Static and dynamic tests of pear bruise sensitivity

J. BLAHOVEC[1], V. MAREŠ[1], F. PAPRŠTEIN[2]

[1]*Czech University of Agriculture, Prague, Czech Republic*
[2]*Research Institute for Pomology, Ltd., Holovousy, Czech Republic*

ABSTRACT: The paper is a continuation of the preceding research of bruising sensitivity applied to different pear varieties. This study was based on quasi-static fruit testing in compression between two plates. One part of the method is based on determining the hysteresis losses corresponding to the predetermined low level bruising. This paper contains an attempt to apply the hysteresis loss concept to dynamical impact tests, which are simpler and quicker then quasi-static ones. Moreover the impact tests are closer to the character of deformations that initiating the bruising process in real conditions. Nine pear varieties were tested quasi-statically by the method developed previously. The same varieties were tested also dynamically in a special pendulum with flat and round indentors. The results show that the dynamic test is less sensitive in determining the bruising susceptibility than the previous quasi-static one. Moreover the success of the dynamic test depends on the shape of the indentor. Acceptable results were obtained with a flat indentor in contrast to the round indentor. For the last modification of the indentor we obtained the results, from which it was practically impossible to determine the maximal value of the hysteresis losses at which no bruise spots were formed.

Keywords: pears; bruising; compression; impact; bruise volume; absorbed energy; hysteresis losses; degree of elasticity; quality; indentor; spherical; indentor with a flat head

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. Bruise extent is usually described in terms of bruise volume (BLAHOVEC et al. 1991), which closely relates to product quality. 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). 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 greater 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 higher quality, the conditions corresponding to no and/or very little bruise damage are of the most importance. The evaluation of this area by two separate BRC (BS) values was proposed (BLAHOVEC 1999). In a previous papers (BLAHOVEC et al. 2002, 2003; BLAHOVEC, MAREŠ 2003) 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. This idea was applied to quasi-static loading between two plates, the test in which the characteristic values can be easily determined. Most of bruise spots are of dynamic origin and this is why dynamic loading is usually used for testing fruit susceptibility to bruising.

In this paper the susceptibility to bruising is analysed for nine pear varieties by the quasi-static method developed previously and also by a dynamic method based on a similar philosophy to that applied previously to the quasi-static method.

MATERIALS AND METHODS

The pears of nine varieties were harvested in the orchard of the Research Institute for Pomology, Ltd., at Holovousy in North-Eastern Bohemia at a stage of harvesting maturity. Testing date details are given in Table 1. Every test was conducted on thirty or forty defect-free fruits that were divided into three or four

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Table 1. Main characteristics of the tested fruits

Variety	Test dates		Fruit mass m (g)		Fruit index h/d_{max}		m/d_{max}^2 (kg/m^2)	
	loading date	bruise analysis	mean	CV (%)	mean	CV (%)	mean	CV (%)
Beta	06/02/04	11/02/04	212.0	18.0	1.51	6.1	41.9	6.9
David	15/11/03	20/11/03	160.5	13.5	1.41	11.0	39.9	17.3
Decora	14/11/03	19/11/03	193.5	19.0	1.14	8.0	37.6	9.1
Delta	05/02/04	09/02/04	256.5	29.6	1.34	10.0	41.9	11.3
Dicolor	15/11/03	20/11/03	146.0	19.0	1.17	7.0	33.5	11.4
Dita	06/02/04	10/02/04	253.8	24.2	1.15	6.2	40.2	8.0
Erika	06/02/04	10/02/04	239.4	12.0	1.35	5.7	43.0	6.4
Konference	14/11/03	18/11/03	183.3	15.6	1.59	11.1	42.0	7.9
Milada	14/11/03	19/11/03	310.5	20.1	1.38	9.1	44.8	9.9

h – length of fruit, d_{max} – maximum fruit diameter, CV – coefficient of variation

ten-fruit groups. The fruits were than compressed individually between two plates at a constant deformation rate of 0.167 mm/s. The fruits' axis was oriented to be parallel with the compression plates. After reaching the desired force (100, 150, 200, and 250 N for fruits included in the separate groups – in some cases with very hard fruits, e.g. David, Dita, and Erika, the desired forces were higher up to 450 N in case of David) the fruit was unloaded at the opposite deformation rate. All the loading-unloading tests were performed in a Universal Testing Machine (UTM) Instron™ (model 4464) at usual laboratory conditions (temperature 20–22°C). The UTM software was used to evaluate the loading curves. The following parameters were obtained (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 ($HL = W_A/W_L$).

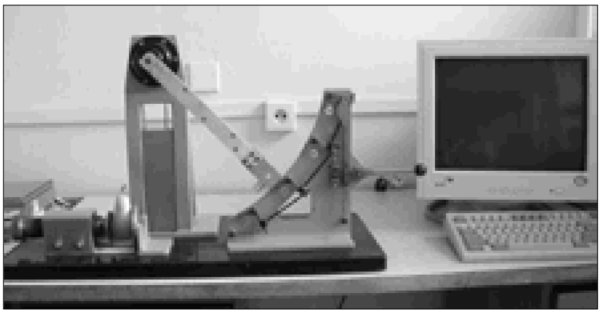

Fig. 1. Photo of the pendulum device used for study of the pear impact bruising. The light-weight aluminium pendulum arm is fixed in 45° position of the mechanical initiating mechanism. The changeable brass indentor with the flat head is placed on the end of the arm. The optical sensor for angle detection is rigidly connected with the arm axis. In the right side of the figure there is a fixation mechanism with fixed pear prepared for a test

Every pear tested quasi-statically was tested also dynamically by an impact pendulum (Fig. 1). The pendulum has a 30 cm long arm with removable weight and changeable impactors with a flat and a spherical head of diameter 15 mm. The basic parameters of the pendulum are given in Table 2. The tested pear was fixed in a special jig and pre-stressed by the spring of a micrometer screw. The impact test were performed on the fruit "equator" (the place of maximum fruit diameter) in a direction perpendicular to the deformation axis used in the quasi-static compression test. The pendulum arm was then fixed in one of the initial positions and dropped on the fruit. After rebounding of the arm into the highest position, the arm was caught by hand. The initial (α_1) and rebounding (α_2) angles were detected by special optical sensor. The measurements were computer controlled and the resulting hysteresis losses of the individual impact were calculated directly under the formula:

$$HL = \frac{\cos \alpha_2 - \cos \alpha_1}{1 - \cos \alpha_1} \quad (1)$$

The parameters of the pendulum set up are concentrated in Table 3.

The pears were stored after the harvest at about 4°C and tested approximately after 24–72 hour tempering at room temperature. After test the fruits were left on the

Table 2. The main pendulum parameters for spherical and flat indentors

Angle	Load energy (J)		Impact velocity (m/s)	
	spherical	flat	spherical	flat
30	0.064	0.065	0.719	0.721
45	0.140	0.142	1.063	1.066
60	0.239	0.242	1.389	1.393
75	0.354	0.359	1.691	1.696

Table 3. List of dynamical tests

Variety	Indentor	Angle
Beta	Flat, both**	45
David	Spherical	30, 75*
Decora	Spherical	30, 75*
Delta	Flat	45
Dicolor	Spherical	30, 60*
Dita	Flat	45
Erika	Flat, both**	45
Konference	Spherical	30, 60*
Milada	Spherical	30, 60

*Double stroke into one tested place
**Comparative measurement by both the indentors on a limited number of specimens

table in a laboratory at room temperature (20–22°C) for about 24–72 hours (for exact information, see Table 1). 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):

$$V = \pi d^2 t/6 \qquad (\text{cm}^3) \qquad (2)$$

This formula gives results (BLAHOVEC 2001) comparable to the values of bruise volume obtained by the classical formula (MOHSENIN 1970; HOLT, SCHOORL 1977).

The variety characteristic values were obtained from quasi-static tests by analysis of the relations between the total bruise volume (in two separate spots) on one side and the deformation parameters: 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. The similar analysis was tried on bruise spots obtained from the dynamic tests.

RESULTS AND DISCUSSION

Shape of spots

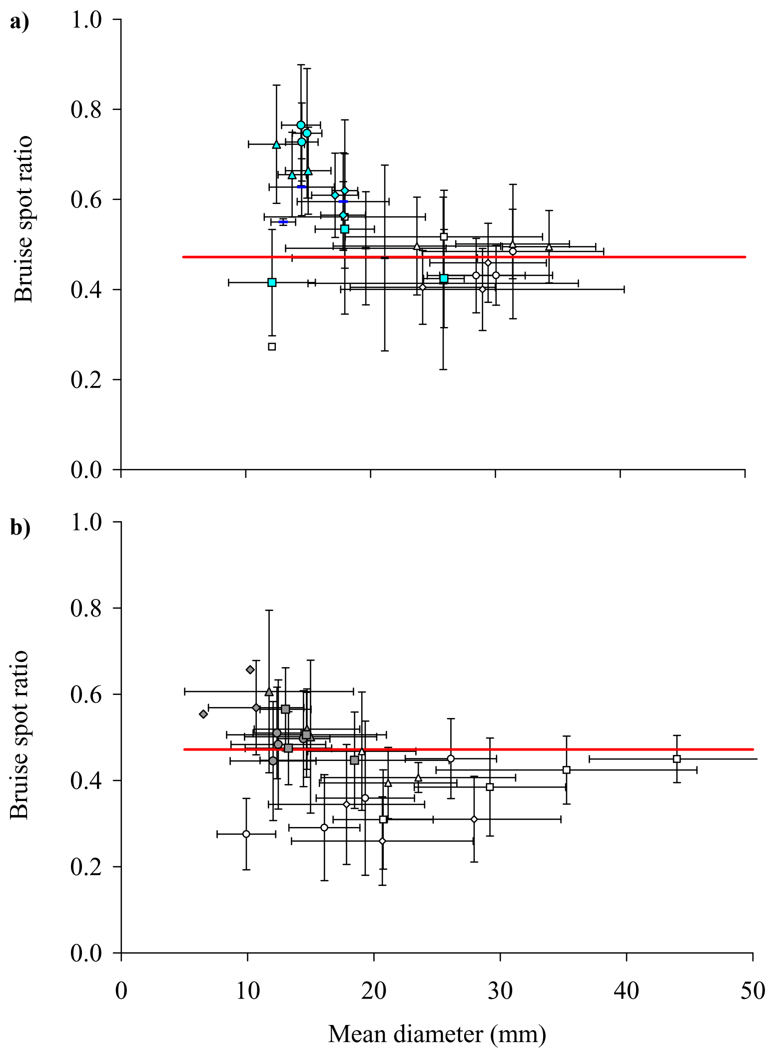

Fig. 2. Bruise spot ratio plotted against spot diameter. S denotes results obtained in the quasi-static tests, D denotes results of dynamic tests: a) dynamic tests with spherical indentor, b) dynamic tests with flat indentor. Horizontal line denotes value 0.472 obtained previously (BLAHOVEC et al. 2003) for quasi-static compression between two plates

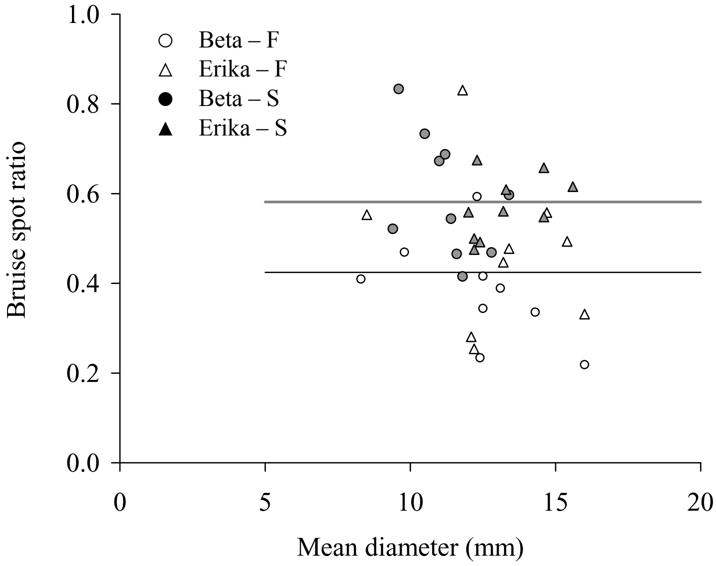

Fig. 3. Bruise spot ratio plotted against bruise spot diameter, results obtained in comparative dynamic tests with spherical and flat indentors. F – flat indentor, S – spherical indentor

The bruise spots have characteristic shapes expressed by bruise spot ratio (BSR), the ratio of the bruise spot thickness (t) to the bruise spot diameter (d). Our results are concentrated in Figs. 2 and 3. The bruise spots obtained in the quasi-static testing were very similar to those obtained in previous work (BLAHOVEC et al. 2003) with mean bruise spot ratio about 0.472. The February measurement led to rather lower values, especially at smaller bruise spots (Fig. 2b).

The bruises obtained in the dynamical tests had rather lower diameter and greater thickness so that the BSR of dynamically produced bruises reached higher values than the BSR from the quasi-static tests. This difference was more pronounced for the dynamical tests with the spherical indentor than for bruises formed by the flat indentor. The difference between BSR for both the indentors is also clear from Fig. 3, in which the results of the dynamic tests performed by both the indentors on the same fruits of two different varieties are presented. Mean value of BSR obtained for the spherical indentor was nearly about 50% higher than the mean BSR value for the flat indentor.

Bruise volume and quasi-static deformation characteristics

The plots of bruise volume versus hysteresis losses and/or degree of elasticity for every variety were analysed separately by polynomial approximation (BLAHOVEC, MARE 2003) and three characteristic values for both the parameters (DE, and HL) were determined: for values at which the first bruises were formed – initial degree of elasticity (DE_0) and initial hysteresis losses (HL_0), for formation of bruises of volume 0.5 cm^3 – $DE_{0.5}$ and $HL_{0.5}$, and for formation of bruises of volume 5 cm^3 – DE_5 and HL_5. The results of this analysis are given in Table 4.

The higher the hysteresis losses HL_0, $HL_{0.5}$, and HL_5 the less susceptible was the tested variety to bruising. The degree of elasticity correlated negatively with the hysteresis losses (BLAHOVEC et al. 2003), so that the opposite rule had to be used for the degree of elasticity: the higher the parameters DE_0, $DE_{0.5}$, and DE_5, the more susceptible was the tested variety to bruising. Our results from Table 4 are in agreement with this rule. This

Table 4. Quasi-static 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
Beta	49.86	57.02	75.47	71.20	64.66	40.69
David	60.77	61.95	72.83	62.03	61.35	54.47
Decora	70.94	72.88	83.70	51.80	51.02	42.94
Delta	64.88	68.80	85.36	59.33	53.55	31.15
Dicolor	72.16	74.31	81.54	53.46	51.76	41.16
Dita	64.06	67.11	78.73	59.16	55.74	44.25
Erika	63.15	64.27	70.78	59.84	58.32	50.82
Konference	65.68	69.63	86.49	66.51	60.40	30.91
Milada	71.78	73.17	79.57	50.97	49.03	41.79

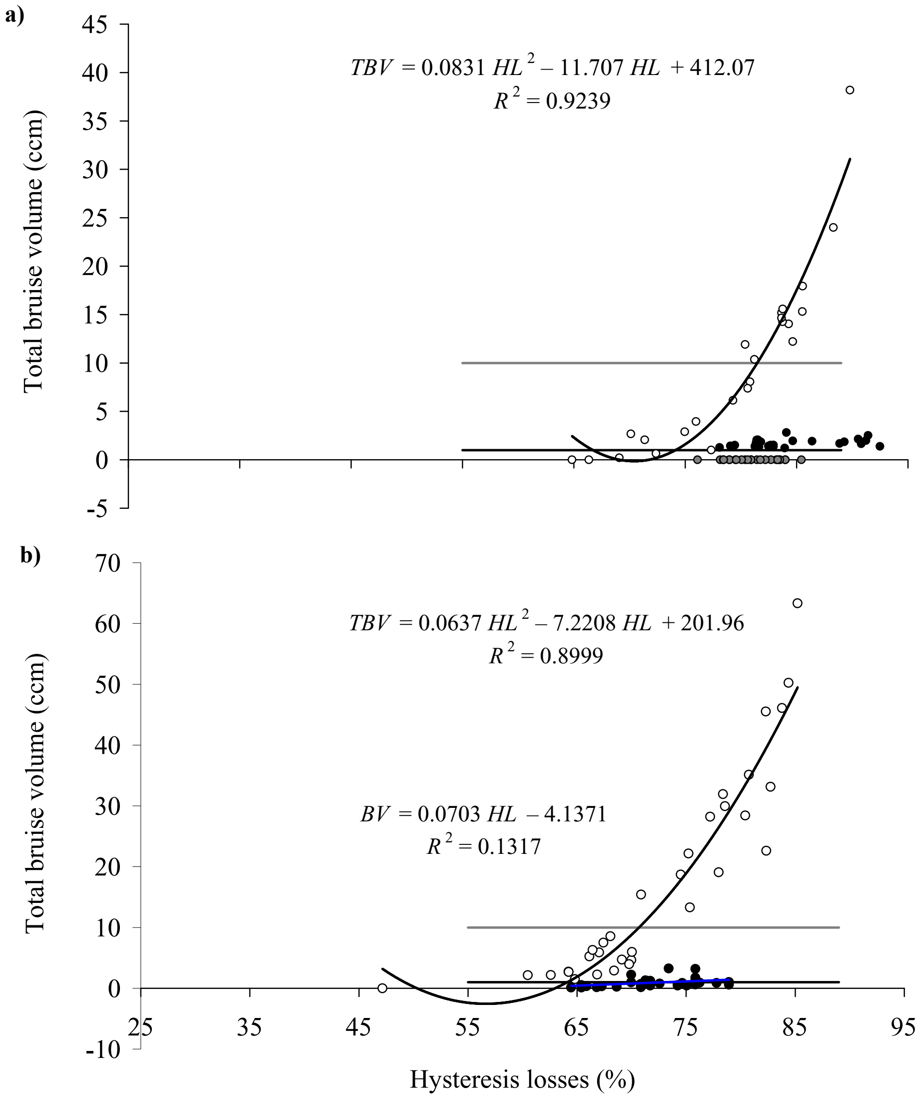

Fig. 4. Total bruise volume (i.e. in static test volume of two bruise spots formed at the pear surface and volume of one bruise spot in dynamic test) plotted against the loading energy. The symbols represent data from the individual tests. Open circles denote the results from the quasi-static tests, full circles denote the results from dynamic tests. a) dynamic test represented by double-stroke by spherical indentor, b) dynamic test represented by simple stroke by flat indentor. The equations in the figures are used for characteristic *HL*-values in quasi-static tests (quadratic equation) and for dynamical tests (linear equation only in case b)

fact indicates consistency of both the methods: based either on *HL* or on *DE*. Both methods of classification were 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.

Bruise spot volume and hysteresis losses in dynamical tests

Dynamic impact tests gave information on bruise volume and hysteresis losses – analysis of these tests led to *V-HL* plots similar to those from the quasi-static tests. Examples of such attempts are in Fig. 4. Fig. 4a shows that the response to dynamic impact with the spherical indentor was practically insensitive to hysteresis losses and that no characteristic values of the *V-HL* plot could be determined by simple impact tests with the spherical indentor. The observed decrease in bruise volume with decreasing *HL* was too small to determine the *HL* corresponding to bruises of the characteristic dimensions. Moreover, variation of the bruise volume decreased any chance to do it.

The flat indentor results were more optimistic than the previous ones (Fig. 4b). Decrease of the bruise volume with decreasing *HL* was not perfect, but generally detectable and describable by linear equation as was done in Fig. 4b. The obtained characteristic *HL* values were plotted against the corresponding values from parallel quasi-static tests (Fig. 5). This figure showed that the dynamical test seems to give higher characteristic values than the quasi-static test. The observed differences were lower at HL_0 and they increased with increasing bruise volume.

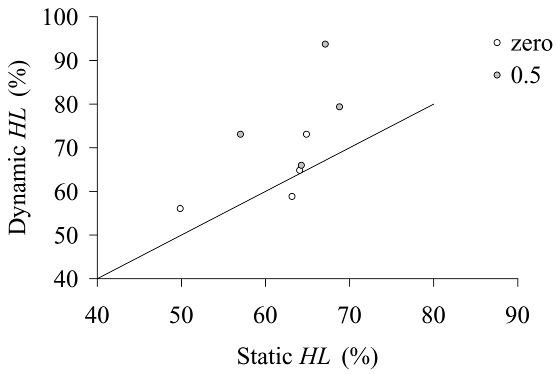

Fig. 5. The characteristic *HL* values (HL_0 and $HL_{0.5}$) obtained in the dynamical test with the flat indentor (see Fig. 4b) plotted against the corresponding parameters obtained in the quasi-static test (varieties Beta, Delta, Dita, and Erika)

Pear surface susceptibility to bruising

The quasi-static test results can be easily applied to assessment of the pear surface susceptibility to bruising (BLAHOVEC et al. 2003). For this purpose the ratio of the characteristic *HL* and *DE* values were calculated (BLAHOVEC, MAREŠ 2003):

$$BI_i = HL_i/DE_i \qquad (3)$$

and termed as bruising index. This index increases with decreasing susceptibility of the pear surface to bruising. The values of bruising index $BI_{0.5}$ obtained from our quasi-static tests are presented in Fig. 6. The figure shows that fruit surface of the Beta-variety was more susceptible to bruising than the other tested varieties. On the other hand the fruit surface of the Milada-variety seems to be more resistant to bruising than the other tested varieties. The comparison with previous year results (2002) showed good agreement in many cases (Fig. 6) The important seasonal disagreement was observed only for the variety Delta leaving in mind possibility of seasonal differences.

Variety susceptibility to bruising

The above mentioned characteristic values (for *HL* and/or *DE*) could not 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 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 should be more easily bruised than those with the fruit index close to 1. Pear bruising in relation to shape and mass will be analysed later in a special paper.

CONCLUSIONS

Hysteresis losses and degree of elasticity are the main parameters of loading-unloading tests that make it possible to determine the parameters expressing susceptibility of the tested variety to bruising – to determine the bruising index (BLAHOVEC et al. 2003; BLAHOVEC, MAREŠ 2003). 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.

Measurement of rebound in the dynamic impact test can determine bruise sensitivity of an individual pear variety only for the flat indentor. The assessment is based on determining the characteristic *HL* values in plots of bruise volume versus the hysteresis loss. Success of the method should be supported in future tests by increasing the number of the tested fruits and by the bigger extent of the impact energy.

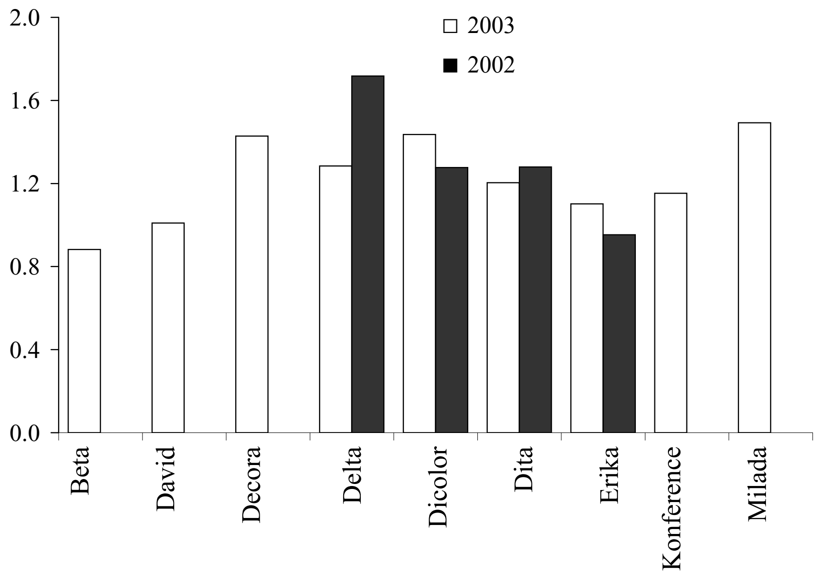

Fig. 6. Bruising index $BI_{0.5}$ obtained in quasi-static tests

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Statické a dynamické testy hrušek po mechanické zátěži

ABSTRAKT: Otlaky, které vznikají v dužnině plodů enzymatickým hnědnutím po předchozí mechanické zátěži, jsou důležitým limitujícím indikátorem kvality měkkých plodů, jako jsou jablka, třešně, hrušky apod. a měkké zeleniny (např. hlízy brambor). Rozsah otlaku je popsán jeho objemem, který závisí na celkové zatěžovací práci, popř. energii absorbované během zatěžování. Hrušky 16 odrůd byly podrobeny zatěžovacímu tlakovému testu mezi dvěma tuhými plochými deskami s následným odtížením s cílem určit odrůdovou citlivost k vytváření otlaků. Vzniklé otlaky byly příčně rozříznuty a jejich objem byl odhadnut z příčných průřezů. Testy ukázaly, že obvyklé parametry použité k hodnocení citlivosti plodů k otlakům (BRC, BS) mají omezenou schopnost popsat meziodrůdové rozdíly a také speciální vlastnosti v chování plodů při nízkých hladinách jejich mechanického zatěžování. Jako vhodné parametry pro tyto účely byly vybrány: stupeň elasticity a hysterezní ztráty při charakteristických nízkozátěžových stavech (BV = 0 a BV = 0,5 cm^3). Některé parametry pro posouzení otlačitelnosti byly určeny také z tvaru a hmotnosti plodů. Získané výsledky byly aplikovány ke klasifikaci devíti testovaných odrůd. Paralelně probíhající rázové dynamické testy, využívající měření úhlu odskoku od testovaného plodu, ukázaly, že trn se sférickým čelem je pro tento účel nevhodný. Určité možnosti pro daný záměr poskytuje trn s plochým čelem použitý v testech zaměřených na určování hysterezních ztrát. První měření ukazují některé nadějné výsledky, které mohou být precizovány v experimentech s větším počtem vzorků testovaných v širším spektru zátěže.

Klíčová slova: hrušky; otlaky; stlačení; ráz; objem otlaku; absorbovaná energie; hysterezní ztráty; stupeň elasticity; kvalita; trn; sférický; trn s plochým čelem

Corresponding author:

Prof. RNDr. Ing. JIŘÍ BLAHOVEC, DrSc., Česká zemědělská univerzita v Praze, Technická fakulta, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 384 581, fax: + 420 220 921 361, e-mail: blahovec@tf.czu.cz