Effect of Tytanit® on the yield and yield components of very early-maturing potato cultivars

Wpływ Tytanitu® na plon i elementy składowe plonu bardzo wczesnych odmian ziemniaka

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Abstract

The growing period for early potatoes is extremely short, only 50-80 days from planting to harvest. To obtain a high marketable tuber yield in such a short period good conditions for plant growth must be ensured. In modern agriculture, plant growth stimulants have been gaining increasing importance. Although titanium (Ti) is neither a major nor minor nutrient for plants, it is classified as a beneficial element for plant growth. This paper analyses the effect of dose (0.2 dm^3*ha^{-1} or 0.4 dm^3*ha^{-1}) and date (leaf development stage – BBCH 14-16, tuber formation stage – BBCH 41-43, leaf development stage and tuber formation stage) of the application of Tytanit® (8.5 g Ti in 1 dm^3) on the yield and yield components of very early-maturing potato cultivars (‘Lord’ and ‘Miłek’). Potatoes were harvested 75 days after planting (the end of June). Tytanit® caused an increase in the tuber number and tuber weight per plant, particularly under stress conditions, although the effect of cultivars was not consistent. The growth stimulant did not have any effect on the average tuber weight. Following the application of Tytanit®, the total tuber yield was higher, on average, by 2.26 $t*ha^{-1}$ (7.5%), and the marketable tuber yield (diameter above 30 mm) by 1.88 $t*ha^{-1}$ (6.4%). The tuber number per plant was higher when Tytanit® was applied at the dose of 0.2 dm^3*ha^{-1}. Potato plants produced greatest tubers when Tytanit® was only applied in the leaf development stage (BBCH 14-16). With double Tytanit® applications, i.e. in the leaf development stage and with repeated treatment in the tuber formation stage, both the tuber number and tuber weight per plant were lower. The Tytanit® application contributed to improved marketable value of the early potato yield due to a decreased share of small tubers (diameter below 40 mm) and an increased share of large tubers (diameter above 51 mm) especially in a year with a periodical water shortage in the tuber growth period. The examined very early-maturing potato cultivars showed a differential response to Tytanit®. The growth stimulant had a greater effect on the tuber number and tuber weight per plant for the ‘Lord’ cultivar. Following the Tytanit® application, the total tuber yield of ‘Lord’ cultivar was higher , on average by 3.71 $t*ha^{-1}$ (12.7%) and marketable tuber yield by 3.22 $t*ha^{-1}$ (11.4%). Tytanit® caused an increase in tuber yield of ‘Miłek’ cultivar only in year with the highest air temperature and water shortage in June – the total tuber yield was higher, on average by 2.16 t*ha^{-1} (8.5%) and marketable tuber yield by 2.02 t*ha^{-1} (8.2%).

Keywords: average tuber weight, titanium, tuber number per plant, tuber weight per plant, tuber yield, tuber yield structure

Streszczenie

Okres wegetacji ziemniaków wczesnych jest bardzo krótki, tylko 50-80 dni od sadzenia do zbioru. Aby uzyskać wysoki plon handlowy w tak krótkim czasie, należy zapewnić roślinom dobre warunki wzrostu. We współczesnym rolnictwie coraz większe znaczenie mają stymulatory wzrostu roślin. Chociaż tytan (Ti) nie jest głównym ani drugorzędnym składnikiem pokarmowym roślin, zaliczany jest do pierwiastków korzystnych dla wzrostu roślin. W pracy omówiono wpływ dawki (0.2 dm^3*ha^{-1} i 0.4 dm^3*ha^{-1}) i terminu (faza rozwoju liści – BBCH 14-16, faza zawiązywania bulw – BBCH 41-43, faza rozwoju liści i faza zawiązywania bulw) stosowania Tytanit® (8.5 g Ti w 1 dm^3) na plon i elementy składowe plonu bardzo wczesnych odmian ziemniaka 'Lord' i 'Miłek'). Ziemniaki zbierano po 75 dniach od sadzenia (koniec czerwca). Tytanit® powodował zwiększenie liczby i masy bulw z rośliny, szczególnie w warunkach stresowych, chociaż reakcja odmian nie była jednakowa. Stymulator wzrostu nie miał wpływu na średnią masę bulwy. Po zastosowaniu Tytanitu® plon bulw ogółem był większy średnio o 2.26 t*ha^{-1} (7.5%), a plon handlowy o 1.88 t*ha^{-1} (6.4%). Liczba bulw z jednej rośliny była większa, gdy Tytanit® był stosowany w dawce 0.2 dm^3*ha^{-1}. Rośliny zawiązywały najwięcej bulw, gdy Tytanit® był stosowany tylko w fazie rozwoju liści (BBCH 14-16). Przy dwukrotnym stosownaiu Tytanitu®, tj. w fazie rozwoju liści i powtórzeniu zabiegu w fazie zawiązywania bulw, liczba i masa bulw z rośliny były mniejsze. Stosowanie Tytanitu® przyczyniło się do zwiększenia wartości handlowej wczesnego plonu ziemniaka, przez zmniejszenie udziału w plonie bulw małych (o średnicy poniżej 40 mm), a zwiększenie udziału bulw dużych (o średnicy powyżej 51 mm), szczególnie w roku z okresowymi niedoborami wody w okresie wzrostu bulw. Badane bardzo wczesne odmiany ziemniaka wykazywały zróżnicowaną reakcję na Tytanit®. Stymulator wzrostu miał większy wpływ na liczbę i masę bulw z jednej rośliny odmiany 'Lord'. Po zastosowaniu Tytanitu®, plon bulw ogółem odmiany 'Lord' był większy średnio o 3.71 t*ha^{-1} (12.7%), a plon handlowy o 3.22 t*ha^{-1} (11.4%). Tytanit® powodował przyrost plonu bulw odmiany 'Miłek' tylko w roku z najwyższą temperaturą powietrza i niedoborem wody w czerwcu – plon bulw ogółem był większy średnio o 2.16 t*ha^{-1} (8.5%), a plon handlowy o 2.02 t*ha^{-1} (8.2%).

Słowa kluczowe: liczba bulw z rośliny, masa bulw z rośliny, plon bulw, struktura plonu bulw, średnia masa bulwy, tytan

Introduction

The production profitability of edible potatoes for early harvest is higher compared to other ways of usage. The growing period for early potatoes is extremely short, only 50-80 days from planting to harvest. A condition for achieving a high marketable tuber yield in such a short period (in addition to the proper selection of very early-maturing cultivars and the pre-sprouting of seed potatoes) is to provide plants with good growth conditions. Plant growth and development and, as a result, the tuber yield, are influenced by many stress factors, such as low or high temperatures, water deficit, excessive sunlight, supply of plant nutrients, herbicides applied and pest and disease occurrence. In modern agriculture, 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 cultivar area (Calvo et al., 2014; Brown and Saa, 2015; Bulgari et al., 2015). Titanium (Ti) exhibits the properties of a plant growth stimulant. Although titanium (Ti) is neither a major nor minor nutrient for plants, it is classified as a beneficial element for plant growth. Titanium is present in soil mostly in the form of minerals as TiO_2 or $FeTiO_3$ that are insoluble in water. Although in this form it is not bioassimilable, when applied in a water-soluble, pH-stable Ti-chelate organic acids form such as ascorbate, citrate or malate, it has a beneficial effect on various physiological processes, i.e. it stimulates the chlorophyll biosynthesis and the activity of many enzymes (catalase, peroxidase, lipoxygenase and nitrogen reductase) and the uptake of some nutrients for plants, as well as accelerates plant growth, increases crop yield and improves the crop quality (Dumon and Ernst, 1988; Pais et al., 1991; Carvajal and Alcaraz, 1998; Hrubý et al., 2002; Du et al., 2010). Titanium 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, 1988). The effect of foliar titanium application was substantially influenced by the nutrient nitrogen status of the plants. The plant response to titanium application was almost negligible under nitrogen deficiency (Tlustoš et al., 2005). The biological effect of titanium can be increased by simultaneous magnesium application (Kužel et al., 2007). Pais (1983) reported that following foliar fertilizer Titavit (1 g Ti in 1 dm^3 in the form of Ti-ascorbate, Hungary) application, the yield of cultivated crops (sugar beet, corn, fruits) was higher by 10-20% and sometimes up to 30%. In recent field experiments, the titanium source was foliar fertilizer Tytanit® (8.5 g Ti in 1 dm^3 in the form of Ti-ascorbate, 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 (crop cover complete stage – BBCH 39 with repeated treatment after two weeks) in the dose of 0.2 dm^3*ha^{-1} resulted in an increase in tuber yield of medium-early potato cultivar 'Muza' by 3.5 $t*ha^{-1}$ (10.5%). According to Jabłoński (2000), 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}, in an early crop potato culture increased the marketable tuber yield by 10-15%. 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}, the tuber yield of early cultivar 'Drop' and medium-early cultivar 'Maryna' was higher, on average, by 2.43 $t*ha^{-1}$ (5.3%) on Luvisol and by 2.13 $t*ha^{-1}$ (8.8%) on Cambisol. The increase in tuber yield of 'Drop' cultivar was higher than 'Maryna'. Tytanit® caused an increase in the share of marketable tuber yield in the total tuber yield only on Cambisol. The positive effect of Tytanit® on potato tuber yield was confirmed in a study carried out by Szewczuk (2009a; 2009b). With a double Tytanit® application in a 0.07% concentration, the tuber yield of medium-late cultivar 'Bryza' on Luvisol was higher on average by 3.8 $t*ha^{-1}$ (16%). The use of Tytanit® also reduced potato plant infestation by *Phytophthora infestans*. A study carried out on Haplic Luvisol in south-eastern Lithuania showed that Tytanit® in the dose of 0.2 dm^3*ha^{-1} and liquid complex microelement fertilizers combined treatment (at the beginning of crop cover – BBCH 31 or at the beginning of crop cover – BBCH 31 and at the beginning of flowering – BBCH 60-62) did not have any effect on the tuber number per plant but increased the tuber weight per plant of the early cultivar 'Goda' and considerably reduced tuber damage by the common scab (*Streptomyces scabies*) and the number of tubers affected by scarab beetle (*Melolontha melolontha* L.) larvae (Asakavičiūtė and Lisova, 2009; 2010). Świerczewska and Sztuder (2004) showed that triple application of foliar titanium-containing fertilizer INSOL X-3 (0.026% Ti as Ti- ascorbate) increased the potato tuber yield by 0.48 $t*ha^{-1}$ (8.6%) compared to the control object without foliar feeding and by 0.35 $t*ha^{-1}$ (7.8%) compared to microelement INSOL-type fertilizer without titanium. A study carried out at the loamy Chernozem site in the Czech Republic showed that triple titanium foliar application as the Ti-citrate (at the beginning of June with a plant height of 30 cm and repeated treatment in two-week interwals) in the dose of 10 g $Ti*ha^{-1}$ in each treatment, alone or in combination with magnesium ($MgSO_4 \cdot 7\ H_2O$), did not have any effect on the dry weight of potato tuber yield of 'Cordoba' cultivar (Tlustoš et al., 2005). According to Kužel et al. (2007), titanium is more efficient on Fluvisol than on Chernozem and Luvisol. A study carried out in China showed that the triple application of foliar titanium-containing fertilizer Fengtaibao (at the seedling stage, squaring stage, and flowering stage) increased potato tuber yield by 11-16% and the percentage of large-sized tuber (Tan and Wang, 2011). Titanium has significant biological effects on plants, being beneficial at low concentrations and toxic at higher concentrations (Kužel et al., 2003). The optimal doses and dates of titanium application for many crops have not yet been determined.

There is a lack of research on the effect of using titanium in early crop potato culture. The aim of the study was to determine the effect of dose and date of foliar application of the plant growth stimulant Tytanit® on the yield and yield components of very early-maturing potato cultivars.

Materials and methods

Experimental site and season

A field experiment was carried out at the Agricultural Experimental Station of Siedlce University of Natural Sciences and Humanities in Zawady, in mid-eastern Poland (52°03'N, 22°33'E), during three growing seasons 2009, 2010 and 2012, on Luvisol with a high-to-very high content of available phosphorus, a medium-to-very high content of potassium and a low-to-medium content of magnesium (Table 1).

Table 1. Selected soil chemical properties at the experimental site

Tabela 1. Wybrane właściwości chemiczne gleby przed założeniem doświadczenia

Years	pH_{KCl}	C_{org} ($g*kg^{-1}$)	Available forms ($g*kg^{-1}$)		
			P	K	Mg
2009	6.68	8.7	12.8	10.4	3.8
2010	6.09	14.21	8.8	12	4.5
2012	4.71	7.89	12.2	20.8	2.2

The organic carbon content in the soil ranged from 7.89 to 14.21 $g*kg^{-1}$ of soil, pH in 1 $mol*dm^{-3}$ KCl from 4.7 to 6.7. In each year of the study, spring triticale was grown as a potato forecrop. 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 spring.

Experimental design

The experiment was established in a split-block-split-plot design with a control object without Tytanit® in three replications. The effect of dose (0.2 dm^3*ha^{-1} and 0.4 dm^3*ha^{-1}) and date of Tytanit® application (the leaf development stage – BBCH 14-16, tuber formation stage – BBCH 41-43, the leaf development stage and tuber formation stage – BBCH 14-16 and BBCH 41-43) on the yield and yield components of very early-maturing potato cultivars 'Lord' and 'Miłek' was investigated. In successive years, 6-week pre-sprouted seed potatoes were planted on 15, 13 and 12 April, with a row spacing of 25 cm and 67.5 cm between rows. The plot area was 15 m^2 (96 plants). Potato cultivation was carried out according to the rules of agronomical practice. Potatoes were harvested 75 days after planting (the end of June). The tuber number and tuber weight per plant, average tuber weight, total and marketable tuber yield (diameter above 30 mm) and tuber yield structure, i.e. percentage weight of very small tubers (diameter below 30 mm), small tubers (31-40 mm), medium-sized tubers (41-50 mm), large tubers (51-60 mm) and very large tubers (above 61 mm). The tuber number and tuber weight per plant, and the tuber size in the yield were determined on ten successive plants per plot, whereas the total and marketable tuber yield were calculated on the basis of tuber yield per plot.

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 orthogonal contrast to compare the control object without Tytanit®

with the remaining objects. Significance of sources of variation was checked with the F-Snedecor test and the significance of differences between means was analyzed using Tukey's test at $P<0.05$.

Weather conditions

Weather conditions during the potato growing season are presented based on meteorological data recorded in the Meteorological Station in Zawady. Sielianin's hydrothermal coefficient (K) was calculated according to the formula: $K = P/0.1\sum t$, where P – total monthly precipitation, t – monthly sum of air temperature >0°C (Bac et al., 1993).

Table 2. Mean air temperature and precipitation sums in the potato growing period

Tabela 2. Średnia temperatura powietrza i suma opadów w okresie wegetacji ziemniaka

Years	Months and ten-day periods								
	April			May			June		
	I	II	III	I	II	III	I	II	III
	Temperature (ºC)								
2009	9.9	8.7	12.4	12.3	12.3	14	13.9	14.3	19
2010	7.8	9.7	9.2	12.7	14.8	14.6	18.6	16.7	16.9
2012	3	8.9	14.9	15.1	12.2	16.4	13.9	17.6	17.5
	Rainfalls (mm)								
2009	2.8	5.3	0	4.8	14.5	49.6	35.6	43.4	66.2
2010	5.9	2.4	2.4	30.3	41.2	21.7	12.5	47.3	2.8
2012	4.6	21.1	4.2	17.3	33	3.1	26.4	37.7	12.1
	Sielianin's hydrothermal coefficient								
2009	0.3	0.6	0	0.4	1.2	3.5	2.6	3	3.5
2010	0.7	0.2	0.3	2.4	2.8	1.5	0.7	2.8	0.2
2012	1.5	2.4	0.3	1.1	2.7	0.2	1.9	2.1	0.7

Hydrothermal coefficient value: up to 0.5 strong drought, 0.51-0.69 drought, 0.7-0.99 mild drought, ≥1 no drought (Bac et al., 1993).

Results

Tuber number and tuber weight per plant

Tytanit® had a significant effect on the tuber number and tuber weight per plant. In the three-year period of the study, the tuber number per plant was higher by 0.5, on average, and the tuber weight per plant was higher by 48 g (8%) compared to the control object without this plant growth stimulant (Table 3).

Table 3. Effect of Tytanit® on the tuber yield and tuber yield components

Tabela 3. Wpływ Tytanitu® na plon bulw i elementy składowe plonu

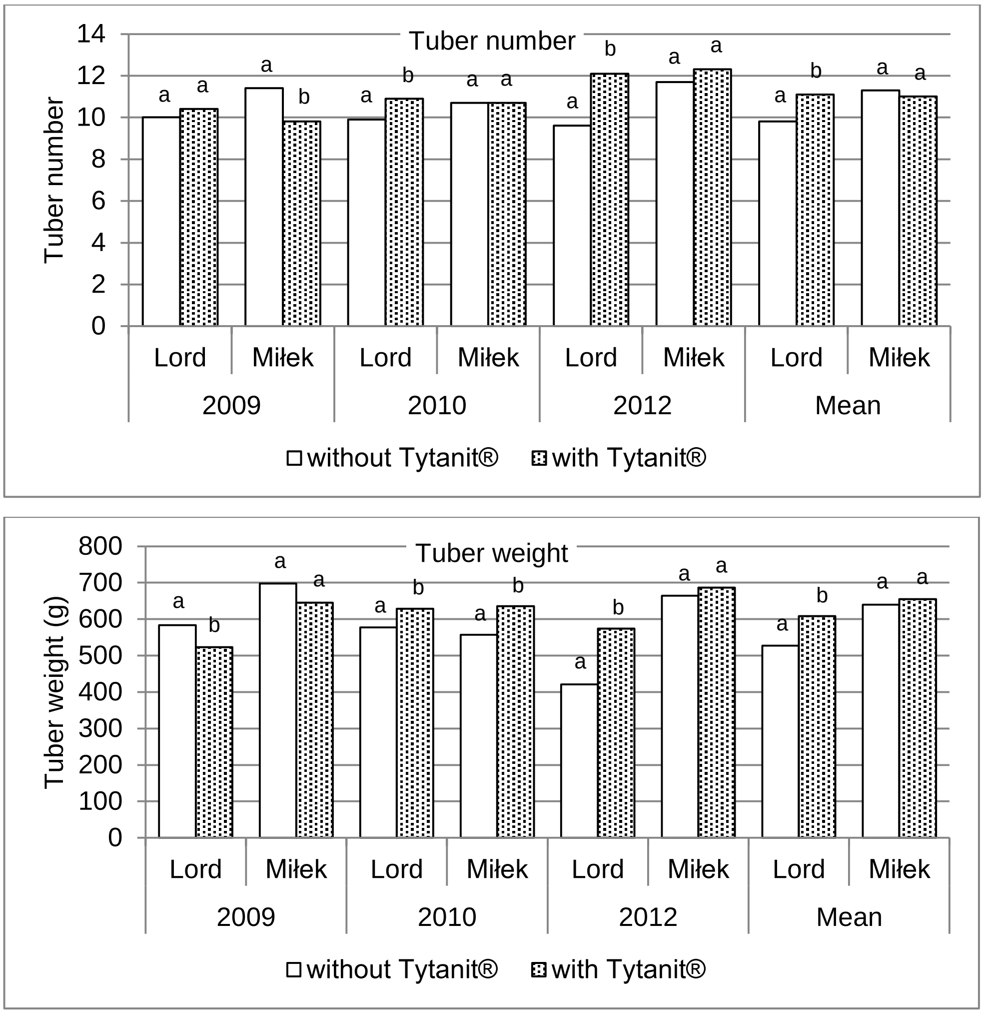
Treatment	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield ($t*ha^{-1}$)	Marketable tuber yield ($t*ha^{-1}$)
Without Tytanit®	10.5^a	584^a	55.2^a	30.14^a	29.35^a
With Tytanit®	11^b	632^b	56^a	32.4^b	31.23^b

a, b Means within columns followed by the same letters do not differ significantly at P<0.05.

Tytanit® had a greatest effect on the tuber number per plant in 2012 with the highest air temperature and simultaneously the lowest rainfall in the tuber formation period (Figure 1). In that year, with the Tytanit® application, the tuber number per plant was higher by 1.6, on average, than the control object without the growth stimulant.

The potato cultivars showed a differential response to Tytanit®. The growth stimulant had a greater effect on the tuber number and tuber weight per plant for the 'Lord' cultivar (Figure 1). With the Tytanit® application, the tuber number per plant of 'Lord' cultivar was higher, on average, by 1.3 and the tuber weight per plant was higher by 81 g (15%) compared to the cultivation without the growth stimulant. For the 'Miłek' cultivar, the differences were smaller and not statistically confirmed. Tytanit® caused an increase in the tuber weight per plant of 'Miłek' cultivar only in 2010 with the highest air temperature and the periodically water shortage in June. In that year, with the Tytanit® application, the tuber weight per plant of the 'Miłek' cultivar was higher by 78 g (14%), on average, compared to the cultivation without the growth stimulant.

The Tytanit® dose had a significant effect on the tuber number per plant but slightly affected the tuber weight per plant (Table 4). Following the application of 0.2 dm^3*ha^{-1} of Tytanit®, the tuber number per plant was higher by 0.5 compared to the dose of 0.4 dm^3*ha^{-1}. The difference is small but was statistically confirmed. The dose of Tytanit® and cultivar interaction effect on the tuber number per plant was not statistically confirmed. The study demonstrated a significant effect of the interaction of the years, cultivar and the dose of Tytanit® on the tuber weight per plant (Figure 2). In the cold and very moist growing season of 2009, after the application of 0.4 dm^3*ha^{-1} of Tytanit®, the tuber weight per plant of 'Lord' cultivar was higher by 76 g (13%) compared to the dose of 0.2 dm^3*ha^{-1}.



a, b: Means followed by the same letters do not differ significantly at P<0.05.

Figure 1. Effect of Tytanit® on the tuber number and tuber weight per plant

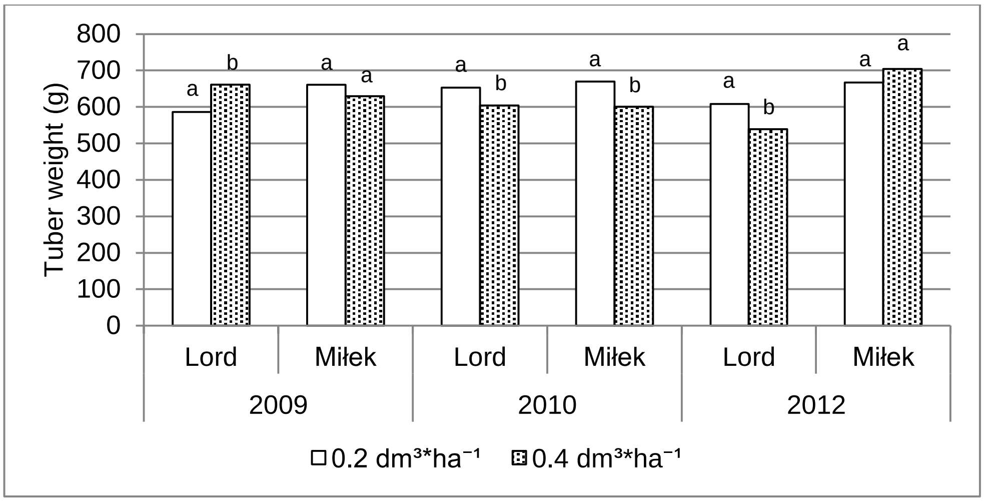
Rysunek 1. Wpływ Tytanitu® na liczbę i masę bulw z rośliny

Table 4. Effect of Tytanit® dose on the tuber yield and tuber yield components

Tabela 4. Wpływ dawki Tytanitu® na plon bulw i elementy składowe plonu

Tytanit® dose	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield ($t*ha^{-1}$)	Marketable tuber yield ($t*ha^{-1}$)
0.2 dm^3*ha^{-1}	11.3[a]	641[a]	57.5[a]	32.42[a]	31.18[a]
0.4 dm^3*ha^{-1}	10.8[b]	623[a]	58.5[a]	32.37[a]	31.27[a]

[a, b] Means within columns followed by the same letters do not differ significantly at P<0.05.



a, b: Means followed by the same letters do not differ significantly at P<0.05.

Figure 2. Tuber weight per plant in relation to the Tytanit® dose and cultivar

Rysunek 2. Masa bulw z rośliny w zależności od dawki Tytanitu® i odmiany

The date of Tytanit® application had a significant effect on the tuber number and tuber weight per plant (Table 5, Figure 3). The number of tubers produced per plant was greatest when the growth stimulant was only applied in the leaf development stage (on average 11.6). With Tytanit® application in the tuber formation stage, the tuber number per plant was lower by 0.6, however with double Tytanit® application (in the leaf development stage and with a repeated treatment in the tuber formation stage) the tuber number per plant was lower by 1.2. The date of Tytanit® application and cultivar interaction effect on tuber number per plant was not statistically confirmed.

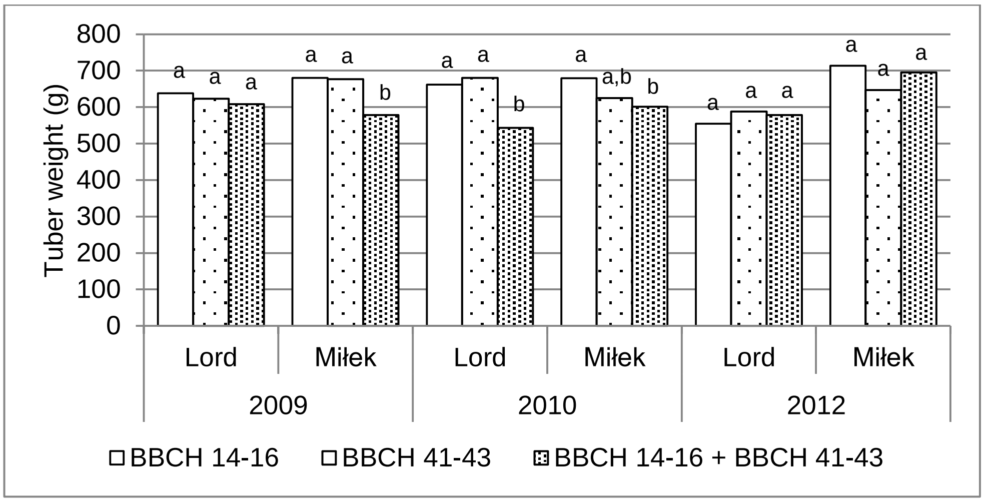
With the single application of the growth stimulant, the tuber weight per plant did not differ significantly in either the leaf development stage or in the tuber formation stage. With double Tytanit® application (in the leaf development stage and with a repeated treatment in the tuber formation stage) the tuber weight per plant was, on average, lower by 48 g (8%) compared to a single treatment performed on each of these dates. The date of Tytanit® application had the greatest effect on the tuber weight per plant in 2010 with the highest air temperature and a periodical water shortage in June (Figure 3). In that year, with double Tytanit® application, in the leaf development stage and with a repeated treatment in the tuber formation stage, the tuber weight per plant was, on average, lower by 89 g (16%) compared to a single treatment performed on each of these dates. The study demonstrated a significant effect of the interaction of the years, cultivar and the date of Tytanit® application on the tuber weight per plant (Figure 3). Under thermal and moisture conditions in 2010, the date of growth stimulant application had a greater effect on the tuber weight per plant for the ‘Miłek’ cultivar than for the ‘Lord’ cultivar. The dose and date of Tytanit® application interaction effect on the tuber number and tuber weight per plant was not statistically confirmed.

Table 5. Effect of date of Tytanit® application on the tuber yield and tuber yield components

Tabela 5. Wpływ terminu stosowania Tytanitu® na plon bulw i elementy składowe plonu

Date of Tytanit® application	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total tuber yield (t*ha^{-1})	Marketable tuber yield (t*ha^{-1})
BBCH 14-16	11.6[a]	655[a]	57.2[a]	32.78[a]	31.74[a]
BBCH 41-43	11[b]	640[a]	58.8[a]	31.96[a]	30.64[a]
BBCH 14-16 + BBCH 41-43	10.4[c]	600[b]	58[a]	32.46[a]	31.31[a]

[a, b, c] Means within columns followed by the same letters do not differ significantly at P<0.05.



a, b: Means followed by the same letters do not differ significantly at P<0.05.

Figure 3. Tuber weight per plant in relation to the date of Tytanit® application and cultivar

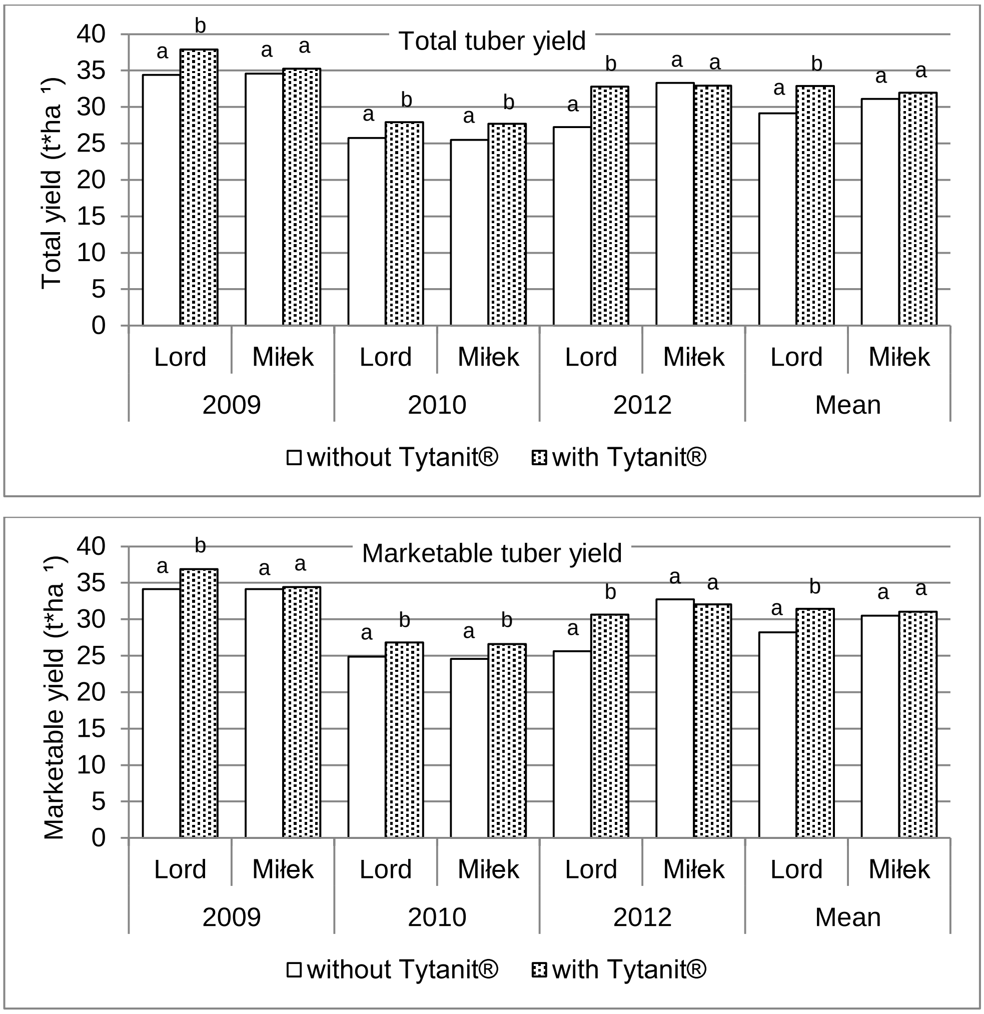
Rysunek 3. Masa bulw z rośliny w zależności od terminu stosowania Tytanitu® i odmiany

Average tuber weight

Tytanit® did not have a significant effect on the average tuber weight (Tables 3-5). The average tuber weight depended to a greater extent on the cultivar and weather conditions during potato growing season.

Tuber yield

The plant growth stimulant application caused an increase in tuber yield (Table 3). With the Tytanit® application, the total tuber yield was higher, on average, in the three-year study period by 2.26 t*ha^{-1} (7.5%) and the marketable tuber yield by 1.88 t*ha^{-1} (6.4%) compared to the control object without the growth stimulant. Tytanit® had a greater effect on the tuber yield for the 'Lord' cultivar (Figure 4).



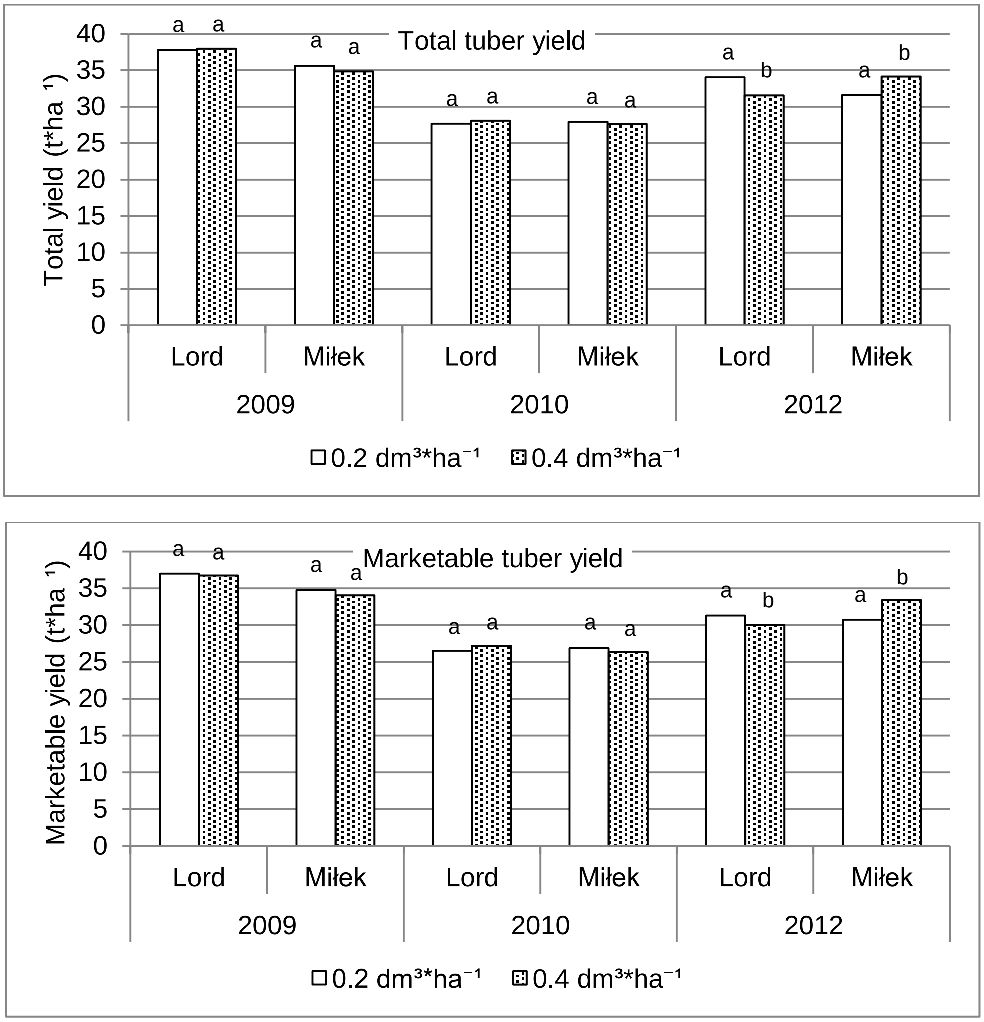
a, b: Means followed by the same letters do not differ significantly at P<0.05.

Figure 4. Effect of Tytanit® on the tuber yield

Rysunek 4. Wpływ Tytanitu® na plon bulw

Following the Tytanit® application, the total tuber yield of 'Lord' cultivar was higher, on average, by 3.71 t*ha^{-1} (12.7%) and marketable tuber yield by 3.22 t*ha^{-1} (11.4%) compared to the cultivation without the growth stimulant. Tytanit® caused an increase in the tuber yield of 'Miłek' cultivar only in 2010 with the highest air temperature and periodically water shortage in June. In that year, with the Tytanit® application, the total tuber yield of 'Miłek' cultivar was higher, on average by 2.16 t*ha^{-1} (8.5%) and marketable tuber yield by 2.02 t*ha^{-1} (8.2%) compared to the cultivation without the growth stimulant.

The Tytanit® dose had a significant effect on the tuber yield only in 2012 with the highest air temperature and the lowest rainfall during the tuber growth period. In that year, the tuber yield of the 'Lord' cultivar was higher when Tytanit® was applied at a dose of 0.2 dm^{3}*ha^{-1} and the tuber yield of 'Miłek' cultivar at a dose of 0.4 dm^{3}*ha^{-1} (Figure 5). Under thermal and moisture conditions more favourable for rapid tuber growth, the Tytanit® dose did not significantly affect the tuber yield.



a, b: Means followed by the same letters do not differ significantly at P<0.05.

Figure 5. Tuber yield in relation to the Tytanit® dose and cultivar

Rysunek 5. Plon bulw w zależności od dawki Tytanitu® i odmiany

The date of Tytanit® application slightly affected the tuber yield (Table 5). With the growth stimulant application in the leaf development stage the tuber yield was only slightly higher than with the application in the tuber formation stage. With double Tytanit® application (in the leaf development stage and with a repeated treatment in the tuber formation stage) the total and marketable tuber yields were similar compared to a single treatment performed on each of these dates.

Tuber yield structure

The main weight of the potato yield was made up of medium-sized tubers, with diameters of 41-50 mm. The Tytanit® application caused a decrease in the share of small tubers with diameters below 40 mm and an increase in the share of large tubers, with diameters above 51 mm, especially in 2010, with the highest air temperature and a periodical water shortage in June (Figures 6 and 7). In that year,

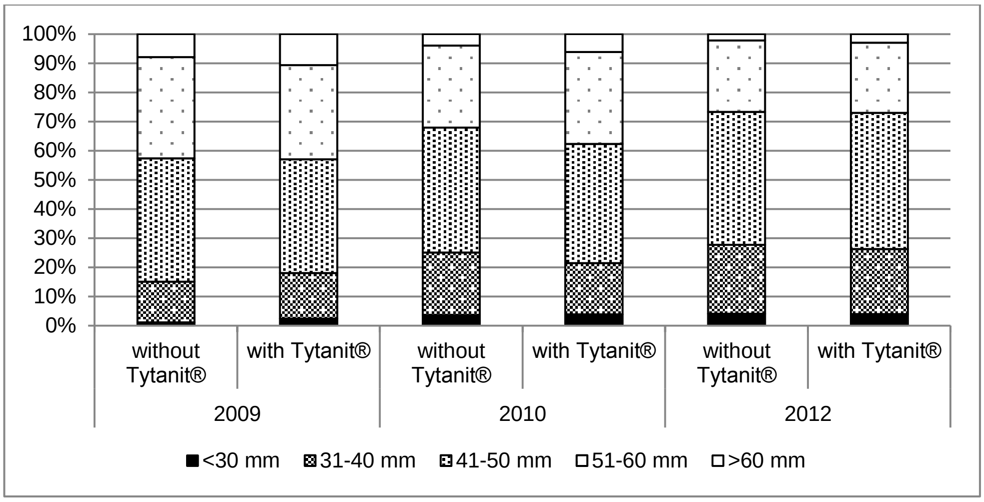


Figure 6. Effect of Tytanit® on the tuber yield structure

Rysunek 6. Wpływ Tytanitu® na strukturę plonu bulw

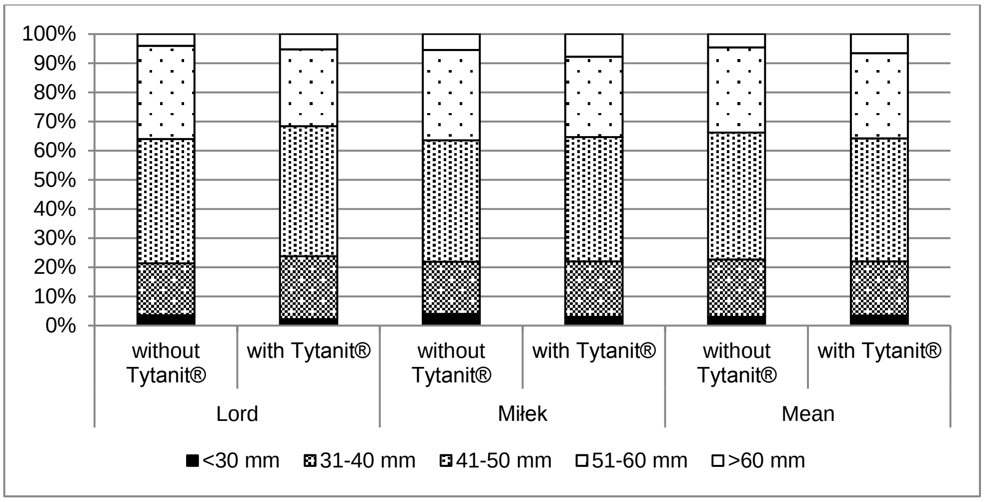


Figure 7. Tuber yield structure in relation to the Tytanit® application and cultivar

Rysunek 7. Struktura plonu bulw w zależności od stosowania Tytanitu® i odmiany following Tytanit® application the share of tubers with diameters below 40 mm in the yield was smaller on average by 3.6%, however, the share of tubers with diameters above 51 mm was higher on average by 5.7%. Tytanit® had a greater effect on the tuber yield structure for the 'Miłek' cultivar. Following the Tytanit® application, the share of tubers with diameters above 60 mm in the yield of this cultivar was higher, on average, by 2.3% compared to the cultivation without the growth stimulant .

The Tytanit® dose slightly affected the tuber yield structure of the 'Miłek' cultivar. The share of large tubers (diameter above 51 mm) in the yield of 'Lord' cultivar was higher, on average, by 5.4% following the application of 0.4 dm^3*ha^{-1} (Figure 8).

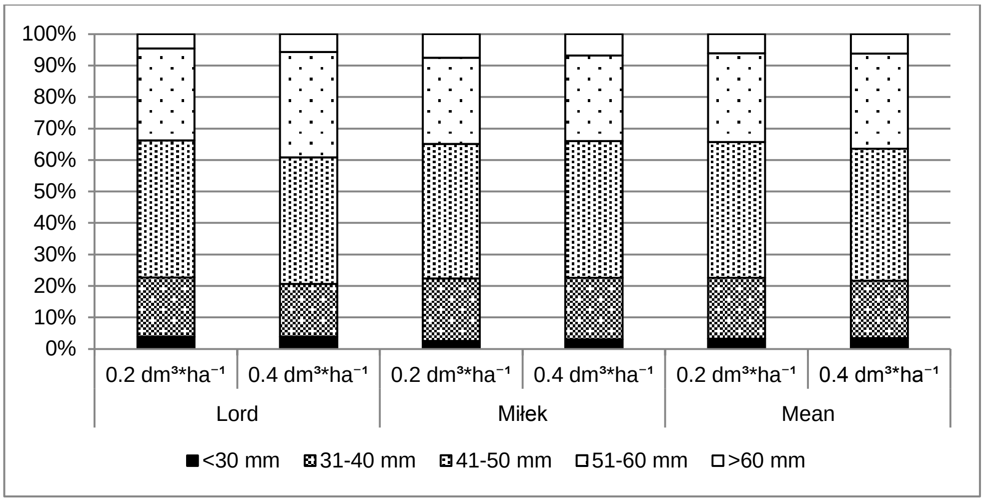


Figure 8. Tuber yield structure in relation to the Tytanit® dose and cultivar

Rysunek 8. Struktura plonu bulw w zależności od dawki Tytanitu® i odmiany

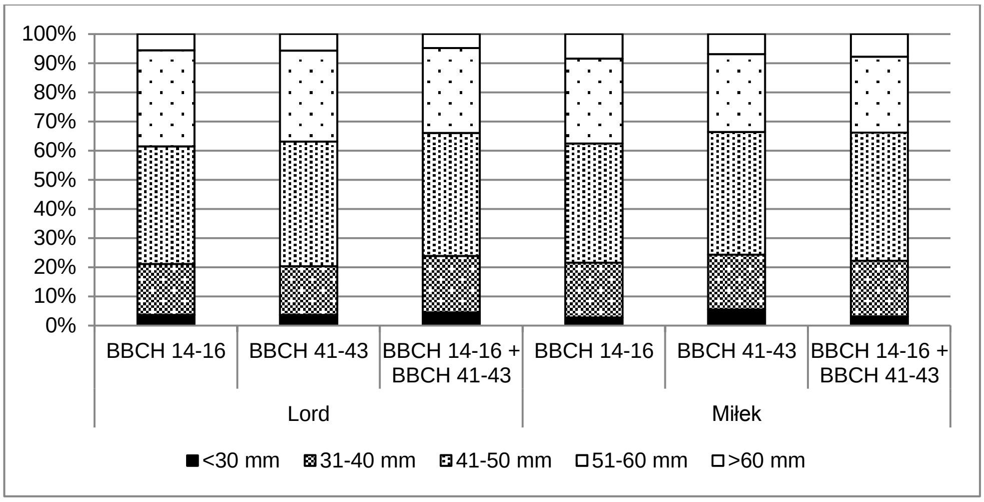


Figure 9. Tuber yield structure in relation to the date of Tytanit® application and cultivar

Rysunek 9. Struktura plonu bulw w zależności od terminu stosowania Tytanitu® i odmiany

With the Tytanit® application in the tuber formation stage, medium-sized tubers (diameter 41-50 mm) constituted a higher share of the yield than with a treatment performed in the leaf development stage (Figure 9). With two Tytanit® application, in the leaf development stage and with a repeated treatment in the tuber formation stage, the tuber yield structure did not differ compared to the single treatment performed in the tuber formation stage.

Discussion

The actual potato yields are usually much lower than the potential yields, defined as the theoretical yields that could be assessed for a certain cultivar, grown from the best possible seed, under optimal conditions, without any limiting or reducing factor present. The ratio between actual and potential yield ranges from 10% to 75%, but typical values are between 30% and 40% (Haverkort and Struik, 2015). Actual potato yields depend on the genetic gain, impact of environment conditions, the introduction of improved agronomic practices and the interaction between these factors. Plant growth and development are influenced by many stress factors. Growth stimulant increases plant resistance to abiotic and biotic stresses, which allows better use of the cultivar production potential under the environmental conditions of the cultivar area (Calvo et al., 2014; Brown and Saa, 2015; Bulgari et al., 2015). Although titanium is neither a major nor a minor nutrient for plants, it is classified as a beneficial element for plant growth. Titanium exerts a beneficial effect on various plant physiological processes, leading to earlier and higher crop production. Titanium applied via roots or leaves stimulates plant growth in a species-specific manner (Dumon and Ernst, 1988; Pais et al., 1991; Carvajal and Alcaraz, 1998; Du et al., 2010). According to Jabłoński (2000), a double Tytanit® application in the dose of 0.3 $dm^3 * ha^{-1}$ in the early crop potato culture (formation of basal side shoots stage – BBCH 21-23 and in the beginning of flowering – BBCH 61) can increase the marketable tuber yield by 10-15%. The present study showed the Tytanit® usefulness for application in an early crop potato culture under stress conditions, although the effect of cultivars was not consistent. In the conditions of central-eastern Poland, the Tytanit® application caused an increase in the tuber number and tuber weight per plant, but did not have any effect on the average tuber weight. As the result, the total tuber yield after 75 days from planting (the end of June) was higher, on average, by 2.26 $t * ha^{-1}$ (7.5%) and the marketable tuber yield increased by 1.88 $t * ha^{-1}$ (6.4%) compared to the cultivation without the growth stimulant. Similar results were obtained by other authors in later date of potato harvest. The increase in tuber yield of the early cultivar ‘Drop’ and medium-early cultivar ‘Maryna’ amounted to 2.17 $t * ha^{-1}$ (5.3%) on Luvisol and 2.18 $t * ha^{-1}$ (5.3%) on Cambisol (Kołodziejczyk and Szmigiel, 2007), whereas the increase in tuber yield of medium-late cultivar ‘Bryza’ on Luvisol amounted to 3.8 $t * ha^{-1}$ (16%) (Szewczuk, 2009a). A study carried out in southeast Lithuania on Haplic Luvisol showed that Tytanit® and liquid complex microelement fertilizers combined treatment did not have any effect on tuber number per plant. However, they increased tuber weight per plant and, as a result, increaseed the tuber yield of the early cultivar ‘Goda’ by 0.9-1.9 $t * ha^{-1}$ (3.1-6.5%) compared to control object (Asakavičiūtė and Lisova, 2009). A study carried out in China demonstrated that the application of the foliar titanium-containing fertilizer Fengtaibao increased potato tuber yield by 11-16% (Tan and Wang, 2011). Potato cultivars show a differential response to Tytanit®, which was confirmed by other authors. Kołodziejczy and Szmigiel (2007) showed a higher increase in the tuber yield of the early cultivar ‘Drop’ than the medium-early cultivar ‘Maryna’. In that study, under the same soil and climatic conditions, the use of Tytanit® increased the tuber yield of the very early cultivar ‘Lord’ more than ‘Miłek’. The growth stimulany caused an increase in the tuber yield of ‘Miłek’ cultivar only in the year with the highest air temperature and the periodically water shortage in June.

Titanium exerts a favourable effect on plant growth only at low concentrations, while at higher concentrations, it may exhibit toxic effects (Hruby et al., 2002; Kužel et al., 2003). Tuber number and tuber weight per plant depended on the dose and date of Tytanit® application. The tuber number per plant was higher when Tytanit® was applied at the dose of 0.2 dm^3*ha^{-1}. Potato plants formed greatest tubers when Tytanit® was only applied in the leaf development stage (BBCH 14-16). With double Tytanit® application (i.e. in the initial growth period and with repeated treatment in the tuber formation stage) the tuber number and tuber weight per plant were lower. In a study carried out in southeast Lithuania on Haplic Luvisol, the tuber weight per plant was greatest with two Tytanit® applications (at the beginning of crop cover BBCH 31 and at the beginning of flowering BBCH 60-62) in the dose of 0.2 $dm^3* ha^{-1}$ and liquid complex microelements fertilizers of differing composition (Asakavičiūtė and Lisova, 2009). A positive correlation was found between the tuber yield and the tuber number and tuber weight per plant (Abraham et al., 2014; Darabad, 2014). The potential number of tubers may be determined by the number of stolons and the environmental conditions affecting stolon formation and development (Wurr et al., 1997). Hoverkort et al. (1990) showed a highly significant linear relationship between the number of tubers per stem and total rainfall during the first 40 days after planting. In the present study, Tytanit® had a greatest effect on the tuber number per plant in 2012 with the highest air temperature and, simultaneously, the lowest rainfall in the tuber formation period. With the application of Tytanit®, the tuber number per plant was higher, on average, by 1.6 than in the cultivation without the growth stimulant. In central-eastern Poland, the risk for early crop potato culture connected with frequent rainfall deficits. The greatest rainfall deficit is in June (Radzka and Lenartowicz, 2015). The Tytanit® dose had a significant effect on the tuber yield only in 2012 with the highest air temperature and, at the same time, the lowest rainfall during the tuber growth period. The tuber yield of ‘Lord’ cultivar (more drought tolerant cultivar) was higher when the Tytanit® was applied at a dose of 0.2 dm^3*ha^{-1} and the tuber yield of ‘Miłek’ cultivar at a dose of 0.4 dm^3*ha^{-1}. Under thermal and moisture conditions more favourable for the rapid tuber growth, the Tytanit® dose did not significantly affect the tuber yield. With the growth stimulant applied in the leaf development stage the tuber yield was only slightly higher than with the application in the tuber formation stage.

The Tytanit® application contributed to improved marketable value of the early potato yield due to a decreased share of small tubers (diameter below 40 mm) and an increased share of large tubers (diameter above 51 mm) especially in a year with periodical water shortage in June, which was confirmed in a study carried out by other authors (Kołodziejczyk and Szmigiel, 2007; Tan and Wang, 2011). In early potato production, a lower yield of large-sized tubers produces higher marketable value than a high yield of smaller tubers with non-marketable value. Tytanit® dose

(0.2 or 0.4 dm^3*ha^{-1}) slightly affected the tuber yield structure of 'Miłek' cultivar, although the share of large tubers in the yield of the 'Lord' cultivar was higher following the application of 0.4 dm^3*ha^{-1}. The highest share of medium-sized tubers (diameter 40-50 mm) in the yield was found with the Tytanit® application in the tuber formation stage. Determining the optimal doses and dates of titanium application is very important in the optimisation of early potato production.

Conclusions

The present study demonstrated the stimulating effects of Tytanit® on the tuber number and tuber weight per plant of very early-maturing potato cultivars, although the effect of cultivars was not consistent. Tytanit® had the greatest effect on the tuber number per plant in the growing season with the highest air temperature and simultaneously the lowest rainfall in the tuber formation period. The growth stimulant did not have any effect on the average tuber weight. Following the Tytanit® application, the total tuber yield was higher, on average by 2.26 t*ha^{-1} (7.5%) and the marketable tuber yield (diameter above 30 mm) was higher by 1.88 t*ha^{-1} (6.4%). The examined very early-maturing potato cultivars showed a differential response to Tytanit®. The growth stimulant had a greater effect on the tuber number and tuber weight per plant for the 'Lord' cultivar. Following the Tytanit® application, the total tuber yield of 'Lord' cultivar was higher , on average by 3.71 t*ha^{-1} (12.7%) and marketable tuber yield by 3.22 t*ha^{-1} (11.4%). Tytanit® caused an increase in the tuber yield of 'Miłek' cultivar only in the year with the highest air temperature and the water shortage in June – the total tuber yield was higher, on average by 2.16 t*ha^{-1} (8.5%) and marketable tuber yield by 2.02 t*ha^{-1} (8.2%).

A Tytanit® dose (0.2 dm^3*ha^{-1} or 0.4 dm^3*ha^{-1}) had a significant effect on a number of tubers produced by potato plant. The tuber number per plant was higher when Tytanit® was applied at the dose of 0.2 dm^3*ha^{-1}. Potato plants produced greatest tubers when Tytanit® was only applied in the leaf development stage (BBCH 14-16). With double Tytanit® application (i.e. in the leaf development stage and with repeated treatment in the tuber formation stage) the tuber number and tuber weight per plant were lower.

The Tytanit® application contributed to improved marketable value of the early potato yield due to a decreased share of small tubers (diameter below 40 mm) and an increased share of large tubers (diameter above 51 mm) especially in a year with the periodical water shortage in the tuber growth period.

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References

Abraham, L., Yohannes, P., Mebeaselassie, A. (2014) Correlation and path coefficient analysis between yield and yield components in potato (*Solanum tuberosum* L.). Plant Science Today, 1 (4), 196-200. DOI: 10.14719/pst.2014.1.4.79

Asakavičiūtė, R., Lisova, R. (2009) The influence of liquid complex fertilizers on potato yield and pest prevention. Žemdirbyste-Agriculture, 96 (4), 232-245.

Asakavičiūtė, R., Lisova, R. (2010) The influence of complex fertilizers on potato pest. Lžuu Mokslo Darbai, 87 (40), 7-12.

Bac, S., Koźmiński, C., Rojek, M. (1993) Agrometeorolog. Warsaw: Scientific Publishing PWN.

Brown, P., Saa, S. (2015) Biostimulants in agriculture. Frontiers in Plant Science, 6, 671. DOI: 10.3389/fpls.2015.00671

Bulgari, R., Cocetta, G., Trivellini, A., Vernieri, P., Ferrante, A. (2015) Biostimulants and crop response: a review. Biological Agriculture and Horticulture, 31 (1), 1-17. DOI: 10.1080/01448765.2014.964649

Calvo, P., Nelson, L., Kloepper, J.W. (2014) Agricultural uses of plant biostimulants. Plant and Soil, 383, 3-41. DOI: 10.1007/s11104-014-2131-8

Carvajal, M., Alcaraz, C.F. (1998) Why titanium is a beneficial element for plants. Journal of Plant Nutrition, 21 (4), 655-664. DOI: 10.1080/01904169809365433

Darabad, G.R. (2014) Study the relationships between yield and yield components of potato varieties using correlation analysis and regression analysis and causality. International Journal of Plant, Animal and Environmental Sciences, 4 (2), 584-589.

Du, J., Xu, Z., Li, Z., Su, Y., Chen, Y., Wang, X. (2010) Study progress in titanium nutrient of plants. Acta Agriculturae Jiangxi, 1, 42-44.

Dumon, J.C., Ernst, W.H.O. (1988) Titanium in plants. Journal of Plant Physiology, 133 (2), 203-209. DOI: 10.1016/s0176-1617(88)80138-x

Grześkiewicz, H., Trawczyński, C. (1998) Foliar application of compound fertilizers in the potato cultivation. Folia Universitatis Agriculturae Stetinensis, 190, Agricultura, 72, 75-80.

Haverkort, A.J., Van De Waart, M., Bodlaender, K.B.A. (1990) The effect of early drought stress on numbers of tubers and stolons of potato in controlled and field conditions. Potato Research, 33, 89-96. DOI: 10.1007/bf02358133

Haverkort, A.J., Struik, P.C. (2015) Yield levels of potato crops: Recent achievements and future prospects. Field Crops Research, 182, 76-85. DOI: 10.1016/j.fcr.2015.06.002

Hrubý, M., Cígler, P., Kužel, S. (2002) Contribution to understanding the mechanism of titanium action in plant. Journal of Plant Nutrition, 25, 577-598. DOI: 10.1081/pln-120003383

Jabłoński, K. (2000) The benefits of microelements foliar fertilization of potatoes. Ziemniak Polski, 2, 22-30.

Kołodziejczyk, M., Szmigiel, A. (2007) Effect of selected agro and technical factors on potato yielding and chemical composition of tubers. Fragmenta Agronomica, 2, 151-159.

Kužel, S., Hrubý, M., Cígler, P., Tlustoš, P., Van, P.N. (2003) Mechanism of physiological effects of titanium leaf sprays on plants grown on soil. Biological Trace Element Research, 91 (2), 179-189. DOI: 10.1385/bter:91:2:179

Kužel, S., Cígler, P., Hrubý, M., Vydra, J., Pavlíková, D., Tlustoš, P. (2007) The effect of simultaneous magnesium application on the biological effects of titanium. Plant Soil and Environment, 53 (1), 16-23.

Pais, I. (1983) The biological importance of titanium. Journal of Plant Nutrition, 6 (1), 3-131. DOI: 10.1080/01904168309363075

Pais, I., Fehér, M., Bokori, J., Nagy, B. (1991) Physiologically beneficial effects of titanium. Water Air and Soil Pollution, 57-58, 675-680. DOI: 10.1007/bf00282931

Radzka, E., Lenartowicz, T. (2015) Rainfall deficit and excess rainfall during vegetation of early potatoes varieties in central-eastern Poland (1971-2005). Nauka Przyroda Technologie, 9 (2), 1-14. DOI: 10.17306/j.npt.2015.2.25

Szewczuk, C. (2009a) The influence of foliar fertilization on potato tubers yield. Annales Universitatis Mariae Curie-Skłodowska, Sectio E Agricultura, 64 (1), 7-12.

Szewczuk, C. (2009b) The influence of potato foliar fertilization on *Phytophthora infestans* infestation. Annales Universitatis Mariae Curie-Skłodowska, Sectio E Agricultura, 64 (1), 13-18.

Świerczewska, M., Sztuder, H. (2004) Foliar application of the micronutrient compounds containing titanium. Zeszyty Problemowe Postępów Nauk Rolniczych, 502, 377-385.

Tan, Z., Wang, Z. (2011) Demonstration for application of "Fengtaibao", a new water soluble titanium-containing foliar fertilizer, in potato. Chinese Potato Journal, 4, 234-237.

Tlustoš, P., Cígler, M., Hrubý, M., Kužel, J., Száková, J., Balík, J. (2005) The role of titanium in biomass production and its influence on essential elements' contents in the field growing crops. Plant Soil and Environment, 51 (1), 19-25.

Wurr, D.C.E., Hole, C.C., Fellows, J.R., Milling, J., Lynn, J.R., O'Brien, P.J. (1997) The effect of some environmental factors on potato tuber numbers. Potato Research, 40, 297-306. DOI: 10.1007/bf02358011