Potato bruise spot sensitivity dependence on regimes of cultivation

J. BLAHOVEC, J. ŽIDOVÁ

Technical Faculty, Czech University of Agriculture, Prague, Czech Republic

ABSTRACT: Potato tuber bruising was simulated by impact pendulum at temperature 7°C. Two varieties (Agria and Samantana) cultivated under five different regimes were tested one month and/or five months after harvest. The regimes of cultivation differ by fertilising and/or irrigation. The obtained black spots were measured carefully to obtain detailed shape and volume. The obtained results are discussed in relation to tuber anatomy (vascular ring), regime of cultivation and mean tuber density. It is shown that contrary to bruising in fruits the black spots had maximum diameter not close to the surface but close the vascular ring. The relation between spot volume and the mean tuber density seems to be variety dependent.

Keywords: potato; bruising; black spot; impact; cultivation regime

Fruit and/or tuber bruising is one of the most important factors limiting 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 is closely related to product quality. The bruises belong to the whole scale of potato mechanical damage leading to yield losses expressed in tens of percent (BARITELLE et al. 1999). The important bruise factor is the loading extent, which is usually expressed in the terms of loading energy or absorbed energy (HOLT, SCHOORL 1977).

Bruises are usually classified as a special type of mechanical damage (BARITELLE et al. 1999) termed also as black-spot bruises that: *"have no visible cell wall or cell debonding damage although the cells are often damaged. Typically, recent bruises are blue black and in perimedulary tissue rather than in cortex. Discoloration appears within 48 hours at 10–20°C. Black-spot occurs in warmer more flaccid tubers, especially if potassium is deficient; and is associated with lower damaging drop heights (lower impact velocities)."* These conclusions are in agreement with MOLEMA's study (1999) on variety Bintje. The susceptibility of a potato sample to bruising is usually assessed by frequency of black-spot formation (BARITELLE et al. 1999), dimensions of the black spots formed (NOBLE 1985) and/or black spot volume (MOLEMA 1999). No universal and clear relation of bruising sensitivity of potato tuber to any physical property has been observed.

HOLT and SCHOORL (1977) originally described the relation between bruise volume and the absorbed energy in apples as a simple linear function where the constant term (intercept) is equal to zero and the slope is termed the Bruise Resistance Coefficient (*BRC*). Other factors affecting the apple bruising may be reflected in *BRC*. This very fruitful, but yet controversial idea, can also be applied to potato bruising (HOLT, SCHOORL 1983). 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 that the commodity is less easily bruised.

For fruits 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 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.

In this paper the susceptibility to bruising is analysed by dynamic impact methods for two potato varieties cultivated at five different conditions (regimes of cultivation).

MATERIALS AND METHODS

Two varieties (Agria and Samantana) cultivated in five different regimes were tested one month and/or five months after harvest. The regimes of the potato cultivation are given in Table 1. The whole field experiment was organised on the experimental station Valečov (Research Potato Institute) close to Havlíčkův Brod in

Table 1. Cultivation regimes used for both potato cultivars

Regime	1	2	3	4	5
Mineral N (kg/ha)	0	120	60 + 60*	60 + 30*	60 + 30*
Animal manure (t/ha)	0	30	30	37	37
Application		autumn	autumn	spring	spring
Form		manure**	manure**	slurry***	slurry***
Irrigation	0	0	full	full	saving

*organic N added to irrigation, **pig farmyard manure, ***pig slurry

the Eastern Bohemia. The tubers were cold stored in an air ventilated room at 6–10°C. After transport the tubers were stored in a refrigerator for a few days at (7 ± 1)°C. The day prior to testing the tubers were washed in cold water and then 50 defect-free tubers of mediate size (5–8 cm in diameter) were selected for the test. After determining the density of the individual tubers (method of by weighing in air and in water) at room temperature the surface water was dried by placing the tubers about one hour on the table in laboratory conditions. The tubers were then put into the refrigerator (at about 7 ± 1°C) for about 20 hours.

The tubers of a sample were removed sequentially from the refrigerator and tested dynamically by impact pendulum (BLAHOVEC et al. 2004). The pendulum had a 30 cm long arm with removable weight and changeable impactors with flat and/or spherical heads of diameter 15 mm. The basic parameters of the pendulum are given in Table 2. The impact tests were performed on the tuber "equator" in the direction perpendicular to a tuber axis (connection of the bud and stem parts). The tested tubers were fixed in a special jig and pre-stressed by the spring of a micrometer screw. Two pendulum impacts by the spherical impactor were done into the same place on a tested tuber: the preparing (initial arm angle 30°) followed by the initiating one (initial arm angle 75°). The preparing impact was presumed to cause no bruising; the initiating impact was presumed to cause bruising. This procedure was reproduced onto two places at the side of every tuber (in direction of the maximal tuber thickness – B1 and in direction of the minimal tuber thickness – B2). The pendulum arm was then fixed in the corresponding initial position and dropped on the tuber. 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 a special optical sensor connected with the pendulum axis. The measurements were computer controlled and the resulting hysteresis losses of individual impacts were calculated directly under the formula (BLAHOVEC et al. 2004):

Table 2. The basic parameters of the pendulum with spherical impactor and additional weight

Angle	Load energy (J)	Impact velocity (m/s)
30	0.123	0.787
45	0.269	1.164
60	0.460	1.521
75	0.682	1.851

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

The quantity $CE = 1 - HL$ represents the relative part of the impact energy conserved during the impact; we will term it relative conserved energy. After test the tubers 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 tuber flesh changed from the original to dark grey (BARITELLE et al. 1999). Then the impacted parts of tubers were sliced by a calibrated peeler into planar 1.4 mm thick slices parallel to the tuber surface (MOLEMA 1999). The slices were visually inspected to detect the presence of "black spots". Mean diameters of the discoloured tissue were measured manually (MOLEMA 1999). The set of measured diameters gave on the bruise volume profile.

The tested tissue was characterised by two values of HL, the first obtained from the first, so called preparing impact (initial angle 30°), HL_{30}, and the second from the second, so called initiating impact (initial angle 75°), HL_{75}. The first value can be understood as information on the rebound properties of the undamaged tuber tissue, the second value then informs on rebound properties of the damaged tuber tissue.

RESULTS AND DISCUSSION

Tuber density

The results obtained for tuber density are plotted in Fig. 1. This figure shows that the density of both the tested varieties is comparable one month after the harvest. Little higher values were observed for cultivation regimes 2 (fertilised, no irrigation) and 5 (modified fertilisation and reduced irrigation). The tuber density was reduced during storing in all the tested 'regimes' and varieties. Moreover, the observed increase of the standard

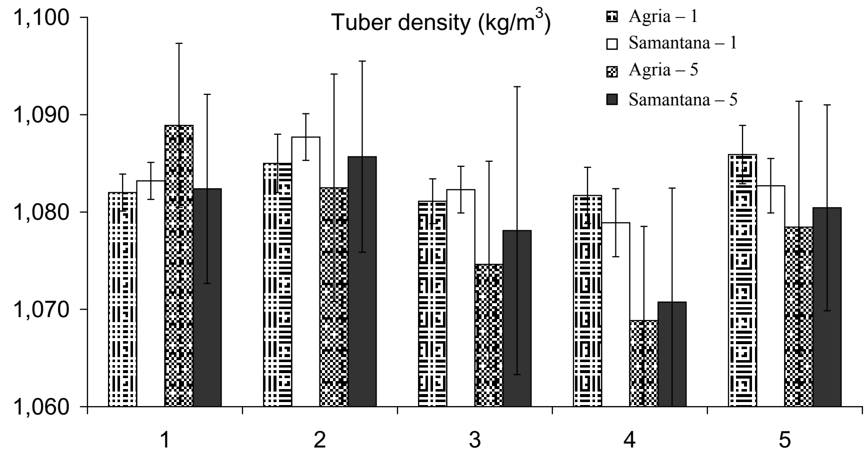

Fig. 1. Density of the measured tubers. Numbers 1–5 denote the regimes of cultivation (see Table 1), the increasing degree of grey denotes successively varieties Agria, and Samantana (both tested one month after harvest); and Agria, and Samantana (both tested five months after harvest). The bars denote standard deviations of the individual measurement

deviations during the storing indicates higher variability of the processes controlling the density reduction. The density of all the irrigated 'regimes' decreased during storing.

Impact parameters

The hysteresis losses as well as the relative conserved energy (*CE*) are the basic parameters characterising the impact process. The *CE*-value of the preparing impact is usually higher than 0.25. The variability of this value is very low (with CV lower that 10%). The similar results were also given by the initiating impacts five months after harvest. No such conclusion can be made for a potato of the varieties tested one month after harvest. Such a potato was turgid enough that it was mechanically damaged in many cases and *CE* is then lower (up to 0.20). The same process is a source of increasing variability with CV increasing up to values higher than 0.20. These facts led us to the conclusion to use different modes of the impact test for assessing the impact properties the potatoes in different stages of storage. For the potatoes in the turgid state (one month after the harvest) the preparing impacts were used while the assessment of the more flaccid tubers after five months storage was based on the initiating impacts.

The obtained results are displayed in Fig. 2. The relative conserved energy is higher for short stored tubers of both the varieties than the values obtained four months later. The figure also shows further significant results.

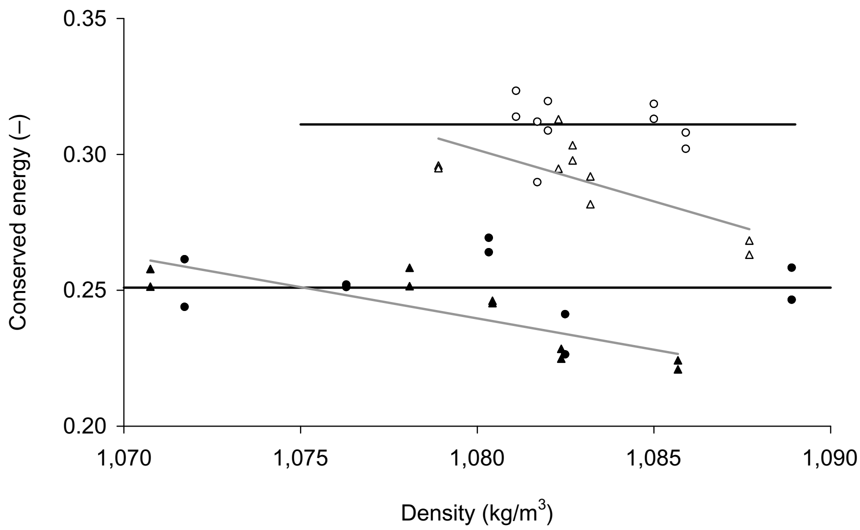

Fig. 2. Mean values of Relative Conserve Energy plotted against Mean Tuber Density. Circles and triangles denote variety Agria and Samantana, respectively. The empty and filled marks represent results one month after the tuber harvest (preparing impact) and five months after the tuber harvest (initiating impact), respectively. Agria was characterised by constant values of *CE* (black horizontal lines in Fig. 2): 0.311 ± 0.010 (preparing impact one month after harvest) and 0.251 ± 0.013 (initiating impact three months after harvest). For Samantana the following linear plots *CE* versus density (ρ) were obtained (grey lines in Fig. 2): $CE = 4.397 - 0.0038\rho$, $R^2 = 0.539$ (preparing impact one month after harvest), and $CE = 2.723 - 0.0023\rho$, $R^2 = 0.683$ (initiating impact five months after harvest)

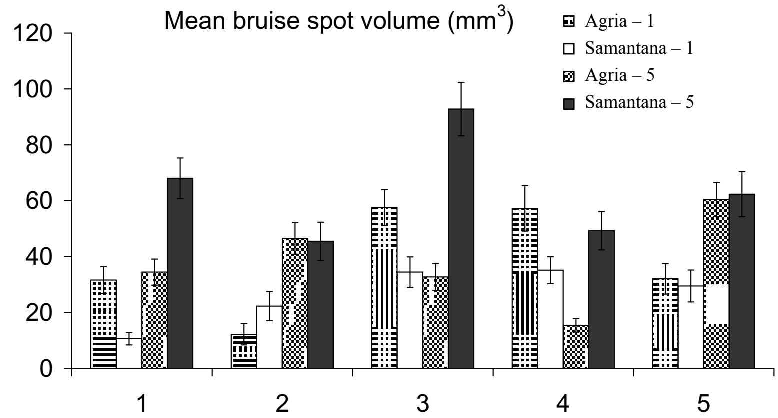

Fig. 3. Mean bruise volume of the tested varieties in five regimes (numbered 1–5 at the horizontal axis – see also Table 1). The mean values were calculated for all the variety and regime results, i.e. for both surface locations on the tuber surface. The figure legend contains shortened name of the variety and storage time in months after harvest. The bars denote standard deviation of the obtained **mean values**

The *CE* obtained for Samantana decreased with increasing mean tuber density, very similarly (with very similar slope of the line) for both the testing dates. In contrast, for Agria the *CE*-values seem to be independent of the tuber mean density and/or the possible dependence has to be much weaker than in Samantana. This indicates that the frequently-cited dependence (e.g. BARITELLE et al. 1999) of the impact properties as well as the bruising sensitivity on tuber density is not general.

Bruise volume

The inspected bruise spots had the shape of a thick lens (BLAHOVEC 2004) located just under the tuber surface. The observed spot dimensions were quite variable from non-damaged (no spot was observed) up to spots penetrated more than 10 mm under the surface of the impacted tuber. The coefficient of variation – calculated for the bruise volume – oversteps 100 per cent in many cases. This is why we plotted in Fig. 3 mean values of the bruise volume with bars expressing the SD for the mean values (not for the individual measurement). Figure 3 shows that one month after the tuber harvest the Agria tubers were more sensitive to bruising than Samantana (regimes 2 and 5 are exclusion) while four months later the opposite relation was observed. The sensitivity of the Samantana tubers increased during storage, the similar trend at Agria was observed only for regimes 2 and 5. No significant dependence of the bruise spot volume on the tuber density was observed.

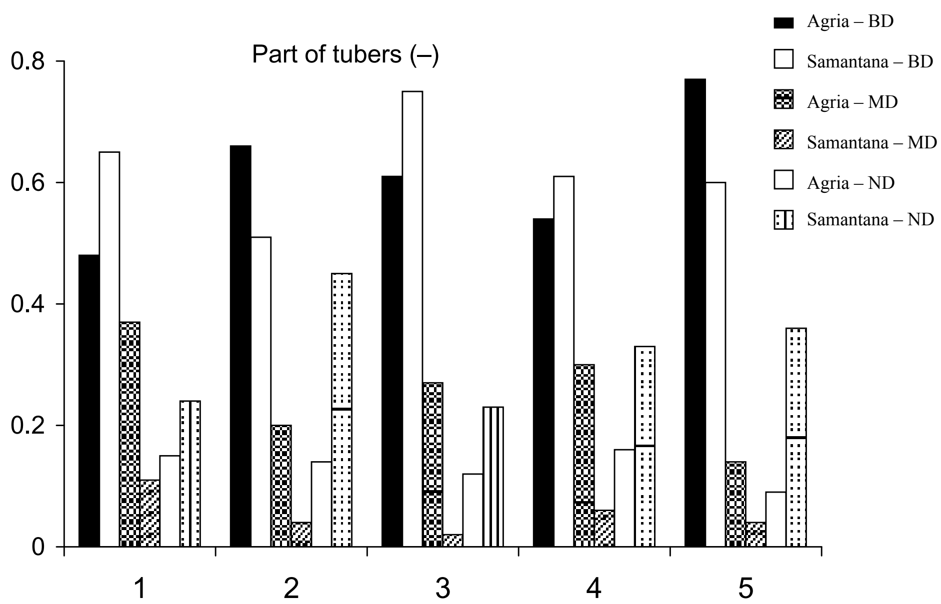

Fig. 4. Relative number of the sample tubers classified under their damage plotted against the tests performed five months after harvest: BD (bruise damages), MD (mechanically damaged – crushes and shatters – see BARITELLE et al. 1999), and ND (non-damaged). The ND tubers were used for determination the mean value of the bruise spot volume (Fig. 3) with the zero bruise spot volume equalled, the MD tests were excluded from this process. The number at the horizontal axis denote 5 different regimes of cultivation

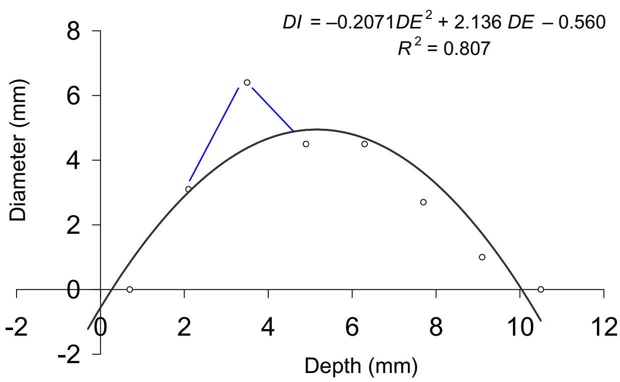

Fig. 5. Typical bruise spot profile: plot of the spot diameter versus the depth. The circles represent the measured values approximated by a polynomial of the second order. The area under the polynomial curve corresponds to the area of an idealised axially symmetric bruise spot longitudinal section. The lighter lines approximate the increasing width of the bruise spot close to the potato vascular ring

The source of the observed variety differences can be found in different variety properties – see e.g. differences in *CE* given Fig. 2. Further forms of mechanical damage such as shattering and crushing (BARITELLE et al. 1999) can be important, playing different roles in different varieties and/or cultivation regimes. Fig. 4 shows that crushing and the different forms of shattering played a more important role in Agria than in Samantana. It seems that fertilising and irrigation of potatoes did not increase the mechanical damage (bruising – BD and crushing and shuttering – MD – see Fig. 4) for the both the tested varieties. For Samantana the increase of non-damaged tubers (ND) with introducing the fertiliser and/or irrigation was well documented in Fig. 4 (see regimes 2–5 comparing with the regime 1). Similar behaviour was not observed at Agria, for which ND was approximately the same for all the regimes of cultivation.

Shape of the bruise spot

The bruise spots had a lens form as is described by the depth-diameter plot in Fig. 5. This dependence was approximated simply by a symmetric second order polynomial. The details of the approximation will be described separately (BLAHOVEC 2004). There are two important characteristics of such an approximation: the bruise spot ratio (BSR) and the bruise spot extension (BSE). The first one (BSR – BLAHOVEC et al. 2003) was expressed as a ratio of the maximum penetration depth (thickness) and maximum penetration width (diameter) – see Fig. 5. The BSE was originally defined as a mean for description of a bruise spot local extension usually observed close to the tuber vascular ring. It is expressed as the ratio of the maximal bruise spot diameter and the maximal value of the polynomial approximation. It could be demonstrated in Fig. 5: the third value from the left repre-

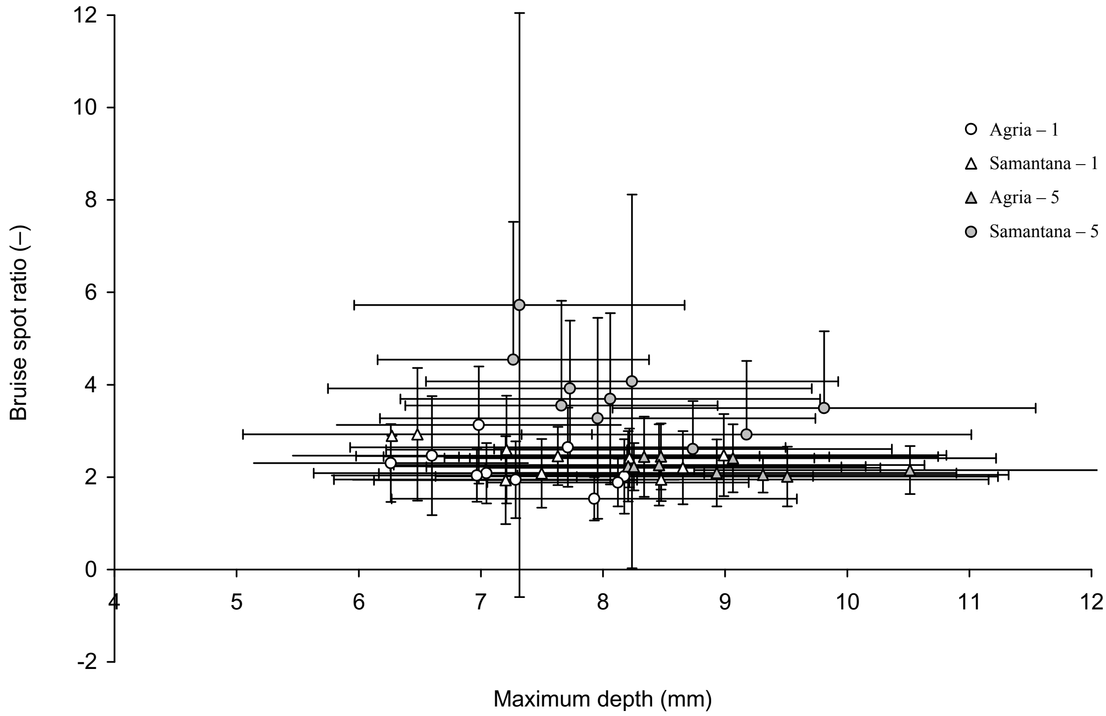

Fig. 6. Bruise spot ratio (BSR – ratio of the maximal spot depth and maximal spot diameter) plotted against maximal spot depth. For legends see Fig. 3. The bars denote standard deviations of the individual measurements

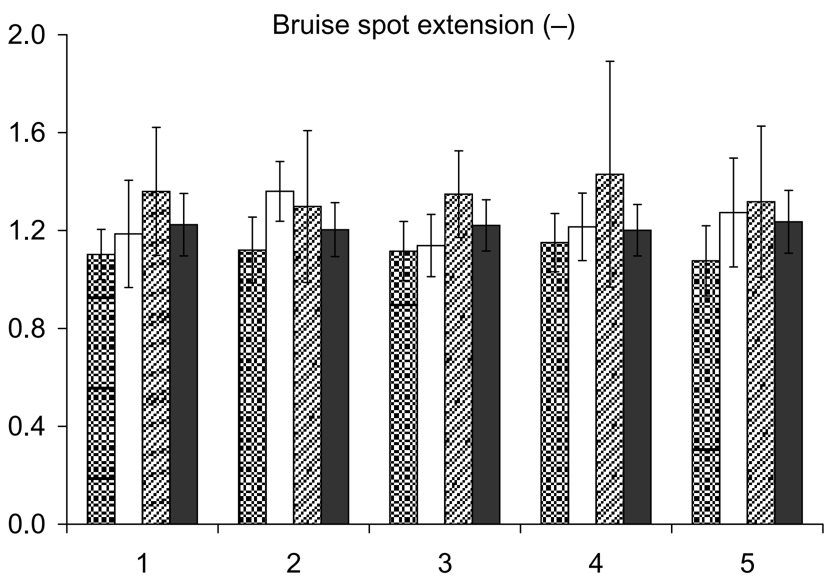

Fig. 7. Mean values of the bruise spot extension (BSE). For legend see Fig. 3

sents the maximal measured diameter (6.4 mm) close to the tuber vascular ring and the maximal diameter given by the approximation (4.95 mm at depth 5.16 mm). The resulting bruising extension is then: 6.4/4.95 = 1.29.

The bruise spot ratio was plotted against the maximum spot depth (Fig. 6). The figure shows that the BSR reaches values 1.5–3 in most cases, only for variety Agria tested after 5 months the higher values were obtained. This case can be caused by the worse approximation of the obtained data by the polynomial of the second order. The problem will be solved in a special paper later (BLAHOVEC 2004). The other cases can be well approximated by a mean value ≈ 2, the value is approximately four times higher than the BSR usually obtained at fruits (BLAHOVEC et al. 2003).

Mean values of the bruise spot extension are given in Fig. 7. The BSE values were the same for the Agria cultivation regimes tested one month after harvest. Only small deviations were obtained for all Samantana's BSE, even if the BSE-s obtained five months after harvest were higher in all cases than the corresponding BSE values obtained a month after harvest. The bruise spot extension in Agria five months after harvest is much higher than four months before. Also the Agria's BSE standard deviations were much higher five months after harvest than before. Similarly as in the previous case also the Agria behaviour five months after harvest can be influenced by the worst approximation of the experimental data (spot diameter and depth) by the second order polynomial. Also this problem will be solved later in the special paper (BLAHOVEC 2004).

CONCLUSIONS

The tuber density depends on the cultivation regime and the variety, and decreases during storage. The impact properties (*CE*) depend on both the storage time and variety. The variety plays the principal role for storage dependence of the impact properties; it pre-determines the form of the *CE* dependence on the storage dependent parameters (e.g. density). Bruise spot forming depends also on the other forms of the mechanical damage: shattering and especially crushing, the processes that are variety dependent. The bruise volume and its changes during storage are variety dependent. The bruising spots have a lens shape with a profile describable in many cases by a second order polynomial. The bruise spot ratio is approximately 2, i.e. the value was much higher than that usually observed in fruit. The real spot diameter in the area close to the vascular ring is higher than the maximal diameter obtained by the polynomial approximation. This increase represents 10–40%.

Acknowledgements

The authors thank to Professor G. M. HYDE from Washington State University (USA) for reading the manuscript, valuable comments, and stimulating discussion.

References

BAJEMA R.W., HYDE G.M., 1998. Instrumented pendulum for impact characterization of whole fruit and vegetable specimens. Trans. ASAE, *41* (5): 1399–1405.

BARITELLE A., HYDE G.M., THORNTON R., BAJEMA R., 1999. A classification system for impact related defects in potato tubers. Presented at 38th Annual Washington State Potato Conference & Trade Fair. In: Amer. J. Potato Res., 2000, *77*: 143–148.

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

BLAHOVEC J., 2004. Shape of bruise spots in impacted potatoes. To be published.

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

BLAHOVEC J., PATOČKA K., PAPRŠTEIN F., 1996. Inelasticity and bruising of cherries. J. Texture Stud., *27*: 391–401.
BLAHOVEC J., PATOČKA K., BAREŠ J., 1997. Low-level bruising of stored apples due to quasi-static loading up to constant compression strain. J. Texture Stud., *28*: 87–89.
BLAHOVEC J., VLČKOVÁ M., PAPRŠTEIN F., 2002. Static low-level bruising in pears. Res. Agr. Eng., *48*: 41–46.
BLAHOVEC J., MAREŠ V., PAPRŠTEIN F., 2003. Static low-level pear bruising in a group of varieties. Sci. Agric. Bohem., *34*: 140–145.
BLAHOVEC J., MAREŠ V., PAPRŠTEIN F., 2004. Static and dynamic tests of pear bruise sensitivity. Res. Agr. Eng., *50*: 54–60.
BLAHOVEC J., PATOČKA K., BAREŠ J., MIKEŠ J., PAPRŠTEIN F., 1991. Vyšetřování otlačitelnosti jablek. Zahradnictví, *18*: 195–204.
HOLT J.E., SCHOORL J., 1977. Bruising and energy dissipation in apples. J. Texture Stud., *7*: 421–432.
HOLT J.E., SCHOORL J., 1983. Fracture in potatoes and apples. J. Mater. Sci., *18*: 2017–2028.
MATHEW R., HYDE G.M., 1997. Potato impact damage tresholds. Trans. ASAE, *40*: 705–709.
MOLEMA G.-J., 1999. Mechanical force and subcutaneous discolouration in potato. [PhD. Thesis.] Wageningen Universiteit: 117.
NOBLE R., 1985. The relationship between impact and internal bruising in potato tubers. J. Agr. Engng. Res., *32*: 111–121.

Received for publication June 17, 2004
Accepted after corrections July 12, 2004

Citlivost brambor k šednutí v závislosti na způsobu jejich pěstování

ABSTRAKT: Šednutí hlíz brambor bylo simulováno s použitím rázového kyvadla při teplotě 7 °C. Dvě odrůdy (Agria a Samantana) pěstované pěti různými způsoby byly testovány jeden měsíc a pět měsíců po jejich sklizni. Jednotlivé způsoby pěstování se od sebe lišily dávkami a způsoby hnojení a také závlahou. Tvar a objem zšedlé dužniny byly pečlivě proměřovány u každého jednotlivého bodu. Získané výsledky byly diskutovány ve vztahu k anatomii hlízy (vaskulární prstenec), k režimu pěstování a k průměrné hustotě hlízy. Ukázalo se, že oproti otlakům ovoce nemá zšedlá dužnina největší průměr pod povrchem hlízy, ale v blízkosti vaskulárního prstence. Zdá se, že vztah mezi objemem zšedlé dužniny a střední hustotou hlízy, pokud existuje, je odrůdově závislý.

Klíčová slova: brambor; šednutí; šedé pletivo; úder; podmínky pěstování

Corresponding author:

Prof. RNDr. Ing. JIŘÍ BLAHOVEC, DrSc., Česká zemědělská univerzita v Praze, Technická fakulta, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 384 281, fax: + 420 220 921 361, e-mail: blahovec@tf.czu.cz