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Possibility of increasing early potato yield with foliar application of silicon

Możliwość zwiększenia plonu ziemniaka wczesnego
przez stosowanie dolistne rzemu

Summary. This paper analyses the effect of dosage (0.25 dm^3 ha^{-1} or 0.50 dm^3 ha^{-1}) and time (the leaf development stage – BBCH 14–16, tuber initiation stage – BBCH 40–41, at both the leaf development stage and tuber initiation stage) of silicon-based stimulant Optysil application (200 g SiO_2 and 24 g Fe in 1 dm^3) on early potato yield and yield components. Optysil resulted in an increase in tuber number and tuber weight per plant. As a result, under periodic water deficits during tuber bulking, Optysil increased marketable tuber (with a diameter above 30 mm) yield by an average of 6.90 t ha^{-1} (50%) and under drought conditions during the potato growth period by 0.70 t ha^{-1} (8.6%). Under periodic water deficits during tuber bulking, the marketable tuber number per plant and marketable yield were greatest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40–41). Under drought conditions, the most practical were two Optysil applications at 0.25 dm^3 ha^{-1}. The Optysil application improved the market value of the early potato yield by increasing the share of medium-sized tubers (with a diameter of 41–50 mm).

Key words: stimulant, sodium metasilicate, early potato, tuber number, tuber weight, tuber yield

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food crop historically contributing to food security in the world [Wijesinha-Bettoni and Mouillé 2019]. Potato growth and tuber yield depend on the site-specific interaction between the cultivar and the environment and on the agronomic practices. In recent years, the growth and productivity of crop plants have been greatly influenced by abiotic stresses caused by climate change. Among abiotic stresses, drought is one of the most serious regarding crop plant productivity. Drought decreases photosynthesis and induces oxidative stress in plants [Reddy et al. 2004]. Potato is a relatively drought-sensitive crop. Even short periods of water deficit negatively impact potato growth and yield. Potato response to water deficits varies widely among cultivars and also differs according to the extent and timing of the water deficit. The most sensitive periods for water shortage are the vegetative and tuberization stage [Chang et al. 2018, Wagg et al. 2021]. The climate change impact simulations for potato production suggest a decline in global potato production of between 18% and 32% by 2055 [Hijmans 2003]. To maintain sustainable potato production it is necessary to adapt cultivation practices to a changing environment and breeding stress-tolerant potato cultivars [Adavi et al. 2018, Dahal et al. 2019].

Stimulant application is a low-input environmentally friendly cropping management tool for sustainable crop production. These products containing bioactive molecules stimulate plant growth and activates their natural defense mechanisms against stress, acting on primary and secondary metabolism. Environmental factors, agricultural practice and the timing of treatment can influence the effectiveness of plant stimulants [Drobek et al. 2019, Shahrajabian et al. 2021].

Although silicon is a non-essential nutrient for plants, it plays an important role in plant growth. Silicon can influence plant-water relations, improve the process of photosynthesis and nutrient uptake, regulate phytohormone biosynthesis and the activities of certain enzyme, and decrease oxidative stress [Savvas and Ntatsi 2015, Malik et al. 2021, Verma et al. 2021]. Since silicon plays an important role in regulating physiological and biochemical processes, it has a potential role in mitigating various environmental stresses. Silicon has been proven to play an important role in mitigating drought stress [Kaur et al. 2021, Malik et al. 2021, Rehman et al. 2021, Wang et al. 2021].

Silicon can be applied as a plant growth stimulant through foliar spraying, incorporation into the soil, or fertigation. The foliar spraying is the most effective method of silicon application but has not been adequately tested on crop plants [Savvas and Ntatsi 2015, Kaushik and Saini 2019]. Foliar application of silicon improved the productivity of several agricultural and horticultural plants under abiotic stress. Silicon increased wheat yield by 25% [Kowalska et al. 2021], sugar beet by 14–16% [Artyszak et al. 2015], cucumber by 26% [Ługowska 2019] and sweet pepper by 53–56% [Abdelaal et al. 2020].

To date, few studies have focused on the effect of silicon on potato yield. Although potato is silicon low-accumulator, silicon foliar application may contribute to enhancing tuber yield [Vulavala et al. 2016]. A greenhouse pot experiment in Brazil showed that foliar silicon (orthosilicic acid [H_4SiO_4] and disilicic acid [H_2SiO_5] in the commercial product Silamol) application maintained relative water content and increased the tuber yield of very early potato cultivar Agata (the most widely grown in Brazil) on a Typic Acrortox soil under simulated drought conditions. Tuber yield of water-stressed plants treated with silicon was similar to well-watered plants [Pilon et al. 2014]. A field experiment in Brazil showed that foliar silicon (potassium silicate [K_2SiO_3]) application could increase the commercial yield of late potato cultivar Atlantic by up to 22% [Luz et al. 2008]. Another field experiment in Brazil showed that the yield-forming effect of silicon (stabilized silicic acid [$Si(OH)_4$]) foliar application depended on the potato cultivar and its location. Silicon increased the commercial yield of the very early potato cultivar Agata by 40% and the late cultivar Atlantic by 14% in Botucatu (São Paulo state), but had no effect on Agata cultivar yield in Itaí (São Paulo state) [Soratto et al. 2012]. A one-year field experiment in the Netherlands showed that foliar sprays with stabilized silicic acid increased potato tuber yield by 6.5% [Laane 2017]. Another one-year field experiment in Iran showed that foliar application of silicon in the form of sodium silicate nanoparticles (Nano-$NaSiO_3$) or silica (SiO_2) increased the tuber number per plant and the tuber yield of late potato cultivar Agria on silty loam soil under salinity stress [Kafi et al. 2019]. In previous studies in Poland, foliar silicon (orthosilicic acid [$Si(OH)_4$] in the commercial product Krzemian) application increased the yield of the medium-early potato cultivar Oberon cultivated on light soil by 6.4–17.6%. The yield-forming effect of silicon depended on the weather conditions and the number of treatments performed [Trawczyński 2021]. Foliar application of silicon is practical only at very low dosage and starting early in the vegetative stage [Laane 2017, Dorneles et al. 2018].

The current study aimed to determine the effect of foliar silicon application on early potato yield and yield components. The obtained results suggested that foliar silicon application could increase early potato yield under abiotic stress conditions and improve its market value by an increased share of marketable-size tubers. Likewise, was assumed that potato response to foliar silicon application depends on the dosage and time of application.

MATERIALS AND METHODS

Location and meteorological conditions

A field experiment was carried out in central-eastern Poland (52°03'N, 22°33'E), over three growing seasons (2016–2018). The experiment was performed in Haplic Luvisol soil (LV-ha) with a sandy loam texture [FAO 2015], characterized by acid-to-slightly acid reaction (pH_{KCl} 5.2–5.7), a high content of available phosphorus (97–114 mg P kg^{-1} of soil), a medium-to-high content of potassium (93–124 mg K kg^{-1} of soil) and a low-to-medium content of magnesium (23–42 mg Mg kg^{-1} of soil). Soil samples were taken in the autumn 2015. The soil chemical properties were determined using soil laboratory procedures at the National Chemical and Agricultural Station: pH with potentiometric method in 1 M KCl solution, available forms of phosphorus with spectrophotometric method, potassium with the flame atomic emission spectroscopy (FAES) method and magnesium with flame atomic absorption spectroscopy (FAAS) method.

The meteorological conditions during the potato growth period were different (Tab. 1). The year 2016 was warm with drought periods during potato growth. The year 2017 was warm and moderately wet, whereas 2018 was warm and very dry. In 2016 total precipitation in May was similar and in June over 40% lower than the long-term average. In 2018, the total precipitation in May and June was two times lower than the long-term average.

Plant material and management

The drought-sensitive very early potato cultivar Catania (Europlant Pflanzenzucht GmbH, Germany) registered on the Common Catalogue of Varieties of Agricultural Plant Species (CCA) was grown. It is one of the most widely grown very early potato cultivar in central-eastern Poland with a cream-white flesh and multi-purpose cooking type (B).

In each year of the study, the previous crop to potato was spring triticale. Potato cultivation was carried out according to common agronomical practices. Farmyard manure was applied in autumn, at the rate of 25 t ha^{-1}, and mineral fertilizers were applied at rates

Table 1. Meteorological conditions during potato growing period

Years	Months		
	April	May	June
Air temperature (°C)			
2016	9.1	15.1	18.4
2017	6.9	13.9	17.8
2018	13.1	17.0	18.3
Multi-year mean (1981–2010)	8.3	12.2	16.8
Rainfall (mm)			
2016	28.7	54.8	36.9
2017	59.6	49.5	57.9
2018	34.5	27.3	31.5
Multi-year mean (1981–2010)	41.2	53.0	63.8
Hydrothermal index			
2016	1.05	1.17	0.67
2017	2.88	1.15	1.08
2018	0.88	0.52	0.57

Hydrothermal index: up to 0.4 – extremely dry; 0.41–0.7 – very dry; 0.71–1.0 – dry; 1.01–1.3 – rather dry; 1.31–1.6 – optimal; 1.61–2 – rather humid; 2.01–2.5 – humid; 2.51–3 – very humid; >3 – extremely dry [Skowera 2014].

of 80 kg N (ammonium nitrate), 35 kg P (superphosphate), and 100 kg K (potassium sulfate) per hectare in spring. Potatoes were planted on 6 April 2016, 10 April 2017 and 9 April 2018, with an in-row spacing of 0.25 m and 0.675 m between rows. Seed potatoes were previously pre-sprouted for six weeks. The average length of sprouts at the time of planting was 15–20 mm. The plot area was 16.2 m^2 (96 plants per plot). Colorado potato beetle (*Leptinotarsa decemlineata*) was controlled using thiamethoxam (Actara 25 WG; Syngenta Crop Protection AG, Basel, Switzerland). Potatoes were harvested 75 days after planting (the end of June).

Experimental design

In this experiment, the silicon (Si) source was liquid stimulant Optysil, produced by Intermag Ltd., Olkusz, Poland. Optysil contains 200 g SiO_2 (16.5 m/m) and 24 g Fe (2 m/m) in 1 dm^3, in the form of sodium metasilicate (Na_2SiO_3) and iron chelate (Fe-EDTA).

The effect of the dosage and time of Optysil application on early potato yield and the yield components were determined. The field experiment was established as a two-factor (2 × 3) split-plot design with a control object without the stimulant, in three replications. The main plots received the following Optysil dosage: 0.25 dm^3 ha^{-1} or 0.50 dm^3 ha^{-1}, and the time of Optysil application on the subplots were as follows: in the leaf development stage (under the terms of uniform codes of phenologically similar growth stages of plant species, by Biologishe Bundesanstalt, Bundessortenamt and Chemical Industry; BBCH 14–16 stage), tuber initiation stage (BBCH 40–41), or in both leaf development stage and tuber initiation stage (BBCH 14–16 and BBCH 40–41) [Meier 2018]. Potato plants sprayed with water were used as a control. A single plot control was located between the main plots.

The total and marketable tuber number and tuber weight per plant, average tuber weight, total and marketable yield were determined. The tuber size in a potato yield, i.e. the percentage weight of very small tubers (diameter below 30 mm), small tubers (30–40 mm), medium-sized tubers (41–50 mm), large tubers (51–60 mm) and very large tubers (above 60 mm) was also determined. Tuber number and tuber weight per plant and the tuber size in the yield were determined on ten successive randomized plants per plot. The size of the tuber was determined by a hand calibrator with a square mesh. The total and marketable yields were calculated on the basis of tuber weight per plot. Marketable yield consisted of tubers with a diameter above 30 mm [UNECE Standard FFV-52].

Statistical analysis

The study results were analyzed statistically using a two-factor analysis of variance (ANOVA) for the split-plot design (Optysil dosage × time of Optysil application × year) with a control object. The analysis of the results was conducted using the orthogonal contrast to compare the control, without Optysil, with the test objects treated with Optysil. The significance of orthogonal contrast was tested on the basis of the error resulting from the interaction of this contrast with the replications. The significance of sources of variability was tested using the *F* Fisher-Snedecor test, and the differences between the compared averages were verified using Tukey's test ($p \leq 0.05$). Calculations were performed using Statistica 12 PL software (StatSoft Inc., Tulsa, OK, USA).

RESULTS

Tuber number and tuber weight per plant, and tuber yield

The silicon-based stimulant Optysil caused an increase in tuber number and tuber weight per plant and, as a result, the total and marketable tuber yield (Tabs 2 and 3). The yield-increasing effect of the stimulant depended on weather conditions during potato growth. Optysil significantly affected tuber number and tuber weight per plant under

Table 2. Effect of Optysil on the total yield and yield components

Treatment	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total yield (t ha^{-1})
Control	10.7 ±3.9^{b}	313 ±109^{b}	29.6 ±6.8^{a}	18.55 ±6.65^{b}
With Optysil	12.1 ±4.6^{a}	354 ±120^{a}	30.0 ±7.0^{a}	20.98 ±7.09^{a}

Means within columns for each data type followed by the same letter do not differ significantly at $p \leq 0.05$.

Table 3. Effect of Optysil on the marketable yield and yield components

Treatment	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Marketable yield (t ha^{-1})
Control	6.4 ±2.6^{b}	249 ±105^{b}	39.6 ±4.2^{b}	14.74 ±6.20^{b}
With Optysil	7.0 ±2.4^{a}	298 ±117^{a}	42.0 ±5.4^{a}	17.71 ±6.94^{a}

Means within columns for each data type followed by the same letter do not differ significantly at $p \leq 0.05$.

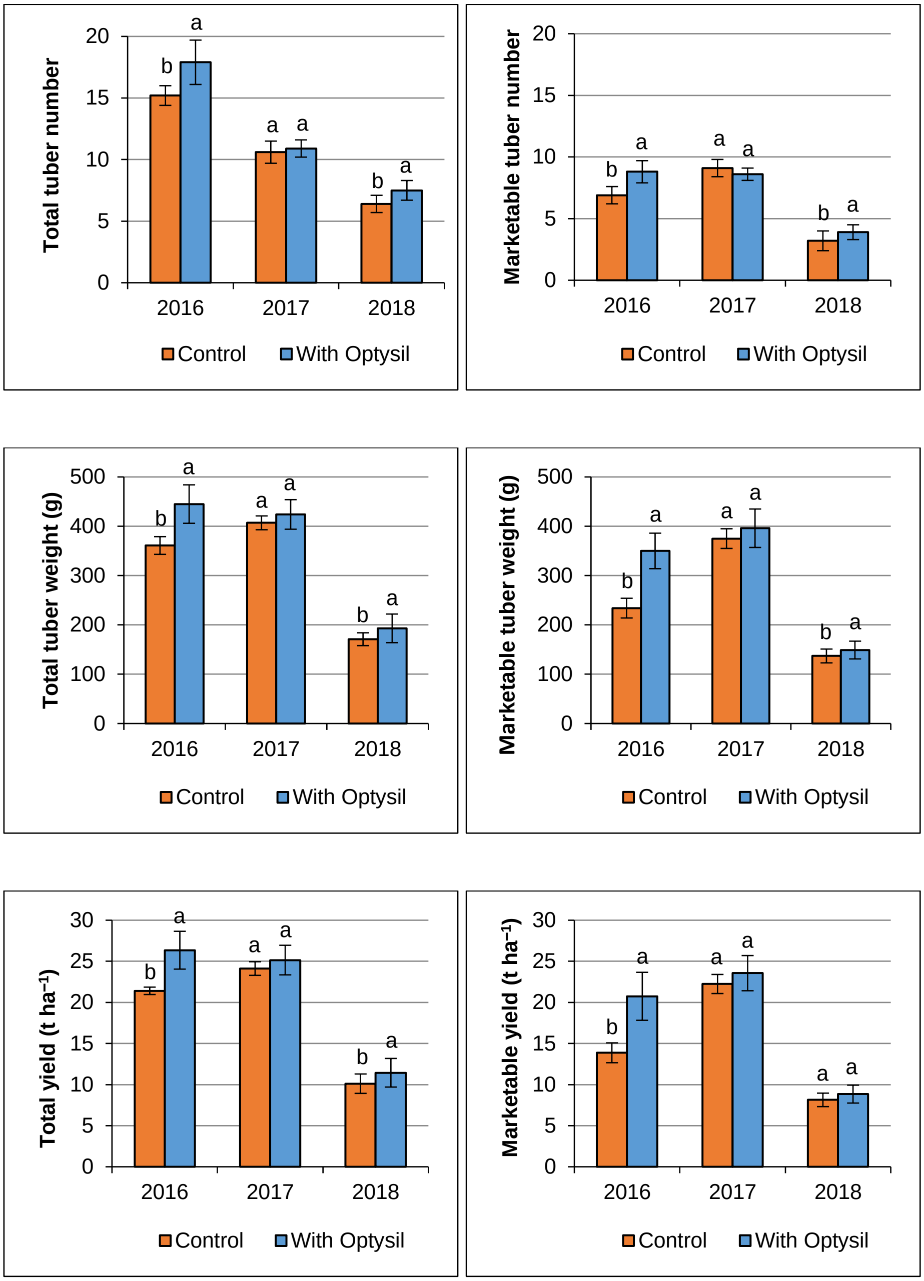

Fig. 1. Effect of Optysil on total and marketable tuber number and tuber weight per plant, and total and marketable yield (mean ± standard deviation). Means followed by the same letters do not differ significantly at $p \leq 0.05$

Table 4. Effect of dosage and time of Optysil application on the total yield and yield components

Dosage and time of Optysil application	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Total yield (t ha^{-1})
Optysil dosage				
0.25 dm^3 ha^{-1}	12.0 ±4.0^{a}	355 ±115^{a}	30.1 ±6.6^{a}	21.01 ±6.81a
0.50 dm^3 ha^{-1}	12.2 ±5.1^{a}	354 ±126^{a}	30.0 ±7.5^{a}	20.95 ±7.49^{a}
Time of Optysil application				
BBCH 14–16	11.9 ±4.2^{a}	366 ±129^{a}	30.9 ±7.1^{a}	21.66 ±7.88^{a}
BBCH 40–41	12.1 ±4.6^{a}	350 ±125^{a}	29.5 ±6.8^{a}	20.77 ±9.02^{a}
BBCH 14–16 + BBCH 40–41	12.3 ±5.1^{a}	346 ±110^{a}	29.7 ±7.4^{a}	20.51 ±7.49^{a}

Time of Optysil application: leaf development stage – BBCH 14–16; tuber initiation stage – BBCH 40–41; both leaf development stage and tuber initiation stage – BBCH 14–16 + BBCH 40–41. Means within columns for each data type followed by the same letter do not differ significantly at $p \leq 0.05$.

Table 5. Effect of dosage and time of Optysil application on the marketable yield and yield components

Dosage and time of Optysil application	Tuber number per plant	Tuber weight per plant (g)	Average tuber weight (g)	Marketable yield (t ha^{-1})
Optysil dosage				
0.25 dm^3 ha^{-1}	7.1 ±2.3^{a}	298 ±105^{a}	41.5 ±4.5^{a}	17.70 ±6.25^{a}
0.50 dm^3 ha^{-1}	6.9 ±2.7^{a}	299 ±130^{a}	42.5 ±6.3^{a}	17.73 ±7.70^{a}
Time of Optysil application				
BBCH 14–16	7.3 ± 2.6^{a}	313 ±130^{a}	42.4 ±6.7^{ab}	18.56 ±7.68^{a}
BBCH 40–41	6.9 ±3.1^{b}	301 ±123^{ab}	42.8 ±4.3^{a}	17.84 ±7.29^{ab}
BBCH 14–16 + BBCH 40–41	6.9 ±2.1^{b}	281 ±100^{b}	40.8 ±5.2^{b}	16.74 ±6.04^{b}

Time of Optysil application: leaf development stage – BBCH 14–16; tuber initiation stage – BBCH 40–41; both leaf development stage and tuber initiation stage – BBCH 14–16 + BBCH 40–41. Means within columns for each data type followed by the same letter do not differ significantly at $p \leq 0.05$.

water-deficit conditions in 2016 and 2018 (Fig. 1). In the warm growing season in 2016, with periodic water deficits during potato growth, the average total tuber number for the treated plants was 2.7 greater, and the total tuber weight was 84 g greater compared with the control plants. The differences in the average marketable tuber number and tuber weight were 1.9 and 116 g, respectively. In the warmer and very dry growing season of 2018, following the application of Optysil, the total tuber number per plant was greater by an average of 1.1, and total tuber weight by 22 g, compared with the control plants. The average marketable tuber number and tuber weight for treated plants were 0.7 and 12 g greater, respectively. As a result, in 2016, with drought periods during potato growth, Optysil caused an increase in the total yield by an average of 4.94 t ha^{-1} (23%), and marketable yield by 6.90 t ha^{-1} (50%) compared with the cultivation without the stimulant (Fig. 1). In the very dry growing season of 2018, following the application of Optysil, the total yield and marketable yield were 2.43 t ha^{-1} (13%) and 0.70 t ha^{-1} (8.6%) higher, respectively.

The dosage and time of Optysil application did not affect total tuber number or tuber weight per plant (Tab. 4). The study demonstrated the significant effect of the interaction of year, dosage and time of Optysil application on marketable tuber number and tuber weight per plant, and marketable yield (Tab. 5). In 2016, with drought periods during potato growth, the marketable tuber number and tuber weight per plant were greatest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40–41). In the very dry growing season of 2018, the plants produced the greatest marketable tuber number and tuber weight with two Optysil applications at 0.25 dm^3 ha^{-1}, first in the leaf development stage, with a repeat treatment in the tuber initiation stage (BBCH 14–16 and BBCH 40–41). As a result, the marketable yield of these plants was higher than those of the other treated plants (Fig. 2). Even in a year favorable for early potato culture (2017), Optysil applied at 0.50 dm^3 ha^{-1} in the leaf development stage caused an increase in the marketable yield.

Tuber size in marketable yield

Regardless of the treatment (with or without Optysil), the main weight of the marketable yield was made up of small tubers, with diameters of 30–40 mm (Fig. 3). Optysil caused an increase in the share of medium-sized tubers, with diameters of 41–50 mm, especially in 2016 with the highest air temperature and periodical water deficits in June, as well as an increase in the average weight of one marketable tuber (Tab. 3).

In 2016 and 2018, with drought periods during tuber bulking, the share of medium-sized tubers (with diameters of 41–50 mm) in the marketable yield was the highest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40–41) – Figure 4.

DISCUSSION

In sustainable crop production, the application of silicon has been increasing as a low input and environmentally friendly technique to stimulate plant growth and alleviate abiotic stresses [Kaur et al. 2021, Malik et al. 2021, Rehman et al. 2021, Wang et al. 2021]. Althought potato is a silicon low-accumulator, foliar silicon application may contribute to enhancing potato yield [Luz et al. 2008, Soratto et al. 2012, Vulavala et al. 2016, Laane 2017], which was confirmed in the present study. The silicon-based (sodium metasilicate [Na_2SiO_3]) stimulant Optysil improved yield and yield components of the drought-sensitive very early potato cultivar Catania under water deficit in Haplic Luvisol soil. The plants treated with Optysil produced more tuber and higher tuber weight, and the resulting higher tuber yield than that in the cultivation without the stimulant. The yield-increasing effect of the stimulant depended on hydrothermal conditions during potato growth. Potato response to water deficits and on the extent and timing of the water deficit varies widely among cultivars [Lahlou et al. 2003, Chang et al. 2018]. The most sensitive periods for water shortage are the vegetative and tuberization stages [Wagg et al. 2021]. In the present study, Optysil increased the total yield of drought-sensitive very early potato cultivar Catania 75 days after planting on average by 4.94 t ha^{-1} (23%) and marketable yield by

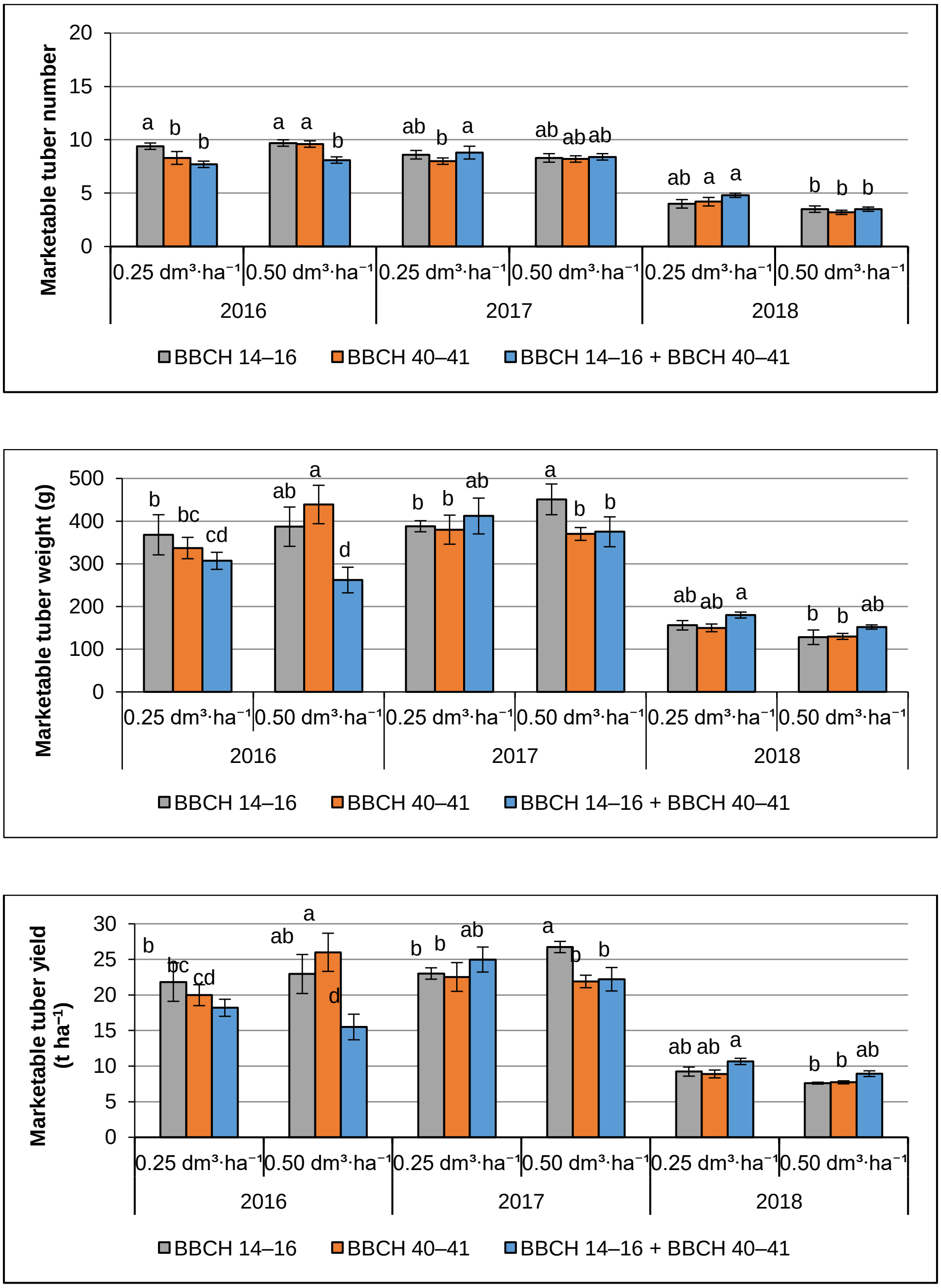

Fig. 2. Marketable tuber number and tuber weight per plant, and marketable yield in relation to year, dosage and time of Optysil application (mean ± standard deviation)

Time of Optysil application: leaf development stage – BBCH 14–16; tuber initiation stage – BBCH 40–41; both leaf development stage and tuber initiation stage – BBCH 14–16 + BBCH 40–41. Means followed by the same letters do not differ significantly at $p \leq 0.05$.

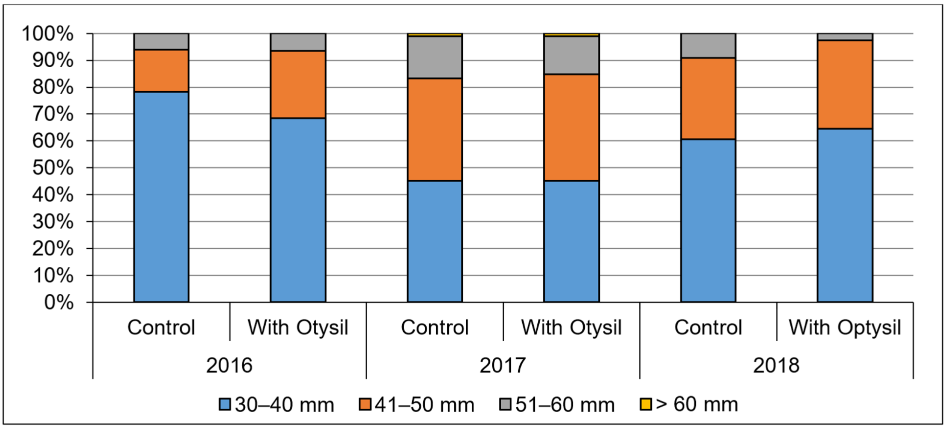

Fig. 3. Effect of Optysil on tuber size in marketable yield; percentage weight of small tubers (with diameters of 30–40 mm), medium-sized tuber (41–50 mm), large tubers (51–60 mm) and very large tubers (above 60 mm)

6.90 t ha^{-1} (50%) under periodic water deficits during tuber bulking (2016 season), and by 2.43 t ha^{-1} (13%) and 0.70 t ha^{-1} (8.6%), respectively, under drought conditions (2018 season). In central-eastern Poland, the risk for early crop potato culture is connected with the frequent rainfall deficits. The greatest rainfall deficit is in June, during tuber bulking [Radzka and Lenartowicz 2015]. Silicon induces drought tolerance in crop plants by regulating physiological and biochemical processes. It may increase the plant adaptation to water deficit by enhancing water status, osmotic adjustment, antioxidant defense system, genes expression associated with the mitigation of drought stress, phytohormone biosynthesis, photosynthetic activity and nutrient uptake [Malik et al. 2021, Verma et al. 2021, Wang et al. 2021]. In addition, silicon taken up by a plant can be deposited in the form of SiO_2 on the leaf apoplast and can reduce the evapotranspiration rate and osmotic stress [Rizwan et al. 2015]. Foliarly applied silicon increased proline, the activity of catalase (CAT) and superoxide dismutase (SOD), and decreased the hydrogen peroxide (H_2O_2) concentration in water-stressed potato plants [Pilon et al. 2014]. Silicon ($NaSiO_3$) added to a nutrient solution at low concentration (0.5 mM Si) induced enlargement of the leaf area and increased the leaf number and leaf and stem biomass of potato plants grown in a hydroponic system [Dorneles et al. 2018]. Previously, field experiments in Brazil and the Netherlands showed that foliar application of silicon increased potato yield from 6.5% to 22%, depending on cultivar and location [Luz et al. 2008, Soratto et al. 2012, Laane 2017].

Foliar application of silicon is practical only at very low dosage and starting early in the vegetative stage [Laane 2017, Dorneles et al. 2018]. In a greenhouse pot experiment in Brazil, the foliar application of silicon was performed five times (10, 20, 30, 40 and 50 days after planting of very early cultivar Agata) using 1.425 mM Si water solution (orthosilicic acid [H_4SiO_4] and disilicic acid [H_2SiO_5] in a commercial product Silamol) [Pilon et al. 2014]. There is scarce knowledge of the effect of different dosages and time of silicon foliar application on potato yield and yield components under uncontrolled environmental conditions in the field. In a one-year field experiment in Iran, foliar application of silicon at 400 ppm sodium silicate nanoparticles (Nano-$NaSiO_3$) or 1000 ppm silica

Fig. 4. Tuber size in marketable yield in relation to year, dosage and time of Optysil application; percentage weight of small tubers (with diameters of 30–40 mm), medium-sized tuber (41–50 mm), large tubers (51–60 mm) and very large tubers (above 60 mm)

Time of Optysil application: leaf development stage – BBCH 14–16; tuber initiation stage – BBCH 40–41; both leaf development stage and tuber initiation stage – BBCH 14–16 + BBCH 40–41.

(SiO_2) were performed two times (40 and 50 days after planting late cultivar Agria). The application of 400 ppm sodium silicate nanoparticles affected the tuber number per plant and tuber yield on silty loam soil under salinity stress more strongly than 1000 ppm silica [Kafi et al. 2019]. In another one-year field experiment in Brazil, a commercial product was applied containing 0.8% of soluble Si as concentrated, stabilized silicic acids [$Si(OH_4)$] at 2 dm^3 ha^{-1}. The silicon dose was split in four applications with one or two-week intervals during the growth of very early cultivar Agata and late cultivar Atlantic [Sorrato et al. 2012]. In the present study, the dosage and time of Optysil application slightly affected the total tuber number per plant and total yield of the drought-sensitive very early potato cultivar Catania in Haplic Luvisol soil but significantly affected the marketable tuber number per plant and marketable yield. Under periodic water deficits during tuber bulking (2016 season), the marketable tuber number per plant and marketable yield were greatest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40–41), whereas under drought conditions (2018 season), the most effective were two Optysil applications at 0.25 dm^3 ha^{-1}, first in the initial plant growth period (BBCH 14–16), with a repeat treatment in the tuber initiation stage (BBCH 40–41). Previously, a field experiment in Poland showed the highest increase in tuber yield of medium-early cultivar Oberon under water deficit with two applications of silicon fertilizer Krzemian (2.5% [$Si(OH)_4$]) at 0.8 dm^3 ha^{-1}, first when the plants meet between rows (BBCH 39), with a repeat treatment after flowering (BBCH 70) [Trawczyński 2021]. In Brazil, the effect of six different dosages of silicate (0, 0.2, 0.4, 0.6, 0.8 and 1% K_2SiO_3 in the spray mixture) on plant architecture and yield of late potato cultivar Atlantic was investigated. The plants were sprayed weekly, with a total of 14 sprays before harvest. The highest potato yield of the extra and commercial classes was obtained at 1% K_2SiO_4 in the spray mixture [Luz et al. 2008].

In early potato production, a lower yield of larger-sized tubers produces a higher marketable value than the high yield of smaller tubers. In the present study, Optysil caused an increase in the share of medium-sized tubers (with a diameter of 41–50 mm) in the early yield of very early cultivar Catania. The share of medium-sized tubers in the marketable yield was the highest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40–41). Previously, a study in Poland showed an increase in the share of large-sized tubers (with a diameter above 60 mm) in the yield of late cultivar Oberon in response to the application of silicon fertilizer Krzemian [Trawczyński 2021].

CONCLUSIONS

Foliar silicon application can effectively improve early potato yield and yield components under a water deficit. The plants treated with silicon-based (sodium metasilicate [Na_2SiO_3]) stimulant Optysil produced more tubers and higher tuber weight than those in the cultivation without the stimulant. The yield-increasing effect of the stimulant depended on the dosage and time of application and the hydrothermal conditions during potato growth. Under periodic water deficits during tuber bulking, the marketable tuber number per plant and marketable yield were greatest after applying 0.50 dm^3 ha^{-1} of Optysil in the tuber initiation stage (BBCH 40-41). Under drought conditions, the most practical were two Optysil applications at 0.25 dm^3 ha^{-1}, first in the initial plant growth period (BBCH 14–16), with a repeat treatment in the tuber initiation stage (BBCH 40–41). The Optysil application improved the market value of the early potato yield by an increased share of medium-sized tubers (with a diameter of 41–50 mm). This study's results provided data for recommendations for foliar silicon application in early potato culture under a water deficit. However, future studies are necessary to evaluate the responses of various potato cultivars on silicon and optimize the dosage and time of silicon application for various environmental condition to achieve the expected benefits for farmers.

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