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Silicon application as an auxiliary method to control diamondback moth in cabbage plants

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ABSTRACT

Integrated pest management (IPM) strategies are among the factors promoting plant resistance to pests, and silicon application may increase this resistance. Thus, the aim of this research was to evaluate the control of diamondback moth (DBM), *Plutella xylostella* (Lepidoptera, Plutellidae) through foliar application of silicon in cabbage crops. The experiment was conducted in the vegetable producing area of Água Limpa Farm, Universidade de Brasília, Distrito Federal, Brasil. The experimental design was of randomized blocks with nine treatments and four replicates, totaling 36 plots. The applied treatments consisted of Agrosilicon® (10.5% Si) (T1), Sifol® (12% Si) (T2), deltamethrin 25 g L^{-1} (Decis® 25 EC) (T3), *Bacillus thuringiensis*, 33.60 g L^{-1} (Dipel® SC) (T4), Agrosilicon® + deltamethrin 25 g L^{-1}(Decis® 25 EC) (T5), Agrosilicon® + *Bacillus thuringiensis*, 33.60 g L^{-1} (Dipel® SC) (T6), Sifol® + deltamethrin 25 g L^{-1} (Decis® 25 EC) (T7), Sifol® + *Bacillus thuringiensis*, 33.60 g L^{-1} (Dipel® SC) (T8) and control (T9). Agrosilicon® and Sifol® were applied weekly and the products deltamethrin and *Bacillus thuringiensis* were applied according to the damage level established for DBM in cabbage crops. Foliar application of silicon, alone or in combination with chemical and biological insecticides - T2, T7 and T8, were the best strategy to control DBM in cabbage crops, resulting in the lowest number of caterpillars per plant, lowest leaf damages and best aesthetic value of plants. Silicon foliar application can be considered as an auxiliary method of DBM management in cabbage crops, followed by the doses recommended by the manufacturers.

Keywords: *Brassica oleracea* var. *capitata*, *Plutella xylostella*, *Bacillus thuringiensis*, insecticides, mechanical resistance.

RESUMO

Aplicação de silício como método auxiliar no controle da traça das crucíferas na cultura do repolho

Entre as estratégias de Manejo Integrado de Pragas (MIP) estão os fatores que induzem a resistência da planta hospedeira. A adubação mineral com silício pode aumentar a resistência de plantas ao ataque de pragas. Este trabalho teve como objetivo avaliar o potencial da aplicação de silício no controle da traça-das-crucíferas (TDC), *Plutella xylostella* (Lepidoptera, Plutellidae), na cultura do repolho. O experimento foi conduzido na área de produção de hortaliças da Fazenda Água Limpa, Universidade de Brasília, Brasília-DF. O delineamento experimental foi em blocos ao acaso, com nove tratamentos e quatro repetições, totalizando 36 parcelas. Os tratamentos foram T1= aplicação foliar de Agrosilício® (10,5 % Si); T2= aplicação foliar de Sifol® (12% Si); T3= aplicação do inseticida deltametrina 25 g/L (Decis® 25 EC); T4= aplicação do bioinseticida *Bacillus thuringiensis* 33,60 g/L (Dipel®SC); T5= Agrosilício® (10,5% Si) + deltametrina 25 g/L (Decis® 25 EC); T6= Agrosilício® (10,5% Si) + *Bacillus thuringiensis* 33,60 g/L (Dipel®SC); T7= Sifol® (12% Si) + deltametrina 25 g/L (Decis® 25 EC); T8= Sifol® (12% Si) + *Bacillus thuringiensis* 33,60 g/L (Dipel®SC) e T9= tratamento controle. As aplicações de Agrosilicio® e Sifol® foram realizadas semanalmente via foliar. As aplicações dos produtos deltametrina e *Bacillus thuringiensis* foram realizadas quando se atingiu o nível de controle definido para a TDC na cultura do repolho. A aplicação de silício via foliar, isolada ou associada aos inseticidas químicos e biológicos, T2, T7 e T8, resultou na melhor estratégia de controle da TDC na cultura do repolho, com menor número de lagartas por planta, menor número de perfurações nas folhas e melhor avaliação estética das plantas de repolho. O uso do silício via foliar apresenta potencial como método auxiliar de manejo da TDC em repolho, seguindo-se as doses recomendadas pelos fabricantes.

Palavras-chave: *Brassica oleracea* var. *capitata*, *Plutella xylostella*, *Bacillus thuringiensis*, inseticidas, resistência mecânica.

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Silicon is the second most abundant element in the earth's crust. It is absorbed by plant roots as soluble silicic acid [$Si(OH)_4$] and converted into insoluble silica in cell walls, intercellular spaces and subcuticular layers of leaves (Ma *et al*., 2011). The activation of plant protection mechanisms, observed with silicon applications (Gozzo & Faoro, 2013), denotes its potential in disease control. Moreover, the indirect action of silicon on the third trophic level increases the attraction of natural enemies to herbivorous insects (Reynolds *et al*., 2009).

Although silicon is not considered an essential element for plant, silicondeprived plants are often structurally weaker than silicon-replete plants, *i.g*., abnormal in growth, development, viability, and reproduction, more susceptible to abiotic stresses, and easier prey to disease organisms and to phytophagous insects (Epstein, 1999). The increased yield, with silicon foliar application, was observed in corn (Sousa *et al*., 2010), soybean (Teodoro *et al*., 2015) and in the production of eucalyptus seedlings (Navas *et al*., 2016).

Silicon applications induce plant resistance to insect pests by forming mechanical barriers on the outer cell wall of plants (Goussain *et al*., 2002; Costa & Moraes, 2006; Freitas *et al*., 2014), increasing the synthesis of phenolic compounds and lignin (Currie & Perry, 2007) and activating endogenous chemical defenses of attacked plants (Epstein, 2009; Kvedaras *et al*., 2009). The use of silicon in integrated pest management (IPM) have been reported with promising results to control several insect pests in crops of economic importance, such as *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in maize (Goussain *et al*., 2002), *Eldana saccharina* and *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae) in sugarcane (Vilela *et al*., 2014), *Schizaphis graminum* (Hemiptera: Aphididae) in sorghum (Costa & Moraes, 2006) and wheat (Costa *et al*., 2007), *Cinara atlantica* (Hemiptera: Aphididae) in pinus (Camargo *et al*., 2008), *Diabrotica speciosa* (Coleoptera: Chrysomelidae) in potato (Assis *et al*., 2013), *Bemisia tabaci* (Hemiptera: Aleyrodidae) in soybean (Ferreira *et al*., 2011), *Tuta absoluta* (Lepidoptera: Gelechiidae) in tomato (Santos *et al*., 2012), and *Chlosynela ciniasaundersii* (Lepidoptera: Nymphalidae) in sunflower (Assis *et al*., 2013) crops. Laboratory experiments with DBM on cabbage confirmed the effect of silicon on its feeding preference, mortality and on the anatomy of their mandibles, indicating its use as a complementary tool in IPM (Freitas *et al*., 2012).

The diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae) is the main pest of cabbage (*Brassica oleracea* var. *capitata*) and frequently infests cabbage crops causing serious damage (Freitas *et al*., 2012). DBM caterpillars feed on leaves leaving them with a perforated appearance (Luz *et al*., 2002). The control of this pest is performed through intense use of insecticides, which has caused selection of resistant populations (Zhuang *et al*., 2011), environmental impacts and risks to human health (Ribas & Matsumura, 2009). Therefore, studies on IPM practices to control this insect have been conducted (Monnerat *et al*., 2000; Neri *et al*., 2005; Gomes *et al*., 2008; Freitas *et al*., 2012).

In this context, the aim of this work was to evaluate the control of *P. xylostella* through foliar fertilization with silicon in cabbage crops.

MATERIAL AND METHODS

The experiment was conducted in the vegetable producing area of Água Limpa Farm of the Universidade de Brasília, Distrito Federal, Brasil (15°57’10”S, 47°57’13”W, 1,100 m altitude), from August to November 2013. According to Köppen classification, the climate of the region is Aw tropical of savannah, with dry winters and rainy summers. The soil of the area is classified as Oxisol (Red-Yellow Latosol, SiBCS) of clayey texture.

Cabbage seedlings were produced in 128-cell polypropylene trays under protected environment using commercial substrate (Bioplant Agrícola Ltda). Seedlings were transplanted with four permanent leaves. The planting area (322 m^2) was divided into 8.96 m^2 plots (2.8 x 3.2m). Plots consisted of four cabbage (cultivar Kenzan) plant rows, 0.4 m between plants and 0.8 m between rows, totaling 28 plants per plot. The evaluation area of each plot consisted of the two central rows (ten plants), from which five plants were evaluated.

The experimental design was of randomized blocks with nine treatments and four replicates, totaling 36 plots. Treatments consisted of weekly foliar fertilization with Agrosilicon® (10.5% Si) (T1), weekly foliar fertilization with Sifol® (12% Si) (T2), chemical insecticide application with deltamethrin 25 g L^{-1}(Decis® 25 EC) (T3), biological insecticide application with *Bacillus thuringiensis*, 33.60 g L^{-1}(Dipel® SC) (T4), Agrosilicon® + deltamethrin 25 g L^{-1} (Decis 25 EC) (T5), Agrosilicon® + *Bacillus thuringiensis*, 33.60 g L^{-1}(Dipel® SC) (T6), Sifol® + deltamethrin 25 g L^{-1}(Decis® 25EC) (T7), Sifol® + *Bacillus thuringiensis*, 33.60 g L^{-1}(Dipel® SC) (T8) and a control with water application (T9).

The eight foliar applications with silicon (Agrosilicon® and Sifol®) were carried out during the cabbage cycle and the first insecticide (deltamethrin) and bio-insecticide (*Bacillus thuringiensis*) applications were performed in the morning, using a 20 L backpack sprayer with conical nozzle, from 30 days after the seedling transplanting until the cabbage heads were completely formed.

Treatments with deltamethrin and *Bacillus thuringiensis*, alone or in combination with silicon, were performed according to the manufacturer recommendations, whenever the economic damage level for DBM, six perfurations in the four central leaves (Castelo Branco *et al*., 1996), was reached. Seven applications were required during the crop cycle.

The number of DBM caterpillars and injuries caused by DBM were weekly evaluated from one week after the first foliar application of silicon until the end of the cycle. The number of perfurations and caterpillars in the four central leaves of the cabbage plant was counted, according to Castelo Branco *et al*. (1996). Cabbage heads were harvested and their aesthetic appearance score was evaluated according to the scale of grades suggested by Castelo Branco *et al.* (1996) and Villas Bôas *et al*. (2004), based on leaf damage caused by DBM, e.g., 1= leaves scraped or undamaged, 2= leaves with small perfurations, little damaged, 3= leaves with large perfurations, damaged, 4= leaves totally damaged, not marketable. The lowest the score, the fewer damages caused by DBM. The cabbage marketable production was also evaluated, considering their fresh weight and head circumference.

Data collected by three independent subjects were submitted to analysis of variance and means were compared by the Scott-Knott test at the 5% of probability.

RESULTS AND DISCUSSION

Number of DBM caterpillars

The lowest number of caterpillars per cabbage plant was found in treatments containing Sifol® (T2, T7 and T8) (Table 1). The mean number of caterpillars in these treatments was significantly lower than those in the treatments with the products deltamethrin (T3) and *Bacillus thuringiensis* (T4), applied alone or in combination with Agrosilicon® (T5 and T6).

The control efficiency of the products deltamethrin and *Bacillus thuringiensis*, applied in combination with Sifol® (T7 and T8), increased in 76 and 82.5%, respectively, compared with their applications alone (T3 and T4). These results denote that the good performance of treatments T7 and T8 is due to the silicon, since there were no significant differences between treatments T2, T7 and T8. The largest caterpillar infestations were observed in treatments with Agrosilicon® (T1) and control (T9).

The number of caterpillars in cabbage plants treated by Agrosilicon® (T1) did not differ from the control (T9) at 37, 58, 65 and 79 days after transplant (DAT). Sifol® treatments in different evaluation periods, alone or in combination, had lower average number of caterpillars, except Sifol® + deltamethrin (T7), at 72 DAT, that showed an average number higher than other treatments performed with Sifol®.

The significant results of silicon treatments with Sifol® in the field confirm laboratorial studies carried out with DBM caterpillars by Freitas *et al.* (2012), in which silicon application (12 kg ha^{-1}) affected feeding of caterpillars causing their death. Goussain *et al.* (2002) found significant effect of silicon fertilization in maize on mortality of second instar caterpillars of *S. frugiperda* fed on leaves treated with this mineral, with twice the mortality occurred in the control (6.8 and 3.3%, respectively). Neri *et al.* (2005) found positive effect of soil and foliar applications of silicon and their interaction with the insecticide lufenuron to control *S. frugiperda* in maize plants, allowing them to reduce 50% of the physiological insecticide rate. Gomes *et al.* (2008) evaluated the control of *Myzus persicae* (Hemiptera: Aphididae) in potato with applications of silicon and imidacloprid and recommended silicon fertilization in IPM in potato. The use of silicon to induce plant resistance to pests was discussed by Camargo *et al.* (2008), Epstein (2009), Reynolds *et al.* (2009) and Kvedaras *et al.* (2009). In the present work, Agrosilicon® had lower efficiency than Sifol® to control DBM.

Injury caused by DBM

The number of perfurations caused by DBM caterpillars on cabbage leaves reduced with the treatments applied (Table 2).

The lowest mean number of perfurations was found in plants treated with Sifol® (T2, T7 and T8), which did not differ from the means found in plants treated with Agrosilicon® + *Bacillus thuringiensis* (T6) (Table 2).

No additional applications of deltamethrin and *Bacillus thuringiensis* were required by plants in T7 (Sifol® + deltamethrin) and T8 (Sifol® + *Bacillus thuringiensis*). Eight foliar fertilizations with Sifol® controlled the DBM. The damage level adopted for DBM, six perfurations in the four central leaves (Castelo Branco *et al*., 1996), was not reached in the treatments T2, T7 and T8. According to Freitas *et al.* (2012), foliar fertilization with silicon affect the feeding preference and anatomy of mandibles of DBM caterpillars, increasing their mortality rates and decreasing the number of perforations in cabbage leaves. Applications of Sifol® with insecticide (T7 and T8), considering a single application, increased the control efficiency, reducing the number of perforations in 71.9% and 50%, respectively, compared with the insecticides deltamethrin (T3= with four applications) and *Bacillus thuringiensis* (T4= with two applications) applied alone.

Injury caused by DBM on the cabbage plants treated with Agrosilicon® (T1) was similar to that observed

Table 1. Number of *Plutella xylostella* caterpillars on cabbage plants (*Brassica oleraceae* var. *capitata* cv. Kenzan), with single and combined applications of silicon and insecticides during the crop cycle. Brasília, UnB, 2013.

Treatment		Days after transplanting							Mean
		37	44	51	58	65	72	79	
T1	Agrosilicon	1.4 b	0.2 a	1.4 b	1.0 b	1.0 b	1.0 b	1.2 b	1.0 c
T2	Sifol	0.2 a	0.0 a	0.0 a	0.2 a	1.0 b	0.2 a	0.0 a	0.2 a
T3	Deltamethrin	1.8 b	1.4 b	1.0 b	0.0 a	0.8 b	0.0 a	0.0 a	0.7 b
T4	*Bacillus thuringiensis*	0.6 a	1.0 b	1.0 b	0.0 a	1.0 b	0.8 b	0.0 a	0.6 b
T5	Agrosilicon + deltamethrin	1.2 b	1.0 b	1.0 b	0.0 a	0.2 a	1.0 b	0.0 a	0.6 b
T6	Agrosilicon + *B. thuringiensis*	0.6 a	0.4 a	1.2 b	0.0 a	0.4 a	1.4 b	0.0 a	0.6 b
T7	Sifol + deltamethrin	0.2 a	0.0 a	0.0 a	0.0 a	0.0 a	1.0 b	0.0 a	0.2 a
T8	Sifol + *B. thuringiensis*	0.4 a	0.0 a	0.0 a	0.0 a	0.0 a	0.4 a	0.0 a	0.1 a
T9	Control	1.2 b	1.6 b	2.6 c	1.2 b	0.6 b	0.4 a	0.0 a	1.1 c

Means followed by same letters in the columns do not differ, Scott-Knott test at 5%.

Table 2. Number of perfurations caused by *Plutella xylostella* caterpillars on cabbage plants (*Brassica oleraceae* var. *capitata* cv. Kenzan), with singly and combined applications of silicon and insecticides. Brasília, UnB, 2013.

Treatment		Days after transplanting							Mean
		37	44	51	58	65	72	79	
T1	Agrosilicon	6.4 b	7.0 b	6.2 b	10.0 b	10.8 b	6.2 b	5.4 b	7.4 c
T2	Sifol	1.2 a	2.8 a	2.6 a	3.2 a	3.0 a	1.0 a	3.6 a	2.5 a
T3	Deltamethrin	8.6 b	8.8 b	6.0 b	4.6 a	4.0 a	4.4 b	2.0 a	5.5 b
T4	*Bacillus thuringiensis*	4.4 a	4.0 a	5.4 b	4.7 a	3.2 a	6.6 b	2.2 a	4.4 b
T5	Agrosilicon + deltamethrin	7.2 b	7.4 b	4.8 b	4.0 a	3.6 a	3.6 a	1.2 a	4.5 b
T6	Agrosilicon + *B. thuringiensis*	3.6 a	3.4 a	4.2 b	3.6 a	2.4 a	5.2 b	1.4 a	3.4 a
T7	Sifol + deltamethrin	1.6 a	2.2 a	0.2 a	2.6 a	1.6 a	1.6 a	1.0 a	1.5 a
T8	Sifol + *B. thuringiensis*	2.2 a	2.0 a	1.0 a	3.4 a	1.3 a	2.0 a	3.4 a	2.2 a
T9	Control	9.6 b	10.2 b	16.2 c	12.6 b	8.4 b	8.0 b	6.4 b	10.2 d

Means followed by same letters in the columns do not differ, Scott-Knott test at 5%.

Table 3. Average head weight, circumference and *Plutella xylostella* (DBM) aesthetic score for cabbage plants (*Brassica oleracea* var. *capitata* cv. Kenzan), with single and combined applications of silicon and insecticides during the crop cycle. Brasília, UnB, 2013.

Treatment		Average head weight (g)	Circumference (cm)	Aesthetic score (1 to 4)
T1	Agrosilicon	713.0 a	45.9 a	2.2 c
T2	Sifol	722.8 a	47.1 a	1.0 a
T3	Deltamethrin	603.2 a	44.1 a	2.6 c
T4	*Bacillus thuringiensis*	725.0 a	46.7 a	1.8 b
T5	Agrosilicon + deltamethrin	643.4 a	45.1 a	3.2 d
T6	Agrosilicon + *B. thuringiensis*	715.4 a	45.2 a	2.2 c
T7	Sifol + deltamethrin	675.2 a	43.0 a	1.0 a
T8	Sifol + *B. thuringiensis*	1041.6 b	53.1 a	1.0 a
T9	Control	602.0 a	43.4 a	3.6 d

Scores given according to the scale suggested by Castelo Branco *et al.* (1996) (1= leaves scraped or undamaged, 2= leaves with small perfurations, little damaged, 3= leaves with large perfurations, damaged, 4= plants with leaves totally damaged, not marketable). The lowest the score, the fewer damages caused by DBM.

in the control (T9) during different evaluation periods, except at 51 DAT. Treatments composed by Sifol®, alone or in combination, showed lower mean number of perfurations caused *by P. xylostella* in all evaluation dates.

Although Agrosilicon® were not as effective as Sifol®, the number of leaf perforations was significantly lower in plants treated with Agrosilicon® + *Bacillus thuringiensis* (T6); a single application of Agrosilicon® + *Bacillus thuringiensis* was sufficient to maintain the DBM below the damage level throughout the crop cycle. According to Bortoli *et al.* (2012), some biological characteristics of *P. xylostella* changed with application of *B. thuringiensis*; the survival of caterpillars and pupae and pupae weight were the most affected biological parameters by this treatment, with lower rates compared with the control. Monnerat *et al.* (2000) assessed effects of *B. thuringiensis* and chemical insecticides on DBM and observed intoxication of caterpillars by *B. thuringiensis*-based bio-insecticides, without affecting their parasitoids, complementing the control of this pest. These results confirm the hypothesis that foliar applications of silicon combined with bio-insecticides can reduce the intensity of *P. xylostella* on cabbage leaves, and can be used as an additional tool to control DBM.

Production and agronomic characteristics of plants

The cabbage head weight from plants treated with Sifol®+ *Bacillus thuringiensis* (1041.6 g) was significantly higher than those observed in other treatments. Cabbage crop yield is variable, usually higher than 50.000 kg ha^{-1}, with head weights of 1.5 to 2.0 kg, according to market preferences (Filgueira, 2008). The cabbage head circumference was not significantly affected by treatments. The lowest score of DBM damages, i.e., best aesthetic aspect, were found in plants treated with Sifol®, and the heads with highest DBM grades, i.e., worse aesthetic aspect, were found in treatments control and T5 (Table 3).

Plants treated with Sifol®, alone or in combination with deltamethrin or *Bacillus thuringiensis*, had lower number of *P. xylostella* caterpillars, fewer leaf perforations and cabbage heads with better commercial value. The mean weight of cabbage heads was significantly higher in the treatment with Sifol®+*Bacillus thuringiensis* (T8). The effect of treatments with Agrosilicon® to control DBM was lower than that with Sifol®. This result can be due to the difference in silicon concentrations of these two sources (Agrosilicon® 10,5% and Sifol® 12%). Fertilization with Sifol®, alone or combined with chemical or biological insecticides, was the best strategy to control DBM, reducing its infestation, plant damage and number of insecticide applications, since the damage level was not reached within these treatments.

The results denote the importance of researches aiming to precise recommend silicon alone or in combined application with chemical and biological insecticides to control and manage *P. xylostella*. The possibility of reducing the number of insecticide applications or using lower rates than those recommended, with positive effects on yield and production costs, are highly required in pest management systems. Thus, foliar application of silicon has significant potential to control DBM in cabbage crops.

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