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Improving biological control of stalk borers in sugarcane by applying silicon as a soil amendment

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Abstract: The sugarcane stalk borers, *Sesamia* spp. (Lepidoptera: Noctuidae) are the most destructive sugarcane insect pests in Iran. The efficiency of *Telenomus busseolae* Gahan (Hymenoptera: Scelionidae) used alone or in combination with silicon fertilization was investigated for controlling the sugarcane stalk borers under field conditions. The treatments were: a combination of silicon plus multiple releases of 2,500 *T. busseolae*, and multiple releases of 5,000, 2,500 and 1,250 *T. busseolae* alone. Plots receiving no soil amendment or parasites were included as the controls. Three weeks after the first application of each treatment, 100 shoots were selected randomly from each plot and the percentage of dead heart was determined. Then, three months after the first application of parasites, the percentage of stalks damaged, the percentage of internodes bored, and the level of parasitism were determined. Finally, at harvest the percentage of stalks damaged, the percentage of internodes bored, and sugarcane quality characteristics were determined. Results indicated that the efficiency of parasitism increased when combined with an application of silicon fertilizer. The release of 2,500 *T. busseolae* followed by an application of silicon fertilizer decreased dead hearts to 4%, while 12% dead hearts was observed in the control plots. For the combination treatment, the percentages of stalk damage were 1.5% and 17.2%, at 3 weeks and 3 months after time release, respectively. However, the percentages of stalk damage were 35.2% and 51% when no treatment was applied. Cane quality was significantly higher with the application of silicon fertilizer plus the release of 2,500 *T. busseolae*, followed by releasing 5,000 Hymenoptera. The level of parasitism was also greater when parasites were released in combination with an application of silicon. We conclude that biological control by egg parasitoids can be enhanced with concurrent applications of silicon fertilizer as a soil amendment and thereby creating a more robust, Integrated Pest Management (IPM) program of stalk borers in Iranian sugarcane fields.

Key words: Khuzestan, *Sesamia*, silicon, stalk borers, sugarcane, *Telenomus busseolae*

Introduction

Sugarcane (interspecific hybrids of *Saccharum*) is a strategically important cash crop that has a prominent economic role in social and governmental issues in many countries around the globe (James 2004). The most important region for the production of sugarcane in Iran is the province of Khuzestan where it is cultivated on more than 100,000 ha per annum, under the supervision of ten, government run sugar agro-industries (Sadeghzadeh-Hemayati *et al*. 2011).

As a mono-cultural system, sugarcane is sensitive to a wide range of biotic stresses including insect pests and pathogens. Lepidopteran stalk borers are the most destructive and harmful arthropod pests of sugarcane in many sugar producing countries (Kuniata *et al*. 2001; Sallam 2006; Rutherford and Conlong 2010; Showler and Reagan 2012; Goebel *et al*. 2014). Two species of pink stalk borers, *Sesamia cretica* Lederer and *Sesamia nonagrioides* Lefebvre (Lepidoptera: Noctuidae), are important insect pests in Khuzestan Province. Both are capable of causing economic damage to the varieties grown in Khuzestan Province and affect sugar yields by direct and indirect damage (Askarianzadeh *et al*. 2008).

Direct effects are caused by larval feeding. The larvae cause damage by opening galleries which results in gross weight loss of cane, thereby reducing the quality of the cane juice. When the attack occurs at the area of crop elongation, the apical meristem is usually damaged and the symptom of that damage is easily recognized by its yellowing to whitening and eventually drying of the leaf spindle. This condition is referred to as "dead heart" (Goebel *et al*. 2011; Showler and Reagan 2012). During internode formation, infestation by stalk borers can interrupt the transportation of nutrients, thus preventing the full development of internodes. Tunneling into stalks leads to reduced growth, which weakens the stalks and results in stalk breakage. When severely damaged, stalks can rot, apical dominance can be lost, resulting in the formation of side-shoots, and late tillering may occur (Long and Hensley 1972).

The indirect effects caused by the stalk borers are due to the inversion of sucrose stored in the sugarcane stalk caused by fungi, predominantly *Fusarium moniliforme* Sheld and *Colletotrichum falcatum* Went, that gain access into stalks through the entrance holes made by feeding larvae. The fungi (*F. moniliforme* and *Penicillium cyclopium*)

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cause a reduction of energy consumption during the inversion process, and the sugars resulting from this split do not crystallize during the industrial processes. In addition, contamination of the broth and fungi causes losses in the production of sugar and alcohol (Zhen *et al*. 1988; Showler and Reagan 2012).

Effective management of lepidopteran borers through area-wide pest management programs is multi-strategic and requires several ecologically and sound control methods (Rutherford and Conlong 2010). One environmental-friendly method is biological control by releasing parasitic Hymenoptera for control of lepidopteran borers. *Telenomus* spp. and *Trichogramma* spp. are parasitoids of stalk borer eggs, while *Cotesia* spp. are widely distributed larval parasitoids. Both groups are effective in reducing damage by stalk borers (White *et al*. 2008; Goebel *et al*. 2010; Veiga *et al*. 2013). The genus *Telenomus* is comprised of several species. All of them are egg parasitoids of lepidopteran stalk borers. They play an important role in the regulation of insect pest populations world-wide (Polaszek *et al*. 1993). *Telenomus busseolae* Gahan (Hymenoptera: Scelionidae) is the major biological control agent of stalk borers in Iran and this species is routinely mass reared and released in sugarcane fields across Khuzestan Province (Nikpay *et al*. 2014).

Another strategy proposed for controlling sugarcane stalk borers is the application of silicon to soil. This is called nutritional Integrated Pest Management (IPM) and it imparts resistance by improving crop health (Ma 2004; Reynolds *et al*. 2009; Korndörfer *et al*. 2011; Keeping *et al*. 2014). 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 (Jones and Handreck 1967). After the uptake and transport from roots to vegetative shoots, silicic acid becomes concentrated in the cell walls due to water loss or physiological processes, and ultimately as silica gel (Ma and Yamaji 2006). Sugarcane is a typical Si accumulating graminaceous species (Ma and Yamaji 2006). Augmentation of soil using soluble silicon is one crop management tactic that promotes plant growth and enhances resistance against arthropod pests (Ma 2004; Reynolds *et al*. 2009; Juma *et al*. 2015; Reynolds *et al*. 2016). Silicon has been considered as a beneficial agronomic element for sustainable sugarcane and rice production. Various silicate fertilizers, both solid and liquid, have been investigated and applied in various crop production systems around the world including USA, South Africa, China, Brazil and Japan to increase yields and improve disease and insect control (Savant *et al*. 1999). Silicon can affect sugarcane stalk borers both directly and indirectly. Direct potential effects include inhibiting the growth, development, and reproduction of borers due to reduced feeding tissue indigestibility (Anderson and Sosa 2001). Indirectly silicon affects stem borers by delaying stalk penetration, thereby exposing larvae to natural enemies and other mortality factors like detrimental climatic conditions (sun light and drought), and increased exposure to chemical control (Kvedaras and Keeping 2007; Reynolds *et al*. 2009; Sidhu *et al*. 2013). Also, silicon fertilization can indirectly enhance the attraction of beneficial insects to infested plants thus amplifying their efficacy of control (Kvedaras *et al*. 2010). We have been unable to find any references reporting research using biological control in conjunction with silicon supplements for the control of pink stalk borers *Sesamia* spp. in sugarcane.

The goal of this study was to compare different biological treatments alone and in combination with silicon to control two species of *Sesamia*. Efficacy in control was determined by quantifying the levels of stalk borer damage, yield and cane quality, as well as assessing the level of parasitism of stalk borer eggs.

Materials and Methods

Laboratory rearing of *Telenomus busseolae*

The initial colony of *T. busseolae* was started from parasitized eggs of *Sesamia* spp. collected from fields of the Salman Farsi Agro Industry (48°35′E, 31°8′S), Ahvaz, Iran. Procedures for mass rearing of parasitoids were based on those developed by Ranjbar-Aghdam (1999). Eggs of *Sesamia* spp. serving as parasitoid hosts were glued to radiological films (16 × 2.5 cm) using a 10% sugar solution. The strips of radiological films were put inside U-shaped tubes by hand (17 cm length and 3 cm diameter) and parasitoid Hymenoptera were released into tubes to parasitize the *Sesamia* eggs. The glass tubes were placed in an incubator (Memert Company, Schwabach, Germany) set at 27±1°C and 65±3% relative humidity (RH). The adult parasitoids emerged after 16 days, and 1–2 days old adults were released into experimental plots.

Experimental design and plot configuration

Experiments were carried out during 2013–2014 (planted in summer 2013 and harvested in fall 2014) at the Salman Farsi Agro Industry Farms, Ahwaz, Iran. The variety used in this study was CP69-1062, a variety ranked as susceptible to *Sesamia* spp. (Askarianzadeh *et al.* 2008). The soil was a loam (40.9% silt, 31.6% sand and 27.5% clay, 158 mg · · kg^{-1} Ca, 46 mg · kg^{-1} Mg and 122 mg · kg^{-1} K), with a pH of 7.8 (pH water) and EC of 4.95 ds · m^{-1}.

A randomized complete blocks design with four blocks (each block consisted of five experimental plots) was used for the study. Each experimental plot (within a block) consisted of six rows, 10 m long, and 1.8 m between rows (108 m^2 for each plot). This plot configuration was used for our study as previous studies have shown that sugarcane trials should be at least 25 m^2 (Laycock 2004). Each plot was separated by a 10 m buffer of standing cane to inhibit *T. busseolae* dispersion between plots. Five treatments were included in the study (Goebel *et al*. 2014; Khan *et al*. 2014). Treatment one (T1) consisted of releasing 2,500 *T. busseolae* adults on three occasions (early April, early June and late July) plus the application of 1,200 kg · ha^{-1} silicon (Ca_2SiO_4) (powder formulation; soluble SiO_2 ≥ 20%; Dalian Siliconfat Co., Ltd., Dalian, China; imported by Ghaem Agricultural & Chemical Company, Tehran, Iran) (Savant *et al*. 1999). Silicon was applied before herbicide applications and the first watering of planted canes. All plots received the same irrigation regime as locally recommended. Silicon samples in plastic bags were weighed precisely with a digital balance (Sartorius BP1200, Gottingen, Germany). The silicon samples were sprinkled by hand into furrows, and thoroughly mixed into the soil to a depth of 30 cm.

Treatments two, three, and four (T2, T3, and T4) consisted of releasing 5,000, 2,500 and 1,250 of *T. busseolae* adults three times (early April, early June and late July), respectively. Treatment five was a control represented by plots infested naturally with moth borers and untreated with parasitoids or silicon fertilization.

Damage assessment and quantification of quality characteristics

Three weeks after the first release of parasitoids, 100 shoots were selected randomly to determine the percentage of dead hearts in each plot. For assessing damage by *Sesamia* spp. 3 months after the first release of parasitoids and just before harvest, 50 whole stalks were selected randomly from the center rows (to avoid any border effects) of each experimental plot. Before weighing stalk samples, the leaves were removed up to the last fully expanded internode. The percentage of stalk damage (number of stalks bored per plot/total number of stalks sampled per plot × 100) and the percentage of bored internodes (number of internodes bored per plot/total number of internodes sampled per plot × 100) were calculated. Mean stalk weight was also determined at this time. For each plot, the level of parasitism (number of parasitized eggs per plot/total collected eggs per plot × 100) was determined. For evaluating the effects of treatments on sugar quality, 20 whole stalks were selected randomly from each plot prior to harvest in 2014. These stalks were topped by hand at the last fully expanded internode). Each bundle of 20 stalks was fed through a chipper/disintegrator and sub-samples (200 g) were analyzed to determine cane juice quality including %Pol (the apparent sucrose content), %Brix (the sugar content of an anqueous solution), Purity and %Refined sugar. The polarity (%Pol) and %Brix of cane juice were obtained from a polarimeter (Optical Activity Ltd, Cambridgeshire, England) and a refractometer (Index Instruments, Cambridgeshire, England), respectively.

Data analysis

All data were analyzed for normality and homogeneity of variance (Bartlett's test). Appropriate transformations [arcsin, log(x) and log(x+1)] were applied where normality and homogeneity were not met and before analysis of variance was performed. All analyses were performed with SPSS software version 16, SPSS International, Chicago, USA (SPSS 2007). Tukey's HSD test was used for means comparisons between treatments ($p = 0.01$). Untransformed means and standard errors are shown in the tables and graph. A linear regression model is also presented to show the relationship between the percentage of stalk damage and yield components.

Results

The efficacy of the different treatments in controlling stalk borers is presented in Table 1. The percentage of dead hearts caused by stalk borers was significantly reduced as a result of all treatments compared with the untreated control ($F_{4,19} = 93.77$; $p = 0.001$). The percentage of dead heart was lowest for T1 and T2 (8.0–8.2%) followed by T3 and then T4 (14.0% and 18.7%). Three months from the initial release of parasitoids, there were significant differences between treatments for both the percentage of stalk damage ($F_{4,19} = 164.44$; $p = 0.001$) and the percentage of internodes bored ($F_{4,19} = 125.29$; $p = 0.001$). Again the results indicated that biological control in combination with a silicon soil amendment had the lowest mean of stalk damage (10.5%) and internodes bored (1.2%), whereas the untreated control had the highest mean of stalk damage (35.2%) and internodes bored (4%). At harvest, silicon plus biological control significantly reduced the percentage of stalk damage ($F_{4,19} = 128.55$; $p = 0.001$) and the percentage of internodes bored ($F_{4,19} = 558.21$; $p = = 0.000$) in comparison with the other treatments. The highest level of damage was observed in the untreated control plots with 51.0% of stalks damaged and 15.5% of internodes bored.

Table 1. The effects (mean±SE) of different treatments on stalk borer damage

Treatments	After 3 weeks	After 3 months		At harvest	
	DH [%]	SD [%]	IB [%]	SD [%]	IB [%]
T1	8.0±0.40 d	10.5±0.65 d	1.2±0.06 d	17.2±1.25 d	1.8±0.12 d
T2	8.25±0.47 d	16.2±0.48 c	1.8±0.03 c	29.0±1.68 c	3.5±0.16 c
T3	14.0±0.70 c	18.7±0.85 c	2.1±0.19 c	37.5±0.96 b	4.7±0.15 b
T4	18.75±0.85 b	26.7±0.85 b	3.2±0.15 b	41.0±0.91 b	5.5±0.16 b
T5	25±1.05 a	35.2±0.85 a	4.0±0.11 a	51.0±0.41 a	15.5±0.33 a
F test$_{(4,19)}$	93.77	164.44	125.29	128.55	558.21
p value	0.001	0.001	0.001	0.001	0.001
CV%	45.74	41.62	43.56	33.74	60.38

T1 – calcium silicate (1,200 kg · ha^{-1}) and 2,500 *T. busseolae*; T2 – 5,000 *T. busseolae*; T3 – 2,500 *T. busseolae*; T4 – 1,250 *T. busseolae*; T5 – untreated control. DH – dead heart; SD – stalk damage; IB – internodes bored. Means followed by the same letter in each column are not significantly different using Tukey's HSD test at $p < 0.05$

Table 2. The effects (mean±SE) of different treatments on quality characteristics of sugarcane variety CP69-1062

Treatments	Sampling at harvest			
	%Pol	%Brix	Purity	%Refined sugar
T1	18.82±0.38 d	20.7±0.16 c	90.9±0.11 d	11.77±0.41 d
T2	18.62±0.32 c	20.65±0.21 c	90.1±0.06 c	11.49±0.44 c
T3	18.32±0.22 b	20.31±0.17 b	89.7±0.10 b	11.31±0.36 b
T4	18.13±0.37 b	20.28±0.36 b	89.4±0.04 b	11.23±0.30 b
T5	17.62±0.32 a	19.86±0.24 a	88.7±0.12 a	10.96±0.20 a
F test$_{(4,19)}$	180.88	197.38	82.43	74.29
p value	0.001	0.001	0.001	0.001
CV%	2.38	1.52	0.86	2.50

T1 – calcium silicate (1,200 kg · ha^{-1}) and 2,500 *T. busseolae*; T2 – 5,000 *T. busseolae*; T3 – 2,500 *T. busseolae*; T4 – 1,250 *T. busseolae*; T5 – untreated control. DH – dead heart; SD – stalk damage; IB – internodes bored. Means followed by the same letter in each column are not significantly different using Tukey's HSD test at p < 0.05; %Pol – the apparent sucrose content; %Brix – the sugar content of an anqueous solution

Table 3. The effects (mean±SE) of different treatments on yield components for the sugarcane variety CP69-1062

Treatments	Sampling at harvest		
	mean stalk weight [g]	cane [t · ha^{-1}]	sugar [t · ha^{-1}]
T1	798.7±4.27 e	79.87±0.43 e	9.39±0.07 e
T2	756.3±5.54 d	75.62±0.55 d	8.69±0.07 d
T3	726.3±2.39 c	72.62±0.24 c	8.21±0.04 c
T4	703.7±4.73 b	70.37±0.47 b	7.91±0.07 b
T5	675.3±2.04 a	67.25±0.14 a	7.36±0.02 a
F test$_{(4,19)}$	140.36	148.63	160.86
p value	0.001	0.001	0.001
CV%	6.16	6.15	8.62

T1 – calcium silicate (1,200 kg · ha^{-1}) and 2,500 *T. busseolae*; T2 – 5,000 *T. busseolae*; T3 – 2,500 *T. busseolae*; T4 – 1,250 *T. busseolae*; T5 – untreated control. Means followed by the same letter in each column are not significantly different using Tukey's HSD test at p < 0.05

The effects of different treatments on cane quality are presented in Table 2. The combination treatment of a silicon amendment plus 2,500 parasites was sufficient to increase %Pol ($F_{4,19}$ = 180.88; p = 0.001), %Brix ($F_{4,19}$ = = 197.38; p = 0.001), Purity ($F_{4,19}$ = 82.43; p = 0.001), and %Refined sugar ($F_{4,19}$ = 74.29; p = 0.001). The effect of different treatments on yield components is presented in Table 3. Mean stalk weight increased when silicon was applied in combination with 2,500 Hymenoptera ($F_{4,19}$ = 140.36; p = 0.001). The second most effective treatment was releasing 5,000 *T. busseolae*. This treatment (T1) significantly increased both cane ($F_{4,19}$ = 148.63; p = 0.001) and sugar yield ($F_{4,19}$ = 160.86; p = 0.001) when compared to the other treatments.

All yield parameters were inversely related to the percentage of stalks damaged (Fig. 1). The efficiency of *T. busseolae* parasitizing eggs of stalk borers is shown in Figure 2. The treatment of silicon plus the releasing of 2,500 *T. busseolae* resulted in significantly increased levels of parasitism at harvest, followed by T2, T3, and T4 ($F_{4,19}$= = 67.34; p = 0.000) (Fig. 2).

Discussion

Sugarcane stalk borers adversely impact sugarcane production worldwide. Many sugarcane producing countries, especially developing countries, do not use chemical applications to control sugarcane stalk borers due to their harmful effects on beneficial arthropods, their hazardous effects on pesticide applicators and human health, the high cost of insecticide application as well as the development of target pest resistance (James 2004). Native biological control or inundative releases of parasitoids play an important role in reducing stalk borer population levels, and the consequent damage by stalk borers (Polaszek *et al*. 1993; Goebel and Sallam 2011; Nikpay *et al*. 2014). Here, releasing parasitoids significantly decreased the percentage of dead-hearts, the percentage of stalks damaged and the percentage of internodes bored compared to the untreated controls. In Pakistan, Ullah *et al*. (2012) reported that releasing the egg parasitioid *Trichogramma chilonis* (Ishii) was an environmental-friendly alternative to synthetic insecticides and reduced the infestation level of the stalk borer, *Chilo infuscatellus* (Snellen). They found that a triple release of *T. chilonis* was more effective than

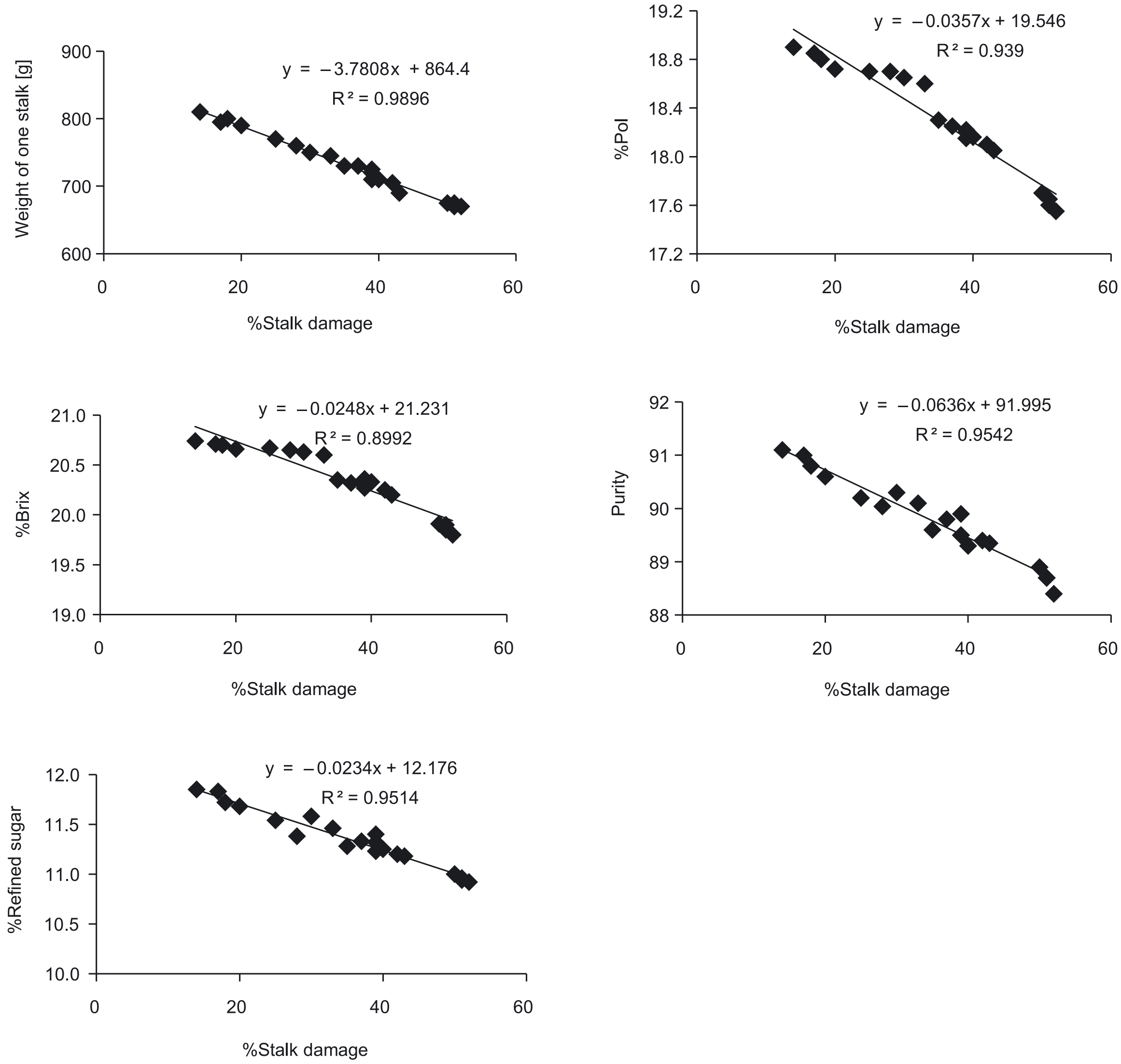

Fig. 1. Relationship between stalk damage and mean weight, %Pol, %Brix, Purity and %Refined sugar

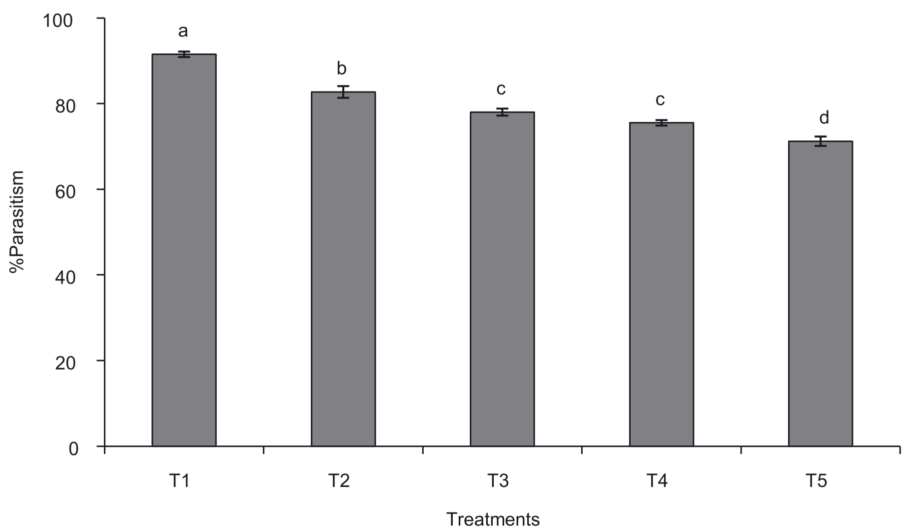

Fig. 2. Mean percent parasitism of *T. busseolae* on stalk borers ±SE for all treatments: T1 – calcium silicate (1,200 kg · ha^{-1}) and 2,500 *T. busseolae*; T2 – 5,000 *T. busseolae*; T3 – 2,500 *T. busseolae*; T4 – 1,250 *T. busseolae*; T5 – untreated control. Means followed by the same letter in each column are not significantly different using Tukey's HSD test at $p < 0.05$

a double or single release. According to Khan *et al*. (2014), releasing the parasitoid *Telenomus beneficiens* (Zehntner) can reduce the damage level caused by the sugarcane top borer *Scirpophaga excerptalis* (Walker) by increasing the level of egg parasitism. The authors concluded that four releases of *T. beneficiens* maximized parasitism of the top borer eggs in comparison with other treatments. On Reunion Island, Goebel *et al*. (2010) found that *T. chilonis* could be used effectively as a biological control agent of the sugarcane borer, *Chilo sacchariphagus* (Bojer). The authors concluded that by releasing *T. chilonis*, the percentage of internodes bored was reduced on treated plots versus control plots. In this study, the first on sugarcane pink stalk borers, the results were in agreement with several previous studies performed in sugarcane ecosystems.

An IPM program for sugarcane borers should comprise of different ecologically-based strategies. One potential new strategy being investigated in many sugarcane ecosystems world-wide is the application of silicon fertilization to alleviate biotic stresses such as arthropod herbivory. Silicon fertilization provides several beneficial aspects for crop resistance against chewing and sucking arthropod pests (Reynolds *et al*. 2009; Korndörfer *et al*. 2011; Keeping *et al*. 2014; Nikpay and Soleyman Nejadian 2014). Silicon interferes with pest feeding thereby reducing pest damage and subsequent adult emergence due to incomplete uptake of food and water by larvae (Reynolds *et al*. 2016). Silicon also accumulates in the tissues of stalks and leaves, providing a barrier layer against chewing and sucking pests (Panda and Khush 1995; Ma 2004; Sidhu *et al*. 2013).

White and White (2013) showed that the tunnel length for larvae of *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae) decreased 27% in a susceptible sugarcane variety HoCP96-540 following fertilization with silicon. Under field conditions, Keeping *et al*. (2013) tested silicon amendments on both plant and ratoon crops of different sugarcane varieties. The authors demonstrated a significant reduction in the percent of stalks damaged, the percent of bored internodes, and tunnel length bored per stalk in susceptible varieties N27 and N35. Recently, Nikpay *et al*. (2015) applied silicon as a pre-planting application and found that silicon fertilization could significantly reduce the percentage of stalk damage, the percentage of moth borer exit holes, the percentage of moth borers (larvae + pupae) per 100 stalks, the percentage of internodes bored, and the length of borer tunnels in the varieties CP69-1062, IRC99-01, and SP70-1143. In this study a combination of releasing parasitoids concurrent with silicon fertilization could enhance stalk borer control up to harvest, and improve the juice quality of a borer susceptible variety, CP69-1062.

Under field conditions, silicon can increase natural enemies' attraction to infested plants, resulting in increases in the level of parasitism in plants treated with silicon (Kvedaras *et al*. 2010). Nikpay *et al*. (in press) also found that the application of liquid silicon fertilizers enhanced the percentage of parasitism of stalk borers' eggs of five sugarcane varieties when compared with control plots in two successive field trials. In this study the level of egg parasitism was significantly higher at harvest as a result of the treatment of silicon plus biological control versus the other treatments receiving only biological control.

Both stalk damage and bored internodes have been reported to be inversely correlated with yield parameters such as sugarcane juice purity, tonnage of sugarcane, and sugar per hectare (Legaspi *et al*. 1999; White *et al*. 2008; Goebel *et al*. 2014). This study confirmed that sugarcane stalk borers have a significant economic impact on sugarcane yield and quality components. In Iran, Askarianzadeh *et al*. (2008) noted that an increase in stalk borer (*Sesamia* spp.) infestations significantly reduced yield components and cane quality of three sugarcane varieties: CP69-1062 (susceptible), CP48-103 (susceptible) and SP70-1143 (semi susceptible). In the Lower Rio Grande Valley of Texas, U.S., Legaspi *et al*. (1999) reported that both *D. saccharalis* and *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae) had a negative effect on cane yield and quality components of commercial sugarcane varieties NCo310 and CP70-321. In Indonesia, Goebel *et al*. (2014) reported that, under field conditions, the untreated plots had lower sucrose and cane yield in comparison with biological and insecticidal treatments. Our results showed similar trends and indicated that with increasing stalk borer infestations, quality parameters including %Pol, %Brix, Purity and %Refined sugar were significantly reduced. In addition, cane yield including mean stalk weight, sugar per hectare and cane per hectare also decreased. The application of pesticides to sugarcane in developing countries to control stalk borers provides poor control and involves the risk of environmental pollution and adverse impacts on beneficial arthropods. These factors will continue to encourage the development of reduced-risk pest management tactics including improving biological control with routine applications of silicon fertilizers.

Conclusions

Sesamia cretica and *S. nonagrioides* are the principle insect pests of sugarcane in Iran. Successful control of these pests is best achieved by a multi-tactic approach to pest management. Currently biological control is the primary control strategy, and with good results. Including silicon as a soil amendment has shown promise for alleviating several biotic stresses including stalk borer. A combination of these two methods provided enhanced control of stalk borer, improved cane quality and increased egg parasitism beyond that which can be achieved when the biocontrol agents are used alone. The concurrent release of parasitoids in combination with silicon fertilization, can lead to the sustainable production of sugarcane that is based on ecologically-sound practices, while increasing profits for the sugar industry.

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