Acta Sci. Pol. Hortorum Cultus, 17(3) 2018, 17–28

www.acta.media.pl ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2018.3.2

ORIGINAL PAPER

Accepted: 19.09.2017

TUBER QUALITY OF VERY EARLY POTATO CULTIVARS IN RESPONSE TO TITANIUM FOLIAR APPLICATION

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ABSTRACT

Potato is an important nutrient source in human nutrition. Potato tuber quality is affected by a cultivar, environmental conditions and agricultural practices. The study examined the effect of dose (0.2 dm^3 ha^{-1} and 0.4 dm^3 ha^{-1}) and date of Tytanit® application (a single foliar application at the leaf development stage – BBCH 14–16 or at the tuber formation stage – BBCH 41–43, and a double foliar application at the BBCH 14–16 and BBCH 41–43 stages) on the tuber quality of very early potato cultivars ('Lord' and 'Miłek'). Potatoes were harvested 75 days after planting (the end of June). Tytanit® (8.5 g Ti in 1 dm^3) did not affect the content of dry matter, starch, monosaccharides, protein, L-ascorbic acid or nitrates in potato tubers. The very early potato cultivars responded differently to the Tytanit® applied. This growth stimulant caused an increase in total sugars content in the tubers of 'Miłek' and had a greater effect on the discoloration of tuber flesh after cooking of this cultivar. The contents of dry matter, starch, total sugars and protein in 'Miłek' tubers were higher than in 'Lord' tubers, while the content of monosaccharides, L-ascorbic acid and nitrates in tubers of both cultivars did not differ significantly.

Key words: dry matter, starch, sugars, protein, L-ascorbic acid, nitrates, after-cooking darkening

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the one of the most important food crops in the world in terms of human consumption. Potato tubers are a significant source of protein of high biological value (the highest of all plant proteins), vitamin C (mainly L-ascorbic acid and smaller amounts of dehydroascorbic acid), minerals and other health-promoting compounds. Many compounds in potatoes contribute to antioxidant activity. Moreover, due to their starch content, potatoes provide energy. Apart from nutrients, potato tubers also contain anti-nutritional substances such as nitrates. Nitrates are non-toxic, but their metabolites can produce a number of health effects [Haase 2008; Love and Pavek 2008; Camire et al. 2009; Leszczyński 2012; Andre et al. 2014]. The darkening of raw and cooked tuber flesh is an important quality characteristics of potatoes [Wang-Pruski and Nowak 2004]. The chemical composition of potato tubers depends on the genetic character of the cultivar, tuber size and maturity, but may change under climatic and agronomic factors [Sawicka and Mikos-Bielak 1995; Wierzbicka 2006; Trawczyński 2016; Wegener et al. 2017]. Potato growth is influenced by various biotic and abiotic stress factors.

In intensive plant production focusing on high value products, plant growth stimulants have been gaining increasing importance. Growth stimulants increase plant resistance to abiotic and biotic stresses, which allows better use of the cultivar production potential under the environmental conditions of the

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cultivar area [Calvo et al. 2014; Bulgari et al. 2015]. Titanium is classified as a beneficial element for plant growth [Carvajal and Alcaraz 1998; Lyu et al. 2017]. Water-soluble and pH-stable chelate forms of titanium such as ascorbate, citrate and malate have a beneficial effect on various physiological processes, i.e. an increase in iron and magnesium contents in plants tissues and chlorophyll biosynthesis, increased activity of many enzymes (catalase, preoxidase, lipoxygenase, nitrogen reductase), strengthening stress tolerance, as well as accelerate plant growth [Carvajal and Alcaraz 1998; Hrubý et al. 2002; Kužel et al. 2003; Du et al. 2010; Bacilieri et al. 2017; Lyu et al. 2017]. This suggest the possible role of titanium in promoting the photosynthetic activity of leaves. Titanium participates in electron transfer processes connected to photosynthesis [Alcaraz et al. 1991]. Titanium supplementation through Ti-ascorbate can encourage carbohydrate production and plant growth [Carvajal and Alcaraz 1998]. Titanium fertilizer applied via roots or leaves stimulates plant growth in a species-specific manner. The effect of titanium depends on the plant species, plant age and the tissue concentration of other minerals [Dumon and Ernst 1998]. Although titanium stimulates the plants at low doses, it is phytotoxic at higher doses [Kužel et al. 2003]. The physiological role of titanium in plants can be elucidated in connection with its distribution and intracellular-localization in plants. The uptake and distribution of Ti-ascorbate by the plants depended on the method of nutrition supply – via roots or via leaves. When sprayed onto the leaf surface, titanium is distributed about equally between the leaves and roots. If supplied through the roots, the majority of titanium taken up remained in the roots, while a relatively small amount are translocated to the leaves. Root-absorbed titanium is transported to shoots through xylem stream, whereas titanium absorbed by leaves is translocated via phloem flow. Titanium taken up by roots is accumulated mainly in the cell nucleus, while taken up by leaves in the chloroplasts. Foliar application is more effective for titanium absorption [Kelemen et al. 1993; Dumon and Ernst 1998; Lyu et al. 2017]. Titanium through stimulating a various physiological processes increases crop yield and can also improve crop quality [Lyu et al. 2017]. Sawicka et al. [2015] indicated that the dry matter content and chemical composition of potato tubers are associated with different extent of the physiological indicators of potato growth such as: assimilation leaf area, chlorophyll *a* and *b* content in leaves, fluorescence yield, efficiency of photosystem in dark and plant growth rate.

One of the foliar fertilizers containing Ti-ascorbate used in central and eastern European countries for improving crop production is Tytanit® (produced in Poland), which has been categorized as a plant growth stimulant since 2013. A study carried out by Grześkiewicz and Trawczyński [1998] showed that a double Tytanit® application (plant cover complete stage – BBCH 39 with repeated treatment after two weeks) in the dose of 0.2 dm^3 ha^{-1} did not have any effect on starch content in tubers and after-cooking darkening of medium-early potato cultivar 'Muza'. In a study carried out by Kołodziejczyk and Szmigiel [2007], using a double Tytanit® application (formation of basal side shoots stage – BBCH 21–23 and in the beginning of flowering – BBCH 61) in the dose of 0.3 dm^3 ha^{-1}, resulted in an increase in starch content and a decrease in protein content in tubers of early cultivar 'Drop' and did not have any effect on the accumulation of these components in tubers of medium-early cultivar 'Maryna'. A study carried out in the Czech Republic showed that triple titanium foliar application in the form of Ti-citrate (at the beginning of June with a plant height of 30 cm and repeated treatment in two-week intervals) in the dose of 10 g Ti ha^{-1} in each treatment did not have any effect on the dry weight of potato tuber yield of 'Cordoba' cultivar [Tlustoš et al. 2005]. A study carried out in south-eastern Lithuania showed that Tytanit® in the dose of 0.2 dm^3 ha^{-1} and liquid complex microelements fertilizers combined treatment (at the beginning of plant cover – BBCH 31 or at the beginning of plant cover – BBCH 31 and at the beginning of flowering – BBCH 60–62) increased the starch content in tubers of the early cultivar 'Goda' [Asakavičiūtė and Lisova 2009]. According to Carvajal et al. [1994], it is very difficult to know whether titanium affected the synthesis or degradation of starch, because starch concentration increased only in fruits of titanium-treated pepper plants, whereas decreases in starch content in roots and leaves were observed. If one od the effects of titanium is the enhancement of plant growth, a higher energy will be required, so inducing more starch degradation with a concomitant decrease of the levels in root and leaf [Carvajal and Alcaraz 1998]. Titanium foliar applications caused an increase in ascorbic acid content in pepper fruits [Martinez-Sanchez et al. 1993], an increase in the ascorbic acid and total sugars contents in carrot roots and significantly reduced the nitrate content, but did not have any effect on the dry matter, carotenoid or phenolic content [Kwiatkowski et al. 2013, 2015]. Biacs et al. [1988] reported that Titavit® (titanium ascorbate) caused an increase in vitamin C, total organic acid and sugar content in tomato fruit, whereas a study carried out by Kleiber and Markiewicz [2013] showed no significant effect of Tytanit® on dry matter or sugars contents in tomato fruits grown in a greenhouse, or their active acidity. Titanium as a nutrient solution additive caused a significant increase in dissolved sugar contents and a drop in nitrate and nitrite content in Chinese cabbage [Zheng et al. 2010].

Many beneficial effects, as well as a few adverse effects of titanium application on crop quality, are described in the literature. Taking into account the above premises, a hypothesis was made in the study that the stimulation of potato plant growth by titanium foliar application would contribute to improve tuber quality. An assumption was also made that the potato response to titanium depends on the dose and date of titanium application, as well as that the result of titanium application depends on the potato cultivar and environmental conditions. The aim of the study was to determine the effect of the dose and date of plant growth stimulant Tytanit® (Ti-ascorbate) application on the tuber quality of very early potato cultivars.

MATERIAL AND METHODS

Plant material and experimental design. The study material included potato tubers obtained from a field experiment carried out at the Agricultural Experimental Station of the Siedlce University of Natural Sciences and Humanities, in central-eastern Poland (52°03'N; 22°33'E) during three growing seasons (2009, 2010 and 2012). The field experiment was carried out on loamy soil (Luvisol) with an acidic-to-slightly-acid reaction (pH in 1 mol dm^{-3} KCl from 4.7 to 6.6). The content of available phosphorus in the soil ranged from 88 to 128 mg P kg^{-1}, potassium from 104 to 204 mg K kg^{-1} and magnesium from 22 to 45 mg Mg $kg^{-1}$of soil.

The titanium (Ti) source was the mineral plant growth stimulant Tytanit® produced by INTERMAG Ltd., Olkusz, Poland. Tytanit® contained 8.5 g Ti per 1 dm^3 (0.8% m/m), in the form of Ti-ascorbate. The effect of dose (0.2 dm^3 ha^{-1} and 0.4 dm^3 ha^{-1}) and date of Tytanit® application (a single foliar application at the leaf development stage – BBCH 14–16 or at the tuber formation stage – BBCH 41–43, and a double foliar application at the leaf development and tuber formation stages – BBCH 14–16 and BBCH 41–43) on the tuber quality of very early potato cultivars (‘Lord’ and ‘Miłek’) was investigated. The field experiment was established in a split-block-split-plot design with a control object without Tytanit® in three replication. The forecrop for the potato was spring triticale. Farmyard manure was applied in autumn, at the rate of 30 t ha^{-1} and mineral fertilizers were applied at the rates of 80 kg N (ammonium nitrate), 35 kg P (superphosphate) and 100 kg K (potassium sulphate) per hectare in the spring tillage. In successive years, 6-week pre-sprouted seed potatoes were planted on 15th, 13th and 12th April, with a row spacing of 25 cm and 67.5 cm between rows. Potato cultivation was carried out according to correct agronomical practice. Potatoes were harvested 75 days after planting (the end of June).

Laboratory studies were conducted on samples of 50 different-sized tubers taken from each treatment. Fresh tubers were used in chemical analyses which were conducted immediately after potato harvest. The contents of dry matter were determined with the weight method [PN-90/A-75101/03:1990], starch with polarimetric method according to Ewers [Mitchell 1990], total sugars and monosaccharides with the Luff-Schoorl method [PN-90/A-75101/07:1990], total protein with the Kjeldahl method [Rutkowska 1981], L-ascorbic acid with the titration method with 2,6-dichlorphenolindophenol according to Tillmans [PN-A-04019:1998] and nitrates with ion-selective nitrate electrode and chlorine-silver reference electrode [Kolbe and Müller 1987]. Potato after-cooking darkening were also determined. The assessment of potato after-cooking darkening was performed after 10 minutes and 2 hours from boiling based on the 9-point Danish scale, where 9 means no darkening and 1 is the strongest darkening. The assessment of potato after-cooking darkening was conducted on ten tubers [Roztropowicz 1999].

Statistical analysis. The results of the study were analysed statistically by means of analysis of variance (ANOVA) for the split-block-split-plot design. The analysis of the results was conducted using the orthogonal contrast to compare the control object without Tytanit® with the remaining objects. The significance of differences was verified using Tukey's test at P = 0.05.

Weather conditions. Weather conditions in the years of the study were varied (tab. 1). The year 2009 was very cold and with the highest amount of precipitation in the third decade of May and in June. 2010 was warm and with a heavy rainfall in May and a drought in the first decade of June. The most favourable thermal and moisture conditions for early crop potato culture were in the warm and moderately wet growing season of 2012.

RESULTS

Tytanit® did not affect the content of dry matter, starch, monosaccharides, protein, L-ascorbic acid or nitrates in tubers (tab. 2). Following Tytanit® application, there was only a slight decrease in starch content and an increase in L-ascorbic acid content in the tubers of 'Miłek', and an increase in the protein content in the tubers of 'Lord'. The differences were small and were not statistically confirmed.

Table 1. Mean air temperature and precipitation total in the potato growing period

Month	Ten-day period	Mean air temperature (°C)			Precipitation total (mm)			Sielianin's hydrothermal coefficient		
		2009	2010	2012	2009	2010	2012	2009	2010	2012
April	I	9.9	7.8	3.0	2.8	5.9	4.6	0.3	0.7	1.5
	II	8.7	9.7	8.9	5.3	2.4	21.1	0.6	0.2	2.4
	III	12.4	9.2	14.9	0.0	2.4	4.2	0.0	0.3	0.3
	monthly mean/sum	10.3	8.9	8.9	8.1	10.7	29.9	0.3	0.4	1.1
May	I	12.3	12.7	15.1	4.8	30.3	17.3	0.4	2.4	1.1
	II	12.3	14.8	12.2	14.5	41.2	33.0	1.2	2.8	2.7
	III	14.0	14.6	16.4	49.6	21.7	3.1	3.5	1.5	0.2
	monthly mean/sum	12.9	14.0	14.6	68.9	93.2	53.4	1.7	2.1	1.2
June	I	13.9	18.6	13.9	35.6	12.5	26.4	2.6	0.7	1.9
	II	14.3	16.7	17.6	43.4	47.3	37.7	3.0	2.8	2.1
	III	19.0	16.9	17.5	66.2	2.8	12.1	3.5	0.2	0.7
	monthly mean/sum	15.7	17.4	16.3	145.2	62.6	76.2	3.1	1.2	1.5

Hydrothermal coefficient value: up to 0.5 strong drought, 0.51–0.69 drought, 0.70–0.99 mild drought, ≥1 no drought [Bac et al. 1993]

Table 2. Effect of Tytanit® on some components content in potato tuber

Component	Treatment	Cultivar		Year			Mean
		Lord	Miłek	2009	2010	2012	
Dry matter (%)	without Tytanit®	17.45 a	18.26 a	17.78 a	18.27 a	17.51 a	17.85 a
	with Tytanit®	17.40 a	18.26 a	17.89 a	18.14 a	17.47 a	17.83 a
	mean	17.41 A	18.26 B	17.87 A	18.16 A	17.48 A	17.83
Starch (g kg^{-1} f.w.)	without Tytanit®	112.4 a	129.0 a	122.7 a	121.3 a	118.1 a	120.7 a
	with Tytanit®	112.5 a	125.7 a	120.7 a	120.3 a	116.4 a	119.1 a
	mean	112.5 A	126.2 B	121.0 A	120.4 A	116.6 A	119.3
Monosaccharides (g kg^{-1} f.w.)	without Tytanit®	1.76 a	1.87 a	1.67 a	1.49 a	2.27 a	1.81 a
	with Tytanit®	1.83 a	1.85 a	1.81 a	1.52 a	2.19 a	1.84 a
	mean	1.82 A	1.85 A	1.79 A	1.52 A	2.20 B	1.84
Total sugars (g kg^{-1} f.w.)	without Tytanit®	7.38 a	7.17 a	7.02 a	7.59 a	7.22 a	7.27 a
	with Tytanit®	7.26 a	7.55 b	7.12 a	7.78 a	7.32 a	7.40 a
	mean	7.27 A	7.50 B	7.10 A	7.76 B	7.30 A	7.39
Protein (g kg^{-1} f.w.)	without Tytanit®	13.51 a	14.38 a	13.75 a	14.18 a	13.90 a	13.94 a
	with Tytanit®	13.90 a	14.65 a	14.56 a	14.00 a	14.27 a	14,28 a
	mean	13.85 A	14.61 B	14.44 A	14.03 A	14.22 A	14.23
L-ascorbic acid (mg kg^{-1} f.w.)	without Tytanit®	120.8 a	118.4 a	125.3 a	117.3 a	116.2 a	119.6 a
	with Tytanit®	118.9 a	120.9 a	120.2 a	120.5 a	119.1 a	119.9 a
	mean	119.2 A	120.5 A	120.0 A	120.0 A	118.7 A	119.9
Nitrates (mg NO_3^- kg^{-1} f.w.)	without Tytanit®	73.22 a	73.00 a	71.67 a	71.33 a	76.33 a	73.11 a
	with Tytanit®	74.48 a	73.67 a	73.11 a	73.50 a	75.61 a	74.07 a
	mean	74.30 A	73.57 A	72.90 A	73.19 A	75.71 A	73.94

Mean followed by the same letters do not differ significantly at P = 0.05

Table 3. Effect of dose and date of Tytanit® application on some components content in potato tuber, mean for years and cultivars

Component	Tytanit® dose		Date of Tytanit® application		
	0.2 dm^{3}ha^{-1}	0.4 dm^{3}ha^{-1}	BBCH 14–16	BBCH 41–43	BBCH 14–16 + BBCH 41–43
Dry matter (%)	17.81 a	17.85 a	17.58 a	17.84 a	18.08 a
Starch (g kg^{-1} f.w.)	118.3 a	120.0 a	118.4 a	119.6 a	119.5 a
Monosaccharides (g kg^{-1} f.w.)	1.87 a	1.81 a	1.85 a	1.83 a	1.84 a
Total sugars (g kg^{-1} f.w.)	7.42 a	7.39 a	7.41 a	7.30 a	7.45 a
Protein (g kg^{-1} f.w.)	14.37 a	14.19 a	14.30 a	14.28 a	14.26 a
L-ascorbic acid (mg kg^{-1} f.w.)	120.0 a	119.8 a	119.6 a	118.3 a	121.8 a
Nitrates (mg NO_3^- kg^{-1} f.w.)	74.65 a	73.50 a	74.06 a	74.48 a	73.70 a

Mean followed by the same letters do not differ significantly at P = 0.05

Table 4. Effect of Tytanit® on potato after-cooking darkening (9-point Danish scale)

Darkening of tubers after cooking	Treatment	Cultivar		Year			Mean
		Lord	Miłek	2009	2010	2012	
10 minutes	without Tytanit®	8.94 a	8.94 a	8.92 a	9.00 a	8.92 a	8.94 a
	with Tytanit®	8.98 a	8.79 a	8.94 a	8.94 a	8.76 a	8.88 a
	mean	8.98 A	8.81 B	8.94 A	8.95 A	8.79 B	8.89
2 hours	without Tytanit®	8.89 a	8.89 a	8.83 a	9.00 a	8.83 a	8.89 a
	with Tytanit®	8.87 a	8.56 b	8.82 a	8.79 b	8.53 b	8.71 b
	mean	8.87 A	8.60 B	8.82 A	8.82 A	8.57 B	8.74

Mean followed by the same letters do not differ significantly at P = 0.05

Table 5. Effect of dose and date of Tytanit® application on potato after-cooking darkening (9-point Danish scale), mean for years and cultivars

Darkening of tubers after cooking	Tytanit® dose		Date of Tytanit® application		
	0.2 dm^3ha^{-1}	0.4 dm^3ha^{-1}	BBCH 14–16	BBCH 41–43	BBCH 14–16 + BBCH 41–43
10 minutes	8.87 a	8.90 a	8.89 a	8.89 a	8.88 a
2 hours	8.69 a	8.73 a	8.74 a	8.72 a	8.68 a

Mean followed by the same letters do not differ significantly at P = 0.05

The Tytanit® application did not affect the content of monosaccharides but caused an increase in the content of total sugars in the tubers of 'Miłek', on average, by 0.38 g kg^{-1} of fresh weight (over the three-year period), compared to the cultivation without the growth stimulant (tab. 2). The difference, although not very high, was statistically significant. The greatest difference was found in the warm and moderately moist growing season of 2012 (data not presented). In that year, with the Tytanit® application, the total sugars content in the tubers of 'Miłek' was higher by 0.80 g kg^{-1} of fresh weight, on average, compared to the control object without the growth stimulant. The dose and date of Tytanit® application had no effect on the total sugars content in tuber (tab. 3).

The content of examined compounds in potato tuber depended to a greater extent on the cultivar and weather conditions during the potato growing season (tab. 2). Regardless of the treatment, 'Miłek' tubers contained more dry matter, on average, by 0.85%, starch by 13.7 g $kg^{-1}$of fresh weight, total sugars by 0.23 g kg^{-1} of fresh weight and protein by 0.76 g kg^{-1} of fresh weight compared to the 'Lord' tubers. The contents of monosaccharides, L-ascorbic acid and nitrates in tubers of examined potato cultivars were similar. The most monosaccharides were accumulated by potato tubers in the warm and moderately moist growing season of 2012, whereas the most total sugars were accumulated in tubers in 2010, with the highest air temperature and a periodical moisture shortage in June.

Tytanit® did not affect the potato darkening directly after cooking but did cause an increase in the susceptibility to darkening two hours after cooking (tab. 4). The examined potato cultivars showed a different response to Tytanit®, which had a greater effect on the discoloration of tuber flesh after cooking for the 'Miłek' cultivar. Following Tytanit® application, 'Miłek' tubers showed greater susceptibility to darkening two hours after cooking, on average by 0.33 points, than tubers collected from a control plot without growth stimulant. The dose and date of Tytanit® application slightly affected the potato susceptibility to after-cooking darkening (tab. 5). Potato after-cooking darkening depended to a greater extent on the cultivar and weather conditions during the potato growing season (tab. 4). The 'Miłek' tuber had greater darkening after cooking. The greatest potato after-cooking darkening was observed in 2012, a warm and moderately moist growing season.

DISCUSSION

Potato tuber quality is affected by a cultivar, environmental conditions and agricultural practices [Leszczyński 1994; Sawicka and Mikos-Bielak 1995; Mazurczyk and Lis 2001; Trawczyński 2016, Wegener et al. 2017]. In intensive potato production for an early harvest, plant growth stimulants have been gaining increasing importance. Plant growth stimulant affected on various physiological processes can affect the potato tuber quality. Some study demonstrated the stimulating effect of titanium ions on the assimilation leaf area and chlorophyll biosynthesis in potato leaves [Tan and Wang 2011; Wadas and Kalinowski 2017]. Titanium due to the possibility of valence change participates in electron transfer process connected to photosynthesis [Alcaraz et al. 1991]. According to Bacilieri et al. [2017] a foliar application of titanium during potato growth reduces the activity of urease, but increases the activity of peroxidase and nitrate reductase. During tuberization, there is a positive correlation between superoxide dismutase and peroxidase activity and titanium application. Sawicka et al. [2015] indicates that the dry matter, starch and protein content in potato tuber are determined by leaf assimilation area as well as chlorophyll *a* and *b* content in leaves. Reducing the assimilation leaf area along with increasing the chlorophyll *a* content and simualtaneously decreasing the chlorophyll *b* leves in leaves resulted in an increase in dry matter content in tubers. Starch content is associated with assimilation leaf area, chlorophyll *a* content in leaves and photosynthetic capacity of PSII in the dark, while protein content is dependent on assimilation leaf area and chlorophyll *a* concentration in leaves. Reduction of assimilation of leaves and maximum photosynthetic capacity resulted in a decrease of the starch content in tubers, whereas a reduction in assimilation leaf area and a decrease in chlorophyll *b* content resulted in an increase of protein content. In the our study, a single or a double titanium foliar application (a commercial product called Tytanit®) at the doses 0.2 dm^3 ha^{-1} or 0.4 dm^3 ha^{-1} caused an enlargement of the assimilation leaf area and an increase in chlorophyll content in leaves of very early potato cultivars 'Lord' and 'Miłek' [Wadas and Kalinowski 2017], however did not affect the content of dry matter, starch or protein in tubers. In the study carried out by other authors, a double Tytanit® application in a dose of 0.2 dm^3 ha^{-1} did not have any effect on starch content in tubers of the medium-early potato cultivar 'Muza' [Grześkiewicz and Trawczyński 1998], whereas a double Tytanit® application in the dose of 0.3 dm^3 ha^{-1} did not have any effect on starch and protein content in tubers of medium-early potato cultivar 'Maryna', but resulted in an increase in starch content and a decrease in protein content in tubers of the early cultivar 'Drop' [Kołodziejczyk and Szmigiel 2007]. Based on this results is difficult to know whether titanium affects the synthesis or degradation of starch in potato tuber. Starch is also accumulated in potato leaves due to various disturbances in carbohydrate metabolism in a stress conditions [Starck 2010]. During a drought, when potato tubers are poorly supplied with nutrients, starch accumulation is induced in chloroplasts in excessive amounts [Basu et al. 1999]. Some studies indicate the enhancement of the physiological activity of titanium-treated plants which have higher energy requirements, thus inducing more starch degradation with a concomitant decrease of the levels in the roots and leaves. The energy requirements are higher in titanium-treated plants because their biomass production increases, so that starch degradation can be higher than synthesis [Carvajal et al. 1994]. According to Sawicka et al. [2015], the content of reducing sugars and total sugars in potato tubers depends on chlorophyll *a* and chlorophyll *b* content in leaves as well as fluorescence yield. Decresaing the chlorophyll *a* concentration and simultaneously increasing other physiological indicators resulted in a decrease of total sugars content, whereas lowering the chlorophyll *a* content with increasing the chlorophyll *b* content contributed to an increase of reducing sugars content. In the present study, a change in chlorophyll content in potato leaves as a result of the Tytanit® application [Wadas and Kalinowski 2017] did not affect the content of monosaccharides but caused an increase in the content of total sugars only in the 'Miłek' tubers. The dose and date of Tytanit® application slightly affected the total sugars content in the tuber. In the study carried out by other authors, titanium application caused an increase in total sugars content in tomato fruit [Biasc et al. 1988] and in carrot roots [Kwiatkowski et al. 2013]. Ascorbic acid is a very important nutritional compound in potato tubers. According Sawicka et al. [2015] vitamin C accumulation in potato tuber is only determined by chlorophyll *a* concentration in leaves. An increase in chlorophyll *a* concentration resulted in an increase in vitamin C content. In the present study, a change in chlorophyll content in potato leaves as a result of Tytanit® application [Wadas and Kalinowski 2017] did not have any effect on L-ascorbic acid content in tuber. In the study carried out by other authors, titanium foliar application caused an increase in ascorbic acid content in tomato and pepper fruits [Biacs et al. 1988; Martinez-Sanchez et al. 1993] and in carrot roots [Kwiatkowski et al. 2013]. Although potatoes accumulate small amounts of nitrates [Santamaria 2006; Wierzbicka 2006], due to high potato consumption, they are a source of substantial quantities of these compounds. According to Matin et al. [1998], up to 27% of the daily nitrate intake with food can be derived from potatoes. Nitrate level in potato tuber is dependent on a many of physiological indicators [Sawicka et al. 2015]. Titanium stimulates the assimilation leaf area and chlorophyll biosynthesis in leaves [Wadas and Kalinowski 2017] and the activity of some enzymes, i.e. nitrogen reductase in potato plant [Bacilieri et al. 2017] can affected a nitrate level in tuber. In our study, Tytanit® did not affect the content of nitrates in tubers of very early potato cultivars. In the study carried out by other authors, Tytanit® significantly reduced the nitrate content in carrot roots [Kwiatkowski et al. 2015]. Titanium, as a nutrient solution additive, caused a significant decrease in nitrate and nitrite content in Chinese cabbage [Zheng et al. 2010]. The mechanisms of photosynthesis and nutrient distribution process in plant under stress conditions depend on the intensity and duration of those unfavourable conditions. The coordination between photosynthesis and acceptor supply with photoassimilates depends not only on the physiological indicators, but first of all on their activity under stress conditions. [Starck 2010; Sawicka et al. 2015].

The nutritional value of potato tubers depended to a great extent on the cultivar and weater conditions during the potato growing season, which was confirmed by other authors. According to Pereira et al. [2008], starch content is the most stable characteristics of tuber chemical composition. Trawczyński [2016] reported that the starch content in potato tuber was determined mainly by the genetic factors, the level of nitrates by the weather conditions during the growing season and the levels of protein and vitamin C by the interaction of cultivars and years. In the present study, 'Miłek' tubers contained more dry matter, starch, total sugars and protein than 'Lord' tubers. The content of monosaccharides, L-ascorbic acid and nitrates in tubers of both cultivars did not significantly differ. The most monosaccharides were accumulated by potato tubers in a warm and moderately moist growing season and total sugars (glucose, fructose and sucrose) in the year with the highest air temperature and a periodical moisture shortage in June. The effect of weather conditions during the growing season on the sugar content in potato tuber was confirmed by other authors [Rodriguez et al. 2010; Grudzińska et al. 2014]. Short-term water deficit affects sucrose and starch metabolism in potato tubers. Incorporation of glucose into starch was inhibited in water stress and labelling of sucrose was increased. Increasing the extent of water stress changed the relation between sucrose breakdown and sucrose synthesis, in favour of synthesis [Geigenberger et al. 1997]. Drought stress caused a decline in glucose and fructose content in potato tubers, while sucrose content was increased [Wegener et al. 2017], which was confirmed in the present study. The sugar content of potato tubers is associated with physiological ages [Morales-Fernández et al. 2015]. According to Mazurczyk and Lis [2001], wet wegetation conditions worsened tuber chemical composition (less dry matter, starch, protein and ascorbic acid) compared with dry or intermediate conditions. In the present study, the weather conditions during potato growing season did not affect the content of dry matter, starch, protein, L-ascorbic acid or nitrates in tubers of the 'Lord' and 'Miłek' very early potato cultivars.

After-cooking darkening is a one of the most important undesirable characteristics of potato with respect to tuber quality. It is caused by the non-enzymatic oxidation reaction of the colourless ferrous-chlorogenic acid compound formed during cooking, exposure to air and to coloured ferri-dichlorogenic acid [Wang-Pruski and Nowak 2004]. The tendency of a potato tuber to darken after cooking is genetically featured but also depends on the environmental and agronomic factors and on the length and conditions of storage [Wang-Pruski and De Jong 2003; Wang-Pruski et al. 2007; Krochmal-Marczak et al. 2016]. Tytanit® did no affect potato darkening directly after cooking, but increased the susceptibility to darkening two hours after cooking. The dose and date of Tytanit® application slightly affected the susceptibility of potato to after-cooking darkening. Grześkiewicz and Trawczyński [1998] did not find any effect of Tytanit® on after-cooking darkening of the 'Muza' medium-early potato cultivar. The 'Lord' and 'Miłek' very early potato cultivars examined in this study showed a different response to Tytanit®. This growth stimulant had a greater effect on the discoloration of tuber flesh after cooking of the 'Miłek' cultivar. According to Wang-Pruski et al. [2007], the effect of soil type and management practices on after-cooking darkening was small in comparison to the effect of cultivar and climatic conditions, which was confirmed in the present study. The greatest potato after-cooking darkening was observed in the warm and moderately most growing season, which was confirmed by Krochmal-Marczak et al. [2016]. According to Wang-Pruski et al. [2007], the degree of after-cooking darkening generally increased under drier climatic conditions and in soil that was more susceptible to drought, however, these effects were not measured in all cases. It suggests that no single factor is uniformly responsible for the potato after-cooking darkening; rather, a combination of factors is involved.

CONCLUSIONS

1. Tytanit® did not affect the content of dry matter, starch, monosaccharides, protein, L-ascorbic acid or nitrates in potato tubers.

2. The very early potato cultivars responded differently to the Tytanit® applied. This growth stimulant caused an increase in total sugars content only in the tubers of 'Miłek' and had a greater effect on the discoloration of tuber flesh after-cooking of this cultivar.

3. The contents of dry matter, starch, total sugars and protein in 'Miłek' tubers were higher than in 'Lord' tubers, while the content of monosaccharides, L-ascorbic acid and nitrates in tubers of both cultivars did not differ significantly.

Acknowledgements

Research supported by the Polish Ministry of Science and Higher Education as part of the statutory activities of the Siedlce University of Natural Sciences and Humanities, Faculty of Natural Science. The authors wish to acknowledge the Editors and Revievers for their valuable comments and suggestions of this paper.

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