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.

Keywords: 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)
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; Kornndörfer 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), Ahwaz, 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 m² for each plot). This plot configuration was used for our study as previous studies have shown that sugarcane trials should be at least 25 m² (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 (Ca₂SiO₄) (powder formulation; soluble SiO₂ ≥ 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 aqueous 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<sub>4,19</sub> = 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<sub>4,19</sub> = 164.44; p = 0.001) and the percentage of internodes bored (F<sub>4,19</sub> = 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<sub>4,19</sub> = 128.55; p = 0.001) and the percentage of internodes bored (F<sub>4,19</sub> = 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

<table>
<thead>
<tr>
<th>Treatments</th>
<th>After 3 weeks</th>
<th>After 3 months</th>
<th>At harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DH [%]</td>
<td>SD [%]</td>
<td>IB [%]</td>
</tr>
<tr>
<td>T1</td>
<td>8.0±0.40 d</td>
<td>10.5±0.65 d</td>
<td>1.2±0.06 d</td>
</tr>
<tr>
<td>T2</td>
<td>8.25±0.47 d</td>
<td>16.2±0.48 c</td>
<td>1.8±0.03 c</td>
</tr>
<tr>
<td>T3</td>
<td>14.0±0.70 c</td>
<td>18.7±0.85 c</td>
<td>2.1±0.19 c</td>
</tr>
<tr>
<td>T4</td>
<td>18.75±0.85 b</td>
<td>26.7±0.85 b</td>
<td>3.2±0.15 b</td>
</tr>
<tr>
<td>T5</td>
<td>25±1.05 a</td>
<td>35.2±0.85 a</td>
<td>4.0±0.11 a</td>
</tr>
</tbody>
</table>

F<sub>4,19</sub> = 93.77; p = 0.001  
F<sub>4,19</sub> = 164.44; p = 0.001  
F<sub>4,19</sub> = 125.29; p = 0.001  
F<sub>4,19</sub> = 128.55; p = 0.001  
F<sub>4,19</sub> = 558.21; p = 0.000

T1 – calcium silicate (1,200 kg · ha<sup>-1</sup>) 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.
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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 ($T_1$) 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).

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

<table>
<thead>
<tr>
<th>Treatments</th>
<th>%Pol</th>
<th>%Brix</th>
<th>Purity</th>
<th>%Refined sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>18.82±0.38 d</td>
<td>20.7±0.16 c</td>
<td>90.9±0.11 d</td>
<td>11.77±0.41 d</td>
</tr>
<tr>
<td>T2</td>
<td>18.62±0.32 c</td>
<td>20.65±0.21 c</td>
<td>90.1±0.06 c</td>
<td>11.49±0.44 c</td>
</tr>
<tr>
<td>T3</td>
<td>18.32±0.22 b</td>
<td>20.31±0.17 b</td>
<td>89.7±0.10 b</td>
<td>11.31±0.36 b</td>
</tr>
<tr>
<td>T4</td>
<td>18.13±0.37 b</td>
<td>20.28±0.36 b</td>
<td>89.4±0.04 b</td>
<td>11.23±0.30 b</td>
</tr>
<tr>
<td>T5</td>
<td>17.62±0.32 a</td>
<td>19.86±0.24 a</td>
<td>88.7±0.12 a</td>
<td>10.96±0.20 a</td>
</tr>
</tbody>
</table>

$F_{test(4,19)} = 180.88$ $p = 0.001$, $F_{test(4,19)} = 197.38$ $p = 0.001$, $F_{test(4,19)} = 82.43$ $p = 0.001$, and $F_{test(4,19)} = 74.29$ $p = 0.001$. 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 aqueous solution.

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

<table>
<thead>
<tr>
<th>Treatments</th>
<th>mean stalk weight [g]</th>
<th>cane [t · ha⁻¹]</th>
<th>sugar [t · ha⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>798.7±4.27 e</td>
<td>79.87±0.43 e</td>
<td>9.39±0.07 e</td>
</tr>
<tr>
<td>T2</td>
<td>756.3±5.45 d</td>
<td>75.62±0.55 d</td>
<td>8.69±0.07 d</td>
</tr>
<tr>
<td>T3</td>
<td>726.3±2.39 c</td>
<td>72.62±0.24 c</td>
<td>8.21±0.04 c</td>
</tr>
<tr>
<td>T4</td>
<td>703.7±4.73 b</td>
<td>70.37±0.47 b</td>
<td>7.91±0.07 b</td>
</tr>
<tr>
<td>T5</td>
<td>675.3±2.04 a</td>
<td>67.25±0.14 a</td>
<td>7.36±0.02 a</td>
</tr>
</tbody>
</table>

$F_{test(4,19)} = 140.36$ $p = 0.001$, $F_{test(4,19)} = 148.63$ $p = 0.001$, and $F_{test(4,19)} = 160.86$ $p = 0.001$. 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 ($T_1$) 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 parasitoid *Trichogramma chilonis* (Ishii) was an environmental-friendly alternative to synthetic insecticides and reduced the infestation level of the stalk borer, *Chilo infuscatus* (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.
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 cirtica 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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