L - W_U$), maximum deformation (D_1), inelastic deformation (D_2), degree of elasticity ($DE = 1 - D_2/D_1$) and hysteresis losses ($HL = W_A/W_L$).

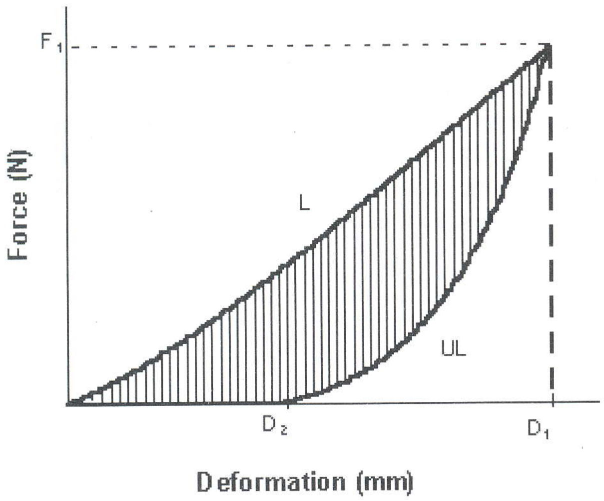

Fig. 1. Schematic representation of the loading test of a pear between two plates. It consists of two parts: loading of the fruit (L) at a constant strain rate up to total compression force F_1, followed by unloading at the same but reversed strain rate (UL). The first parts begin at zero force and zero deformation and ends at force F_1 and deformation D_1, the second part begins at the end state of the first part and ends at zero force and deformation D_2. The area between loading part and the axis D represents loading energy W_L, the unloading energy W_U – the recovered part of the loading energy – is represented by the area between unloading part and the axis D. The marked area between the curves L and UL is the so called absorbed energy.

The pears were stored after the harvest in the cold store at about 4 °C and tested approximately after 24–72 hour tempering at room temperature. After test the fruits were left on the table in a laboratory at room temperature (20–22 °C) for about 24–72 hours. During this interval the colour of the bruised parts of the fruit flesh changed from the original to brown (Holt, Schoorl, 1977). The fruits were then cut in the middle of the two bruised spots perpendicularly to the fruit surface and the diameters (d) and depths (t) (in cm) of the spots were measured. These were used to calculate the bruise volume of the individual spot based on the formula given by Barreiro (1999):

$$V = \pi \,.\, d^2 \,.\, t / 6 \qquad (\mathrm{cm}^3) \qquad (1)$$

This formula gives results (Blahovec, 2001) comparable to the values of bruise volume obtained by the classical formula (Mohsenin, 1970; Holt, Schoorl, 1977).

Variety characteristic values were obtained by analysis of the relations between the total bruise volume (in two separate spots) on one side and the deformation parameters: loading energy, absorbed energy, hysteresis losses and the degree of elasticity on the other side (Blahovec et al., 2002, 2003). The following characteristic values were used for description of bruise spot formation: initial bruising and for bruise spots with volumes 0.5 and 5 cm^3.

RESULTS AND DISCUSSION

Shape of spots

The bruise spots have characteristic shape expressed by bruise spot ratio (BSR), the ratio of the bruise spot thickness (t) to the bruise spot diameter (d). Our results gave approximately the same results of 0.472 for most of the tested varieties, excluding the slightly higher value for variety Astra (Fig. 2). Figure 3 shows that the BSR slightly decreased with increasing spot dimension and

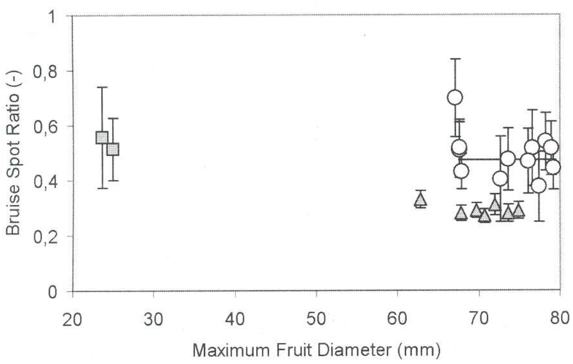

Fig. 2. Bruise spot ratio plotted against maximum fruit diameter (circles – results obtained in this paper). Black horizontal line indicates mean value of all the obtained results with exclusion variety Astra (the first from the left) – 0.472. The triangles denote the results obtained for apples (Blahovec et al., 2001). The squares denote the results obtained for cherries (Blahovec et al., 1996). The standard deviations are indicated.

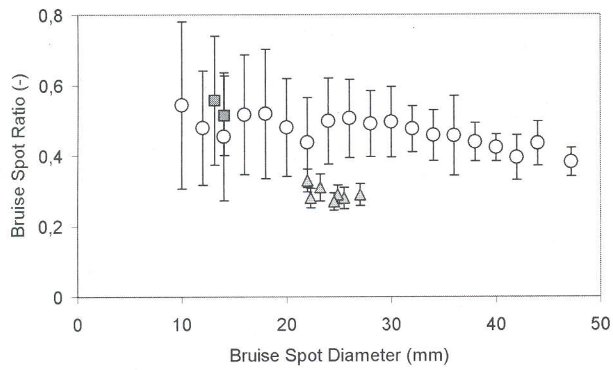

Fig. 3. Bruise spot ratio plotted against bruise spot diameter, marks are the same as in Fig. 2

the same trend was observed also for its variability. The BSR in cherries (Blahovec et al., 1996) are comparable in contrary to apples (Blahovec et al., 1991) that is significantly lower than in pears and cherries (Figs 2 and 3). It seems that bruise spot shapes are fruit dependent.

Bruise spot volume and deformation characteristics

Figures 4–7 represent the relations between total bruise volume and the main deformation characteristics: the loading energy, the absorbed energy, the degree of elasticity and the hysteresis losses. Figs 4 and 5 show that total bruise volume (volume of two bruise spots produced on a fruit during the compression test) increased with increase in both the deformation energies (loading and absorbed). Also, the plots in Figs 4 and 5 are different not only for different tested varieties, but also for different maturity levels. This fact that was observed also in previous paper (Blahovec et al., 2002) showing that susceptibility of the individual varieties to bruising is masked stage of maturity or ripening. Moreover, the most important parts of the plots, which correspond to bruise spots of the least volume, were not too clear in the Figs 4–6. Figs 6 and 7 show that the degree of elasticity and especially the hysteresis losses were more suitable for assessing bruise resistance or sensitivity.

The results of the variety tests were analysed separately by polynomial approximation (Blahovec, Mareš, 2003) and three characteristic values for both the parameters (DE, and HL) were determined: for values at which the first spots were formed – initial degree of elasticity (DE_0) and initial hysteresis losses (HL_0), for formation of spots of volume 0.5 cm^3 – $DE_{0.5}$ and $HL_{0.5}$, and for formation of spots of volume 5 cm^3 – DE_5 and HL_5. The results of this analysis are given in Table 2. This table does not contain the final results for pears of four varieties (Boscova, Decora, Konference, and Vilu),

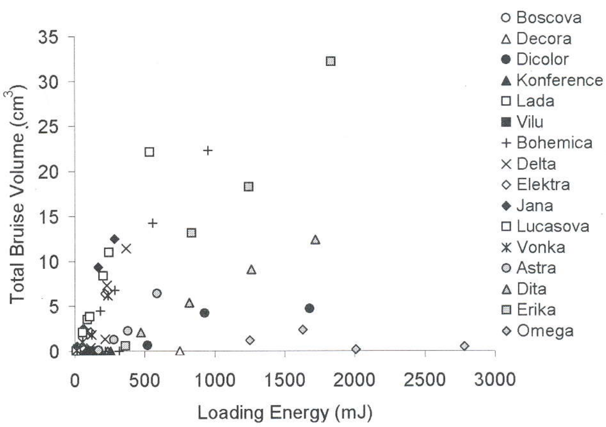

Fig. 4. Total bruise volume (i.e. volume of two bruise spots formed at the pear surface during the test) plotted against the loading energy. The symbols represent mean values obtained for one loading level for a given fruit variety.

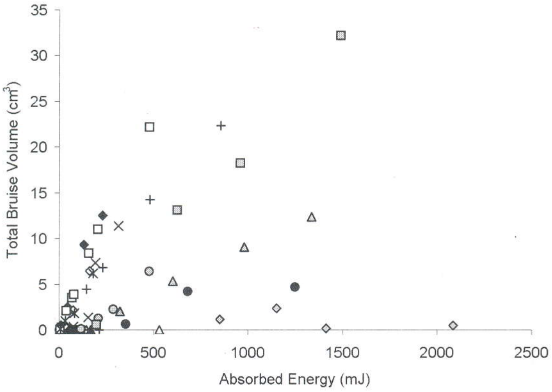

Fig. 5. Total bruise volume (i.e. volume of two bruise spots formed at the pear surface during the test) plotted against the absorbed energy. The symbols are the same as in Fig. 4.

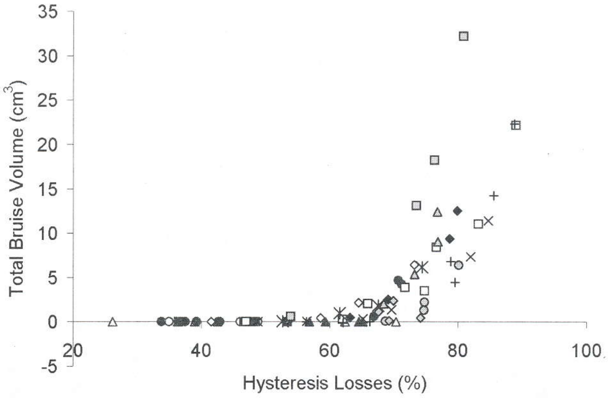

Fig. 7. Total bruise volume (i.e. volume of two bruise spots formed at the pear surface during the test) plotted against the hysteresis losses. The symbols are the same as in Fig. 4.

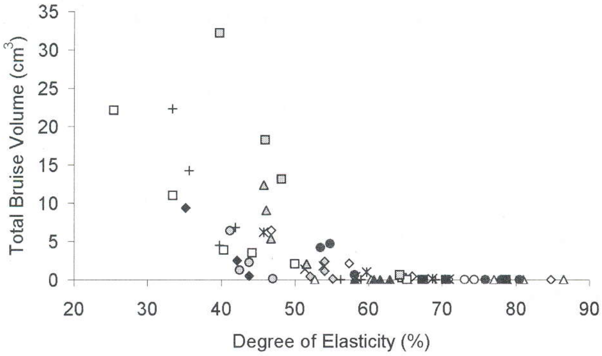

Fig. 6. Total bruise volume (i.e. volume of two bruise spots formed at the pear surface during the test) plotted against the degree of elasticity. The symbols are the same as in Fig. 4.

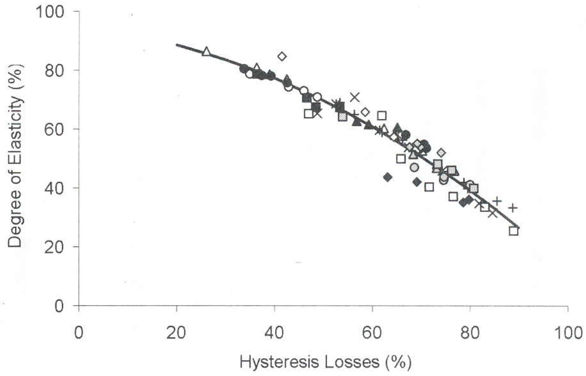

Fig. 8. Degree of elasticity plotted against hysteresis losses. The symbols represent mean values obtained for one loading level. For symbols see Fig. 4.
Equation of approximation: $DE = -0.006488\ HL^2 - 0.1716\ HL + 94.57$, $R^2 = 0.937$

for which the analysis could not be performed due to limited number of the bruise spots observed in the tests.

The higher the hysteresis losses HL_0, $HL_{0.5}$, and HL_5 the less susceptible is the tested variety to bruising. The degree of elasticity correlates negatively with the hysteresis losses (Fig. 8), so that the opposite rule has to be used for the degree of elasticity: the higher are the parameters DE_0, $DE_{0.5}$, and DE_5 the more susceptible is the tested variety to bruising. Our results from Table 2 are in agreement with this rule. The values from Table 2 are also plotted in Figs 9 and 10. The varieties are arranged in these figures under the decreasing susceptibil-

Table 2. Bruising characteristics of the tested varieties

Variety	Hysteresis losses (%)			Degree of elasticity (%)		
	HL_0	$HL_{0.5}$	HL_5	DE_0	$DE_{0.5}$	DE_5
Astra	71.59	74.34	85.05	47.53	44.26	34.16
Bohemica	74.02	75.96	83.74	48.73	46.30	37.16
Delta	72.88	75.15	85.02	47.57	43.76	31.00
Dicolor	68.58	71.81	80.58	58.44	56.24	46.56
Dita	65.69	67.84	77.51	54.99	53.03	44.05
Elektra	53.89	61.66	82.71	70.63	61.26	32.28
Erika	61.15	62.70	71.13	69.16	65.77	52.40
Jana	62.44	66.17	79.45	50.84	46.99	33.14
Lada	68.83	71.38	82.06	52.72	49.65	34.77
Lucasova	61.83	65.93	80.93	57.28	51.11	27.99
Omega	66.79	69.10	77.44	55.24	53.72	48.28
Vonka	58.61	63.30	82.75	62.10	55.22	38.53

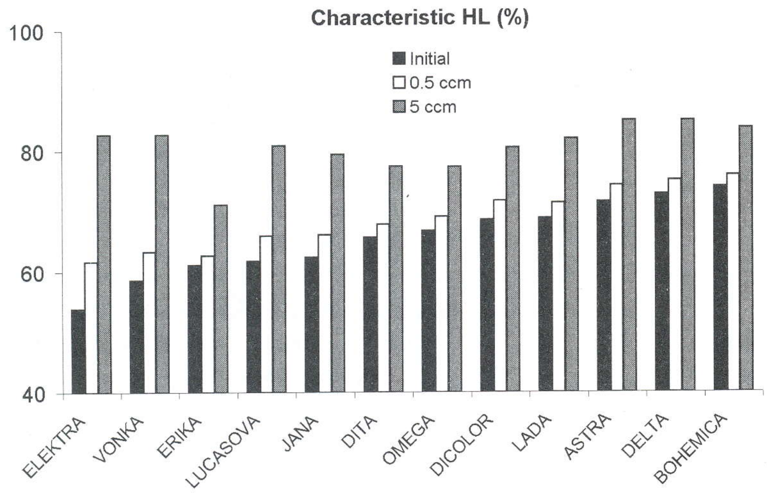

Fig. 9. Characteristic hysteresis losses of the tested varieties arranged under increasing HL_0

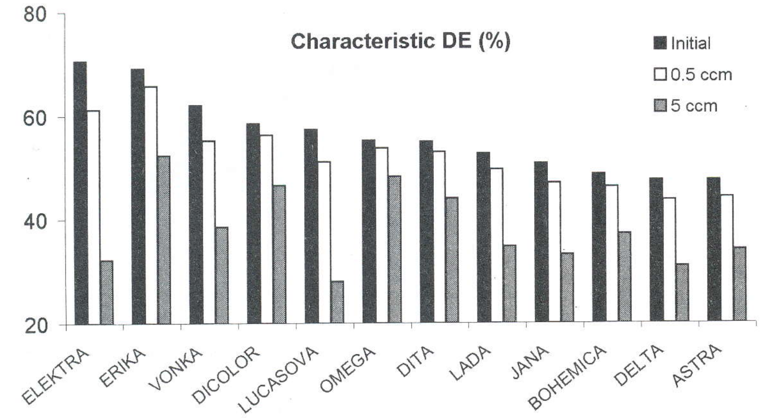

Fig. 10. Characteristic degree of elasticity of the tested varieties arranged under decreasing DE_0

ity to bruising. Comparing Fig. 9 (*HL*) and Fig. 10 (*DE*), we can see very good agreement of these two classifications: the first three varieties in both the figures are Electra, Vonka, and Erika and the last three varieties in both the figures are Astra, Delta, and Bohemica. This fact indicates consistency of both the methods: based either on *HL* or on *DE*. Both methods of classification are successful mainly at low-level bruising (bruise initiation, and 0.5 cm^3 bruise volume). At the highest level (5 cm^3 bruise volume) the method could lead to controversial results (see Figs 9 and 10).

Variety susceptibility to bruising

The above mentioned characteristic values (for *HL* and/or *DE*) cannot fully describe the sensitivities of varieties to bruising. These values should be understood only as a measure of susceptibility of pear surface tissue to bruising. But also other fruit properties could play some role in bruise spots formation, e.g. fruit shape and mass. For example stem parts of long and narrow fruits can be easily damaged and/or bruised. Thus fruits with higher fruit index (Table 1) should be more easily bruised than those its with the fruit index close to 1.

Another important parameter is the fruit mass. Higher mass fruits sustain higher impact forces after free falls. For bruising formation instead of mass the mass parameter m/d_{max}^2 should be preferred (Table 1). It is a measure of loading the surface area during impact after fruit free falling, and is a measure of the loading stress rather than loading local force that can be expressed by fruit mass.

The highest values of parameter m/d_{max}^2 were observed for Electra and Vilu. The variety Electra with low values HL_0, $HL_{0.5}$ (Fig. 9) and high values DE_0, and $DE_{0.5}$ (Fig. 10) has to be classified as variety very sensitive to bruising. This conclusion is also strengthen by higher value of fruit index (1.51 – see Table 1).

CONCLUSIONS

Hysteresis losses and degree of elasticity are the main parameters of loading-unloading test that make it possible to determine the parameters expressing susceptibility of the tested variety to bruising – in agreement with the previous paper (B l a h o v e c et al., 2002). The classification based on such parameters is less sensitive to stage of ripening. Both the parameters lead to the comparable conclusions. The methods operate better at lower level of bruising.

Among the tested varieties Electra, Vonka, and Erika belong to more sensitive and Astra, Delta, and Bohemica to less sensitive to bruising. In analysis of the varieties susceptibility to bruising also some other aspects should be taken into account, especially shape of fruit and also fruit mass divided by its maximum diameter.

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REFERENCES

BAJEMA, R. W. – HYDE, G. M.: Instrumented pendulum for impact characterization of whole fruit and vegetable specimens. Trans. ASAE, *41*, 1998: 1399–1405.

BARREIRO, P.: Detailed procedure for fruit damaging. ASTEQ CA Newsletter 1999, No 2: 3–5.

BLAHOVEC, J.: Bruise resistance coefficient and bruise sensitivity of apples and cherries. Int. Agrophysics, *13*, 1999: 315–321.

BLAHOVEC, J.: Static mechanics and texture of fruits and vegetables. Res. Agric. Eng., *47*, 2001: 144–169.

BLAHOVEC, J. – MAREŠ, V.: Approximation of bruise spots in pears plotted against deformation parameters. Res. Agric. Eng., *49*, 2003: 50–55.

BLAHOVEC, J. – PATOČKA, K. – BAREŠ, J.: Low-level bruising of stored apples due to quasi-static loading up to constant compression strain. J. Texture Stud., *28*, 1997: 87–89.

BLAHOVEC, J. – PATOČKA, K. – PAPRŠTEIN, F.: Inelasticity and bruising of cherries. J. Texture Stud., *27*, 1996: 391–401.

BLAHOVEC, J. – VLČKOVÁ, M. – PAPRŠTEIN, F.: Static low-level bruising in pears. Res. Agric. Eng., *48*, 2002: 41–46.

BLAHOVEC, J. – PATOČKA, K. – BAREŠ, J. – MIKEŠ, J. – PAPRŠTEIN F.: Examination of apple susceptibility to bruising. Zahradnictví, *18*, 1991: 195–204 (in Czech).

BRUSEWITZ, G. H. – BARTSCH, J. A.: Impact parameters related to post harvest bruising of apples. Trans. ASAE, *32*, 1989: 953–957.

HOLT, J. E. – SCHOORL, J.: Bruising and energy dissipation in apples. J. Texture Stud., *7*, 1977: 421–432.

HOLT, J. E. – SCHOORL, J.: Fracture in potatoes and apples. J. Mater. Sci., *18*, 1983: 2017–2028.

HOLT, J. E. – SCHOORL, J.: Mechanical properties and texture of stored apples. J. Texture Stud., *15*, 1984: 377–394.

JOHNSON, N. N.: Contact mechanics. Cambridge, Cambridge University Press 1987.

KAMP, J. – NISSEN, G.: Impact damage susceptibility of Danish apples. Paper presented at International Workshop "Impact Damage in Fruits and Vegetables", 28–29 March 1990.

MATHEW, R. – HYDE, G. M.: Potato impact damage tresholds. Trans. ASAE, *40*, 1997: 705–709.

MOHSENIN, N. N.: Physical properties of plant and animal materials. Vol. 1. Structure, physical characteristics and mechanical properties. New York, Gordon and Breach Sci. Publ. 1970.

SCHOORL, D. – HOLT, J. E.: Post-harvest energy transformations in horticultural produce. Agr. Syst., *19*, 1986: 127–140.

STUDMAN C. J.: A model of fruit bruising. Presented at the 2nd Australasian Postharvest Conf., Monash University Melbourne 1995.

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Otlaky plodů vzniklé při nízké mechanické zátěži u skupiny odrůd hrušek.

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Otlaky vyvolané enzymatickým hnědnutím patří k nejvýznamnějším limitujícím faktorům kvality měkkých plodů (jablek, třešní, hrušek apod.) a měkké zeleniny (např. brambor). Rozsah jednotlivého otlaku bývá určován jeho objemem, který závisí na celkové deformační práci, popř. absorbované energii při jeho vzniku. Zátěžový test mezi dvěma tuhými deskami s následným odtížením byl aplikován na plody 16 odrůd s cílem určit citlivost jednotlivých odrůd ke vzniku otlaků. Objem otlaků byl určován z rozměrů získaných z jejich příčných řezů. Testy ukázaly, že obvyklé parametry používané pro tento účel (*BRC*, *BS*) mají omezenou použitelnost pro stanovení meziodrůdových rozdílů, zejména při vzniku drobných otlaků. Vhodnými mechanickými parametry pro tento účel se ukázaly být: stupeň elasticity a hysterezní ztráty při nízkých hladinách zátěže (objem otlaku 0 až 0.5 cm^3). Některé parametry charakterizující náchylnost odrůd ke vzniku otlaků byly stanoveny také na základě hmotnosti a tvaru plodů. Výsledky umožnily klasifikovat 12 z testovaných odrůd.

hrušky; tvorba otlaků; tlak; úder; objem otlaku; absorbovaná energie; hysterezní ztráty; stupeň elasticity; kvalita

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