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Effect of silicon foliar fertilization on limiting the growth of stem and root necrosis in pepper (*Capsicum annum* L.)

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Abstract

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Botrytis cinerea and *Sclerotinia sclerotiorum* are important fungal pathogens of a wide range of hosts. Infection prevention and control can be extremely difficult. There are no *effective fungicides* to control these soil-borne pathogens, causing gray and white mold on pepper. The results of a study of the influence of liquid fertilizer "Optysil" (Intermag, Poland) are presented: containing silicon: (SiO_2 – 200 g/L) and iron (Fe 16.5 g/L) on the pepper resistance to attack by *Botrytis cinerea* and *Sclerotinia sclerotiorum*. The experiment was carried out in 2022, in field conditions at the Maritsa VCRI with the Stryama variety, planted according to a scheme (60/25 cm) on the area naturally infected with *Pyrenochaeta lycopersici*.

The fertilizer "Optysil" was applied by spraying as an aqueous solution at a concentration of 0.05 ml per L of water three times: one week after transplanting, twice during mass flowering stage with an interval of 14 days. Plants were artificially infected with pure cultures of the pathogens *Botrytis cinerea* and *Sclerotinia sclerotiorum* by the method of decapitation of the main stem, applying a 7-day pure culture of each isolate and wrapping the wounded area with aluminum foil. An increase in the necrotic areas was observed in the variants treated with "Optysil" and the control variants without treating the plants with this preparation. Infection of the young plants was carried out in the beginning of flowering stage.

The degree of infection of the roots with corky root rot is recorded after removing the plants from the soil according to a generally accepted 5-point scale for reporting. Temperature during the trial period: daytime 27–32°C; night – 13–17°C. The length of necrotic lesions in decapitated plants was measured in mm up to and including the 10th day after transplanting. A tendency to strengthen the immune response of pepper plants treated with "Optysil" to infection with the studied fungal pathogens was established. The effect of "Optysil" application against the growth of necrosis from gray mold is 43%, against white mold – 41%, corky root rot – above 50%. The results show that the silicon acts as an immunostimulant, blocking the rapid growth of stem necrosis caused by wound infection with *Botrytis cinerea* and *Sclerotinia sclerotiorum* and inhibiting the process of infection of pepper roots with the pathogen *Pyrenochaeta lycopersici*.

Keywords: Capsicum annuum L.; fungus; *Botrytis cinerea*; *Sclerotinia sclerotiorum*; infection; immune response

Introduction

Silicon is a soil macroelement with an influence on soil fertility (Sommer et al., 2006). A lack of silicon in the soil leads to a decrease in yield (Kim et al., 2010; Guntzer et al., 2012). This effect is most pronounced on saline soils as well as soils with a light granulometric composition (Epstein, 1994; Haynes, 2014; Artyszak et al., 2015). The use of silicone-containing fertilizers increases the productivity and stress resistance of agricultural crops (Sakr, 2016). Active forms of silicon applied to soil increase plant viability at the DNA level and increase resistance to physiological stress (Montpetit et al., 2012; Zargar et al., 2019). Silicon performs a large number of functions in plant life and is particularly important under stressful conditions. Silicon is the second most abundant element (after oxygen) in the Earth‘s crust and soil. The main part of silicon is in the form of insoluble substances and is unavailable to the plant. Silicon is accumulated by plants in quantities often exceeding the absorption of the main macronutrients (NPK). Silicon in plants is unevenly distributed. Plants absorb silicic acids through the root system and through the leaf surface (Lee & Kim, 2007).

The uptake of silicon by leaves is about 30–40%, while through the root system it does not exceed 1–5% (Hodson et al., 2005). Silica helps to form a silicon protective layer on the leaf surface, accumulates in the epidermis, conducting tissue of the stem, leaves, roots and in the seed coats (Ma & Yamaji, 2008). Silicon plays an important role in protecting plants from pests (Reynolds et al., 2016). Strengthening of cell walls by biomineralization of silicon compounds is one of the mechanisms by which this protection occurs (Polanco et al., 2014). It acts as a physical barrier to insects and pathogens (Rodrigues et al., 2015). Some studies have shown that silicon is effective in the fight against fungal and bacterial diseases in different plant species (Andrade, 2013; Araujo, 2015; Jayawardana et al., 2016). Silicon increases the resistance of rice to a wide range of fungal pathogens of Fusarium sp. (Whan et al., 2016), reduces powdery mildew incidence in cucumber, barley and wheat (Belanger et al., 2003; Kanto et al., 2006; Moldes et al., 2016; Ratnayake et al., 2016; Remus-Borel et al., 2005; Resende et al., 2013) and black leaf streak of banana (Kablan et al., 2012). The positive influence of silicon application on the development of leaf mold caused by *Botrytis cinerea* was reported by Brecht et al. (2007).

The aim of this study was to investigate the effect of silicon applied as a liquid foliar fertilizer on the development of wound pathogens causing stem and root necrosis in greenhouse pepper – *Botrytis cinerea*, *Sclerotinia sclerotiorum* and *Pyrenochaeta lycopersici*.

Materials and Methods

Experimental design

The experiment was carried out in field conditions at the „Maritsa“ VCRI with the Bulgarian variety for early and mid-early production Stryama, planted according to a scheme (60/25 cm) on the area with mineral fertilization (fertilizer rate N_{220} P_{160} K_{200} kg/ha).

The fertilizer “Optysil” (SiO_2 + Fe) was applied by spraying as an aqueous solution at a concentration of 0.05 ml per L of water three times: one week after transplanting, twice during mass flowering with an interval of 14 days.

Plants in the beginning of flowering stage were artificially infected with pure cultures of the pathogens *Botrytis cinerea* and *Sclerotinia sclerotiorum* by the method of decapitation of the main stem, applying a 7-day pure culture of each isolate and wrapping the injured area with aluminum foil. An increase in necrosis was observed in the variants treated with “Optysil” and the control variants without treatment the plants with this preparation. Temperature during the trial period: daytime 27–32°C; night – 13–17°C. The length of the necroses in the decapitated plants was measured in mm up to and including the 10th day of infection. The experiment was carried out on soil infected with *Pyrenochaeta lycopersici*, the causative agent of tomato corky root rot. Diagnosis of the disease was made by visual and microscopic methods and isolation of the pathogen in a pure culture. At the end of the growing season, the plants were removed from the soil, the root system was washed under running water in order to calculate the disease index according to the variants. Disease assessment was done by measuring the necrotic areas of the root system using a 5-point scale: 0 – absence of root necrosis, 1 – single necrotic spots, 2 – up to 10%, 3 – 11–25%, 4 – 26–50%, 5 – more than 50% of the root system has necrotic spots. The disease severity percentage was calculated using the same McKinney index (1923).

The experiment was carried out in three replicates, four plants in each replicate (4 x 3 replicates).

In order to study the influence of silicon on the growth manifestations of pepper, the following indicators were measured: stem height (cm), stem diameter (mm), stem mass (g/plant), root mass (g/plant), leaf mass (g/plant), total plant mass (g/plant). From each variant, 5 plants were taken in three replicates. The effect of “Optysil” application was calculated according to Abbott‘s classic formula (Abbott, 1999), mathematical processing of the results – according to Duncan (Duncan, 1955).

Description of the biological and other materials

Botrytis cinerea (Bc) and *Sclerotinia sclerotiorum* (Scsc) – isolates from pepper plants with signs of stem necrosis from the collection of microorganisms of the laboratory of phytopathology with proven pathogenicity by the Koch’s postulates (Campbell & Johnson, 2013).

Fertilizer “Optysil” (Intermag, Poland): Liquid fertilizer containing easily digestible silicon: Si 93 g in 1 L (recalculated as SiO_2 – 200 g/L) and iron (Fe 16.5–2 g/L).

Agrotechnical measures: three manual treatments of the soil in the strips and between the rows; watering during the vegetation period in accordance with the development stage, feeding the plants in the phase of mass harvesting; plant-protective measures against sucking enemies.

The introduction of mineral NPK fertilizers is in accordance with the recommendations of the agrochemical laboratory based on a primary agrochemical analysis of the soil:

Fertilizer rate $N_{220}P_{160}K_{200}$ kg/ha according to active substance (N1.8 P0.7 K2.4 g/plant ammonium nitrate 34% active substance, triple superphosphate 18% active substance and potassium sulfate 50% active substance), at the first application 2/3 of the norm. Ammonium nitrate 6 kg/ha, triple superphosphate 2 kg/ha, potassium sulfate 5 kg/ha.

Results and Discussion

A tendency to strengthen the immune response of pepper plants to infection with wound pathogens, causes of gray and white mold after their treatment with the preparation “Optysil”, applied as an aqueous solution at a concentration of 0.05 mm in 1 L. The effect of application of Optysil against the increase in necrosis from gray mold was 43%, against white mold – 41% (Table 1). The results of the study show that silicon acts as an immunizer, blocking the rapid growth of stem necrosis caused by *Botrytis cinerea* and *Sclerotinia sclerotiorum*.

One of the important functions of the active forms of silicon is the stimulation of the development of the root system (Matichenkov, 2008). Studies on cereals, citrus, vegetable crops and forage grasses show that the number of secondary and tertiary roots increases by 20–100% after silicon application. Silicon deficiency in the soil is one of the limiting factors for the development of the root system of plants. Optimizing silicon nutrition has been found to increase photosynthetic efficiency and root system activity (Ali et al., 2013; Szulc et al., 2015).

In our experiment, the measurement of the biometric indicators of the plants in the mass flowering stage showed that triple spraying of pepper with silicon fertilizer had a positive effect on root and leaf mass of the crop. The increase in root mass was 19.40%, in leaf mass – by 15.53% (Table 2).

Applying the experiment to soil naturally infected with *Pyrenochaeta lycopersici*, the causative agent of tomato corky rot, will allow following the immune response of pepper plants to infection with this soil pathogen. A weaker development of corky root on the roots was reported in the variant with application of “Optysil”, which is an indicator of its immunizing effect on the plants (Table 3). In the “Optysil” variant, 15% of plants with signs of corky root were recorded compared to 61% in the control. The index of infestation from corky root did not differ between variants and ranged from 27 to 31%. According to some researchers (Bocharnikova & Matichenkov, 2012), plants have a mechanism that ensures active and rapid redistribution of silicon in plant tissues. At the same time, silicon is transferred to tissues that are more susceptible to stress. This conclusion is confirmed by the work of the Japanese researcher Ma & Yamaji, (2008).

Table 1. Influence of the preparation “Optysil” on the development of necrosis in Stryama pepper variety, caused by wound pathogens *Botrytis cinerea* and *Slerotinia sclerotiorum*

Variant/mineral background	Length of necrosis (cm) on day 10 of infection with pathogens	
	Botrytis cinerea	*Slerotinia sclerotiorum*
Control	4,67b	7,33a
“Optysil”	2,67c	4,33b
Effect, %	42,82	40,93

Duncan’s Multiple Range test ($P < 0.05$).

Table 3. Influence of the preparation “Optysil” on the development of corky root *Pyrenochaeta lycopersici* in Stryama pepper variety

Variant/ mineral background	Development of corky root on plant roots at the end of the growing season	
	Percentage of diseased plant, %	Index of disease, %
Control NPK	61,00	26,92
NPK + “Optysil”	15,38	30,77
Effect, %	74,78	0,00

Table 2. Influence of the preparation “Optysil” on the biometric parameters of the plants in the Stryama pepper variety in the mass flowering phase

Variant	Stem			Root	Leaves	Plant	Fruit/Plant	Fruit
	(H)	(D)	(M)	(M)	(M)	(M)	(N)	(M)
	cm	mm	g	g	g	g	n	g
Control without NPK	53,33	11,83	44,58	17,46	58,33	120,38	6,20	64,76
Control NPK	60,83	12,25	67,08	21,75	88,33	177,17	8,91	69,64
± to control, %	+12,33	+3,43	+33,54	+19,77	+33,97	+32,05	+30,42	+7,00
NPK + “Optysil”	59,16	13,75	101,25	25,75	109,58	236,58	11,16	75,37
± to control, %	+9,8	+13,96	+55,42	+31,06	+46,77	49,12	+44,44	+14,08
$LSD_{0.05}$	0,13	0,07	0,09	0,07	0,11	0,06	0,05	0,13

Research has shown that silicon fertilizers can be used to further protect plants against infection by wound pathogens. The triple spraying of plants with the preparation "Optysil" in the concentration of 0.05 ml/L aqueous solution: one week after transplanting, twice during mass flowering with an interval of 14 days enhances the immune response of plants to infection with soil pathogens at the expense of more effective formation of the root system. Explanations for the protective role of silicon in plants by some authors include thickening of the epidermal layer, increasing the chemical resistance of DNA, RNA and chlorophyll molecules, functional activation of cell organelles, optimization of transport and redistribution of substances in the plant. It is believed that there is some general universal mechanism for increasing their resistance to stress. This mechanism is due to the ability of polysilicic acids to carry out targeted catalytic synthesis of organic substances (stress enzymes, specific and non-specific antioxidants or intermediate compounds that are necessary for the metabolic synthesis of these molecules) under normal conditions. (Montpetit et al., 2012; Muneer & Jeong, 2015). Our research adds to the data on the role of silicon in the defense mechanism of plants to biotic stress and shows that foliar application of silicon is a promising and environmentally friendly method to reduce plant susceptibility to stem and root diseases.

Conclusion

Optimizing silicon nutrition has been found to improve growth performance in pepper. Spraying the plants three times with silicon fertilizer increases root and leaf mass in pepper. This confirms the research of other researchers regarding the important role of silicon in the process of photosynthesis and root formation. A tendency to strengthen the immune response of pepper plants to infection with *Botrytis cinerea*, *Sclerotinia sclerotiorum* and *Pyrenochaeta lycopersici* was reported in the variants treated with the preparation "Optysil". The effect of application of "Optysil" against the growth of necrosis from gray mold is 43%, white mold – 41%. The reduction in the percentage of corky root diseased plants was over 50% compared to the untreated control. The results of the study show that silicon acts as an immunizer, blocking the rapid growth of stem necrosis caused by *Botrytis cinerea* and *Sclerotinia sclerotiorum,* and also inhibiting the process of infection of pepper roots with the pathogen *Pyrenochaeta lycopersici*.

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