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Influence of mechanical damage and storage on various quality aspects of potatoes

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Summary

The aim of this study was to determine the effects of mechanical damage on both the contents of dry matter and chlorogenic acid and the degree of blackspot for five cultivars of potatoes of various earliness groups. The study was conducted immediately after the harvest as well as after two, four and six months of storage under constant conditions (air temperature +4 °C and RH 95%). Mechanical damage leads to a greater accumulation of chlorogenic acid and increases the tubers' susceptibility to blackening, irrespective of the earliness group. The duration of storage significantly determines the dry matter content of chlorogenic acid and the susceptibility to blackening of raw tuber flesh to the greatest extent for cultivars of the medium-early group. A significant ($P < 0.01$) correlation was demonstrated between the dry matter and chlorogenic acid contents and the degree of blackspot, which was higher on damaged tubers.

Keywords

blackening, chlorogenic acid, early, mechanical damage, potato

Introduction

Potato (*Solanum tuberosum* spp.), along with wheat, maize and rice, is one of the main crops for feeding the world's population (DEVAUX et al., 2014; GANCARZ, 2016). In many countries of the world, an increase in the popularity of potatoes has been noted, which is due to its nutritional value and the high energy value in relation to the area under cultivation. The main trends in the use of the potato in the food processing sector include the production of table potatoes, frozen products (salads, pancakes, dumplings, etc.), wet products (salads, purees, etc.), fried products (crisps, chips) and dried products, as well as the production of starch and ethanol (CIESAROVA et al., 2006; ERTURK and PICHA, 2007). Potatoes are delivered to stores in a packaged and customised form, i.e. cleaned with a brush, washed and pre-packaged (ERTURK and PICHA, 2007).

One of the major problems in the production of potatoes is mechanical damage, which increases the tendency to blacken the tubers and reduces the raw material quality (OPARA and PATHERE, 2014). The process of raw tuber flesh blackening is due to the enzymatic oxidation of phenols (mainly tyrosine and phenolic acids: chlorogenic and caffeic) in the presence of an enzyme called phenolase, which oxidises these compounds to dark coloured products, namely melanins (STEVENS and DAVELAAR, 1996; DELAGO et al., 2001a). Mechanical damage (bruising and abrasions) affects the cell structure and results in an increase in the polyphenolic compound content, primarily the content of chlorogenic acid, which accounts for approx. 90% of all polyphenolic compounds of the potato (KEUTGEN et al., 2014). Damage also results in an increase in polyphenol oxidase activity and, consequently, in intensification of the enzymatic oxidation reaction of polyphenols.

Chlorogenic acid content and the susceptibility of tubers to damage and blackening are, to a great extent, determined by the cultivar and

its earliness group (FINOTTI et al., 2011). High susceptibility to dark spotting after being hit is also a characteristic of starch cultivars with a higher content of dry matter and roughage. During storage, the tendency toward dark spotting increases, which is due to the intensity of life processes. An increased tendency to flesh blackening occurs at lower temperatures. Many authors have observed a more intense blackening of the tuber flesh during storage at a temperature of 2-4 °C, compared to tubers stored at a temperature of 8 °C. In turn, a reduced relative air humidity and the duration of potato storage increases their susceptibility to blackspot (DELAGO et al., 2001a, b; KEUTGEN et al., 2014).

A study was undertaken to examine the relationship between the degree of tuber damage and the susceptibility to tuber blackening as determined by the contents of total dry matter and chlorogenic acid of various potato cultivars and storage durations.

Materials and methods

Materials

The raw material used in the study included five potato cultivars ('Denar' – a very early cv., 'Bila' and 'Rosalind' – early cvs., 'Satina' – a medium-early cv., and 'Tajfun' – a medium early cv.). The different cultivars were studied each year over a three year period. 'Denar', 'Bila' and 'Tajfun' are Polish cultivars, while 'Rosalind' and 'Satina' are German cultivars. All of them are characterised by very large round and oval tubers with shallow eyes and light-yellow flesh. 'Rosalind' has a characteristic, red-coloured skin. 'Denar' is a table AB and salad cultivar, which can also be used for canned and frozen products. 'Bila' and 'Satina' are table B cultivars of general use, while 'Tajfun' is a B-BC table cultivar. 'Tajfun' is characterised by the highest starch content (16.9%) followed by 'Rosalind' (13.5%), 'Bila' (12.8%), 'Satina' (12.3%) and 'Denar' (11.6%). All cultivars are characterised by a low discoloration potential, determined at a level of 8-8.5 points in the opposite Danish scale 9 (9, non-darkening; 1, black), with CHOTKOWSKI and STYPA (2010).

Field experiments were carried out at the Research Station of the Department of Agriculture and Technology, Technical and Natural Science University, in Mochełek (53°13' N, 17°51' E; 100 m a.s.l.). The harvested tubers were stored as 10 kg samples in a storage chamber for 6 months under constant conditions (temperature +4 °C and air relative humidity 95%). This experimental storage chamber was 2 m high, 2 m wide and 3.8 m in depth with milky white translucent polypropylene plate as tank shell material, which was flame retardant, thermally insulating, moisture proof and lightfast. Moreover, to simulate the temperature environment and to reduce heat loss, the experimental storage chamber was covered with foam insulation material of 20 mm thickness.

The contents of total dry matter (TDM) and chlorogenic acid (CA) as well as the susceptibility to tuber blackening (BS) were determined in both damaged and undamaged tubers immediately after the harvest as well as after 2, 4 and 6 months of storage.

In order to determine the potatoes' susceptibility to mechanical damage, a rotary tuber damage simulator was used; the device included a drum with metal rods placed inside (a modified concrete

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mixer operating at a speed of 30 revolutions per minute). During the tests, the potato samples were subjected to damage in the drum for 1 minute. Mechanical damage was inflicted to tubers 24 hours prior to the qualitative assessment.

The chemicals urea, acetic acid, sodium nitrate, sodium hydroxide and phosphate buffer were purchased from Merck KGaA, Darmstadt, Germany, and CA from Sigma-Aldrich Co., LLC, USA.

Determination of Total Dry Matter

The TDM content of potato tubers was determined according to the AOAC method 950.01 (AOAC, 1990). Five tubers were washed, dried, and cut into cubes. The cubes were homogenized in a laboratory mixer (BOSCH, model MSM67170, BSH GmbH Germany) until a homogeneous pulp was obtained. About 10 g of the pulp was poured into a Petri dish and then heated at 60 °C for 15 h. Studies in the dryer were performed using a WAMED, model SUP-100 dryer (Poland). Afterwards, the oven temperature was raised to 105 °C. After three hours at 105 °C, the Petri dish with the dry potato was cooled to room temperature in the desiccators and weighed. The total TDM content of the potato tubers was then calculated.

Measurement of Chlorogenic Acid

The CA content was determined colorimetrically by the method of GRIFFITHS et al. (1992). Briefly, the diluted extract was vortexed with 2 mL of urea (0.17 M) and acetic acid (0.10 M). To this, 1 mL of sodium nitrite (0.14 M) was added, followed by 1 mL of sodium hydroxide (0.5 M) after incubation at room temperature for 2 min. The suspension was then centrifuged (Hettina Zentrifugen, Rotina 420 R, Germany) at 2250 g for 10 min. An aliquot of the supernatant was taken and the absorbance of the cherry red complex formed was read at 510 nm (UV-1800, UV Spectrophotometer System, Japan). A standard curve was prepared using different concentrations of CA and the results were expressed as mg of CA/1 kg of fresh potato tubers.

Measurement of blackspot

Discoloration potential analysis was carried out using the colorimetric method. For the homogenization method, equal portions of 25 g of each of the apical and basal ends of six tubers were homogenized in a laboratory mixer (BOSCH, model MSM67170, BSH GmbH Germany) for 30 s in a 25 mL 0.02 M phosphate buffer as described by DELGADO et al. (2001a, 2001b). The homogenate was left to oxidize for 24 h. The absorbance was measured at 475 nm with an SHIMADZU UV-1800, UV-Vis spectral photometer system (Japan).

The samples were diluted at a 1:3 ratio before the photometric measurements. The results are the mean of three measurements and are presented as Absorbance Units (AU₄₇₅) at 475 nm.

Statistical analysis

Each analysed variant of experimental factors was replicated four times independently with different potato cultivars in three laboratory replications.

The significance of the effects of the tested factors on the analysed characteristics was determined using the two-factor variance analysis (ANOVA) with a Statistica 12.5 software. For the testing of differences between average values at a significance level $P < 0.05$, Fisher's LSD test was used. In addition, coefficients of linear correlation between the tested quality characteristics of potatoes were calculated.

Results and discussion

The results of the determination of TDM content of tubers of five cultivars of undamaged and damaged potatoes, performed immediately after the harvest and after storage, are provided in Tab. 1. The results revealed that the TDM content of table potatoes was genetically conditioned and ranged from 190 to 227 g·kg⁻¹ (Tab. 1). Such a result was confirmed by other authors who found that the TDM content is a varietal characteristic, and for table cultivars, it ranges from 201–230 g·kg⁻¹ (HAASE, 2003; MURNICE et al., 2011). As for undamaged tubers, the early cultivar 'Bila' was characterised by the lowest TDM content (201 g·kg⁻¹) while the highest TDM (227 g·kg⁻¹) was noted for the medium-early cultivar 'Tajfun'. Similar results were obtained by KRZYSZTOFIK and SKONIECZNY (2010) who noted that early cultivars were characterised by a lower content of TDM compared to the medium-early cultivars. However, other authors suggest that the TDM content does not depend on a cultivar's earliness, provided that the harvest is performed in full processing maturity (MURNICE et al., 2011; ZGÓRSKA and GRUDZIŃSKA, 2012). As for damaged tubers, the TDM content results were similar. 'Bila' and 'Rosalind' were characterised by the lowest TDM content, while 'Tajfun' was characterised by the highest TDM content. The greatest changes to the TDM content were noted for damaged tubers after a 2-month storage period for 'Tajfun' (4.7%), and after a 4-month storage period for 'Bila' (3.2%) (Tab. 1).

The storage of potato tubers for a six-month period resulted in the significantly ($P < 0.05$) greatest drop in the TDM content (Fig. 1). The losses ranged from 4.2% for 'Bila' to 8.1% for 'Tajfun' tubers, the greatest drop in the TDM content (5.6%) was noted as early as after 2 months of storage. Further storage led to small, statistically

Tab. 1: The total dry matter (g·kg⁻¹) of potato tubers as affected by mechanical damage and length of storage

Cultivar	Date of investigation							
	Immediate after HARVEST		After STORAGE					
	UD*	D*	2 months		4 months		6 months	
			UD	D	UD	D	UD	D
<i>Denar</i>	207 a	213 a	206 a	210 b	202 bc	204 a	198 bc	200 bc
<i>Bila</i>	201 a	208 a	196 c	201 a	192 a	195 a	190 a	194 ab
<i>Rosalind</i>	206 a	207 a	202 a	203 a	197 ab	203 c	195 ab	199 a
<i>Satina</i>	215 b	218 b	212 b	213 bc	207 cd	211 b	202 c	203 c
<i>Tajfun</i>	227 c	228 c	215 b	217 c	210 d	215 b	209 d	213 d

*UD – undamaged, D – damaged

Means sharing the same letter in column are not significantly different from each other (Fischer's significant difference test, $P < 0.05$).

Data are the averages (n = 12).

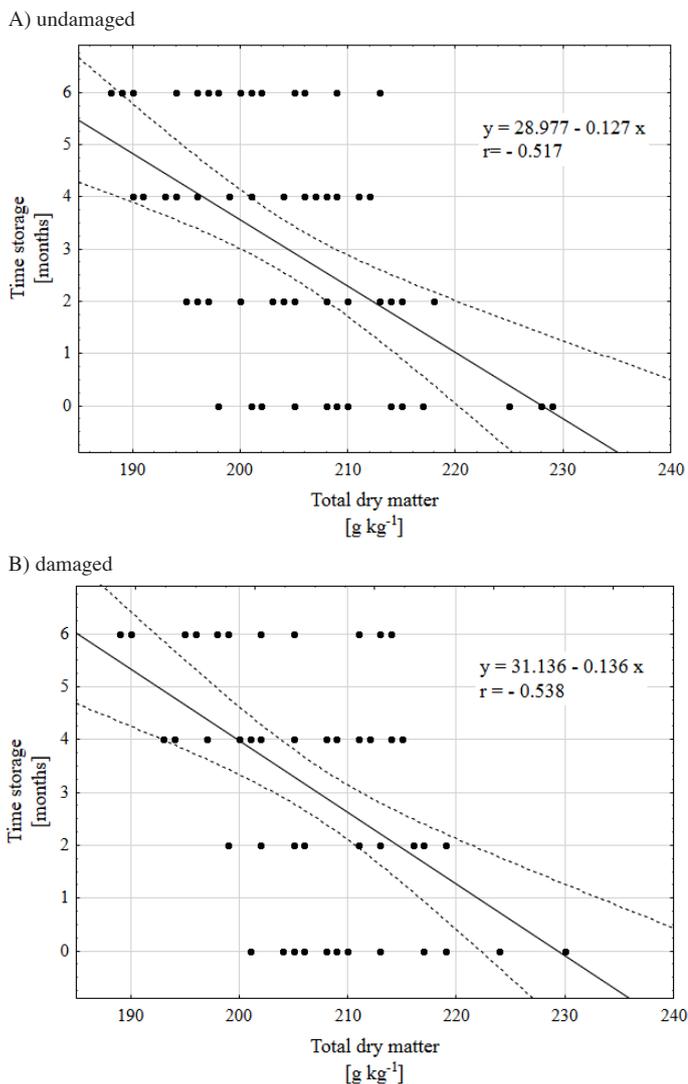


Fig. 1: The significant relationship between the date of investigation and total dry matter content in the potato tubers. A) undamaged, B) damaged. r – indicates that the correlation is significant at the 0.05 probability level.

insignificant changes to the TDM content for the cultivar concerned. On the other hand, for ‘Bila’, the greatest drop in the TDM content was noted after 4 months and amounted to 6.6%; the extension of the period to 6 months had no significant effect. For ‘Satina’ and ‘Denar’, a significant drop in the TDM content was noted after a longer duration of storage, namely, after 4 and 6 months (Tab. 1). Similar relationships for table potatoes stored for 3 and 6 months were obtained by POBEREŻNY and WSZELACZYŃSKA (2011) in a study in which TDM losses were at an average level of 7.1%. According to ZGÓRSKA and GRUDZIŃSKA (2012), storage at higher temperatures of 8-10 °C results in an increase in the TDM content, which is false and associated with the loss of water. It results from the more intense life processes (i.e. transpiration and respiration) at higher temperatures. In their study, the authors obtained an increase in the TDM content from 10.5% to 18.5% when storing tubers of various cultivars at 8 °C. The damage and earliness group of a potato is also of significance to the TDM content of tubers after the storage (Fig. 2). Irrespective of the time of a study, damaged tubers of the medium-early group exhibited the greatest increase in the TDM content. This is associated with an increase in transpiration rate due to life processes and the

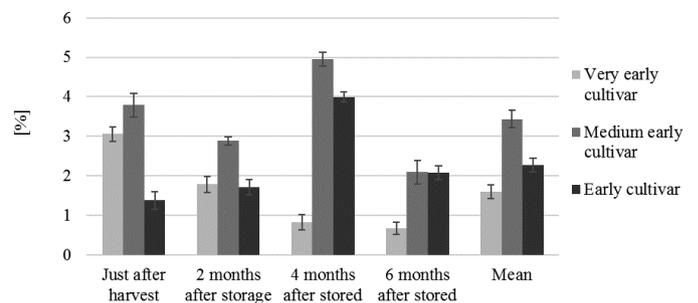


Fig. 2: The effect of damage on the total dry matter content of early potato tubers. Vertical bars show \pm SE of means ($n = 12$). The interaction between storage duration and damage was significantly different at $P < 0.05$.

sprouting of tubers during storage (CASANAS et al., 2003). During the study, the smallest increase in the TDM content was noted for damaged potatoes of the early cultivars immediately after the harvest and two months of storage. On the other hand, after four and six months of storage, the smallest increase in the TDM content was noted for the very early potato cultivars. Obtaining such a result may be due to the more rapid completion of the natural dormancy period during the storage of tubers, resulting from genetic predispositions in relation to other earliness groups (MURNICE et al., 2011; CASANAS et al., 2003).

As for damaged tubers, for all cultivars except ‘Tajfun’ (Tab. 1), greater losses in the TDM content were noted during storage than for undamaged tubers stored under the same conditions. The average TDM content of damaged tubers analysed after 6 months of storage dropped considerably, which was confirmed by the analysis of variance, and ranged from 19.4% for ‘Bila’ to 21.3% for ‘Tajfun’. A change to the TDM concentration is at the same time associated with the change to starch content (POBEREŻNY and WSZELACZYŃSKA, 2011). In addition, mechanical damage resulted in an increase in starch losses at a level of 2%-3%, which at the same time leads to a decrease in the TDM content during the storage. According to WANG et al. (2015) and OLSEN et al. (2003), healing of wounds during storage is an energy intensive process. The intensity of respiration increases three- to fourfold during the initial three days after damaging the tubers. However, after a few more days it decreases but remains 1.5-2 times higher than the intensity of respiration for undamaged tubers. As reported by PAGAN et al. (2010), structural carbohydrates found in undamaged tubers are responsible for the intact structure and the rigidity of the potato tuber skin. Even though the percentage content of structural carbohydrates (cellulose, hemicellulose) in the skin is lower than the starch content, damage leads to an intensified activation of enzymes (cellulase, xylanase), which results in the loosening or breaking of the bonds of the complex of these polymeric units. Consequently, processes of exo- and endo-corrosion of starch granules occur due to the intensified activity of enzymes (e.g. amylase), which results in losses (BISHAI et al., 2015; COLLINS et al., 2005; SUJKA and JAMROZ, 2007), but fructose, sucrose and total sugar content increased (ERTURK and PICHA, 2007). The CA content in undamaged tubers immediately after the harvest ranged from 174 mg · kg⁻¹ f.w. for the medium-early cultivar ‘Satina’ to 232 mg · kg⁻¹ f.w. for the very early cultivar ‘Denar’ (Tab. 2). As reported by FINOTTI et al. (2011), ANDRE et al. (2007), NAVARRE et al. (2010), SHAKYA and NAVARRE (2006), the CA content in potato tubers varies widely from 600 to 2,920; 1,000 to 2,220; 174.0 to 12,746 mg · kg⁻¹ d.m. and from 33 to 6,370 mg · kg⁻¹ f.w., respectively. In the authors’ own study, storage resulted in a significant increase in the CA content of undamaged tubers, and the highest values were noted for tubers stored for a period of 6 months. An increase in the content in relation to tubers after the harvest ranged from 39.5% for

Tab. 2: The chlorogenic acid ($\text{g} \cdot \text{kg}^{-1}$ f.w.) of potato tubers as affected by mechanical damage and length of storage

Cultivar	Date of investigation							
	Immediate after HARVEST		After STORAGE					
	UD*	D*	2 months		4 months		6 months	
UD			D	UD	D	UD	D	
<i>Denar</i>	232 c	294 bc	243 ab	329 b	282 a	390 a	353 b	399 d
<i>Bila</i>	187 ab	271 b	248 ab	282 ab	251 c	362 a	285 a	367 c
<i>Rosalind</i>	224 bc	311 c	319 c	316 b	352 d	360 d	376 b	430 e
<i>Satina</i>	174 a	216 a	212 a	238 a	234 b	313 b	251 a	324 a
<i>Tajfun</i>	204 abc	235 a	268 b	250 ab	278 a	277 c	285 a	282 b

*UD – undamaged, D – damaged

Means sharing the same letter in column are not significantly different from each other (Fischer's significant difference test, $P < 0.05$).

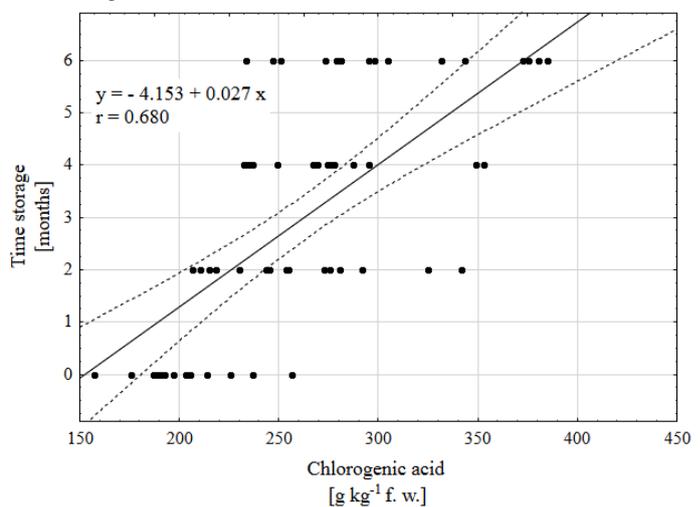
Data are the averages ($n = 12$).

'Tajfun' to 67.7% for 'Rosalind'. In relation to the content after the harvest, each of the storage periods resulted in a significant ($P < 0.05$) increase in CA content in all tested cultivars (Fig. 3). Only for 'Denar' tubers, no significant increase was obtained after two months of storage. For 'Rosalind' and 'Tajfun', the extension of the storage period from two to four and six months had no significant effect on the content of the tested compound (Tab. 2). This is consistent with the results obtained by STUSHNOFF et al. (2008). On the other hand, GRUDZIŃSKA and ZGÓRSKA (2011) demonstrated that the duration of storage had no significant effect on the changes to the content of polyphenolic compounds, the main component of which is CA. In turn, KEUTGEN et al. (2014) noted a drop in the total polyphenolic compound content after a 6-month period of storage of tubers of various cultivars by as much as 81%. However, as an indicator of antioxidant activity, total polyphenol content was determined in industrially dehydrated potatoes (lyophilized material) instead of fresh materials. As expected, total polyphenol content was variable according to the vegetable composition; the lowest phenolic content was found in potatoes (GAMBOA-SANTOS et al., 2012).

For tubers subjected to mechanical damage, the CA content was significantly higher than in undamaged tubers and ranged from $216 \text{ mg} \cdot \text{kg}^{-1}$ f.w. for 'Satina' to $311 \text{ mg} \cdot \text{kg}^{-1}$ f.w. for 'Rosalind' (Tab. 2). An increase in CA content due to mechanical damage was also found in studies by CANTOS et al. (2002) and TORRES-CONTRERAS et al. (2014). As shown by WANG et al. (2015) and FALLER and FIALHO (2009), this is associated with the physiological response of potato tubers to damage, since under conditions stressful to the plant an intensified attack of pathogens occurs, which results in an intensified synthesis of polyphenolic compounds. For damaged tubers, the duration of storage was of less significance. The increase in CA content due to the extension of storage duration was smaller. It should be noted that, similar to undamaged tubers, the highest acid content was reported for damaged tubers stored for 6 months. The increase in the content of this compound may also result from the release of polyphenols from damaged potato flesh cells, as it was demonstrated by TORRES-CONTRERAS et al. (2014) in a study in which the content of CA increased with an increase in the extent of mechanical damage.

Similar to the TDM, damaged tubers of the medium-early group exhibited the greatest increase in CA content (Fig. 4). The smallest increase in CA content was noted for tubers of early cultivars after two months and for tubers of very early cultivars after six months. It should be noted that mechanical damage resulted in an increase in CA content by as much as 84% in tubers of the medium-early group. This confirms that mechanical damage has a greater effect on the

A) undamaged



B) damaged

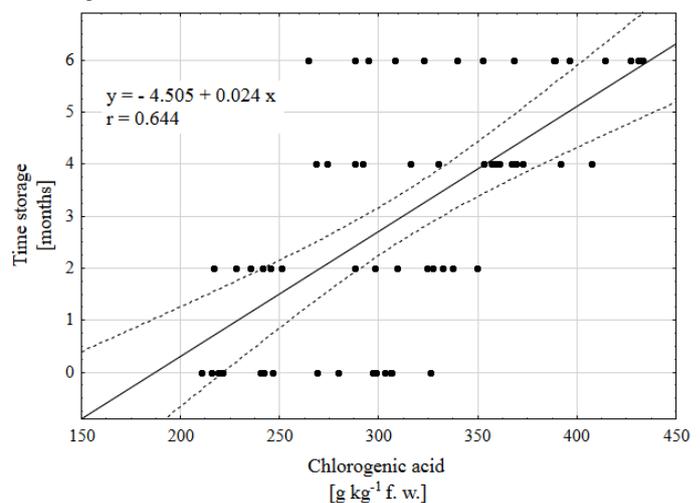


Fig. 3: The significant relationship between the date of investigation and chlorogenic acid content in the potato tubers. A) undamaged, B) damaged. r – indicates that the correlation is significant at the 0.05 probability level.

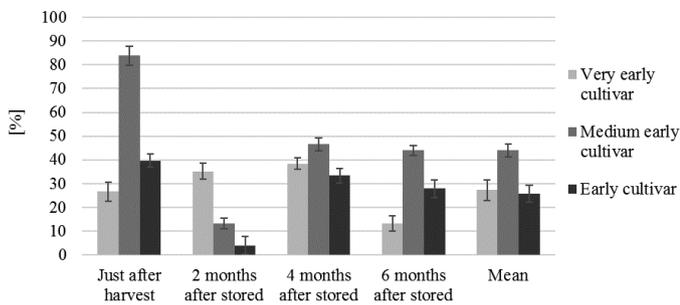


Fig. 4: The effect of damage on the chlorogenic acid content of early potato tubers. Vertical bars show \pm SE of means (n = 12). The interaction between storage duration and damage was significantly different at $P < 0.05$.

synthesis of phenolic compounds than the duration of storage. This study demonstrated that the cultivars differed significantly in the tendency to blacken the flesh of both undamaged and mechanically damaged tubers (Tab. 3). As for the tested cultivars, ‘Rosalind’ was characterised by the greatest tendency for BS, which was followed by ‘Denar’, ‘Satina’, ‘Bila’, and ‘Tajfun’. Susceptibility of potato tubers to the BS processes is a varietal characteristic, which is also proven by results of studies by other authors (KEUTGEN et al., 2014; ZGÓRSKA and GRUDZIŃSKA, 2012; PRAEGER et al., 2012). The flesh of undamaged and mechanically damaged tubers of the tested cultivars exhibited a significant ($P < 0.05$) tendency toward intensified BS after each storage period and reached the highest absorbance values (AU_{475}) after six months (Fig. 5). DEAN et al. (1993) and LAERKE (2002) have a different opinion, as they obtained changes in the tendency to blacken tuber flesh during storage. These changes did not take place consistently throughout the entire period. During the initial months of the storage they noted an increase in the tendency to blacken, and a drop at the end of the storage period. According to WSZELACZYŃSKA (2004), an increase in the susceptibility to BS of raw tuber flesh after the storage is not due to the duration of the storage period but is associated with changes in its chemical composition. These changes relate primarily to the decrease in the concentration of both ascorbic and citric acid and to the increase in CA content.

The BS of the flesh in mechanically damaged tubers immediately after the harvest was greater than for the flesh of undamaged tubers by an average of 10% (Tab. 3). This is associated with the damage to plant cells, which results in an increase in enzyme activity. This process results in an increase in the content of phenolic compounds,

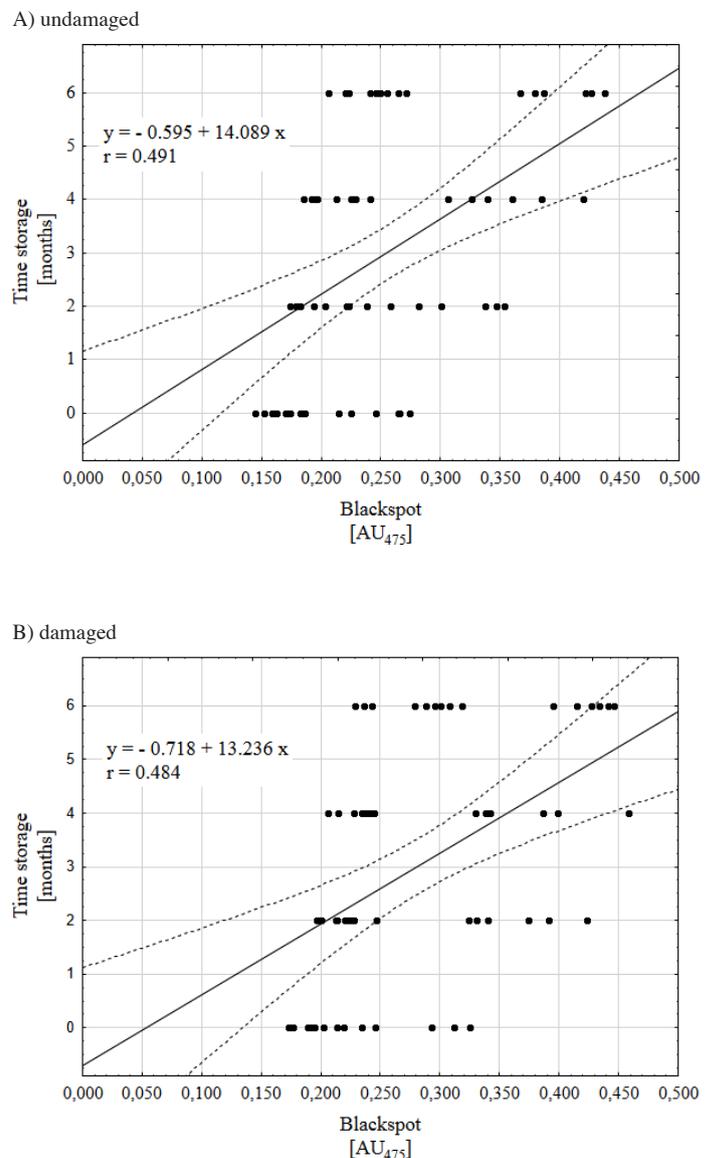


Fig. 5: The significant relationship between the date of investigation and discoloration potential of potato tubers. A) undamaged, B) damaged. r – indicates that the correlation is significant at the 0.05 probability level.

Tab. 3: The discoloration potential ($AU_{475} \cdot 1000$) of potato tubers as affected by mechanical damage and length of storage

Cultivar	Date of investigation							
	Immediate after HARVEST		After STORAGE					
	UD*	D*	2 months		4 months		6 months	
		UD	D	UD	D	UD	D	
<i>Denar</i>	229 c	231 b	280 c	332 a	324 c	337 a	378 c	419 c
<i>Bila</i>	173 a	196 a	190 a	220 a	213 ab	238 a	240 ab	309 a
<i>Rosalind</i>	268 d	310 c	346 d	396 c	388 d	415 c	429 d	434 b
<i>Satina</i>	180 a	197 a	227 b	224 a	232 b	232 a	262 b	288 a
<i>Tajfun</i>	152 b	179 a	178 a	211 a	19 a	216 a	224 a	236 c

*UD – undamaged, D – damaged

Means sharing the same letter in column are not significantly different from each other (Fischer’s significant difference test, $P < 0.05$).

Data are the averages (n = 12).

which are substrates for oxidising enzymes responsible for the formation of melanin compounds. Melanin pigments are reactive quinone compounds, which lead to the formation of brown, black and red pigments in plant products. For this reason, the appearance of the products is less attractive to the consumer, and some nutritional quality is lost (CANTOS et al., 2002; GONZALEZ-SANTOYO and CORDOBA-AGUILAR, 2012).

The smallest average increase in the tendency to blacken after a mechanical damage was noted for tubers of cultivars of the very early group, and the highest average increase was for tubers of cultivars of the medium-early group (Fig. 6) associated with the highest average CA content (Tab. 3).

The results of the study indicate a high positive correlation between the degree of BS and the CA content ($P < 0.01$) and a high negative correlation between the degree of BS and the TDM content ($P < 0.01$) in both undamaged and mechanically damaged tubers (Tab. 4). More significant relationships between these parameters were noted for damaged tubers. This indicates a significant participation of these compounds in the course of the BS reaction and a great effect of mechanical damage on the relationships concerned (WANG et al., 2015; CANTOS et al., 2002; TORRES-CONTRERAS et al., 2014).

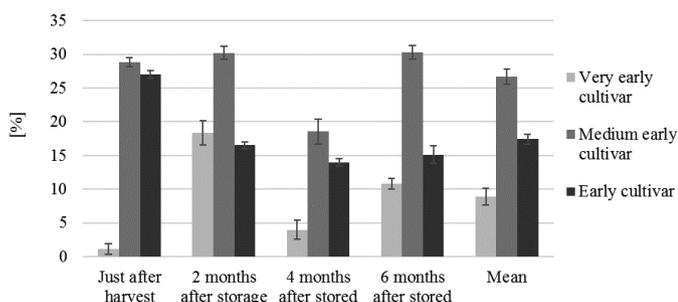


Fig. 6: The effect of damage on the discoloration potential of early potato tubers. Vertical bars show \pm SE of means ($n = 12$). The interaction between storage duration and damage was significantly different at $P < 0.05$.

Tab. 4: The correlation coefficients (r) between the studied characters potato tubers irrespective of the date of investigation

Features	Chlorogenic acid content		Blackspot	
	UD ¹	D ¹	UD	D
Dry matter content	-0.478	-0.756	-0.515	-0.627
Chlorogenic acid content			0.644	0.782
Blackspot				

¹UD – undamaged, D – damaged

$r > 0.333$ – indicates that the correlation is significant at the 0.01 probability level

Conclusions

Based on the study conducted, it was found that genetic predisposition (and thus, the potato earliness group) had a significant effect on the analysed parameters. The storage of potatoes results in a drop in the TDM content and an increase in the CA content and increases susceptibility to BS to the greatest extent in tubers of cultivars of the medium-early group. It was found that mechanical damage leads to a greater accumulation of CA and to an increase of the tubers' susceptibility to BS, irrespective of the earliness group. A significant

relationship was also demonstrated between the TDM and CA contents and the degree of BS. These relationships were more significant for damaged tubers. Potatoes that were not mechanically damaged and were stored for a period of six months under cooling conditions retained a higher quality than tubers subjected to mechanical damage.

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