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RELATION BETWEEN THE CONTENT OF SIMPLE SUGARS IN A POTATO TUBER AND ITS RESISTANCE TO MECHANICAL LOAD

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ABSTRACT

The objective of the paper was to find a relation of the content of simple sugars in a potato tuber and its resistance to mechanical loads. The following potato tuber varieties were investigated: Kuras, Gala, Agata, Ditta, Arrow, Roko and Raja. A force damaging periderm, external and internal damages ratios and mass damages determined potato tubers susceptibility to mechanical damages. Measurement of the sugar content in the potato tubers was carried out with a refractometer. A statistically significant relation, measured with the value of the coefficient of correlation, between the content of simple sugars and susceptibility to internal damages was determined only in potato tubers of Kuras and Raja varieties.

Symbols:

C_{pr} – content of simple sugars, (°Brixa)
F – force which caused damage to periderm of the potato tuber on the border of its biological strength, (N)
W_{zew} – ratio of external damage to potato tuber, (%)
W_{wew} – ratio of internal damage to potato tuber, (%)
W_{mas} – ratio of mass damages to potato tuber, (%)
L – mass of tubers with slight damage – to 1.7 mm of depth, (%)
$Ś$ – mass of tubers with average damage – from 1.7 to 5.1 mm of depth, (%)
C – mass of tubers with heavy damage – more than 5.1 mm of depth, (%)

Introduction

One of many criteria which qualify potato tubers for further use (direct consumption, storing or processing) is their susceptibility to damage both internal and external. According to Marks (2009) potato tuber resistance to mechanical damage is a resultant of many factors: potato variety, growth environment, tuber development and agro-technology of plant cultivation. Factors related to potato plant which determine susceptibility of a plant to

damage are mainly: variety, dimensions and tuber maturity as well as its internal structure and chemical composition (McGarry et al., 1996; Marks, 2009; Laerke et al., 2002). Relations between the above mentioned factors and their impact on a mechanical damage were described, inter alia, in the papers by Marks et al., 2000, Krzysztofik and Nawary 2003, Ganczarz et al. 2005 and Jakubowksi 2009. However, in the available subject literature (Molema, 1999; Konstankiewicz et al., 2001; Marks, 2009) there is a small amount of information concerning relations between the chemical composition of a potato tuber and a degree of its susceptibility to mechanical loads (such researches were carried out on account of the selected cells of the pulp tissue of a potato tuber (Hejtmánková et al., 2013) or damages to starch particles (Yue et al., 2012). Particularly noticeable in literature is absence of researches on the relation of simple sugars content in a potato tuber and its resistance to mechanical damage. In the potato bulb (Solanum tuberosum L.) there are carbohydrates which belong to monosaccharides (aldose and ketose) as well as to oligosaccharides (saccharosis) and such that do not show reductive properties of polisaccharides (starch). Simple sugars (monosaccharides) with reductive properties, are represented in a potato tuber mainly by glucose (which contains aldehyde group – CHO) and fructose (which contains ketonic group =C=O). It should be mentioned that a tuber includes also simple sugars (ribose, deoxyribose, arabinose, rhamnose, galactose or galacturnoci acid) which do not occur in the free state but mainly incorporated in nuclein acids of a potato. A separate group consists of metabolites (0.2-4.5% of dry mass of a potato tuber) in the transfer of sugars (phosphatic esters of sugars as e.g.: glucose-6-phosphate, fructose-6 phosphate, triose-3 phosphate) (Wieczer and Gonczarik, 1977).

The issue related to presence of various forms of carbohydrates (and their impact on mechanical damages) in a potato tuber is significant, because the sugar content in relation to the factors which act on a plant may be variable. Dynamics of these changes depends on e.g. the applied agrotechnology or conditions in which bulbs are stored. Research by Wojdyła et al. (2009), shows that sprinkling the potato plantation influences decrease or increase of the sugar content in tubers. According to Shock et al. (1993) after periods of deficiency of precipitation, a potato tuber contains more dry mass and simple sugars and less starch. Starch, as a reserve material is broken down to simple sugars necessary to intensify the plant growth (number of reducing sugars in tubers grows, which limits their technological usefulness). Higher concentration of some carbohydrates (mainly glucose and fructose) influences also the intensity of the Maillard reaction course (Zgórska and Frydecka-Mazurczyk, 2000; 2002).

The objective of the paper was to find the relation of the content of simple sugars in a potato tuber and its resistance to mechanical loads.

The scope of paper and the methodology of research

Tests were carried out at the turn of 2011-2012 in laboratory conditions. Potato tubers of the following varieties were used: Kuras, Gala, Agata, Ditta, Arrow, Roko, Raja. Material for research (in the full technical maturity stage) came from own field experiment, located on the podzoil soil during which correct principles of agrotechnologies for the potato plant were used. Two types of fertilization were used: multicomponent fertilizer *Hydrokompleks Yara Mila* (12% N, 11% P, 18% K) in the amount of 60: 60: 90 $kg \cdot ha^{-1}$ and *Ekolist Standard* with urea – 3 $l \cdot ha^{-1}$ in two doses. Collection of tubers was carried out in the second half of September after 116 days of vegetation. In the aspect of the used methodology of experiment tubers without visible disease symptoms were qualified for tests. 30 tubers were used in an experiment (with a unit mass 35-45g) for each variety. Tests on the potato tubers resistance to mechanical loads were carried out in laboratory conditions (tests covered determination of resistance to static and dynamic damages). A force damaging periderm, external and internal damages ratios and mass damages determined potato tubers susceptibility to mechanical damages. In order to make a static damage, a single potato tuber was loaded with the use of a static and spring penetrometer to the moment of its damage caused by a roll bolt pressed inside the pulp. Pressure on the sample was transferred by a spring, diffraction of which was proportional to the pressure made. The tuber was damaged in its central part along the direction of thickness measurement (smaller dimension of the biggest cross-section). The measure of the tuber resistance to mechanical damage took a form of the force which caused damage of the potato periderm on the border of its biological strength (force of piercing and pressing the bolt into the tuber pulp). In order to cause a dynamic damage, a device (Jakubowski, 2010), which enabled leaving the potato tuber within the height up to 200 cm, was used. The device was equipped with a trap door, the task of which was to limit the rotational movement of the left tuber and reduction of the initial acceleration, which could be formed if the tuber was manually dropped. Tubers were dropped from the height of 100 cm onto a metal plate with the surface area of 0.5 m^2. The surface, which directly adjusted to the plate edges, was secured in order to avoid secondary damages of a tuber, which could occur in case it got bounced from the ground. Tubers, after damage were stored in a freezer in sisal bags for 3 days. The assessment of the damage size caused to a tuber was made with the use of a fissure knife (fissure width 1.7 mm) by removing the skin (Roztropowicz, 1999). Potato tubers were qualified as: non-damaged (which do not have any external and internal damages), damaged externally (abrasion, periderm crackings, damage to pulp) and internal damages (which do not have visible external damages, however which may have blackspot bruisers visible after the removal of periderm). Tubers with external and internal damages were classified (assuming depth of damage as a criterion) as: slightly damaged (depth of damage to 1.7 mm inclusively); at the average (depth of damage 1.71-5.1 mm inclusively) and very damaged (depth of damage exceeds 5.1 mm). For each size of damages, number of tubers and mass was provided. Then mass index of tuber damages was calculated (W_{mass}) according to the formula 1

(where lower indexes: ext., int. and mass respectively: external damages, internal and mass damages).

$$W_{mas} = 0.1L_{wew} + 0.3Ś_{zew,} + 1C_{zew} + 0.1L_{wew} + 0.3Ś_{wew} + 1C_{wew}\,(\%) \quad (1)$$

Measurement of the sugar content was carried out with the use of refractometer (precision 0.2%) on the prism of which tested potato bulb was placed. This device, equipped with two prisms, using the phenomenon of the total internal reflection (Snellius law), measures the coefficient of refraction of light of the tested substance. The measurement system of the refractometer is lighted with a light beam. In relation to the angle of refraction of this beam, it goes through the border surface to the second prism and then to a spyglass. The field seen in a spyglass is divided into two parts: light and dark. The division line is clear and its location depends on the border angle of the investigated substance. The coefficient of light refraction is proportional to the concentration of the investigated substance. The measurement result is obtained in °Brix scale.

The obtained results were subjected to statistical analysis with the use of STATISTICA 10 at the level of significance of α=0.05. The research included determination of the correlation relations between the content of simple sugars in potato tubers and their resistance to mechanical damage. Moreover, similarities between the potato varieties, accepted for the research were analysed on account of susceptibility of tubers to mechanical damages and the content of simple sugars. Correlation relations were determined with the use of Pearson coefficient and varietal similarities were invetsigated through a one-factor analysis of variance. For statistically significant correlation compounds, with the method of the smallest squares, curves and equations of regression were determined. Varietal differences between the statistically significant averages were investigated with Tukey's test of multiple comparisons. The analysis of variance was carried out with the test on the regularity of distribution in samples (Kolmogorov-Smirnov test) and on the uniformity of variance (Lavene's test). The obtained research results (values expressed in %) for statistical developments were transformed according to the formula $y=arcsin\ \sqrt{x}$ (where x is a researched dependable variable). After the statistical calculations were made, the values were retransformed to the original form.

Table 1 presents the calculated values of Pearson correlation coefficients for linear relations between the content of simple sugars in potato tubers and their susceptibility to mechanical damage. It should be emphasised that interdependence of features determines mutual relations between the selected variables not only through force of the investigated relation but also through its direction. All coefficients of correlation, calculated for the relation $C_{pr} - W_{zew}$, W_{wew} and W_{mas} are additional values, which proves that along with the increase of the simple sugars content in potato tubers also average values of dynamic damages indexes increase. It should be also included that in the presented research results (table 1) only coefficients of correlation calculated for the relation $C_{pr} - W_{zew}$ and W_{wew} (on account of the analysis method and the nature of the analysed variables) express a simple

correlation. Relation $C_{pr} - W_{mas}$ is a multiple correlation, thus informing on the relation of one feature (C_{pr}) with several presented together (W_{zew} and W_{wew}) – thus values for $C_{pr} - W_{mas}$ may be reduced. Statistically significant values of the coefficient of correlation were reported only in case of two varieties of potato (Kuras and Raja) or the relation between the simple sugars content and the index of internal damages of a potato tuber.

Table 1
Coefficients of Pearson correlation between the content of simple sugars in a potato tubers and their susceptibility to mechanical damage

Variety	Value of the coefficient of correlation for the relation			
	$C_{pr} - F$	$C_{pr} - W_{zew}$	$C_{pr} - W_{wew}$	$C_{pr} - W_{mas}$
Kuras	0.16	0.15	0.79*	0.41
Gala	0.15	nrd	0.51	0.51
Agata	-0.36	0.23	nrd	0.23
Ditta	-0.28	0.26	0.53	0.51
Arrow	0.16	0.12	0.52	0.40
Roko	-0.15	0.21	0.57	0.41
Raja	-0.3	0.19	0,72*	0.42

* statistically significant correlation (α=0.05), nrd – no reported damages

The above mentioned varieties differ on account of both their utility and belonging to the group of earliness; also morphology of tuber alone is varied. In principle, the only common feature which joins those two varieties is a higher content of starch, in comparison to the remaining varieties accepted in the experiment. Varieties Gala, Ditta, Arrow and Roko are early (or very early) edible varieties with the starch content of 11.8-13%. Kuras is a late starch variety (19.35 of starch) and Raja is a middle-early edible variety with the content starch of 15.6% *[Characteristics of the national register of potato varieties]* – IHAR [*Plant Breeding and Acclimatization Institute*] 2011). Simple sugars are formed as a result of the reserve material decomposition, which in a potato tuber occurs in the form of starch. Therefore, a hypothesis, that the relation between the internal damages of a tuber and the content of simple sugars shall be determined with the amount of starch in a potato, may be right. Equations of regression (table 2, figure 1) which describe the above mentioned relation (W_{wew}– C_{pr}) had low values of coefficients of determination of the trend line (regression models explain only in 52% in case of Raja variety and in 62% in case of Kuras variety, the impact of the simple sugars content on the formation of internal damages of potato tubers).

Table 2
Equations of regression for statistically significant correlations between factors W_{wew}– C_{pr}

Potato variety	Regression of equations	Value of coefficient of determination
Kuras	$y = 12.67x + 18.8$	$R^2 = 0.62$
Raja	$y = 9.19x + 9.81$	$R^2 = 0.52$

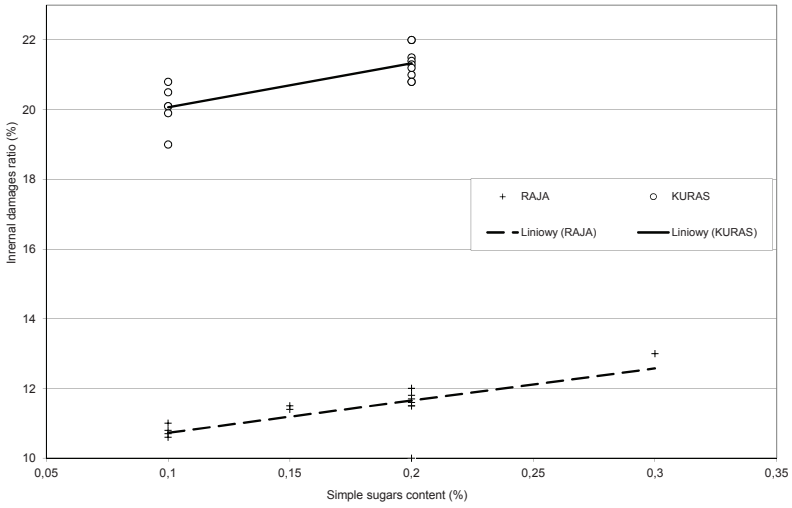

Figure 1. Relation between the content of simple sugars and the content of the ratio of damages to potato tubers of Raja and Kuras variety

Table 3
Results of one-factor analysis of variance - impact of the investigated dependent variables on the differences between the potato varieties accepted in the experiment.

Variable	Sums of squares	Mean sums of squares	Error of the sum of squares	Error of the mean sum of squares	Value of F test	Level p
C_{pr}	0.1069	0.018	0.305	0.003	5.732	0.000
F	92.545	15.424	76.58	0.782	19.738	0.000
W_{zew}	1534.2	255.7	23.8	0.243	1054.8	0.000
W_{wew}	6998.2	1166.4	46.5	0.474	2460.8	0.000
W_{mas}	5411.2	901.9	74.2	0.757	1191.5	0,000

Results of the analysis of variance (table 3) indicate the occurrence of significant differences between the potato varieties accepted in the experiment. Significant value of Snedecor F-test was a premise to carry out multiple comparisons in order to select uniform groups of dependable variables. The post-hoc tests which were carried out (table 4-8) showed existence of 3 homogeneous groups in case of the simple sugars content in tubers of the investigated potato varieties, 4 groups in case of the force value which caused damage to periderm of a tuber on the border of its biological strength and 7 homogeneous groups in case of susceptibility of varieties to both external, internal and mass damages. The structure of homogeneous groups which includes the content if simple sugars in tubers is probably dictated by the similarity of varieties on account of their starch content; Raja and Kuras respectively 15.6 and 19.3%; Ditta, Arrow, Agata and Gala approx. 13% and

Roko 12%. Diversity of the investigated varieties on account of susceptibility of tubers to mechanical damages was the expected result. Potato tubers, used in the experiment may be included to varieties, in relation to a variety, to highly resistant as well as to very susceptible to mechanical damages (3-9 w 9º of IHAR scale). Some discrepancies with regard to the values of ratios of damages obtained in tests referred to ratios included in *Charakterystyce krajowego rejestru odmian ziemniaka IHAR* [*IHAR's Characteristics of the national register of potato varieties]* may be dictated by the fact, that in the presented experiment, all varieties were harvested in one term in order to obtain material in the stage of full technical maturity. In case of tests on the mechanical damages resistance, IHAR collects material according to the date of harvesting predicted for a given earliness of a variety. In such case, it may happen that the collected potato tubers do not have fully shaped periderm and thus their susceptibility to damages will be higher.

Table 4
Tukey's test result for multiple comparisons – differences between the simple sugars content damages in relation to the potato variety

Potato variety	C_{pr} (°Brix scale)	1	2	3
KURAS	0.16	***		
RAJA	0.17	***		
DITTA	0.23		***	
ARROW	0.23		***	
AGATA	0.23		***	
GALA	0.23		***	
ROKO	0.25			***

Table 5
Tukey's test result for multiple comparisons – differences between the values of the force which damages the bulb periderm in relation to the potato variety

Potato variety	F (N)	1	2	3	4
ARROW	8.71	****			
RAJA	9.35		****		
ROKO	9.37		****		
DITTA	10.16			****	
GALA	10.19			****	
AGATA	10.55			****	
KURAS	11.83				****

Table 6
Tukey's test result for multiple comparisons – differences between the value of the tuber internal damages ratio in relation to the potato variety

Potato variety	W_{wew} (%)	1	2	3	4	5	6	7
AGATA	0.00	****						
ARROW	3.92		****					
GALA	8.14			****				
RAJA	11.53				****			
DITTA	19.63					****		
KURAS	20.83						****	
ROKO	22.33							****

Table 7
Tukey's test result for multiple comparisons – differences between the value of the tuber external damages ratio in relation to the potato variety

Potato variety	W_{zew} (%)	1	2	3	4	5	6	7
GALA	0.00	****						
DITTA	1.44		****					
KURAS	4.46			****				
ROKO	6.36				****			
RAJA	7.25					****		
AGATA	9.65						****	
ARROW	11.33							****

Table 8
Tukey's test result for multiple comparisons – differences between the value of the tuber mass damages ratio in relation to the potato variety

Potato variety	W_{mass} (%)	1	2	3	4	5	6	7
GALA	8.08	****						
AGATA	9.64		****					
ARROW	14.96			****				
RAJA	19.12				****			
DITTA	20.67					****		
KURAS	25.33						****	
ROKO	29.01							****

Conclusions

1. A statistically significant relation, measured with the value of the coefficient of correlation, between the simple sugars content and susceptibility to internal damages was determined only in potato tubers of Kuras and Raja varieties.
2. All dependent variables (content of simple sugars, value of the force that damages periderm and indexes of external, internal and mass damages) significantly differentiated potato varieties accepted for the experiment.

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ZALEŻNOŚĆ MIĘDZY ZAWARTOŚCIĄ CUKRÓW PROSTYCH W BULWIE ZIEMNIAKA A JEJ WYTRZYMAŁOŚCIĄ NA OBCIĄŻENIA MECHANICZNE

Streszczenie. W pracy poszukiwano zależności między zawartością cukrów prostych w bulwie ziemniaka a jej wytrzymałością na obciążenia mechaniczne. Badano bulwy ziemniaka odmian: Kuras, Gala, Agata, Ditta, Arrow, Roko i Raja. Wyznacznikiem podatności bulwy ziemniaka na uszkodzenia mechaniczne były: siła uszkadzająca perydermę, wskaźniki uszkodzeń zewnętrznych i wewnętrznych oraz uszkodzeń masowych. Pomiar zawartości cukru w bulwie ziemniaka wykonano przy użyciu refraktometru. Statystycznie istotną zależność, mierzoną wartością współczynnika korelacji, między zawartością cukrów prostych a podatnością na uszkodzenia wewnętrzne stwierdzono wyłącznie w bulwach ziemniaka odmian Kuras i Raja.

Słowa kluczowe: ziemniak, cukier, uszkodzenie