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RESEARCH ARTICLE

Efficacy of Silicon Formulations on Sugarcane Stalk Borers, Quality Characteristics and Parasitism Rate on Five Commercial Varieties

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Abstract Sugarcane is an important cash crop in Iran and it is exclusively cultivated in more than one hundred hectares of Khuzestan province. One proven and ecologically sound best management practice in sugarcane is application of silicon to mitigate for both biotic and abiotic stresses. It has been proved that silicon can enhance resistance of sugarcane against stalk borers. Also, new hypothesis suggests that silicon may increase attraction of biological control agents to infested plants. Field trials were carried out at Salman-Farsi Agro-Industry Farms to determine the effects of three liquid formulations of silicon against infestations of stalk borer, *Sesamia* spp. and parasitism rates of egg parasitoid *Telenomus busseolae* Gahan using varieties CP57-614, CP48-103, CP69-1062, IRC99-01 and SP70-1143. The experiments were conducted as complete block design with three formulations of silicon. Prior to harvest twenty stalks were selected at random to determine percentage of stalk damage, percentage of bored internodes, length of borer tunnel, number of larvae + pupae per 100 stalks, number of exit holes as well as cane yield quality characteristics. In two consecutive years, the rate of parasitism on treated and untreated plots in each variety were recorded. The results from the present study showed that there were some significant differences between silicon treatments and control on borer's damage and quality sugarcane parameters but in some cases the differences were not significant. The present findings on the efficacy of silicon treatments on biological control suggested that silicon enhanced biological control attractions as shown by parasitism rate.

Keywords Biological control · Quality parameters · Resistance · Best management practice · Silicon

Introduction

Sugarcane (hybrids of *Saccharum*) is a strategically important crop that has a profound economic impact on social and governmental issues in many countries around the world [1]. The most important region for production of sugarcane in Iran is the province of Khuzestan where it is cultivated on more than one hundred thousand hectares per annum [2]. As a monoculture system, sugarcane is vulnerable to many abiotic and biotic stresses including insect herbivores and pathogens, and among them lepidopterous stalk-borers are the most detrimental and harmful insect pests of sugarcane in many sugar producing countries [3–7]. Two species of stalk borer are important in Khuzestan. Both are of the genus of *Sesamia* (Lepidoptera: Noctuidae). They are *Sesamia cretica* Led and *S. nonagrioides* Lef. [8]. *Sesamia* moth borers are capable to decrease the plant stands before young shoots form internodes and reduction in stalk gross weight and sugar quality after formation of internodes [9–11]. Infestations can reduce the amount and purity of sugarcane juice and entrance holes provide entrance of the red-rot pathogen [4, 12].

Management of moth borers in sugarcane ecosystem is complicated and several control options are used around

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the world. These tactics include biological control [13, 14], cultural practices [15–17], varietal resistance [18, 19] and insecticide sprays [20]. Using silicon in both laboratories and small and large scale field trials against harmful arthropods is relatively a new approach in integrated pest management [21–24]. Silicon is the second most abundant element in the earth's crust [25] and with no doubt this element is beneficial for plants exposing to abiotic (heavy metal toxicity, drought and salinity) and biotic (arthropod pests and pathogens) stresses [26, 27]. Silicon has several positive roles in plant physiology and many trials have been done to understand benefits of silicon in higher plants [27].

Silicon is absorbed by plants in the form of monosilicic acid ($Si(OH)_4$), the most common form of Si in the soil solution at a pH below 9 [28]. After uptake of silicon, silicic acid becomes concentrated due to water loss or physiological processes, and finally is concentrated as silica gel [29]. Among agricultural crops, sugarcane is the most accumulator of silicon and can use it efficiently in plant growth and resistance to insects [26, 30]. In sugarcane, silicon has both direct and indirect effects on insect pests. Direct effects include in reduction of insect growth, reproduction and damage on stalks and leaves with silicon application [22–24]. Indirect effects result in delays insect development with a delay in crop penetration, resulting in a greater exposure to beneficial natural enemies, adverse climatic conditions, and increase in exposure to chemical sprays [21]. Another new role of silicon is enhancing natural enemies' attraction to infested plants and increasing biological control performance by predators and parasitoids [31–33]. In sugarcane fields in Iran, *Telenemus busseolae* Gahan (Hymenoptera: Scelionidae) is the main biological control agent of stalk borers and this species is now produced in insectariums and widely released in sugarcane fields in Khuzestan province [14]. In response to arthropod pest damage, plants produce a variety of physiological changes and herbivore-induced plant volatiles (HIPVs) [34]. Recent studies indicated that silicon can increase the plant defense enzymes [35, 36] and interestingly amplifies production and emission of HIPVs [31, 32]. Silicon has clear impact on tri-trophic level and has effect on plant attractiveness to parasitoids and predators by changing level of HIPVs. To date very little published literature exists, and today, no published documents on effects of silicon application on natural enemy biological control performance on sugarcane is available. The objective of the present study is to compare liquid silicon fertilizer treatments on sugarcane stalk borers' damage, to investigate the effects of silicon treatments on cane quality characteristics of five commercial varieties and the assessment of parasitism of stalk borers' eggs on silicon treated plots under field conditions.

Material and Methods

Plant Material and Cultivation

Five sugarcane varieties: CP57-614 (Canal Point USA), CP48-103 (Canal Point USA), CP69-1062 (Canal Point USA), IRC99-01 (cross made in Cuba and selected in Iran) and SP70-1143 (Sao Paulo, Brazil) with different susceptibility to stalk borers [37] were cultivated using standard tillage, followed by ridging at 1.8-m furrow spacing. Before planting of sugarcane varieties, phosphorous fertilizer (Super phosphate triple/300 kg per hectare) were added with a pneumatic fertilizer machine based on standard procedure of sugarcane nutrient treatments in Iran. Each sugarcane variety was planted as billets (50–70 cm and free from stalk borers infestation). After following planting of seed cane sets all furrows were treated with Atrazine and Sencor herbicides (3 + 2 kg per hectare) based on local recommendations as early post emergence application for suppressing of annual weeds. During the crop growth, no chemical herbicide was used at experimental plots and all weeds were removed by hand.

Experimental Design and Liquid Silicon Fertilizer Treatments

A complete block design (to assess the effects of silicon treatment on each variety separately) with four blocks was used at Salman Farsi Agro-Industry, Ahwaz-Iran. Each experimental plot (block) consisted of four rows, 8 meter long and 1.8 meter spaced (between two furrows) in different points of field (43.8 m^2 for each plot). This plot configuration was used for sugarcane experiments because plots for trials in sugarcane are recommended to be at least 25-m^2. Each plot was separated by a 3.6-m gap as buffer. The five varieties were treated twice with three different liquid silicon fertilizers as foliar application. The three silicon treatments were, 1. Agrisil (potassium silicate, 28 % silicic acid, potassium salt and potassium as silicate, PQ Corporation, South Africa Ltd), 2. Potassium silicate formulation (17.3 % silicon with 13.5 % potassium as silicate, NTS Corporation, Australia), and 3. Silamol, a silicon based formulation (17.5 % silicon, Roam-Chemie, Belgium). They were used as the source of soluble silicon. All treatments were applied as foliar applications by a 15-l volume knapsack sprayer (Hardi International, England) at the rate of 1.5 l per hectare, in three periods, in mid-April (tillering stage), mid-May (stem elongation stage) and early-June (stem elongation stage) 2012. Control plots were kept free of silicon and water. At the harvest of each variety plots, 20 whole stalks were selected randomly from the central rows (for omitting of border effects of sampling from border rows) of each experimental plot [16] for *Sesamia* spp. damage assessments. The leaves of all stalks were completely removed (at the natural breaking point; after the last fully expanded internode) before weighing of stalk samples. The number of internodes per stalk, number of bored internodes per stalk, number of moth borers emergence exit holes, percentage of stalk damage, percentage of bored internodes, length of each borer tunnel (mm), number of live borers per stalks (expressed as *Sesamia* larvae or pupa per stalk, S/100), height of the plant (at the natural breaking point) and weight of stalks on each plot were determined and recorded. For assessing the effects of liquid silicon fertilizer treatments on sugar quality, prior to harvest on 2013, 20 whole stalks (in each plot) were selected randomly. These stalks were topped by hand at the natural breaking point (after the last fully expanded internode). Each bundle of 20 stalks was fed through a chipper disintegrator and sub-samples were analyzed for cane juice quality (%Pol, Brix, Purity and Refined Sugar). The %polarity (%Pol) and %Brix of cane juice were obtained by polarimeter (Optical Activity Ltd, England) and refractometer (Index Instruments, England).

Effects of Silicon on Natural Enemy Parasitism

The procedure of this trial was similar to the previous experiment with four replications. The five sugarcane varieties as mentioned earlier were planted. Foliar application of the three silicon fertilizers as referred earlier were applied by using a 15-l volume knapsack sprayer (Hardi International, England) at the rate of 1.5 l per hectare, in two periods, in mid-April (tillering stage) and mid-May (stem elongation stage) 2012 and 2013. Each silicon and control treatments were separated by a 10 m as buffer. No chemical herbicide and insecticide were used in treated and control plots. For assessing the effect of silicon fertilizers on natural enemy attraction and role of silicon on rate of parasitism, this trial was done continuously during 2012 and 2013. The main parasitoid of stalk borers' eggs was *Telenomus busseolae* Gahan (Hymenoptera: Scelionidae). 75 days after second application of silicon (early August) in each plot, twenty whole stalks were selected randomly, and brought to laboratory for subsequent evaluation of parasitism. Each stalk was investigated for egg batches of moth borers. As oviposition of stalk borers is under the leaf sheaths [37]; egg batches were taken out from stalks with garden scissors and the total number of eggs was recorded. All of the eggs were counted, put into U-shape glass tubes (16 × 2.5 cm) for 16 days, and then the tubes were placed in incubator (Memmert Company, Germany) at 27 ± 1 °C and 60 ± 5 % RH (parasitised eggs will become black after 3 or 4 days). Rate of parasitism was calculated as under.

$$\text{Rate of parasitism} = \frac{\text{Number of parasitized eggs in each plot}}{\text{Total eggs collected in each plot}} \times 100$$

Data Analysis

All data were analyzed for normality and homogeneity of variance (Bartlett's test), and appropriate transformations (ArcSin, log x and Log x + 1) were applied where normality and homogeneity were not met, before analysis of variance was performed. All analysis was performed with SPSS software version 16 [38] and Tukey HSD test was used for comparison of means between treatments. Untransformed means and standard errors are shown in the tables.

Results and Discussion

Results of the current study indicated that silicon liquid fertilizers had some impact on stalk borers' damage rate. In case of variety CP57-614, silicon formulation Agrisil followed by NTS and Silamol reduced significantly the percent of stalk damage, borer exit holes, length of borer tunnel and increased the height of canes. But there were no significant differences between treatments and control on percent of internodes bored index (Table 1).

For the variety CP48-103, silicon fertilizers were significantly different versus control on % stalk damage, percent of internodes bored, height of canes, borer exit holes and length of borer tunnel. However, there were no significant differences between silicon treatments on all measured factors (Table 1).

For the variety CP69-1062, the results indicated that there were significant differences between silicon treatments and control in the case of percent of stalk damage, percent of internodes bored, borer exit holes and length of borer tunnel. But there were no significant differences among silicon treatments and control for height of canes (Table 1).

The results on variety SP70-1143 demonstrated that silicon formulations showed non-significant effects on percent of stalk damage, percent of internodes bored, borer exit holes and length of borer tunnel. These formulations have significant effects on cane height which increased significantly against control (Table 1).

In case of variety IRC99-01, the results illustrated that the liquid silicon fertilizers could decrease stalk damage against control group, although they were not significant. But for percent of internodes bored, height of canes, borer exit holes and length of borer tunnel, there were significant differences between silicon treatments and control (Table 1).

Table 1 Effect of different formulations of silicon exposed to different varieties

Variety	Treatment	Stalk damage (%)	Internodes bored (%)	Height (cm)	No. exit holes	length of tunnel
CP57-614	Agrisil	18.75 ± 1.25b	1.52 ± 0.17a	205.15 ± 1.05a	0.26 ± 0.02b	17.50 ± 0.73b
	NTS	22.50 ± 1.44ab	1.90 ± 0.23a	204.23 ± 0.42ab	0.30 ± 0.03ab	24.45 ± 2.54ab
	Silamol	23.75 ± 1.25ab	2.05 ± 0.13a	205.48 ± 0.61a	0.32 ± 0.03ab	25.05 ± 0.57ab
	Control	27.50 ± 3.22a	2.42 ± 0.30a	201.24 ± 1.13b	0.45 ± 0.06a	27.61 ± 3.11a
	F3,15, P	3.33, 0.056	2.79, 0.086	5.03, 0.017	3.99, 0.035	4.39, 0.026
CP48-103	Agrisil	35.00 ± 2.04b	4.40 ± 0.29b	199.82 ± 0.40a	0.68 ± 0.05b	41.63 ± 2.39b
	NTS	36.25 ± 1.25ab	4.47 ± 0.18b	199.77 ± 0.23a	0.67 ± 0.03b	43.20 ± 1.67b
	Silamol	36.25 ± 1.25ab	4.57 ± 0.27b	200.00 ± 0.26a	0.73 ± 0.07b	43.68 ± 1.87b
	Control	42.50 ± 1.44a	6.30 ± 0.15a	196.36 ± 1.13b	1.06 ± 0.02a	55.96 ± 1.97a
	F3,15, P	4.89, 0.019	14.9. 0.001	7.75, 0.004	13.65, 0.001	11.01, 0.001
CP69-1062	Agrisil	36.25 ± 1.25b	4.45 ± 0.31b	203.50 ± 2.41a	0.70 ± 0.04b	41.12 ± 2.04c
	NTS	40.00 ± 2.04b	5.15 ± 0.26b	206.41 ± 1.26a	0.86 ± 0.06b	46.73 ± 2.03bc
	Silamol	41.25 ± 1.25b	5.42 ± 0.30b	205.77 ± 0.19a	0.96 ± 0.05b	49.63 ± 1.59b
	Control	53.75 ± 2.39a	8.52 ± 0.31a	201.23 ± 1.29a	1.37 ± 0.08a	76.67 ± 1.43a
	F3,15, P	17.72, 0.001	35.77, 0.001	2.44, 0.11	20.78, 0.001	77.5, 0.001
SP70-1143	Agrisil	20.00 ± 2.04a	2.15 ± 0.19a	202.44 ± 0.34a	0.33 ± 0.03a	23.20 ± 2.35a
	NTS	20.00 ± 2.04a	2.22 ± 0.30a	202.32 ± 0.24a	0.35 ± 0.05a	23.77 ± 2.74a
	Silamol	21.25 ± 1.25a	2.40 ± 0.17a	201.20 ± 0.04a	0.37 ± 0.02a	24.66 ± 1.41a
	Control	25.00 ± 2.04a	2.82 ± 0.25a	198.86 ± 0.81b	0.48 ± 0.04a	28.75 ± 2.27a
	F3,15, P	1.59, 0.24	1.59, 0.24	13.02, 0.001	2.95, 0.076	1.24, 0.34
IRC99-01	Agrisil	25.00 ± 2.04a	2.32 ± 0.10b	201.66 ± 1.08a	0.37 ± 0.03b	25.65 ± 1.10b
	NTS	26.25 ± 1.25a	2.47 ± 0.07b	202.40 ± 0.38a	0.38 ± 0.02b	28.81 ± 1.02b
	Silamol	20.50 ± 6.27a	2.55 ± 0.13ab	202.12 ± 0.83a	0.41 ± 0.01ab	29.18 ± 1.22ab
	Control	32.50 ± 1.44a	2.97 ± 0.14a	198.02 ± 0.28b	0.51 ± 0.02a	34.57 ± 1.83a
	F3,15, P	2.07, 0.15	5.71, 0.012	7.96, 0.003	6.64, 0.007	7.67, 0.004

Means followed by the same letter in each column within the same variety are not significantly different using Turkey's Test at $P < 0.05$

The number of immature stages per 100 stalks on five sugarcane varieties is presented in Table 2. In CP57-614, CP48-103 and SP70-1143, although silicon treatments reduced the number of *Sesamia* immature stages per 100 stalks, there were no significant differences between silicon treatments and control group. But in CP69-1062 and IRC99-01 differences between silicon formulations and control group was significant (Table 2).

The efficacy of different silicon formulations on quality characteristics and yield components of five sugarcane varieties are shown on Tables 3, 4, 5, 6 and 7. The results presented that there were non-significant differences on percent of Brix but the index of percent of Pol, percent of refined sugar, purity and weight of one stalk were significantly different between silicon treatments and control (Table 3).

In case of variety CP48-103, the overall results indicated that there were non-significant differences between silicon treatments and control for percent of Pol, percent of Brix, purity and weight of one stalk but in general, silicon treatments increased the amount of measured characteristics. In this variety, silicon treatments significantly increased percent of refined sugar in comparison with control group (Table 4).

In CP69-1062 variety, effectiveness of silicon formulations on percent of Pol, Percent of refined sugar, purity and weight of one stalk were significantly different from control group, but the results on percent of Brix were not significant (Table 5).

The results on SP70-1143 variety indicated that only refined sugar data was significantly different among silicon treatments and control group, and other measured factors including percent of Pol, percent of Brix, purity and weight of one stalk were non-significant among four treatments (Table 6).

Table 7 showed that in variety IRC99-01, only percent of Pol and weight of one stalk showed significant difference between silicon treatments and control group, whereas other tested factors including percent of Brix, purity and percent of refined sugar were non-significant (Table 7).

Effects of silicon application on attraction of parasitoids and parasitism level are shown in Fig. 1. The rate of parasitism in CP57-614 variety indicated that there were

Table 2 Number of immature stages per 100 stalks on five sugarcane varieties exposed to different formulations of silicon

Treatment	CP57-614	CP48-103	CP69-1062	SP70-1143	IRC99-01
Agrisil	20.00 ± 2.04a	26.25 ± 1.25a	26.25 ± 1.25b	22.50 ± 1.44a	22.50 ± 1.44b
NTS	18.75 ± 2.39a	27.50 ± 1.44a	27.50 ± 1.44b	22.50 ± 1.44a	21.25 ± 1.25b
Silamol	20.00 ± 2.04a	27.50 ± 1.44a	27.50 ± 1.44b	23.75 ± 1.25a	23.75 ± 1.25ab
Control	23.75 ± 1.25a	30.00 ± 2.04a	37.50 ± 1.44a	27.50 ± 1.44a	28.75 ± 1.25a
F3,15, P	1.2, 0.35	1.0, 0.43	14.07, 0.001	2.87, 0.081	6.38, 0.008

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

Table 3 Effects of silicon formulations on quality characteristics of CP57-614 variety

Treatment	Refined sugar (%)	Purity	Brix (%)	Pol (%)	Weigh of one stalk (g)
Agrisil	10.92 ± 0.07a	88.31 ± 0.23a	19.92 ± 0.04a	17.59 ± 0.08a	758.7 ± 4.26ab
NTS	10.94 ± 0.03a	88.40 ± 0.09a	19.95 ± 0.00a	17.63 ± 0.02a	761.7 ± 4.71a
Silamol	10.95 ± 0.05a	88.35 ± 0.11a	19.92 ± 0.11a	17.60 ± 0.10a	760.0 ± 3.53a
Control	10.46 ± 0.11b	87.35 ± 0.29b	19.42 ± 0.28a	16.97 ± 0.20b	743.7 ± 2.39b
F3,15, P	10.09, 0.001	8.29, 0.008	2.72, 0.091	6.69, 0.007	4.69, 0.022

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

Table 4 Effects of silicon formulations of on quality characteristics of CP48-103 variety

Treatment	RS (%)	Purity	Brix (%)	Pol (%)	Weigh of one stalk (g)
Agrisil	10.92 ± 0.06ab	90.22 ± 0.11a	19.20 ± 0.09a	17.32 ± 0.09a	763.75 ± 6.88a
NTS	10.94 ± 0.09a	90.37 ± 0.34a	19.18 ± 0.15a	17.35 ± 0.13a	767.50 ± 5.95a
Silamol	10.96 ± 0.03a	90.25 ± 0.22a	19.24 ± 0.07a	17.37 ± 0.04a	767.50 ± 1.44a
Control	10.67 ± 0.03b	89.70 ± 0.21a	19.02 ± 0.10a	17.07 ± 0.06a	750.00 ± 2.04a
F3,15, P	4.94, 0.018	1.59, 0.24	0.74, 0.55	2.38, 0.12	3.11, 0.067

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

Table 5 Effects of silicon formulations on quality characteristics of CP69-1062 variety

Treatment	RS (%)	Purity (%)	Brix	Pol	Weigh of one stalk (g)
Agrisil	11.28 ± 0.02a	89.52 ± 0.22a	20.10 ± 0.05a	17.99 ± 0.02a	717.50 ± 3.22a
NTS	11.33 ± 0.05a	89.32 ± 0.14a	20.27 ± 0.13a	18.10 ± 0.09a	720.00 ± 4.08a
Silamol	11.13 ± 0.10a	89.27 ± 0.35a	19.87 ± 0.18a	17.76 ± 0.15ab	716.25 ± 3.14a
Control	10.79 ± 0.08b	88.00 ± 0.22b	19.77 ± 0.13a	17.40 ± 0.12b	695.00 ± 4.56b
F3,15, P	10.36, 0.001	7.69, 0.004	2.69, 0.093	7.74, 0.004	9.25, 0.002

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

Table 6 Effects of silicon formulations on quality characteristics of SP70-1143 variety

Treatment	RS (%)	Purity (%)	Brix	Pol	Weigh of one stalk (g)
Agrisil	10.92 ± 0.06ab	90.22 ± 0.11a	19.20 ± 0.09a	17.32 ± 0.09a	763.75 ± 6.88a
NTS	10.94 ± 0.09a	90.37 ± 0.34a	19.18 ± 0.15a	17.35 ± 0.13a	767.50 ± 5.95a
Silamol	10.96 ± 0.03a	90.25 ± 0.22a	19.24 ± 0.07a	17.37 ± 0.04a	767.50 ± 1.44a
Control	10.67 ± 0.03b	89.70 ± 0.21a	19.02 ± 0.10a	17.07 ± 0.06a	750.00 ± 2.04a
F3,15, P	4.93, 0.018	1.58, 0.24	0.73, 0.55	2.38, 0.12	3.11, 0.068

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

Table 7 Effects of silicon formulations on quality characteristics of IRC99-01 variety

Treatment	RS (%)	Purity (%)	Brix	Pol	Weigh of one stalk (g)
Agrisil	0.67 ± 0.10a	86.97 ± 0.21a	9.96 ± 0.16a	7.36 ± 0.16ab	840.00 ± 5.40a
NTS	0.72 ± 0.08a	87.00 ± 0.20a	0.05 ± 0.08a	17.45 ± 0.11a	841.25 ± 5.15a
Silamol	0.64 ± 0.07a	86.75 ± 0.25a	0.03 ± 0.05a	7.38 ± 0.09ab	838.75 ± 3.75ab
Control	0.43 ± 0.01a	86.17 ± 0.14a	9.63 ± 0.11a	16.92 ± 0.08b	821.25 ± 1.25b
F3,15, P	2.55, 0.11	3.38, 0.54	3.04, 0.071	4.19, 0.03	4.98, 0.018

Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

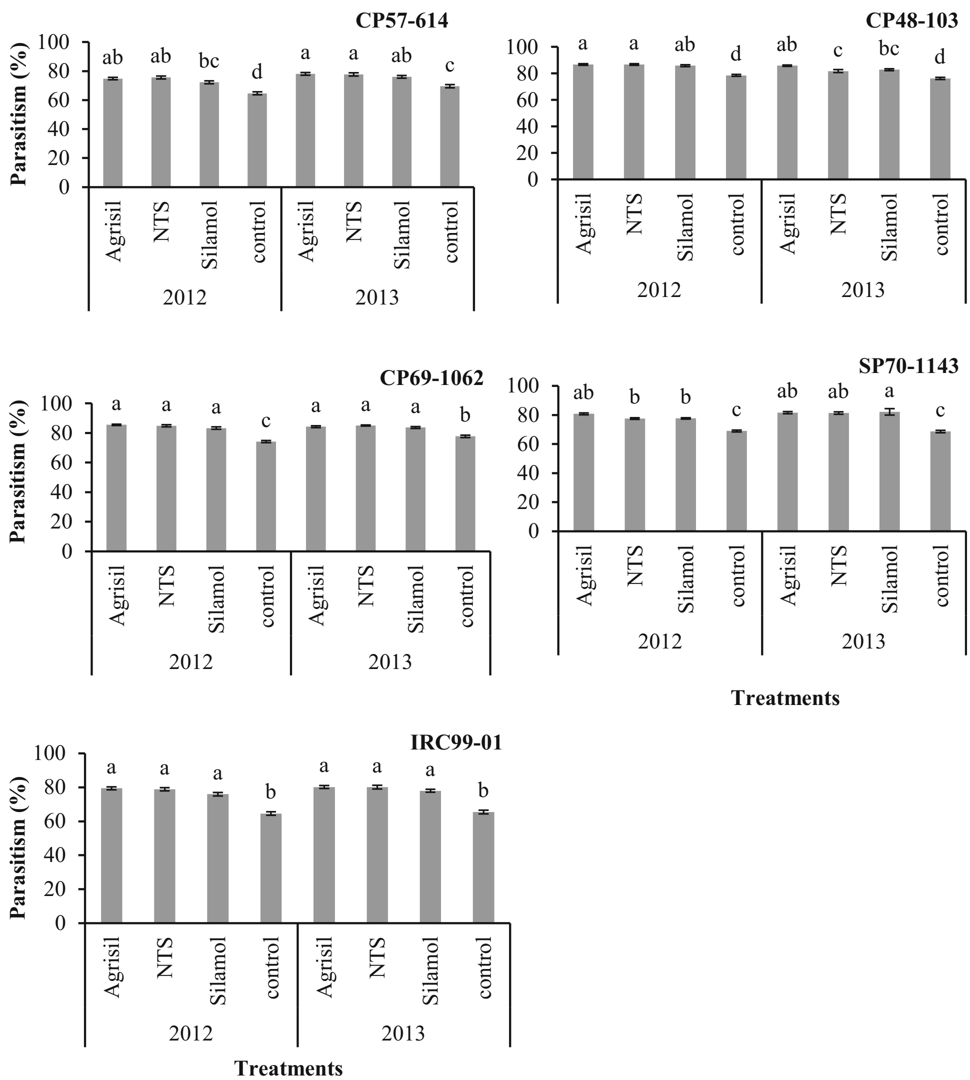

Fig. 1 Rate of egg parasitism of *Sesamia* spp. by *T. busseolae* on different varieties exposed to silicon formulations. Means followed by the same letter at each column are not significantly different using Turkey's Test at $P < 0.05$

significant differences between silicon treatments over the control on the rate of parasitism during both years (2012 and 2013). The highest rates observed on Agrisil and NTS were 78.1 and 77.6 % respectively and the least rate was observed on control (64.6 %).

The results on parasitism level in varieties CP48-103 and CP69-1062 explained that the least level of parasitism belonged to control group and the level of parasitism on treated plots was significantly different with control during both the years.

In the case of varieties SP70-1143 and IRC99-01, the results showed that there were significant differences between treated silicon plots and control group during year 2012 and 2013, but no significant differences existed among silicon treatments.

Among higher plants, sugarcane is the most silicon-accumulating agricultural crops and it has been proved that sugarcane can use this element significantly for growth, development and crop vigor [21, 29]. In addition to crop improvement, silicon has distinctive role in plant resistance to several arthropods pests [22–24, 39]. Accumulated silicon in plant tissues of sugarcane provides a rigid physical barrier against chewing and probing of insect pests [21].

In the present work, application of liquid silicon fertilizers affected level of stalk borers' damage in five tested sugarcane varieties. Significant reduction in stalk damage caused by *Sesamia* spp. were observed in CP57-614, CP69-1062 and CP48-103 varieties but in two other tested varieties IRC99-01 and SP70-1143, the reduction of stalk damage was not significant. Percent of internodes bored were significantly decreased on CP69-1062, CP48-103 and IRC99-01 but in the varieties CP57-614 and SP70-1143 this reduction was not significant. Significantly reduced length of borer tunnel was also recorded in the varieties CP57-614, CP69-1062, IRC99-01 and CP48-103 but was non-significant in SP70-1143 although the tunnel length bored was lower in treated plots.

Studies indicated that silicon deposition in different plant tissues provided a mechanical barrier against probing and chewing insects, and silicification of cells in plant tissues impose a rigid obstacle in the feeding of harmful arthropods [27, 40, 41]. In a recent study, Korndörfer et al. [22] applied potassium silicate on some sugarcane cultivars against sugarcane spittle bug *Mahanarva fimbriolata* Stål (Hemiptera: Cercopidae) under laboratory conditions. The authors found silicon-treated sugarcane amplified nymphal mortality, increased duration of immature stages, and reduced longevity of adult male and female spittlebug, *M. fimbiolata*.

There are relevant published data which indicate that silicon has a great role in plant by inducing defense against stalk borers in row crops [24, 42, 43]. Djamin and Pathak [43] declared that silicon treated rice cultivars showed antibiosis reactions including reduced survival, and mandible deformity and malfunction and hence reduction in feeding behavior. In corn, Sétamou et al. [44] found that application of silicon can reduce larval survival and adult emergence of *Sesamia calamistis* (Lepidoptera: Noctuidae). In a recent study, Keeping et al. [42] applied calcium silicate to induce resistance of three sugarcane cultivars against *Eldana saccharina* (Lepidoptera: Pyralidae). The authors indicated that by the application of silicon percent of stalk damage, percent of internodes bored, length of borer tunnel and number of borers per 100 stalks, in three tested varieties were reduced on both plant and ratoon cane. The present findings showed that some significant reductions on borers' damage are obtained although in some cases the results were non-significant on different varieties.

In other crops, foliar application of silicon showed positive results in reduction of insect infestation. For example, de Almeida et al. [45] applied foliar application of calcium silicate of eggplants and the authors concluded that silicon can cause higher rate of mortality on *Thrips palmi* (Thysanoptera: Thripidae). Massey et al. [46] tested sodium silicate on five grass species against the folivorous feeder, *Spodoptera exempta* (Lepidoptera: Noctuidae). In a preference test, the authors found that *S. exempta* avoided feeding on plants with high content of silica rather than control. The larval growth rate of *S. exempta* was reduced on high silica-content plants by 40–66 % in comparison to low silica plants.

The role of silicon on attraction of natural enemies and increasing biological control is not fully studied. The only published reference [31] declared that silicon may increase induced chemical defenses against arthropod attack by altering and enhancing the volatile compounds emitted by an attacked plant. The authors declared that silicon-treated plants with a pest-infestation were more attractive to natural enemies than Si-untreated cucumber plants with a pest infestation. Furthermore, this effect was reflected in enhanced biological control in the field. The present findings are the first reported results under sugarcane ecosystem in two consecutive years and showed that in all five tested varieties the rate of parasitism in treated plots with different formulations of silicon were significantly higher than that of control plots. Kvedaras et al. [31] suggested that silicon had positive effects on natural enemy recruitment and attraction under pest infestation. The present results support the findings and hypothesis of Kvedaras et al. [31]. This area of research on the role of silicon and biological control agents' attraction is a new momentum for other workers.

Conclusion

Silicon can be accumulated in plant's tissues and can act as a physical barrier against insect pests including stalk borers. Other action of silicon is enhancing natural enemies on treated plants and increasing rate of parasitism. In addition, studies related to efficacy of other commercialized silicon products from different countries on other sugarcane varieties and under different soil conditions would be interesting and results may be incorporated to understand the role of silicon on biotic stresses.

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Compliance with Ethical Standards

Conflict of interest This paper is one part of first author's Ph.D. thesis and published here with the agreement of Islamic Azad University, Arak branch. There is no conflict of interest among the authors.

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