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THE EFFECT OF RIDGE HEIGHT AND HARVEST DATE ON EDIBLE POTATO TUBER QUALITY

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Abstract

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The work presents results of a three-year study undertaken to assess the effect of ridge height and harvest date, determined based on soil temperature, on edible potato tuber quality. A field experiment was arranged as a split-split-plot design with four replicates. Environmental conditions during the growing season, cultivar, and harvest date had a substantial influence on dry matter and starch contents as well as cooking attributes of potato tubers. Starch and dry matter contents were affected by the study years, cultivar and harvest date, the highest levels being found for cv Romula tubers as well as tubers harvested at the soil temperature of 12°C. Cv Sante tubers and tubers harvested at the soil temperature of 12°C, whether raw or cooked darkened least. As the ridge height increased, after-cooking darkening declined and flavour improved.

Key words: starch content, dry matter content, darkening of raw flesh, after-cooking darkening, potato tuber flavour

Introduction

Potato for consumption without processing should possess the right external and internal characteristics as well as high nutritional value (Sadowska et al., 2004; Hamouz et al., 2005; Buono et al., 2009; Kumar et al., 2012). Tuber chemical composition is one of major factors affecting potato quality (Leszczyński, 2002). Dry matter and starch contents affect mainly potato texture and nutritional value (Kaaber et al., 2002; Van Dijk et al., 2002; Weber and Haase, 2005; Thybo et al., 2006; Murnice et al., 2011). In addition to tuber chemical composition, texture is affected by the degree of tuber maturity. According to Rytel (2004) and Lisińska (2006), delayed harvest results in increased starch and dry matter contents of potato but the rate of their accumulation depends on cultivar and growing conditions.

Flavour is the sensory impression of potato which is determined mainly by the chemical senses of taste and smell. This attribute determines potato suitability for consumption and is connected with flesh consistency, mealiness, moisture, texture and chemical composition (Hamouz et al., 2006; Zarzecka et al., 2010; Brazinskiene et al., 2014; Zgórska and Grudzińska, 2012). Darkening of raw flesh and after-cooking darkening are complex cultivar-related attributes which are also affected by environmental conditions (Zimnoch-Guzowska and Flis, 2006).

Many authors (Blenkis et al., 2002; Rymuza and Bombik, 2004; Hamouz et al., 2005; Wang et al., 2008; Lombardo et al., 2013) believe that potato characteristics reflecting tuber quality fluctuate markedly due to a number of various factors. In addition to genotype, they include: meteorological and soil conditions, fertiliser treatment and control of diseases and pests (Zarzecka et al., 2010; Brazinskiene et al., 2014). Also, appropriate soil cultivation contributes to improved yield quality as it changes soil structure and bulk density (Kiełbasa, 2006). Careful formation of ridges is one of the components of appropriate cultivation practices as, according to Szeptycki (2011), the ridge should be high because then potato can be harvested without loss and injuries.

Literature on the subject lacks publications on the effect of ridge height and harvest date (determined based on soil temperature) on edible potato tuber quality so the objective of this work was to examine the impact of these cultivation components on the starch and dry matter content of potato tubers, raw flesh darkening, after-cooking darkening and flavour.

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Materials and Methods

A field experiment was carried out at the Zawady Experimental Farm (52°06'N; 22°56'E) which is part of the University of Natural Sciences and Humanities in Siedlce, from 2004 to 2006.

Temperatures and precipitation during the study period are presented as Sielianinov's hydrothermal coefficients (Table 1). The weather conditions were different each year. In 2004 and 2006, the total precipitation over the growing season was much higher than the long-term mean whereas 2005 was dry although k = 0.92 did not differ much from the mean. The experiment was a split-split-plot arrangement with 4 replicates. The following factors were examined:

- edible potato cultivar (factor A): Sante, Romula, Żagiel;
- ridge height (factor B): low ridge (16 cm), standard ridge (20 cm), high ridge (24 cm);
- harvest date determined based on soil temperature (16, 12 and 8°C) averaged over 3 consecutive days before potato tuber harvest, measured at the depth of 10 cm at 8 o'clock in the morning.

Dry matter was determined by the gravimetric method. Starch content was determined directly after harvest using a Reimann's balance in a 5-kg sample taken from each plot. Darkening of raw flesh (assessed after 4 hours from cutting tubers through) was determined by means of a nine-point scale based on Danish tables where 9 correspond to non-changed flesh colour and 1 denotes black flesh. Examination of after-cooking darkening was done after 24 hours from boiling of peeled and cut tubers using the Danish scale, too. Tuber flavour was determined just after cooking using a nine-point scale where 9 denotes the best flavour, 8-7 corresponds to very good flavour, 6-4 refers to good flavour and 3-1 denotes poor flavour of tubers which are unsuitable for consumption.

The results were statistically analysed by means of ANOVA. The following fixed model was used (Trętowski and Wójcik, 1991):

$$y_{ijlp} = m + a_i + g_j + e_{ij}^{/1/} + b_l + ab_{il} + e_{ijl}^{/2/} + c_p + ac_{ip} + bc_{lp} + abc_{ilp} + e_{ijlp}^{/3/},$$

where: y_{ijlp} – value of the trait for the i-th effect of factor A, l-th effect of factor B, p-th effect of factor C in the j-th block (replicate), m – overall (population) mean, a_i, b_l, c_p – main effects of factors, g_j – effect of j-th block, ab_{il}, ac_{ip}, bc_{lp}, – 2-factor interaction effects, abc_{ilp} – 3-factor interaction effect, $e_{ij}^{/1/}$, $e_{ijl}^{/2/}$, $e_{ijlp}^{/3/}$ – random effects which were assumed to be homogeneous and normally distributed.

Comparison of means and assessment of interactions were based on highly significant differences (HSD) which were calculated using Tukey's test at the significance level of $\alpha = 0.05$. Linear and polynomial regressions were used to examine the nature of the effect of harvest date and ridge height on the studied characteristics (Trętowski and Wójcik, 1991). Calculations were performed using Statistica 10.0 and own algorithm written in Microsoft Excel 2007.

Results

Variance analysis demonstrated that dry matter content of potato depended on study years, cultivars and harvest dates. Also, significant growing season x cultivar and growing season x harvest date interactions were detected. Higher dry matter content (by almost 2%) was found in tubers harvested in 2004 and 2005 vs 2006. Cv Romula and Żagiel had, respectively, the most and least dry matter. The significant cultivar x study year interaction indicates that growing conditions affected the dry matter content of the examined potato cultivars. In 2004 Romula accumulated more dry matter than Sante and Żagiel whereas in 2005 both Romula and Sante had significantly less dry matter than Żagiel. All the cultivars had significantly different dry matter contents in 2006. On average, significantly more dry matter was accumulated in potato tubers harvested in the second than first study year. The significant study year x harvest date interaction means that in 2004 tubers harvested at the soil temperature of 12 and 8°C contained more dry matter, the relationship being parabolic in character. The extreme value indicates that tubers would have the driest matter (21.2%) if harvested at 11.2°C. Dry matter contents of potato tubers produced in 2005 and 2006 were similar irrespective of the soil temperature (Table 2, Figure 1).

Starch content in potato tubers was affected by study years, cultivars and harvest dates. Significantly more starch was ac-

Table 1
Sielianinov's hydrothermal coefficients during the study period

Years	Months						Over the whole potato growing season
	April	May	June	July	August	September	
2004	1.49	2.70	1.14	0.90	1.14	0.50	1.31
2005	0.47	1.60	0.92	1.38	0.83	0.35	0.92
2006	1.18	0.93	0.46	0.23	4.08	0.45	1.22

$k \leq 0.50$ very dry, $0.50 \leq k \leq 0.69$ dry, $0.70 \leq k \leq 0.99$ slightly dry, $k \geq 1$ not dry, according to Baca et al. (1980)

cumulated in potato tubers harvested in 2004 and 2005 as well as at the second and third harvest date. All the cultivars had significantly different starch contents, the most starch being accumulated by cv Romula and the least by Żagiel. A significant study year x harvest date interaction means that starch content of potato tubers harvested at the dates analysed was affected by the study years. In 2004, significantly more starch was accumulated in potato tubers harvested at the second and third date vs the first harvest date. In 2005, potatoes had similar starch contents at all the harvest dates whereas in 2006 significantly more starch was accumulated by tubers harvested at the second than third date (Table 3). The relationship between starch content of potato tubers and harvest date was quadratic in 2004 and 2006. As the harvest date was delayed, starch content of potato tubers increased to the maximum level reached at the soil temperature of 10.4°C in 2004 and 10.8°C in 2006. Theoretically, the starch content would be 14.5% in 2004 and 13.1% in 2006 (Figure 1).

Darkening of raw flesh significantly depended on the growing season, cultivar, and ridge height and harvest date. Also, the growing season x harvest date interaction was significant (Table 4). Least darkening was observed of the raw flesh of potatoes harvested in 2005 (7.99 points) whereas the flesh of tubers produced in 2004 darkened most (7.37 points).The flesh of Romula and Żagiel tubers tended to darken significantly less compared with Sante. Tubers of potatoes grown in standard ridges (20 cm high) were significantly less susceptible to raw flesh darkening (7.74 points) compared with high

Table 2
The dry matter content (%) depending to the study year, potato cultivar and harvest date

Years	Cultivars			Mean
	Sante	Romula	Żagiel	
2004	19.3	23.6	18.2	20.4
2005	21.2	21.4	17.2	19.9
2006	17.8	20.6	14.7	17.7
Mean	19.4	21.9	16.7	19.3
$HSD_{0.05}$ for: years 1.0; cultivars 1.0; year x cultivar 1.7				
Years	Harvest date (soil temperature)			
	1 (16°C)	2 (12°C)	3 (8°C)	Mean
2004	19.6	21.1	20.5	20.4
2005	20.0	19.9	19.9	19.9
2006	17.7	17.9	17.6	17.7
Mean	19.1	19.6	19.3	19.3
$HSD_{0.05}$ for year x harvest date 0.069				

Table 3
The starch content (%) depending to the study year, potato cultivar and harvest date

Years	Cultivars			Mean
	Sante	Romula	Żagiel	
2004	13.3	15.4	11.8	13.5
2005	14.8	15.5	11.3	13.9
2006	10.9	13.0	9.2	11.0
Mean	13.0	14.6	10.8	12.8
$HSD_{0.05}$ for: years 0.9; cultivars 0.9				
Years	Harvest date (soil temperature)			
	1 (16°C)	2 (12°C)	3 (8°C)	Mean
2004	12.1	14.3	14.1	13.5
2005	14.1	13.8	13.8	13.9
2006	11.0	11.3	10.7	11.0
Mean	12.4	13.1	12.9	12.8
$HSD_{0.05}$ for: harvest date 0.3; year x harvest date 0.5				

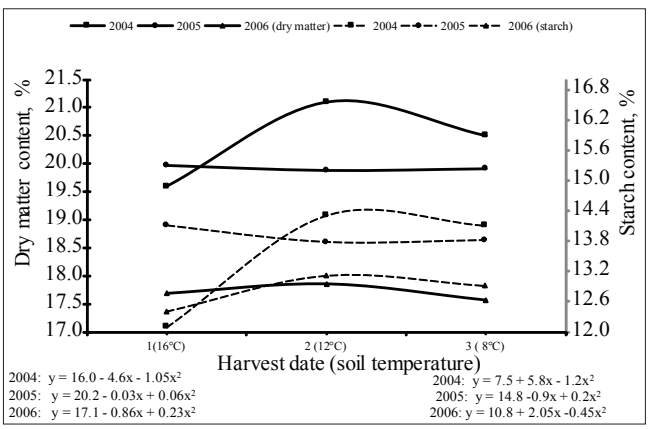

Fig. 1. Dry matter and starch contents (%) depending on the harvest date and growing season

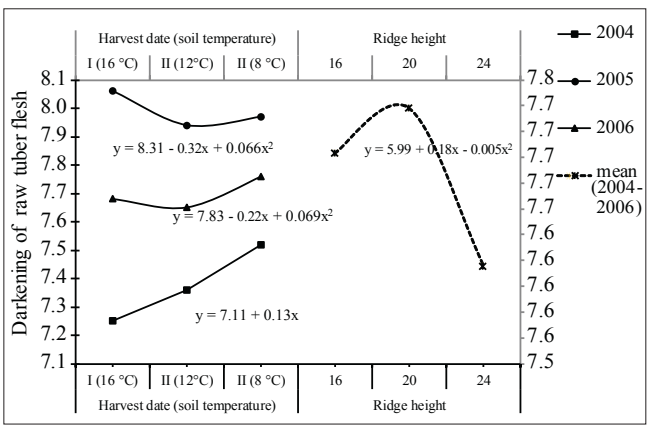

Fig. 2. Darkening of raw flesh (points) depending on the growing season, harvest date (°C) and ridge height (cm)

ridges (7.62 points), the relationship being quadratic. When the ridge height was increased from 16 to 20 cm, darkening of raw flesh declined but when the height was increased from 20 to 24 cm the raw flesh of tubers darkened more intensively. The extreme value of 18.9 cm indicates that potato production at such a ridge height would yield tubers with raw flesh darkening of 7.74 points (Figure 2)

Tubers harvested at the third date were least susceptible to darkening of raw flesh. In 2004 such tubers were collected at the soil temperature of 8°C (7.52 points) compared with 16 and 12°C (7.25 and 7.36 points, respectively). In the second and third study year, darkening of raw flesh was the same irrespective of the soil temperature at harvest. The darkening of raw flesh in 2004 linearly depended on the harvest date. As harvest was delayed, intensity of darkening of raw flesh fell by around 0.13 points (Table 4, Figure 2).

After-cooking darkening was affected by study years, cultivars, and ridge height and harvest date. Potatoes showed significantly different susceptibility to after-cooking darkening in each study year. Tubers of Sante and Żagiel darkened less when cooked compared with Romula. Such effect was also found for potatoes grown in the flat ridge. The flesh of Romula tubers cultivated in flat ridges was significantly less susceptible to after-cooking darkening (7.93 points) compared with the high ridge (7.78 points) (Table 5), the relation being linear. As the ridge height was increased by 1 cm, after-cooking darkening declined by around 0.02 points (Figure 3). The remaining cultivars did not differ significantly regarding the attribute described. Less after-cooking darkening was observed in tubers harvested at the soil temperature of 12°C vs 16 and 8°C. Moreover, tubers of potato cultivated in flat ridges showed less susceptibility to after-cooking darkening when harvested at 8°C rather than 16°C (8.06 and 7.90 points, respectively), the relationship being linear. As soil temperature dropped by 4°C, after-cooking darkening declined by 0.08 points. After-cooking darkening of potato harvested at the second and third date was similar. Tubers cultivated in standard and high ridges showed less susceptibility to darkening of cooked flesh when harvested at the soil temperature of 12°C, the relationship being quadratic. Harvest of tubers at 12°C resulted in less after-cooking darkening but when it was further delayed, the darkening increased. Extreme values, calculated to determine the optimum harvest date, indicated that potatoes cultivated in standard and high ridges should be

Table 4
Darkening of raw flesh (points) depending on the growing season, potato cultivar and soil temperature at harvest

Years	Cultivars			Mean
	Sante	Romula	Żagiel	
2004	7.29	7.45	7.38	7.37
2005	7.85	7.98	8.13	7.99
2006	7.59	7.73	7.77	7.70
Mean	7.58	7.72	7.76	7.69
$HSD_{0.05}$ for: years 0.12; cultivars 0.12				
Years	Ridges			
	low (16 cm)	standard (20 cm)	high (24 cm)	Mean
2004	7.41	7.44	7.27	7.37
2005	7.99	8.02	7.95	7.99
2006	7.70	7.76	7.63	7.70
Mean	7.70	7.74	7.62	7.69
$HSD_{0.05}$ for: ridge height 0.1				
Years	Harvest date (soil temperature)			
	1 (16°C)	2 (12°C)	3 (8°C)	Mean
2004	7.25	7.36	7.52	7.37
2005	8.06	7.94	7.97	7.99
2006	7.68	7.65	7.76	7.70
Mean	7.66	7.65	7.75	7.69
$HSD_{0.05}$ for: harvest date 0.09; year x harvest date 0.15				

Table 5
After-cooking darkening (points) depending on the growing season, potato cultivar, ridge height and soil temperature at harvest

Years	Cultivars			Mean
	Sante	Romula	Żagiel	
2004	8.21	8.04	8.17	8.14
2005	7.80	7.67	7.76	7.74
2006	8.00	7.85	7.98	7.94
Mean	8.00	7.85	7.97	7.94
$HSD_{0.05}$ for: years 0.09; cultivars 0.09				
Ridges	Cultivars			
	Sante	Romula	Żagiel	Mean
Low (16 cm)	8.02	7.93	8.00	7.98
Standard (20 cm)	7.94	7.85	7.99	7.93
High (24 cm)	8.04	7.78	7.92	7.91
$HSD_{0.05}$ for: ridge height 0.06; cultivar x ridge height 0.12				
Ridges	Harvest date (soil temperature)			
	1 (16°C)	2 (12°C)	3 (8°C)	Mean
Low (16 cm)	7.90	8.00	8.06	7.98
Standard (20 cm)	7.88	8.04	7.86	7.93
High (24 cm)	7.84	8.02	7.88	7.91
Mean	7.87	8.02	7.93	7.98
$HSD_{0.05}$ for: harvest date 0.07; ridge height x harvest date 0.13				

harvested at the soil temperature of 12 and 11.6°C, respectively. Then, the respective point scores for both the ridge heights would be 8.04 and 8.03 (Table 5, Figure 4).

Potato tuber flavour was significantly affected by the growing season, cultivar and ridge height. Potatoes grown in 2005 had a better flavour than in 2004. Tuber flavour was similar in 2005 and 2006. All the cultivars studied had different flavour of their tubers. Cv Sante tubers were significantly tastier (7.15 points) than the remaining cultivars. Moreover, the flavour of tubers produced in flat ridges was significantly better than in standard ridges. The cultivar x ridge height interaction indicated that flavour of the cultivars differed depending on ridge height. Cv Sante tubers had a better flavour when grown in high ridges (7.36 points) compared with standard ridges (7.01). Romula tubers were tastier when cultivated in flat vs standard ridges (6.43 and 5.94, respectively). Żagiel tubers had a similar flavour regardless of the ridge height (Table 6). The relationship between the flavour and ridge height of Sante tubers was linear. As the ridge height was increased by 1 cm, the flavour of Sante tubers increased by 0.04 points. The relationship was quadratic for Romula. The extreme values calculated for this cultivar indicated that flavour would be the worst (5.93 points) at the ridge height of 20.5 cm (Figure 3). Statistical analysis demonstrated that the cultivar x harvest date interaction was significant; Cv Sante tubers had a better flavour when harvested at 12 and 8°C and Romula tubers at 16°C whereas the flavour of Żagiel tubers remained unaffected by harvest date. Analysis of the results using orthogonal polynomials revealed that the relationship between the flavour of Sante tubers and harvest date was quadratic. Extreme values calculated for this cultivar indicated that the best flavour would be attained at 11.2°C; the theoretical point score would be 7.46 then. The

Table 6
Tuber flavour (points) depending on the growing season, potato cultivar, ridge height and soil temperature at harvest

Cultivars	Years	Mean		
	2004	2005	2006	
Sante	6.97	7.33	7.13	7.15
Romula	5.81	6.5	6.3	6.20
Żagiel	6.53	6.83	6.63	6.66
Mean	6.44	6.89	6.69	6.67
$HSD_{0.05}$ for: years 0.35; cultivars 0.31				
Cultivars	Ridges			
	low (16 cm)	Standard (20 cm)	high (24 cm)	Mean
Sante	7.01	7.08	7.36	7.15
Romula	6.43	5.94	6.23	6.20
Żagiel	6.80	6.63	6.55	6.66
Mean	6.75	6.55	6.71	6.67
$HSD_{0,05}$ for: ridge height 0.18; cultivar x ridge height 0.32				
Cultivars	Harvest date (soil temperature)			
	1 (16°C)	2 (12°C)	3 (8°C)	Mean
Sante	6.82	7.44	7.18	7.15
Romula	6.56	6.19	5.85	6.20
Żagiel	6.72	6.63	6.63	6.66
Mean	6.82	7.44	7.18	6.67
$HSD_{0,05}$ for: cultivar x harvest date 0.35				

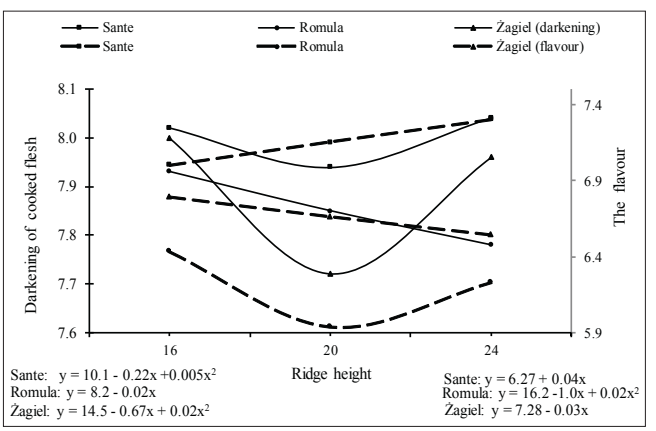

Fig. 3. After-cooking darkening (points) and flavour (points) depending on the growing season and ridge height (cm)

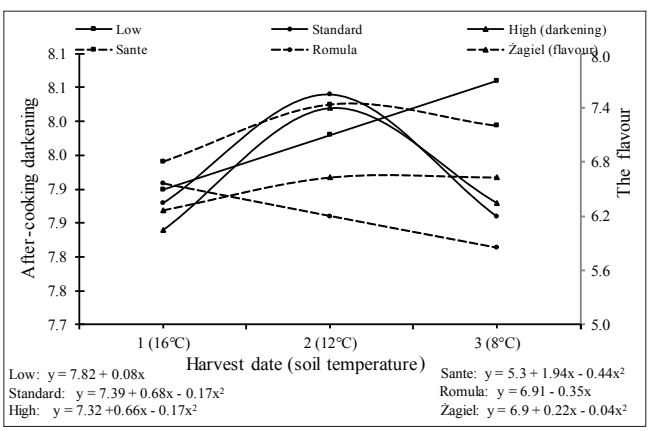

Fig. 4. After-cooking darkening (points) and flavour (points) depending on the ridge height (cm), cultivar and harvest date (°C)

relationship between flavour and harvest date for Romula was linear. Delaying harvest date, established based on soil temperature, by 4°C negatively affected tuber flavour which declined by 0.35 points (Table 6, Figure 4).

Discussion

According to Chotkowski and Rembeza (2005), the most important attributes which consumers take into account while purchasing potatoes include appealing appearance, flavour and cooking quality, the quality being affected by genotype, weather conditions and cultivation factors (Hamouz et al., 2005; Jansen and Flame, 2006; Lombardo et al., 2012; Lombardo et al., 2013).

Zgórska and Frydecka-Mazurczyk (2000) have reported that dry matter content and starch content decline when there is too much rain and temperatures are low towards the end of the growing season. The results of the work reported here demonstrated that unfavourable conditions when dry matter and starch were being accumulated prevailed in 2006 when the precipitation sum was the highest (358.1 mm). Rytel (2004) found that the dry matter and starch content of second earlies increased as the growing season was extended. However, the rate of accumulation of both the components depended on cultivar, which was confirmed in the study by Gąsiorowska and Zarzecka (2002). They reported increasing dry matter and starch contents as the growing season was extended. In the study discussed here, both dry matter and starch in potato tubers were the highest at the second harvest date. It can also be inferred that there is a limit to an accumulation of both the components in potato tubers and an extension of the growing season does not have to be followed by an increase in their contents.

Kołodziejczyk et al. (2005) have pointed out that susceptibility to darkening of raw and cooked flesh is cultivar-related which is only slightly affected by environmental variation. Teodorczyk (1982) and Komorowska-Jędrys (1997) have noted that in wet and cool years raw and cooked tubers are more likely to darken, the finding confirmed by Płaza et al. (2010) who have reported that in years with increased precipitation, particularly in the last months of the growing season, darkening of tuber flesh is more intense compared with dry and warm years. Similar relationships were found in the present study – raw flesh darkened less but after-cooking darkening increased in years with less precipitation. Least darkening was observed in the growing season 2004 when the precipitation sum was 320.9 mm.

The results of this study demonstrated that tubers harvested at 8°C were least susceptible to darkening of raw flesh whereas cooked flesh darkened less when tubers were harvested at the soil temperature of 12°C. It is not possible to relate the results of this work to findings of other authors due to lack of research on the effect of soil temperature at harvest on darkening of potato flesh.

Flavour is one of the most subjective attributes which determines the commercial success of a given cultivar (Styszko et al., 2003; Płaza et al., 2010). The present study revealed that tubers harvested in the growing season when precipitation was the lowest had the best flavour. According to Lombardo et al. (2012), tuber flavour is cultivar-conditioned but also affected by environmental conditions and cultivation practices. In turn, Kolenda and Pyryt (2002), who examined potato cooking quality, observed that tubers with lower starch content were more watery which negatively affects their flavour. Similar relationships were noticed in the present study: the best flavour was determined for cv Sante tubers which contained much starch whereas Romula had the lowest starch concentration 14.6%), and its flavour was the poorest.

Conclusions

- Dry matter and starch contents in potato tubers were affected by weather conditions during the growing season, cultivar and harvest date. The components were the highest in cv Romula tubers. Moreover, tubers contained the most dry matter and starch when harvested at the soil temperature of 12°C.
- Susceptibility of potato tubers to darkening of raw and cooked flesh depended on cultivar, ridge height and soil temperature at harvest. The flesh of raw and cooked tubers darkened least for cv Sante and when potatoes were harvested at 12°C.
- Weather conditions during the growing season, cultivar and ridge height affected potato tuber flavour. The tastiest potatoes were produced in the year with the lowest precipitation and when they were grown in flat ridges. Tubers of cv Sante had the best flavour.
- Weather conditions during the growing season and the remaining factors, including ridge height and harvest date, play a significant when one wants to produce high quality tubers of edible potato. The results of this study may be used to determine optimum conditions of cultivation to obtain high quality yields.

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