Measurement of potato tubers resistance against mechanical loading

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Abstract: The contribution presents a method for the determination of the potato tubers resistance against mechanical loading, the measurement results obtained with the selected potato varieties, and the comparison of the latter. For testing the potato varieties samples, the method developed in Agrartechnik (ATB) Bornim (Germany) was verified and utilised. The potato samples were exposed to vertical vibrations with adjustable amplitude in the device constructed at the Research Institute of Agricultural Engineering, (RIAE) Prague, for testing tuber samples for mechanical loading. The potato samples cutting pictures were scanned by a web camera or a scanner, and the colour changes on the cuttings were evaluated by means of a computer program. In the paper are presented the results of two different measurements. Significant differences were found between four varieties regarding their resistance against equal mechanical load, and in one variety in different degrees of mechanical load for both early and late potatoes.

Keywords: potato; mechanical injuries; flesh darkening; measurement methods; tubers resistance

The potatoes quality is an important factor influencing their success on a broad and in view of quality, very fastidious market. For these reasons, the current research in this sector is aimed at detecting the tubers mechanical injury sources during the harvest period and after-harvest treatment, as well as the mechanisation impact. To find outer and inner potato (and other crops) tubers quality, various simulation and evaluation methods (e.g. artificial electronic potato or loading sensors placed in the potato tuber) were developed abroad and in our country developed. To compare the varieties resistance against loading, we have utilised for our measurements the computer program KABI developed at ATB Potsdam-Bornim in Germany (Wormanns 1996). For the simulation of mechanical loading conditions, the RIAE Prague has developed a device providing the simulation of the motion and impact stress of the potato tubers measured (Figure 1) with parameters similar to the system utilised at ATB Bornim (Schwarz 2001). Further, device for the picture scanning of sample cuttings and their digitalisation was manufactured (Figure 2). The samples were evaluated according to the computer program KABI developed for the picture analysis of potato (Wormanns *et al.* 1996). The intensity and degree of mechanical loading were scanned and registered by the artificial potato PMS-60 (Figure 3). In this contribution are presented the results of flesh darkening (greying, blackening) and colour changes evaluation in the cuttings of four different potato variants (injured or intact at various impact frequency and intensity).

Types of potato tubers mechanical injuries

Potato tubers are particularly sensitive to mechanical injury because of their high water content of up to 75%. Tubers mechanical injuries (%) are expressed by the proportions of injured and intact pieces during the harvest and after-harvest treatments (Fér 2003). The injury occurs in the peel, coating layer, and flesh. This is caused by the tubers mechanical loading during their harvest and after-harvest treatments and processing. The tubers injuries are visible or hardly recognisable under the peel.

The tuber injuries can be considered as outer and inner.

Potato tubers outer injuries

This type of injury is represented by more or less intensive damage in the coating layer and flesh.

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Figure 1. Testing stand of RIAE Prague for samples mechanical loading examination (mechanical loading motion simulator)

Figure 2. Lightening device of RIAE Prague for testing of tubers cuttings colour changes

When observed outwardly, these injuries are hardly visible, the injury is mostly better recognised after 4–6 weeks. The flesh injuries vary considerably and can lead to significant grooves in the tuber flesh. The peel grooves occur mainly in non-matured potatoes in the form of deprived peel during the harvest and consequent processing. As a consequence of this, a considerable loss is observed in the weight caused by more intensive potato respiration and evaporation. Storing such injured tubers is more complicated.

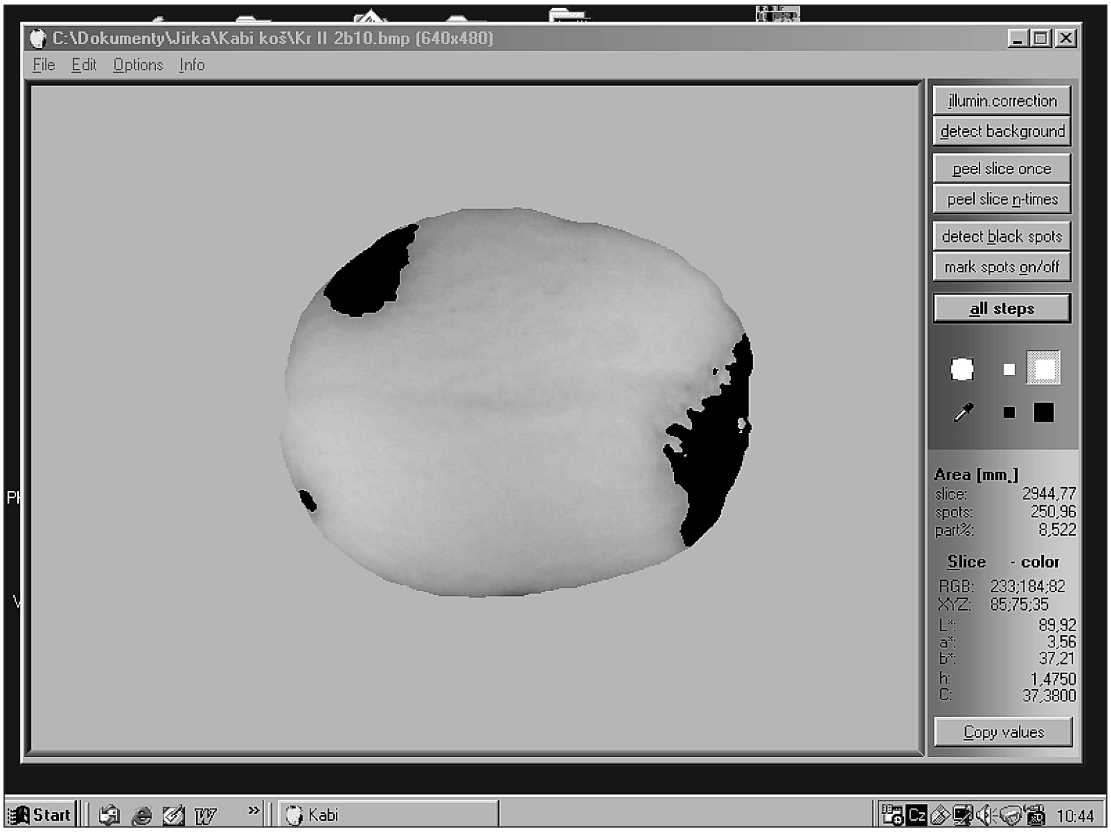

Figure 3. Computer evaluation of tubers cuttings colour changes scanned by web camera via lightening device in the program KABI

Small, shallow damage of potato tubers is observed mainly during their assortment or seeding and usually visible outwardly only for a short time because the cell water is dried quickly and the damaged place is recovered.

Potato tubers inner injuries

This type of injury is caused by tubers mechanical loading and it can be safely recognised after 24 h. The damaged place is characterised by the tuber tissue coloration ranging from red-brown to grey-white spots. The mechanical loading in the period of harvest and after-harvest potato treatment thus can lead to a larger, sharply demarcated inner injury caused by the loaded cells failure. These spots mostly occur in the depth of 2 ÷ 5 mm in the tuber body.

Methods of evaluation of mechanically injured tubers occurrence during the harvest and after-harvest treatment

The mechanical injury of tubers is caused by the impact of the machines activity. The injuries can be divided into the immediate and the consequent, respectively. The immediate injuries can cause a lower potato yield in the case when the tuber tissue is damaged.

The consequent injuries are:

– higher occurrence of diseases during the storage period,
– faster tubers germination in the potato house,
– higher losses of starch during the storage period,
– flesh darkening (greying, blackening),
– tubers shape deterioration,
– vegetation thinning as a consequence of mechanically injured seedlings (diseases during their storage period).

Potato tubers mechanical injury evaluation

This type of injury is expressed mostly in per cents based on the injury depth evaluation. Accordingly, the injury is divided into:

– surface injury to 1.7 mm,
– medium injury from 1.7 mm to 5 mm,
– serious injury above 5 mm.

The individual injuries are then converted to a single injury by means of coefficients. In the evaluation, either one maximum tuber injury or all the tuber injuries are included for the determination of total damage.

MATERIAL AND METHODS

Measurement method used for investigation of potato resistance against tubers mechanical loading

The resistance against mechanical injuries can be investigated in various ways. An objective evaluation of tubers mechanical injury caused during the harvest and after-harvest treatments has a good prospective with the electronic and computer technology development being able to evaluate machines and technological lines quality objectively from both construction and technological aspects.

An individual tuber can be tested as a whole or only by its certain part. The research in this field has proved differences in individual tuber parts resistance. This is also supported by the fact that potato tubers are not a homogenous material. With a wide scale of possibilities of how to find the potato tuber resistance against the mechanical injury is connected also the problem of how to maintain comparable conditions for individual measurements. For this purpose, approaches were developed based on various principles. The laboratory methods belong among the most frequently utilised. The initial device used for the investigation of the injury resistance has been the penetrometer, i.e. a cylinder of a certain diameter is pressed into the tuber and the level of force necessary for its penetration into the tuber is considered the indicator of the resistance. Other methods are based on the tubers loading by circulation in the rotary rod drum.

The RIAE Prague has used a method developed and introduced at ATB Potsdam-Bornim (Germany). The box with potato samples is exposed to vertical vibrations at adjustable amplitude (0–100 mm) and frequency (5–10 Hz) during the required time (30–120 s). In Figure 1 is presented the testing stand, model RIAE Prague, for testing the samples exposed to the mechanical loading (motion simulator). The tuber sample exposed to the mechanical loading in then placed in a space with the temperature of 30°C for 24 hours at 95% of relative humidity. The potato sample cuttings in the place of their largest cross-section are then investigated using a device serving for the assessment of the colour changes caused by tubers mechanical loading. The cuttings are then placed in a box illuminated with 5 halogen lamps. Both the cutting surface size and the surface size where the inner injury was found (colour changes) are automatically evaluated by the program KABI (ATB Bornim) on the basis of the cutting pictures scanned by the web camera in the box with illumina-

tion. The program is able to eliminate automatically the peel in the cutting picture and also other interfaces can be set up and defined (colour analysis and brightness) – Figure 3. The data found are stored in the tabular form and subsequently processed and evaluated with the computer program Microsoft Excel.

Description of material and conditions for measurement of tubers resistance of potato different variants at equal degree of mechanical loading

The objective of the measurement was to compare the resistance of different variants against mechanical loading. For the colour changes measurement of flesh darkening, the four below presented samples of potato varieties were used and their mechanical loading in the simulator was defined. For the measurement, 3 samples were used each of them consisting of 10 tubers in triplicates a, b, c (Table 1).

Conditions of tuber samples mechanical loading

The samples of the potato variety Samanta (9 samples, each consisting of 10 tubers) and the variety Krasa (9 samples, each consisting of 10 tubers) were loaded under the following conditions:

Transducer frequency 55 Hz with the simulator motion corresponding to 7 Hz, i.e. 350 l/min.
Injury time: T = 60 s
Run down time: Td = 11 s
Sample temperature: 5°C
Injured sample storage time: 48 h
Injured sample storage temperature: 30°C

The samples of the potato variety Lenka (9 samples, each consisting of 10 tubers) and the variety Karin (9 samples, each consisting of 10 tubers) were loaded under the following conditions:

The conditions of tubers loading in the motion simulator and during their storage were identical but owing to sudden meteorological thermal changes the sample temperature was not kept and it varied by 10°C and was always identical only for two of the four potato varieties mentioned above. The results of this measurement are shown in Figure 6.

Description of method and conditions of tubers resistance of identical potato variety at different degrees of mechanical loading

The goal of the following measurement was the comparison and objective assessment of the tuber inner quality of a single potato variety (Samanta) through the evaluation of colour changes at different degrees of the mechanical loading.

The tubers samples were exposed to a defined mechanical loading in the testing stand of RIAE (motion simulator). This device enables to load the tuber samples at vibrations of a chosen amplitude (40 mm) and various frequencies (5–10 Hz) of the

Table 1. Description of potatoes varieties measured properties

Measured variant name	Karin	Krasa	Lenka	Samanta
Variety type	early	very early	half-early	half-late, late
Tuber shape	long-oval (LO)	shart-oval (SO)	LO	round (R)
Boiling types	BA	B	AB	B
Size class of the measured tubers	30–50 mm			
Sample size: 10 tubers of total weight	1.2–1.5 kg			
Variant/repetition	1a–3c			
Indication	1 Karin (1Ka)		2 Karin (2Ka)	
	1 Krasa (1Kr)		2 Krasa (2Kr)	
	1 Lenka (1Le)		2 Lenka (2Le)	
	1 Samanta (1Sa)		2 Samanta (2Sa)	
Potato variants indication and their loading				
Intact samples	1 Karin	1 Krasa	1 Lenka	1 Samanta
Advisedly injured samples by the motion simulator	2 Karin	2 Krasa	2 Lenka	2 Samanta

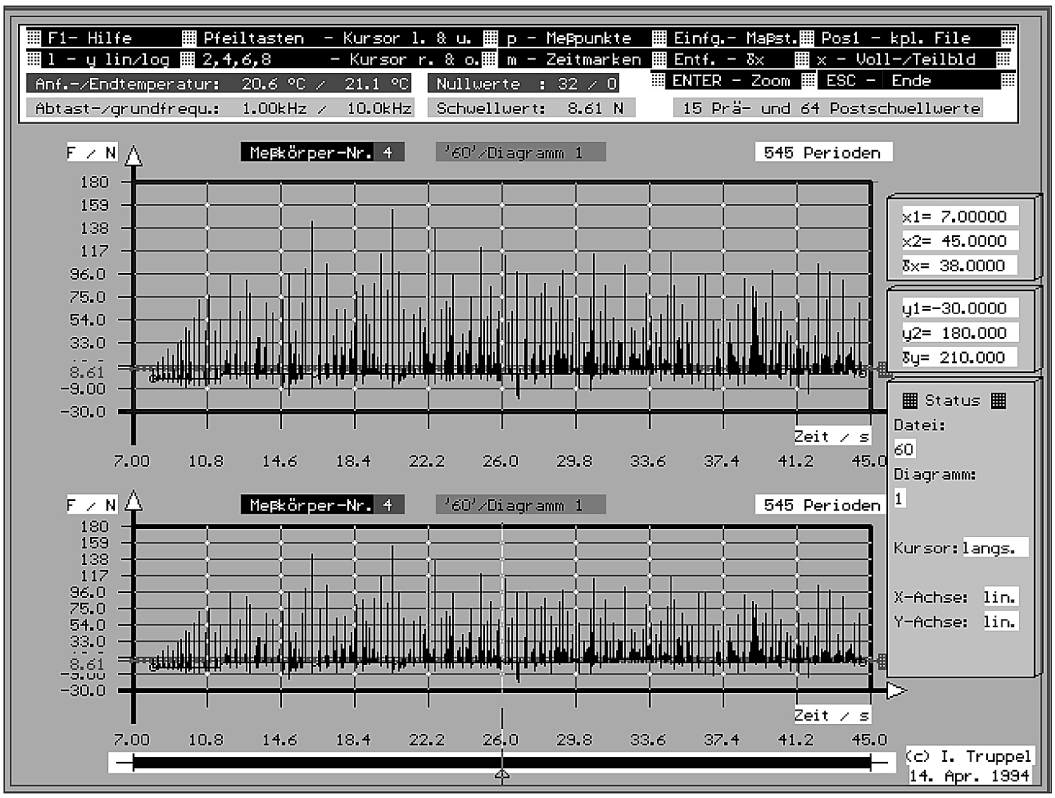

Figure 4. Record of acting forces measurement for tubers loading by the system PMS at 60 Hz

simulator motion. The amplitude is set up through the misalignment of the pulley crank pin. The frequency and exposition time are adjusted by the operating device controlling the frequency transducer of the electromotor. The potato tuber samples are installed in the box. The box dimensions were 0.25 × 0.25 × 0.25 m. The transducer frequency setting up was at 50, 55, 60 and 65 Hz. The loading

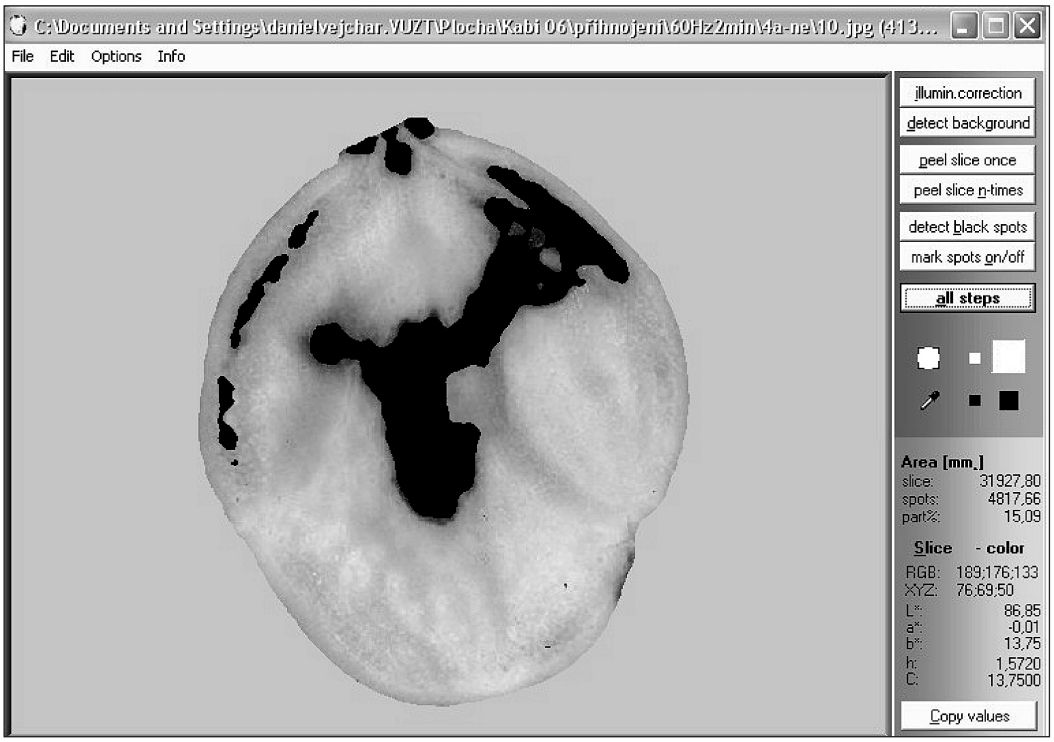

Figure 5. Picture of potato tuber cutting scanned during evaluation of its injury by darkening (flesh greying, blackening) using the computer program KABI

degree was measured by the device PMS (artificial potato) to find the acting forces intensity (Figure 4). The measurement conditions are given in the tables presented below.

This method utilised the computer analysis of the tuber cutting picture in the program KABI. The tuber cutting pictures scanning was performed with a scanner. The tuber cuttings were inserted directly into the scanner and after the scanning the pictures were stored in the computer memory. The brightness, colour, sensitivity of the individual scanned points as well as the uniformity of the scanned surface lightening were not homogenous. For this reason, the primary picture information was converted into the KABI program by means of special algorithms to improve the picture brightness. This was conducted through unambiguous picture data according to the calibrating etalon of the homogeneous black and white surfaces. For the white surface, the basic colours are red (R), green (G) and blue (B) in maximum intensity, for the black surface the same colours in the minimum intensity. From the picture, two matrices of 640 × 680 points and three colour values the coordinates are levelled in the R, G, B colour spaces for each point, the brightness values L, a, b are transformed. It is necessary to verify in the next research period if the tuber cutting pictures can also be analysed by any other picture analysis program.

The tuber cutting samples can also be measured by means of digital sliding meter (length, width) prior to their insertion into the scanning space, and the measured values are transferred again into the table in the Excel program. After the tuber cutting picture scanning with the scanner (Figure 5), the computer evaluation of the inserted tuber cutting (mm^2) in the KABI program followed, the peel black surface was eliminated and the flesh surface (mm^2) colour change as well as the proportion of the colour changed area of the total cutting surface were evaluated by means of the KABI program. The measured values were transposed and stored in tables of the Excel program and evaluated.

Measurement conditions

Measurement of potato variety: Samanta

Degree of mechanical loading – force (N) at the frequency transducer setting up:

Table 2. Results of samples cuttings statistical evaluation – intact samples (results of potato black spotting measurement in the program KABI)

Name of sample – variety	No. of cuttings	Cuttings average surface (mm^2)	Black spots average surface (mm^2)	Average proportion of spots extent on cutting surface (%)	Median of spots extent on cutting surface (%)	Standard deviation of spots surface share (%)
1Ka1	30	1594.65	22.49	1.469	0.438	4.076
1Ka2	30	1520.10	6.39	0.423	0.327	0.491
1Ka3	30	1543.51	22.86	1.434	1.173	0.898
1Karin	90	1552.75	17.25	1.108	0.704	2.448
1Kr1	30	1315.58	7.77	0.554	0.298	0.692
1Kr2	30	1549.05	12.13	0.734	0.509	0.796
1Kr3	30	1414.41	9.10	0.638	0.415	0.832
1Krasa	90	1426.35	9.67	0.642	0.397	0.771
1Le1	30	1377.28	5.45	0.434	0.003	0.938
1Le2	30	1304.40	3.59	0.242	0.009	0.467
1Le3	30	1381.92	10.88	0.673	0.370	1.448
1Lenka	90	1354.53	6.64	0.450	0.036	1.036
1Sa1	30	1517.12	5.34	0.374	0.187	0.423
1Sa2	30	1403.96	4.98	0.357	0.330	0.322
1Sa3	30	1616.58	4.62	0.271	0.165	0.389
1Samanta	90	1512.55	4.98	0.334	0.208	0.379

Varieties: Karin, Krasa, Lenka, Samanta; Sample size: 10 tubers of total weight 1.2 – 1.5 kg; 1 – samples intact: 1Ka, 1Kr, 1Le, 1Sa; 2 – samples mechanically injured: 2Ka, 2Kr, 2Le, 2Sa

50 Hz .....*F* max 120 N, *F* med 27 N
55 Hz .....*F* max 130 N, *F* med 30 N
60 Hz .....*F* max 150 N, *F* med 33 N
65 Hz .....*F* max 160 N, *F* med 35 N
Number of variants/repetition: 50 Hz, 55 Hz, 60 Hz, 65 Hz/3 repetitions
Sample size: 10 tubers of total weight of 1.2 to 1.5 kg

Potato samples testing in device for mechanical loading (motion simulator RIAE Prague)

Potato variety Samanta, 3 samples consisting of 10 potatoes in each variant

Transducer frequency setting up	50 Hz, 55 Hz, 60 Hz, 65 Hz
Loading, injury time	T = 60 and 120 s
Run down time	Td = 11 s
Sample temperature	15°C
Sample storage time	48 h
Sample storage temperature	35°C
Air humidity during the sample storage	75%

RESULTS AND DISCUSSION

Measurement of the resistance of different varieties of potato tubers against the mechanical loading

The values of the cutting surface and colour changes were determined by the PC program KABI and the numerical values were transferred into the program Microsoft Excel. The values were statistically evaluated and the results are presented in Tables 2 and 3. Graphical expression of the percent proportions of the presented four potato varieties black spots before and after mechanical loading in the simulator testing stand is illustrated in Figure 6.

The effect of the tubers mechanical loading on the intense increase of flesh colour changes is evident as compared with the samples without loading, particularly very early variety Krasa and later varieties, as resulted from the investigation of the tuber samples. From the comparison of the verified varieties in 2004 follows that the most susceptible to the mechanical load and black spots occurrence was the variety Samanta, as evident from Figure 6. The varieties Lenka and Karin were very resistant against identical mechanical load. Similar results were found also in the previous measurements in 2002–2003 but with lesser conclusiveness and differences. These previous results are not presented in this paper. The objective of the next investigation will be to find out how the samples temperature influenced the measurement results.

Measurement of resistance of identical potato variety tubers against different degrees of mechanical loading

The evaluation results of the Samanta variety tubers are presented in Table 4 (loading at 50 Hz during 1 min). The results of the loading variants 50 Hz and 65 Hz are presented in Figure 7.

These results confirmed the assumed trend, i.e. that a higher degree of mechanical loading and its duration have a significant effect on the colour changes extent and thus also on the flesh inner injury intensity. As found in the previously performed research, the verified variety has a tendency to be damaged more seriously in comparison with other varieties when exposed to identical loading conditions. The black spots occurrence after the mechanical loading was higher in contrary to other varieties as can be also seen from the results of the varieties comparison in Figure 6. Nevertheless, the results of comparison are not sufficiently conclusive because of the relatively small number of the loading repetitions with for different variants, and therefore this procedure needs more extensive measurements.

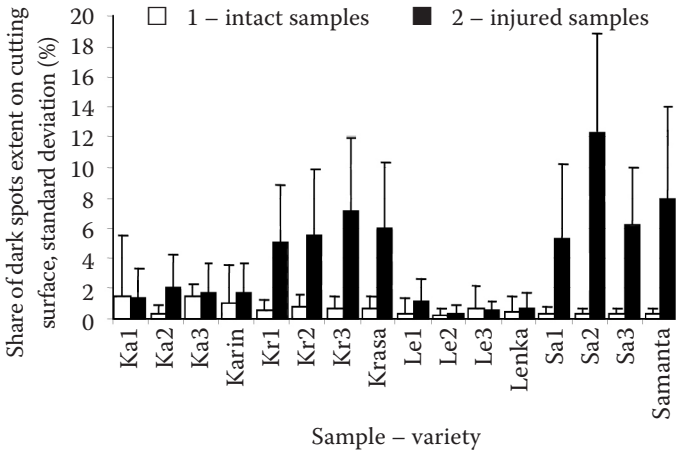

Figure 6. Measuring of potato tuber flesh darkening (standard deviation)

Table 3. Results of samples cuttings statistical evaluation – samples injured by simulator (results of potato black spotting measurement in the program KABI)

Name of sample – variety	No. of cuttings	Cuttings average surface (mm^2)	Black spots average surface (mm^2)	Average proportion of spots extent on cutting surface (%)	Median of spots extent on cutting surface (%)	Standard deviation of spots surface share (%)
2Ka1	30	1613.934	23.363	1.346	0.552	1.973
2Ka2	30	1670.852	36.869	2.076	1.423	2.152
2Ka3	30	1584.712	28.084	1.702	1.032	1.952
2 Karin	90	1623.166	29.438	1.708	1.010	2.027
2Kr1	30	1406.954	67.785	5.040	4.208	3.752
2Kr2	30	1485.227	86.886	5.558	4.471	4.335
2Kr3	30	1515.717	110.177	7.121	6.339	4.812
2 Krasa	90	1469.299	88.283	5.906	4.806	4.364
2Le1	30	1643.972	22.171	1.148	0.695	1.519
2Le2	30	1394.618	5.875	0.380	0.146	0.497
2Le3	30	1562.230	9.196	0.577	0.362	0.635
2Lenka	90	1533.607	12.414	0.702	0.404	1.035
2Sa1	30	1537.993	85.531	5.256	4.787	4.966
2Sa2	30	1610.998	199.041	12.299	10.499	6.572
2Sa3	30	1717.434	106.474	6.221	5.909	3.782
2 Samanta	90	1622.141	130.349	7.925	6.511	6.049

Varieties: Karin, Krasa, Lenka, Samanta; Sample size: 10 tubers of total weight 1.2 – 1.5 kg; 1 – samples intact: 1Ka, 1Kr, 1Le, 1Sa; 2 – samples mechanically injured: 2Ka, 2Kr, 2Le, 2Sa

CONCLUSIONS

The method of the estimation of potato tuber samples resistance against mechnical loading was verified by two measurements. In the first one, four different varieties were compared at an identical degree of the mechanical load, and in the second one the identical potato variety was compared under different degrees of the mechanical load at the set constant temperature and storage moisture. In the first measurement the samples of four potato varieties (Karin, Krasa, Samanta and Lenka) were loaded with vibrations of a given frequency at a given lift in the testing stand. This allowed the comparison of the extent of inner injury, i.e. potato colour changes (darkening, blackening, greying) on the tuber cut after the storage of those different potato varieties samples during 48 h at identical temperature and moisture. In the second

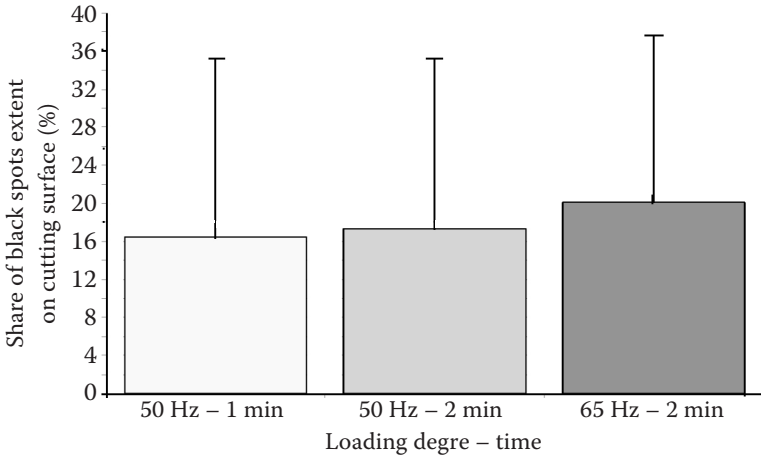

Figure 7. Tubers injuries according to degree of mechanical loading, variety Samanta

Table 4. Results of samples loading evaluation

Loading 50 Hz–1min	Sample No.	Dark spots share injuries (%)	Cutting surface S (mm^2)	Dark spots surface s (mm^2)
Varieties Samanta	1	55.73	18421.80	10265.80
	2	0.00	16825.10	0.00
	3	36.44	11723.10	4271.34
	4	0.00	14079.60	0.00
	5	50.22	17126.20	8600.67
	6	42.72	22981.30	9818.36
	7	49.91	24291.60	12123.10
	8	54.53	25339.90	13816.90
	9	3.75	30033.90	1125.12
	10	28.95	20135.90	5830.31
Average		32.22	20095.84	6585.16
Standard deviation		21.71	5299.19	4832.12

measurement, only the variety Samanta was evaluated at different loadings. The colour changes on the tuber cut were objectively evaluated after the tuber cutting pictures scanning by the web camera in a special equipment or after displaying by the scanner using special computer KABI (Germany). It is necessary to verify scientifically if the tuber colour changes can be evaluated even by other programs for the picture analysis. The total tuber cutting surface and its part with colour changes occurrence (flesh greying, darkening) were evaluated by the computer. Considerable differences in the varieties resistance against different degrees of mechanical loading were found out with both early and late potatoes.

The verified method described above can be recommended for a variety of research institutions testing plants as well as for the agricultural and processing enterprises. Through an objective evaluation of potato and other crops resistance against different degrees of the mechanical loading, the limits and criteria could be specified to avoid the potato quality decrease and the production losses.

The potato tuber inner quality testing methods at identical and different mechanical loadings were realised in cooperation with the Potato Research Institute (PRI) Havlíčkův Brod Ltd, subsidiary Valečov, which provided the potato samples.

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Abstrakt

Mayer V., Vejchar D., Pastorková L. (2008): **Měření odolnosti hlíz brambor proti mechanickému zatížení.** Res. Agr. Eng., **54**: 22–31.

V příspěvku je uvedena metoda, výsledky měření a porovnání odolnosti vybraných odrůd brambor vůči různému stupni mechanického zatížení. Pro testování odolnosti vzorků měřených odrůd brambor byl ověřován a využit způ-

sob vyvinutý v Agrartechnik (ATB) Bornim (SRN). Vzorky brambor byly vystavovány vertikálním vibracím při nastavitelné amplitudě na zařízení zkonstruovaném ve Výzkumném ústavu zemědělské techniky, v.v.i. (VÚZT) Praha pro testování vzorků hlíz na mechanické zatížení. Obrázky řezů vzorků brambor byly snímané webovou kamerou nebo skenerem a barevné změny na řezech vyhodnocovány pomocí počítačového programu. Byly zjištěny významné odlišnosti odrůd v jejich odolnosti vůči různému stupni mechanického zatížení jak u raných, tak i pozdních brambor.

Klíčová slova: brambory; mechanické poškození; tmavnutí dužniny; metody měření; odolnost hlíz

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