Impact induced mechanical damage of Agria potato tubers cultivated in different regimes

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Abstract: The Agria potato tubers were grown in 2005 in cultivation regimes involving different irrigation and fertilisation levels and forms. The impact induced tuber damage was simulated dynamically by an impact pendulum test and studied with the aim to detect some relationship between the cultivation regimes and the type and extent of the damage. The usual bruising presented as black spots is in many cases masked by other mechanisms of damage, e.g. by tuber cracking and/or crushing. The highest degree of tuber cracking and at the same time the least frequent bruising were observed for tubers cultivated in the regime with irrigation and without fertilising. The bruising was more pronounced in the narrower tuber side in comparison to the wider flat side in all cultivation regimes. Some results could be compared with similar previous measurements performed on tubers from the same field experiment organised during three successive years 2003–2005. The flatter side parts of the Agria tubers are more sensitive to bruising than the more oblique ones. The bruise spot shape depends mainly on its dimension. The role of different cultivation regimes can be interpreted in this way.

Keywords: potato; density; stem; bud; cultivation regime; impact; bruising; cracking; crushing; irrigation; fertilisation

The mechanisation in harvesting, sorting and transport of soft fruits and vegetables, including potatoes, is limited by the facile mechanical damaging of the products. The previous forceful mechanical contacts with other bodies induce dark spots appearing near the product surface, i.e. bruising. The potato yield losses caused due to the bruise spots can be expressed in tens of percent (Baritelle *et al.* 1999). The extent of bruising is usually characterised by the bruise volume which is closely related to product quality. The loading extent, mostly expressed in the terms of loading or absorbed energy, is the most important bruise factor (Holt & Schoorl 1977).

Bruise spots are usually classified as a special type of mechanical damage (Baritelle *et al.* 1999) termed also as black-spots 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 h at 10–20°C. Black-spots occur in warmer more flaccid tubers, especially if potassium is deficient; and are associated with lower damaging drop heights (lower impact velocities). These conclusions are in agreement with Molema's study (1999) on variety Bintje. The degree in which a potato sample inclines to bruising is usually assessed by the frequency of black-spot occurred (Baritelle *et al.* 1999), by the dimensions of the black spots to be formed (Noble 1985) and/or by the black spot volume (Molema 1999). No successful relationship between potato tuber sensitivity to bruising and any physical property has been observed. There are other mechanisms causing mechanical damage, mainly cracking, crushing and processes leading to separation of potato tissue, which often mask the bruising mechanism.

A dependence of the bruise spot shape either on the tested product and/or the object shape, which was in contact with the product before forming the spot, was shown previously (Blahovec *et al.* 2003, 2004; Blahovec & Židová 2004; Blahovec 2005b). The bruise spot shape can be simply described by relation of its thickness (depth) to its maximum diameter. This ratio was termed as the bruise spot ratio (*BSR* – see Blahovec & Židová 2004). Moreover, there were observed bruise spots with the maximum spot diameter, which however were not located just under the tuber surface as is usual in other products (apples, cherries, pears

– Blahovec *et al.* 2003, 2004) in agreement with the theoretical studies (e.g. Johnson 1987). In most cases the maximum diameter of the bruise spot is located close to the tuber vascular ring.

In this paper different damage mechanisms taking part in the impacted Agria tubers were studied in association with different cultivation regimes and with similar measurements obtained in previous two years.

MATERIALS AND METHODS

The Agria potato tubers were grown in different cultivation regimes involving different irrigation and fertilisation levels and forms (Table 1). The field experiment was organised on the experimental station Valečov (Research Potato Institute) close to Havlíčkův Brod in the Eastern Bohemia during three successive years 2003–2005. The tubers were cold stored in an air ventilated room at temperature 6–10°C and tested two months after harvest in November and December 2005. After the transport the tubers were stored in a refrigerator for few days at temperature 7 ± 1°C. The day prior to testing the variety (of the selected cultivation regime) the potatoes were washed in cold water and 50 undamaged tubers of moderate size (5 to 8 cm in dimension) were selected for the test. Density of individual tubers was determined by double weighting in air and in water. The surface water was then dried laying the tubers about one hour on a table at the room temperature. The potatoes were then put into the refrigerator (at temperature about 7 ± 1°C) for about 20 h.

The tubers were removed sequentially from the refrigerator and tested dynamically by an impact pendulum (Blahovec *et al.* 2004). The pendulum had a 30 cm long arm with a removable weight and changeable impactors with flat and/or spherical heads of diameter 15 mm. The impactor with spherical head was used in our test; basic parameters of the pendulum for this case are given in Table 2. The impact tests were performed on the tuber "equator" in the direction perpendicular to the 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 carried out against the same place on a tested tuber: the preparing impact (initial arm angle 30°) followed by the initiating one (initial arm angle 75°). This procedure was reproduced on 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 the individual impact were calculated directly under the formula (Blahovec *et al.* 2004):

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

The quantity

$$CE = 1 - HL \quad (2)$$

represents the part of the impact energy that was conserved during the impact and was termed as the relative conserved energy. After the test the tubers were left on a laboratory table at the room temperature (20–22°C) for about 24–72 h. During this interval the colour of bruised parts of the tuber flesh changed from the original to dark grey (Baritelle *et al.* 1999). Then the impacted tuber parts 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

Table1. Cultivation regimes

Regime	1	2	3	4	5	6
Mineral N (kg/ha)	0	120	60 + 60*	60 + 30*	60 + 30*	0
Animal manure (t/ha)	0	30	30	37	37	0
Application		autumn	autumn	spring	spring	
Form		manure**	manure**	slurry***	slurry***	
Irrigation	0	0	full	full	saving	full

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

Table 2. The basic parameters of the pendulum with spherical indentor 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

Table 3. Tuber density

Cultivation regime	*MV*	*CV* (%)
1	1091.2^{b}	0.9
2	1084.0^{a}	1.2
3	1093.9^{c}	0.9
4	1080.4^{a}	0.9
5	1082.2^{a}	0.8
6	1096.8^{c}	0.6

MV – mean value, *CV* – coefficient of variation; the indexes a–c denote the homogenous groups for α = 0.05 (Tukey HSD test with unequal number of observations used)

(Molema 1999). The volume profile of the black spot (initiated by the impact) was derived from the set of measured diameters.

The tested tissue was characterised by two values of HL:HL_{30} obtained from the first, so called preparing impact (initial angle α_{I} 30° in (1)) and HL_{75} obtained from the second, so called initiating impact (initial angle α_{I} 75° in (1)). The HL_{30} value can be interpreted as an information on the rebound properties of an undamaged tuber tissue, the HL_{75} value then characterises the rebound properties of a tuber tissue during its damage. Corresponding CE_{30} and CE_{75} relative conserved energies were calculated according (2).

RESULTS AND DISCUSSION

Tuber density

The density data are given in Table 3. The obtained mean values laid in the range from 1080 to 1096 kg/m^3. High density values were observed in the cultivation regimes without fertilising (regimes 1 and 6) and also in the regime 3 with full fertilising and full irrigation. In other cases lower densities were observed. This was in disagreement with the results obtained previously (Blahovec & Židová 2004; Blahovec 2005a, b) where no significant differences between density values corresponding to different cultivation regimes were observed.

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 was previously observed as higher than 0.25 (Blahovec & Židová 2004; Blahovec 2005b). The variability of this value was very low (with coefficients of variation *CV* lower than 12%). No such a conclusion could be made for the second impact onto the tuber. Such a potato tuber was turgid enough so that it was mechanically damaged in many cases and the *CE* value was then below 0.20. The same process was a source of increasing variability with *CV* reaching up to the values higher than 20% (Blahovec & Židová 2004; Blahovec 2005b).

The obtained results are displayed in Figure 1. Practically all the initiating impacts were accompanied by relative conserved energies lower than 0.2. These results differ from those obtained in the previous year 2004 (Blahovec 2005b), where relative

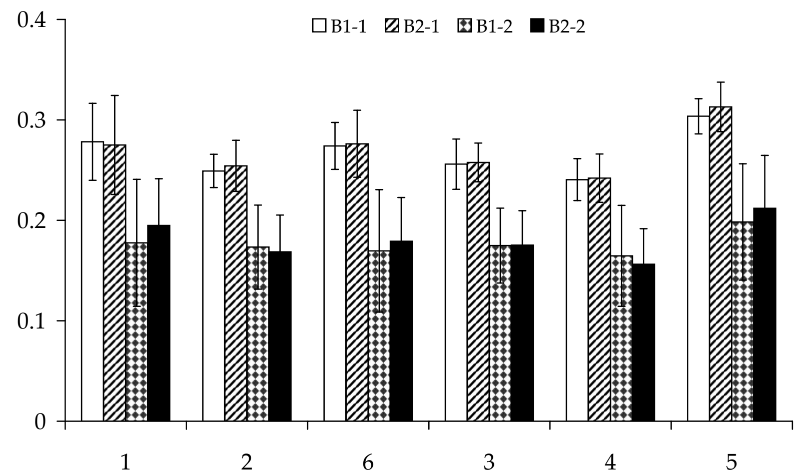

Figure 1. Relative conserved energy obtained for different cultivation regimes (1–6 in Table 1) and different impact positions on the tuber side (B1 and B2 – for details see text); additional numbers (1 and 2) at the symbol (e.g. B1 – 1) denotes the first and second impact on the same place; the bars denote the corresponding standard deviations

conserved energies higher than 0.2 were observed in the cultivation regimes 1, 4 and 5. In our case (Figure 1) higher *CE* values, i.e. less damage (for both, preparing and initiating impacts) were observed only for potatoes cultivated in the regime 5.

Bruise volume

The study of bruising was complicated by the other mechanisms causing mechanical damage (Figure 2). The process of impact was accompanied by both the external and internal cracks. This cracking occurred mainly in the tuber samples in which lower CE_{75} values were observed, similarly as in the previous tests performed in 2004 (Blahovec 2005b). The highest mechanical damage was observed in the regime 6, a regime with irrigation but without fertilising. Low level of mechanical damage was observed in the cultivation regime 5. In other cases the frequency of mechanical damage was approximately the same.

The bruise volume of the individual bruise spots varied from 6 to 1950 mm^3 with the total mean value 993 mm^3. Even if there were observed differences in the mean bruise spot volumes among the different cultivation regimes (810 to 1094 mm^3) the main difference among the samples was rather given by number of the observed bruise spots (Figure 3). Figure 3 gave the similar information as Figures 1 and 2, i.e. the total bruise volume was reduced in the regimes in which more mechanical damage was observed. The corresponding results obtained in 2004 were added for comparison. We can see that the results were comparable only in the cultivation regime 1. In other cases the results differed depending on direct occurrence of mechanical damage, see Figure 4, which reached 89% in regime 3 in 2004.

The bruise spots observed for B1-orientation were regularly bigger than for B2-orientation. The ratio of mean bruise volumes for both the orientations is plotted in Figure 5. A similar trend was

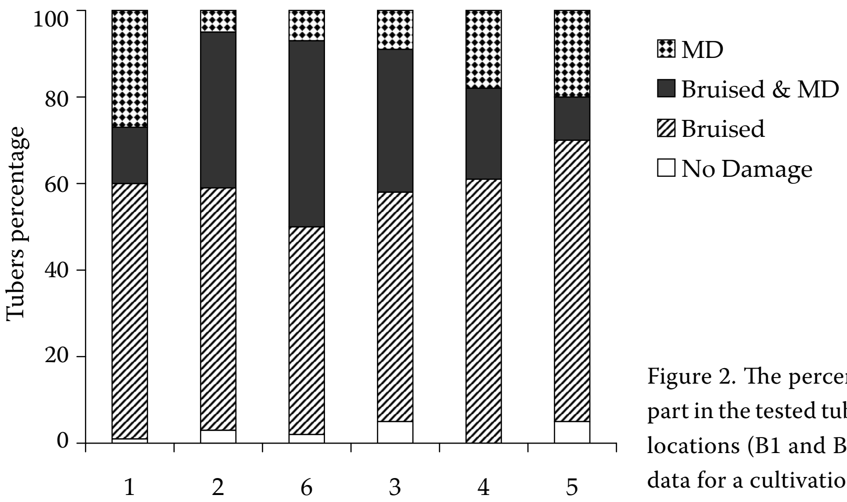

Figure 2. The percentage of different damage modes taking part in the tested tubers; the results obtained at both the side locations (B1 and B2) were unified into one resulting set of data for a cultivation regime

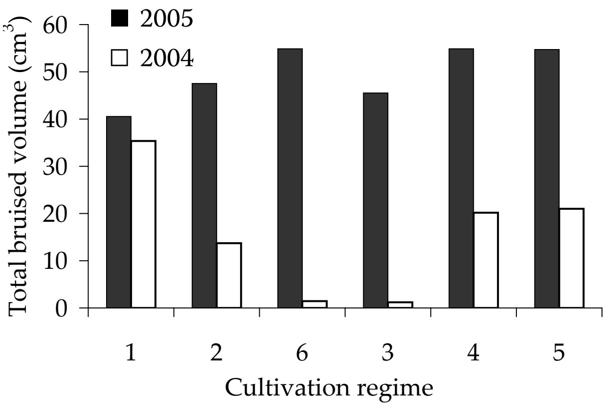

Figure 3. Total bruise volume determined for all the tested tubers in a cultivation regime (the results at B1 and B2 were unified similarly as in Figure 2); for comparison the data from 2004 were added (Blahovec 2005b)

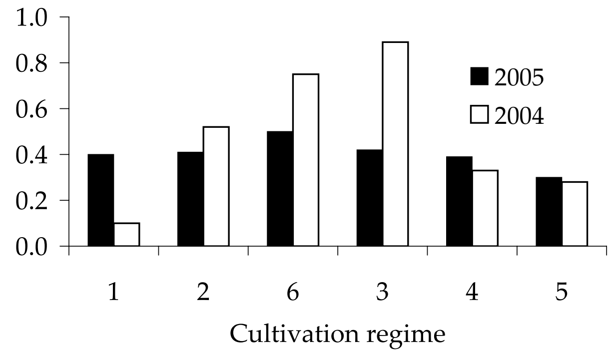

Figure 4. Frequency of mechanically damaged tubers after impact (1 denotes 100%) for all the tested tubers in a cultivation regime (the results at B1 and B2 were unified similarly as in Figure 2); for comparison the data from 2004 were added (Blahovec 2005b)

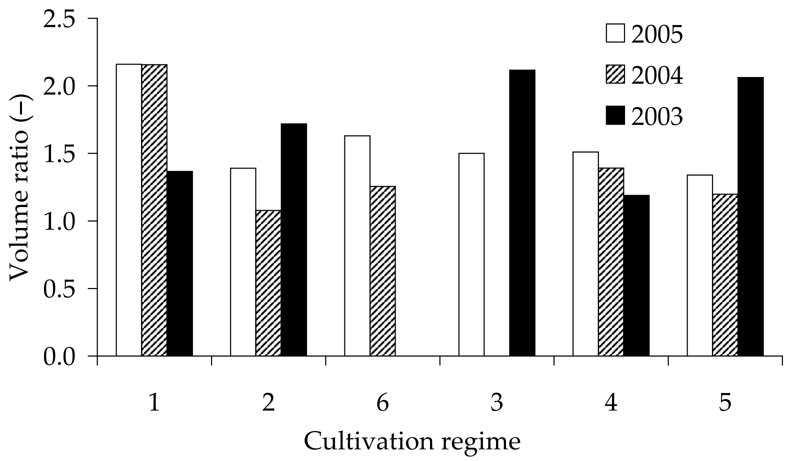

Figure 5. Mean values ratio of the bruise volumes obtained at B1 and B2 (white columns); the same data obtained in previous years (Blahovec 2005b – data for 2004, Blahovec & Židová 2004 – data for 2003) were added

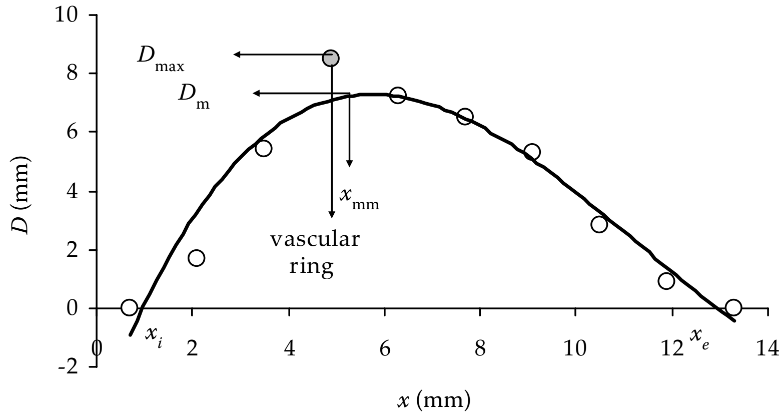

Figure 6. An example of the data approximation (B1) by a third order polynomial : $D = a + b_1x + b_2x^2 + b_3x^3$; approximation data: $a = -3.697 \pm 1.367$, $b_1 = 4.315 \pm 0.855$, $b_2 = -0.5036 \pm 0.1421$, $b_3 = 0.01485 \pm 0.00668$, $R^2 = 0.930$ ($p = 0.000744$), $x_i = 0.96$ mm, $x_e = 12.93$ mm, $D_m = 7.29$ mm, $V = 258.5$ mm^3

observed also in previous experiments. Even if the actual values of the ratio were different in different years and different cultivation regimes, their values higher than 1 were statistically proved in all cases. This result can be understood as an indication of higher tuber sensitivity to bruising on the relatively big flat side parts of a tuber in comparison to the more curved parts.

Shape of the bruise spot

The shape of bruise spots was analysed using a polynomial of the third order as described in Figure 6. The longitudinal profile of the rotationally symmetric bruise spot expressed by a third order polynomial made possible to determine the depth of the initial point (x_i), the depth of the end point of the spot (x_e), the depth (x_{mm}) and diameter (D_m) of the part of bruise spot with the maximum diameter. It enabled also calculation of the most important bruise characteristics: the longitudinal asymmetry (*LA*) defined as $(x_{mm}-x_i)/(x_e-x_i)$ and the bruise spot ratio (*BSR*) defined as x_e/D_m. The differences among the obtained spots were not too big. Longitudinal asymmetry was usually between 0.4 and 0.5. Only at small spots with volumes lower than 200 mm^3 some bigger but not systematic deviations were observed. Similarly the initial point was calculated between 0.5 to 1 mm depth, but the first indications of a bruise spot occurred in the second slice in depth between 1.4 and 2.1 mm. Mean values of *BSR* were calculated between 0.7 and 0.95. The analysis of the actual results showed that *BSR* decreased with increasing dimension of the bruise spot. This tendency that was also observed previously (Blahovec 2006) could be well described by a power function.

CONCLUSIONS

The soft impact properties (*CE*) only slightly depend on the cultivation regime. The higher differences in *CE*-values obtained for different cultivation regimes were observed at more energetic impacts. The lower *CE*-values accompany the impacts with heavier potato damage e.g. with cracking or crushing, the processes masking the main studied process – bruising. The flatter side parts of the Agria tubers are more sensitive to bruising than the more oblique ones. The bruise spot shape depends mainly on its dimension. The role of different cultivation regimes can be interpreted in this way.

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Abstrakt

Blahovec J., Hejlová A., Vacek J. (2006): **Otlaky po nárazu u brambor odrůdy Agria pěstovaných za různých podmínek**. Res. Agr. Eng., **52**: 81–86.

Brambory odrůdy Agria byly pěstovány v roce 2005 v režimech lišících se závlahou a dávkami a formou hnojení. Poškození hlíz vyvolané nárazem bylo simulováno dynamicky kladívkovým testem a studováno s cílem najít souvislosti mezi režimem pěstování a typem a rozsahem poškození. Obvyklé šednutí dužniny je v mnoha případech maskováno jinými mechanismy poškození, jako je praskání a zhmoždění hlíz. Nejvyšší rozsah praskání hlíz a současně nejméně častý výskyt šednutí byl pozorován pro hlízy pěstované se závlahou a bez hnojení. Šednutí dužniny bylo výraznější na užší části boku hlízy ve srovnání s její širší plochou stranou ve všech způsobech pěstování. Některé výsledky mohly být porovnány s podobnými předchozími měřeními na hlízách z téhož polního pokusu organizovaného ve třech po sobě jdoucích letech 2003–2005. Plošší strany hlíz jsou citlivější k otlakům než strany oválnější. Tvar otlaků závisel zejména na jejich velikosti. Úloha různých pěstitelských podmínek může být interpretována zejména tímto způsobem.

Klíčová slova: brambory; hustota; pupek; korunka; režim pěstování; úder; šednutí; praskání; zhmoždění; zavlažování; hnojení

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