Influence of environmental conditions on the quality of potato tubers

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ABSTRACT: In 1995–1997 seven varieties of potatoes were cultivated in field trials in twelve localities in the Czech Republic. Six of the twelve localities were situated in lower, warmer and drier areas with fertile, predominantly loamy soils. The other localities were situated in higher, colder and more humid areas. They represent traditional potato-growing areas in the Czech Republic. After harvest potato tubers of all varieties were analysed for resistance to mechanical damage, dry matter content, reducing sugar (RS) content, nitrate content, polyphenol content. Glycoalkaloid (GA) content was analysed only in Karin variety. In all experimental years potatoes cultivated at lower altitudes contained less RS (by 22%), less polyphenolic compounds (by 5.8%), higher percentage of tubers not mechanically damaged with the rebound pendulum (by 12.7%), compared to tubers from higher localities. On the other hand, tubers grown at lower altitudes contained more nitrates (by 26.8%) in all three years. Over the three years, the average of results in Karin variety did not demonstrate the influence of environmental conditions of the areas on GA content in tubers.

Keywords: environmental conditions; potato; mechanical damage; reducing sugars; dry matter; nitrates; polyphenols; glycoalkaloids

In the Czech Republic a part of areas in which table potatoes were cultivated was displaced from traditional potato-production areas (higher altitudes, above 400 m above sea level with stony soils) to lower altitudes with more fertile soils without stones. This spontaneous displacement was connected with excessive mechanical damage of tubers during harvest on stony soils in a potato-production area. In this connection the quality of potato tubers from this area attracts the attention because soil and climatic conditions could affect it.

The content of dry matter in cold, cloudy years rich in rainfall is usually lower (Nowacki et al. 2000) while in warm sunny years and in longer vegetation periods it is higher (Míča, Vokál 1995). Potatoes respond differently to rainfall periods and water stress regarding growth and development of aboveground biomass (Storey, Davies 1992). In their experiments Zgórska and Frydecka-Mazurczyk (2000) determined high correlations between meteorological conditions of the last 10 days before harvest and the content of dry matter and reducing sugars. Higher sums of precipitation and lower average temperatures in this period result in lower dry matter and starch content, but higher reducing sugar content.

Resistance to mechanical damage (pendulum index) is positively affected by tuber maturity (Storey, Davies 1992; Sowa-Niedzialkowska 2000; Nowacki et al. 2000). The effect of rainfall and temperature distribution during the growing season on the degree of mechanical damage to potato tubers was recently studied in Poland. The index of mechanical damage was positively correlated with rainfall in May–September, particularly that during August–September, and negatively correlated with the temperature sum in May–September, particularly that during ripening (Marks et al. 1993).

Shock et al. (1994) reported that the content of *reducing* sugars in potatoes was strongly affected

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by varietal properties, climatic conditions of production locality, maturity of tubers during harvest, but above all by the temperature and time of tuber storage. Putz (1994) concluded that with increasing degree of tuber maturity a decrease in reducing sugar content could be expected.

Qualified estimations presume as high as 85% share in variability of total content of nitrates in plants (Prugar 1992). Frydecka-Mazurczyk and Zgórska (2000) described a significant effect of nitrogen fertilisation, effect of genotype and also the effect of climatic conditions during the growing season. Especially the absence of precipitation and high temperatures during vegetation cause an increase in nitrate content. From the aspect of soil conditions potatoes accumulate more nitrates on more fertile soils with higher biological effectiveness (Prugar 1992).

Polyphenol content is affected above all by the variety, year and stress factors such as mechanical damage to potato tubers, infestation with pathogens or effect of light on tubers. There is not enough evidence about the light effect in literature (Friedman 1997).

An opinion prevails in literature that a high glycoalkaloid content is connected with drought stress and high temperatures during vegetation (Zrůst et al. 2000; Frydecka-Mazurczyk, Zgórska 1995). But some authors did not agree with this conclusion (Přichystalová-Fialková et al. 1999).

Definite research knowledge of differences in the inner quality of potatoes cultivated in different soil and climatic conditions in lowlands and at higher altitudes of the Czech Republic is missing and this is the reason why we aimed our research at this problem. We focused on these qualitative parameters: tuber resistance to mechanical damage, dry matter content, reducing sugar content, nitrates, polyphenols and glycoalkaloid content.

MATERIAL AND METHODS

Potato samples: The varieties Impala, Karin, Agria, Korela, Rosella, Santé and Ornella were cultivated in field trials according to uniform farming techniques in twelve localities (Table 1) in the Czech Republic in 1995–1997. All the seven varieties were repeated at each site during all experimental years. Six of the twelve localities were situated in lower, warmer and drier areas (average height above sea level 244 m, average temperatures and precipitation see Table 2) with fertile predominantly loamy soils (Orthic Luvisol and black Luvic Chernozem); in this contribution they are called "lower areas". The other localities were situated in higher (average height above sea level 531 m), colder and more humid areas with less fertile predominantly sandy loam soils (Cambisol) and they represent traditional potato-growing areas in the Czech Republic. In our contribution we indicated them as "higher areas". The average main weather parameters in the tested period are shown in Table 2. The tubers of the above-mentioned varieties from all sites were harvested manually and healed at 15°C and 95% humidity for three weeks.

Chemical analyses: Tuber resistance to mechanical damage was determined on the pendulum

Table 1. List of experimental localities

Locality	Area	Above sea level (m)	Av. annual temper. (°C)	Annual sum of precipitation (mm)	Soil type and category
Čáslav	"lower altitudes"	290	8.3	590	TCH-l
Ivanovice na Hané		220	8.6	550	CHdg-l
Přerov nad Labem		178	8.8	622	TBS-sl,l
Praha-Suchdol		286	8.2	510	TBS-l
Uherský Ostroh		196	9.2	551	TC-l
Uhříněves		295	8.4	575	TBS-c
Domanínek	"higher altitudes"	565	6.4	602	PGAC-sl
Hradec nad Svitavou		450	6.5	624	TBS-s
Chrastava		345	7.1	798	LBSi-l
Lípa		505	7.7	632	PGAC-sl
Stachy		860	6.3	755	BPS-ls
Valečov		460	6.9	649	PGAC-sl,l

Soil categories: TCM – typical Chernozem, CHdg – brown Chernozem (degraded), TBS – typical brown soil, TC – typical Cambisol (brown soil), PgAC – pseudogleyic acid Cambisol (brown Gleysol), LBSi – Luvisol (illimerised), BPS – cryptopodzol (brown podzolic soil)
Soil Texture Class Groupings: s – sandy, sl – sandy loamy, ls – loamy sandy, l – loamy, c – clay

Table 2. Main weather characteristics of the areas in 1995–1997

Year	Area	Average temperature (°C)			Sum of precipitation (mm)		
		August	September	April–September	August	September	April–September
1995	LA	18.92	13.57	15.63	90.6	82.4	439.9
	HA	16.15	11.80	13.42	100.2	113.0	527.7
	Aver.	17.53	12.68	14.53	95.4	97.7	483.8
1996	LA	18.23	11.10	14.57	73.3	53.1	463.5
	HA	16.12	9.02	12.40	97.1	69.0	490.9
	Aver.	17.18	10.06	13.48	85.2	61.1	477.2
1997	LA	19.90	13.98	15.02	46.9	29.3	391.8
	HA	18.02	12.70	13.12	33.6	25.6	487.9
	Aver.	18.96	13.34	14.07	40.2	27.3	439.8
Long-term average	LA	18.03	14.28	15.15	71.5	45.4	360.1
	HA	15.83	11.23	12.73	83.2	52.2	424.7
	$\bar{x}$	16.93	12.76	13.94	77.3	48.8	392.4

LA – lower altitudes (average of 6 localities), HA – higher altitudes (average of 6 localities), $\bar{x}$ – average of 12 localities

Table 3. Influence of locality conditions in the growing area on qualitative potato characteristics

Growing area (Significance)	1995	1996	1997	Average
Pendulum index (% of undamaged tubers)				
Lower altitudes	91.6	61.2	69.1	74.0
Higher altitudes	82.4	45.1	58.5	61.3
$D_{\min(p\ 0.05)}$/signif.	5.1/*	6.8/*	5.6/*	3.4/*
Dry matter content (%)				
Lower altitudes	21.6	21.5	22.3	21.8
Higher altitudes	21.4	19.8	23.6	21.6
$D_{\min(p\ 0.05)}$/signif.	2.24/ns	0.71/*	0.70/*	0.45/ns
Reducing sugar content (%)				
Lower altitudes	0.41	0.72	0.18	0.44
Higher altitudes	0.52	0.89	0.26	0.56
$D_{\min(p\ 0.05)}$/signif.	0.09/*	0.16/*	0.09/ns	0.07/*
Nitrate content (mg NO_3^-/kg)				
Lower altitudes	197.8	115.0	122.4	145.1
Higher altitudes	144.7	97.6	100.8	114.4
$D_{\min(p\ 0.05)}$/signif.	25.16/*	18.32/ns	15.78/*	11.37/*
Polyphenol content (mg/100 g)				
Lower altitudes	42.8	44.3	43.5	43.5
Higher altitudes	25.6	48.9	44.2	46.2
$D_{\min(p\ 0.05)}$/signif.	2.75/*	5.63/ns	4.14/ns	2.63/*
Glycoalkaloid content in cv. Karin (mg/kg)				
Lower altitudes	89.1	62.1	67.5	72.9
Higher altitudes	155.0	63.3	60.4	92.9
$D_{\min(p\ 0.05)}$/signif.	43.2/*	10.1/ns	18.9/ns	29.5/ns

*Statistically significant difference (α = 0.05), ns – non-significant difference

MIDAS 88 PP, dry matter content by a gravimetric method, reducing sugar content according to Luff-Schoorl, nitrate content with ion-selective electrode, polyphenol content spectrophotometrically with Folin-Ciocalteu's reagent and glycoalkaloid content (only in cv. Karin) with HPLC method.

RESULTS AND DISCUSSION

Tuber resistance to mechanical damage

The obtained results convincingly describe a significant effect of different ecological conditions of higher and lower areas of the Czech Republic on tuber resistance to mechanical damage. In potatoes grown in lower situated areas significantly higher pendulum index values were determined in all experimental years as compared with potatoes from higher areas (Table 3). Because we have not found an objective cause in the chemical composition of tubers, we assume that this result is connected with the level of tuber maturity – with skin firmness, or if need be with the structure of cell walls and the size of cells in tuber flesh (Blahovec 1996; Sowa-Niedzialkowska 2000). Long-time experience shows that at higher altitudes of the CR we often meet worse tuber maturity because the height above sea level and lower temperatures in these areas cause the extension of the vegetation period of potatoes. This fact evidently appeared regarding tuber maturity in our experiments. In higher situated areas we recorded apparently lower temperature averages and higher sum of precipitation during the vegetation period in all years and in September and October, when potatoes maturated (the exception was only a moderately higher sum of precipitation in lower areas at the end of the vegetation period in 1997, which was however extraordinarily dry in both areas). Experiments proved that lower situated, warmer and more fertile areas of the Czech Republic have basic prerequisites for the production of table potatoes with higher tuber resistance to mechanical damage in comparison with higher situated areas.

Dry matter content (DM)

In our experiments locality did not affect dry matter of tubers significantly. It is evident from Table 3 that the difference in DM content between tubers from lower and higher altitudes was minimal on three-year average (0.2%) and it did not exceed the level of statistical significance. The same result was found for the experimental year 1995. Though in 1996 and 1997 the differences in DM content of tubers between localities were significant, the results were contradictory; whereas in 1996 they indicate the values in favour of lower altitudes (by 1.7% higher DM of tubers in comparison with higher altitudes), in 1997 the results were opposite (DM content at lower altitudes was by 1.3% lower).

The opposite results from the years 1996 and 1997 are apparently connected with weather conditions at the end of vegetation period of these years. The year 1996 was characterised in both localities by cold weather with heavy rainfalls at the end of August and in the first half of September, which did not hit so much the potato plants at lower altitudes (earlier varieties already finished their vegetation), whereas at higher altitudes this course of weather led to an apparent yield increase, in some cases to worse maturity, to second growth of tubers and negatively affected DM content. Moreover the mentioned weather course at the end of vegetation in 1996 was less apparent at lower altitudes with smaller temperature and precipitation differences in comparison with the long-term average at higher altitudes. In 1997 the weather at the end of vegetation period was very warm and dry and as a consequence a significant yield decrease and contemporary DM increase in tubers at higher altitudes was observed compared to lower altitudes (plants at lower altitudes were hit by drought less regarding the earlier vegetation with an earlier date of potato maturity).

Total three-year results did not confirm an assumption of higher DM content at lower altitudes, which could be deduced from drier, warmer weather conditions with longer duration of sunshine (Míča, Vokál 1995; Nowacki et al. 2000). It is evidently connected with the fact that DM content is apparently affected by weather conditions at the end of vegetation period (Zgórska, Frydecka-Mazurczyk 2000) which were extreme in two out of the three years of the period of our experiments (with significant temperature and precipitation deviations from the long-term average).

Reducing sugar (RS) content

In all experimental years potatoes cultivated at lower altitudes contained less RS than potatoes from higher altitudes, and at the same time differences in RS content in potatoes from both areas were statistically significant in 1995, 1996 and on three-year average (Table 3). Our results showed that in colder and more humid climatic conditions of higher altitudes potatoes accumulated more RS in tubers. It is generally known that higher altitudes above sea level and lower temperatures cause the extension of vegetation period in potatoes, and that is why tuber maturity at higher situated localities of the CR is often worse in the harvest period compared to the same varieties from lower situated localities. This fact appeared also in our experiments, when in all years we recorded significantly higher temperature averages and lower sums of precipitation at lower altitudes during the vegetation period and in August and October, when potatoes are maturing, in comparison with higher altitudes. The exception was a moderately higher sum of precipitation at lower altitudes at the end of vegetation period in 1997, which was however extraordinarily dry in both areas. The lower average tuber maturity from higher altitudes confirms also their lower resistance to mechanical damage. With lower tuber maturity a higher RS content is also connected; BURTON et al. (1992) and PUTZ (1994) confirmed this fact.

Nitrate content

In all three years potatoes grown at lower altitudes contained more nitrates than potatoes from higher areas (Table 3). A decisive effect on the higher nitrate content in potatoes from lower areas is evidently exerted by the lower sum of precipitation and higher average temperatures in the vegetation period, especially in stages critical for the plant and tuber development, in this area against higher altitudes, when drought stresses disturbed the process of photosynthesis and restricted nitrogen utilisation by plants (sums of precipitation in lower areas in the vegetation periods of 1995, 1996 and 1997 amounted to 83.3%, 94.4% and 80.4% of the value of higher areas). So our results confirm the knowledge published by CIEŚLIK (1994), FRYDECKA-MAZURCZYK, ZGÓRSKA (2000), HAMOUZ et al. (1999a,b), MÍČA et al. (1991) and HAMOUZ and BLAHOVEC (2001). A higher nitrate content in lower areas could be associated with soil conditions to some extent. Brown and chernozem soils with higher soil fertility and biological activity in connection with higher average temperatures at lower altitudes evidently accumulate more nitrates in consequence of mineralisation (higher supply in the soil solution affects their accumulation by plants) than the soils of higher areas. PRUGAR (1992) drew a similar conclusion: the higher the soil fertility, the higher the potential ability of plants to accumulate nitrates.

Polyphenol content

Potatoes cultivated in warmer and drier conditions in the localities at lower altitudes above sea level with mainly fertile predominantly loamy soils (Orthic Luvisol and black Luvic Chernozem) contained less polyphenolic compounds in all three years than potatoes from colder and more humid localities of traditional potato-growing areas with mainly sandy-loam soils (Cambisol). Differences between the areas on three-year average were statistically significant (Table 3). By a more detailed evaluation of individual years we determined significant differences between the areas only in 1995, in the other two years an identical trend was recorded. Our experiments show that more severe conditions at higher altitudes caused a moderate increase in total polyphenol content. We arrived at similar conclusions also in our previous paper (HAMOUZ et al. 1999a,b). In literature we have found only the information (MAPSON et al. 1963) that in some cases a direct dependence of tyrosine content in potatoes on precipitation in the given locality was recorded. It corresponds to our results obtained for total polyphenols.

Glycoalkaloid content (GA)

On three-year average of the results the effect of soil climatic conditions of areas on GA content in tubers was not demonstrated in Karin variety (Table 3). Differences in GA content in tubers between the areas were minimal in 1996, in 1997 a trend of GA higher content was evident at lower altitudes but in 1995 a significantly higher content of these compounds in tubers from higher altitudes with colder and more humid climate was determined. Our knowledge is in agreement with the results of PŘICHYSTALOVÁ-FIALKOVÁ et al. (1999) but contradicts the results obtained by ZRŮST et al. (2000).

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Vliv podmínek prostředí na kvalitu hlíz brambor

ABSTRAKT: V letech 1995–1997 byly v přesných polních pokusech na 12 stanovištích v ČR vypěstovány brambory sedmi odrůd. Šest stanovišť se nachází v níže položených teplejších sušších oblastech s úrodnými, převážně hlinitými půdami, šest stanovišť se nachází ve výše položených chladnějších a vlhčích oblastech s méně úrodnými, převážně písčitohlinitými půdami. Po sklizni byla stanovena odolnost hlíz k mechanickému poškození, obsah sušiny, obsah redukujících cukrů (RC), obsah dusičnanů, obsah polyfenolů a obsah glykoalkaloidů (GA) pouze u odrůdy Karin. Brambory vypěstované v nižších polohách obsahovaly ve všech pokusných letech méně RC (o 22 %), méně polyfenolických látek (o 5,8 %), vyšší procento nepoškozených hlíz na odrazovém kyvadle (o 12,7 %) než brambory z vyšších poloh tradičně bramborářských oblastí. Naproti tomu brambory vypěstované v nižších polohách obsahovaly ve všech třech letech více dusičnanů (o 26,8 %). Rozdíl v obsahu sušiny mezi hlízami z nižších a vyšších poloh byl v tříletém průměru výsledků minimální (0,2 %) a nepřesáhl hranici statistické průkaznosti. V tříletém průměru výsledků nebyl u odrůdy Karin prokázán vliv půdně klimatických podmínek oblastí na obsah GA v hlízách.

Klíčová slova: přírodní podmínky; brambory; mechanické poškození; redukující cukry; sušina; dusičnany; polyfenoly; glykoalkaloidy

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