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Loss of Cane and Sugar Yield due to Damage by *Tetramoera schistaceana* (Snellen) and *Chilo sacchariphagus* (Bojer) in the Cane-Growing Regions of China

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Authors' Contribution
YKH conceived and designed the study. RYZ, JY, ZML, XYW and HLS performed experimental work. WFL wrote the manuscript.

Key words
Sugarcane borer, Sugar quality, Control, Bisultap, Yunnan.

ABSTRACT

Loss of cane and sugar yield caused by the combined occurrence of *Tetramoera schistaceana* (Snellen) and *Chilo sacchariphagus* (Bojer) were measured in pesticide–treated and untreated areas during 2014-2016. The results indicated that the in untreated areas, percent dead-heart was 8.30% - 58.83%, the percent stalk injured was 26.73% - 96.67%, the percent internodes bored was 4.40% - 25.87%, and the effective stem number was reduced by 4440-21900 stalk/ha. Measured yield and sugar yield loss results showed cane yield was reduced by 5.32-44.53 T/ha; the yield loss percent was5.92% - 44.53%; the sugarcane juice yield decreased by 1.73% - 3.28%; the sucrose content reduced by 0.33% - 5.63%; sugarcane brix dropped by 0.70-6.36 BX; the fibre and reducing sugar increased by 0.22% - 0.98% and 0.11%-1.58%, respectively. It was confirmed that in majority of sugarcane fields in Yunnan, China, *T. schistaceana* and *C. sacchariphagus* cause severe reduction of sugarcane and sugar yield.

INTRODUCTION

Lepidopteran stalk borers are the main pests that severely damage sugarcane in many sugarcane producing countries. Larvae bore either into the shoots or stalks of sugarcane, severely reducing both yield and sugar content (Sallam *et al*., 2010; Goebel *et al*., 2011; McGuire *et al*., 2012; Sattar *et al*., 2016). *Tetramoera schistaceana* (Snellen) and *Chilo sacchariphagus* (Bojer) are widely distributed in planting areas and affecting both the yield and quality of sugarcane in China (Huang and Li, 2011; Leul and Thangavel, 2013). This has become more important in recent years, because the consistently warmer winters and exchange of introduced sugarcane varieties between areas has resulted in a change in the species, occurrence and extent of damage from *T. schistaceana* and *C. sacchariphagus* (Yao *et al*., 2006; An and Guan, 2009; Xiong *et al*., 2010; Xie *et al*., 2012; Li *et al*., 2013). The main changes include infestation from combination of borers, a year-on-year increase in population density, a sharp increase in percent dead-heart and percent stalks damaged in the middle and late stage, and a year-on-year increase in loss of cane and sugar yield which causes considerable economic loss to the main sugarcane planting areas (Yao *et al*., 2006; An and Guan, 2009; Xiong *et al*., 2010; Xie *et al*., 2012; Li *et al*., 2013). Determining the cane yield and sugar losses caused by *T. schistaceana* and *C. sacchariphagus* are essential to for formulate the relevant control strategy For example, the entire sugarcane growing period could be affected by damage from these borer species; the borers cause dead hearts in the seedling stage, and the number of seedlings and cane stalks may be reduced (Feng, 1999; Zhang *et al*., 2008; Li *et al*., 2014). In the middle and later growing stages, *T. schistaceana* and *C. sacchariphagus* attack sugarcane stems and destroy internal tissue of the stalk; this affects the joint growth and leads to the decrease in cane and sugar yield (Feng, 1999; Zhang *et al*., 2008; Li *et al*., 2014). The percent dead-heart in the seedling stage can reach as much as 30% in severely damaged fields, and the percent of stalks damaged can reach above 40% (Pan *et al*., 2009; Lu *et al*., 2011; Huang *et al*., 2014). Many studies have been published about the estimation of sugarcane yield losses due to borers in many counties (Rajabalee *et al*., 1990; Goebel and Way, 2003; Reay-Jones *et al*., 2005; White *et al*., 2008; Rossato *et al*., 2013; Goebel *et al*., 2014). However, studies assessing loss of sugarcane yield due to the occurrence of mixed populations of *T. schistaceana* and *C. sacchariphagus* under natural field conditions

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have not been reported until now in China, so there is a considerable lack of data on this aspect. In this study, the losses of sugarcane yield and sugar yield caused by the occurrence of *T. schistaceana* and *C. sacchariphagus* and the impact of damage of sugarcane borers was assessed under the natural field conditions.

MATERIALS AND METHODS

Field experimental design

The field experiments of newly planted and ratoon cane were carried out in February 2014 to January 2015 and February 2015 to January 2016 respectively using the main cultivars, ROC22, ROC25, Yuetang 83-88, Yuetang 93-159, Yuetang 00-236 and Yingyu 91-59. Experiments were located in Lincang, Yunnan Province in China. Experimental field is located at 23°47' N and 99° 36' E, 1157 meter above sea level. Treated and untreated areas within the same field were examined in three replicates a total of six experimental plots. Each plot was 167-333 m^2 (depending on the size of the field). Plots were arranged in a randomized block design. Soil conditions, fertility, water and fertilizer management, as well as growth of seedlings were comparable between the treated and untreated plots. In treated plots, 90 kg/ha 3.6% Bisultap GR was added in February–March when planting or loosening the soil of ratoon cane took place, and May–June when the soil was 'hilled up', respectively. 3.6% Bisultap GR was mixed with the 1200 kg/ha NPK 20-10-10 fertilizerand spread evenly across sugarcane ditches, sugarcane stump or base of stalks and covered with soil or plastic film. In untreated plots, fertilizer only was applied. All other cultivation management measures were conducted according to the local conventional production methods and were the same of both areas.

Borer damage investigation

The percent dead-hearts was measured in both treated and untreated in June. A five-point sampling method was employed in each plot: at each of five points, 100 plants were selected sequentially to investigate, a total of 500 plants.

The percent dead-hearts was calculated as follows:

Percent dead-hearts (%) = Number of dead heart / Total number of surveyed seedlings ×100

At the sugarcane mature stage, the percent stalk damaged and percent internodes bored in the treated and untreated area were investigated in December. A five-point sampling method was used in each plot: at each of five points 20 stalks were selected sequentially, a total of 100 stalks. The leaf sheath of each stalk was stripped and the total number of damaged stalks was recorded. To assess the percent internodes bored, 20 stalks were randomly selected from the 100 stalks. The total number of internodes on each stalk and the number of internodes damaged were recorded. The percent stalk damaged and the percent internodes bored were calculated as follows:

Percent stalk damaged (%) = Number of damaged stalk/ Total number of surveyed stalk ×100

Percent internodes bored (%) = Number of borer-damaged internode / Total number of surveyed internodes ×100.

At the sugarcane mature stage, the effective stem (more than 1 meter in length) number in the treated and untreated area was assessed in December. Three point sampling method was used in each plot: at each of three points, the average row spacing of five rows of sugarcane were measured and 10 m of row length of each row was chosen to evaluate the total number of effective stems. The number of effective stems per hectare was calculated as follows:

Effective stems (stalks/ha) = [(Total number of effective stem/50) × 10000 (m^2)] / average row spacing (m).

Determination of cane yield and sugar loss

In January when the crops were harvested, the cane yield from treated and untreated areas was assessed. The cane biomass was weighted form 66 m^2 central areas in each plot after cutting and the relative yield loss percent was calculated as follows:

Percent yield loss (%) = (measured yield from treated areas - measured yield from untreated areas) / measured yield from treated areas ×100

When the crops were harvested in January, the sucrose content of treated and untreated area was determined. 10 sugarcane stalks were randomly selected in each plot. Using the two times polarimetric analysis method established by the National Sugar Industry Standardization and Quality Detection Center was used to determine quality indexes including juice yield (%), sucrose content (%), fiber content (%), juice brix (°BX) , gravity purity (%) and reducing sugar content (%). A fully automatic sugar analysis system, Rudolph, Autopol 880+J257 (United States), was used. The loss of each index was calculated as follows:

Sugar yield loss = Loss in treated area – loss in untreated area

Table I.- Effect of *T. schistaceana* and *C. sacchariphagus* damage on sugarcane yield.

Varieties	Treatments (area)	Dead-hearts (%)		Stalk damaged (%)		Internodes bored (%)		No. of effective stem (stalk/ ha)		Measured yield (T/ha)		Percent of relative yield loss (%)	
		Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon
Yuetang93-159	Treated	1.93 a	3.03 a	6.73 a	7.77 a	2.57 a	2.80 a	83865 a	89325 a	80.84 a	111.74 a	17.31	41.74
	Untreated	17.13 b	26.5 b	62.53 b	73.33 b	13.27 b	16.20 b	73125 b	64725 b	66.85 b	65.10 b		
Yuetang00-236	Treated	1.23 a	2.73 a	5.70 a	7.74 a	1.37 a	3.80 a	101265a	90765 a	96.92 a	106.65 a	12.12	43.14
	Untreated	14.8 b	58.83 b	38.30 b	76.70 b	7.23 b	25.87 b	92430 b	67035 b	85.17 b	60.64 b		
Yuetang83-88	Treated	0.43 a	2.30 a	5.13 a	6.70 a	1.27 a	3.00 a	89325 a	97605 a	100.79 a	119.60 a	5.29	21.42
	Untreated	8.30 b	33.33 b	26.73 b	73.37 b	4.40 b	17.33 b	84885 b	79605 b	95.47 b	93.98 b		
ROC22	Treated	0.33 a	2.93 a	5.37 a	8.37 a	0.37 a	3.17 a	92925 a	104280a	116.10 a	158.56 a	12.36	44.53
	Untreated	19.6 b	56.73 b	31.73 b	96.67 b	6.13 b	24.67 b	83910 b	76590 b	101.75 b	87.95 b		
ROC25	Treated	0.20 a	2.40 a	5.30 a	3.67 a	1.67 a	2.30 a	84270 a	108675a	97.34 a	123.67 a	34.62	20.15
	Untreated	9.56 b	49.63 b	36.77 b	73.33 b	9.70 b	10.23 b	62370 b	94965 b	63.64 b	98.75 b		
Yingyu91-59	Treated	1.23 a	2.10 a	60.3 a	5.73 a	1.73 a	2.27 a	85395 a	88455 a	103.15 a	109.46 a	14.00	16.22
	Untreated	9.80 b	15.43 b	49.27 b	53.37 b	9.40 b	10.23 b	74955 b	76380 b	88.71 b	91.71 b		

The means with different letters (a, b) between treated area and untreated area are significantly different at P=0.05 by Tukey's HSD test.

Table II.- Effect of *T. schistaceana* and *C. sacchariphagus* damage on sugar quality parameters.

Varieties	Treatments (area)	Juice yield (%)		Sucrose content (%)		Fibre (%)		Brix (BX)		Gravity purity (%)		Reducing sugar content (%)	
		Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon	Planting cane	Ratoon
Yuetang93-159	Treated	71.13 a	69.95 a	17.00 a	17.12 a	10.56 a	10.36 a	22.43 a	22.46 a	90.03 a	91.04 a	0.23 a	0.33 a
	Untreated	69.40 b	68.32 b	15.96 b	16.03 b	10.99 b	10.88 b	21.20 b	21.30 b	88.86 b	89.01 b	0.56 b	0.46 b
Yuetang00-236	Treated	75.56 a	70.46 a	17.33 a	17.66 a	10.34 a	11.13 a	22.80 a	23.36 a	91.73 a	91.01 a	0.33 a	0.24 a
	Untreated	70.8 b	67.61 b	16.27 b	12.03 b	10.90 b	11.89 b	21.6 b	17.00 b	90.46 b	78.56 b	0.65 b	1.82 b
Yuetang83-88	Treated	71.26 a	70.52 a	16.18 a	16.43 a	11.13 a	11.04 a	22.14 a	21.91 a	88.36 a	87.40 a	0.33 a	0.31 a
	Untreated	69.28 b	68.12 b	15.85 b	14.24 b	11.52 b	11.69 b	19.35 b	19.79 b	86.01 b	83.32 b	0.84 b	0.91 b
ROC22	Treated	69.81 a	73.52 a	16.33 a	16.27 a	10.45 a	12.11 a	22.03 a	21.50 a	87.10 a	92.48 a	0.21 a	0.30 a
	Untreated	67.60 b	71.03 b	14.31 b	14.63 b	11.39 b	12.77 b	20.27 b	20.13 b	85.93 b	88.80 b	0.40 b	0.81 b
ROC25	Treated	71.58 a	71.03 a	16.70 a	17.01 a	11.54 a	11.39 a	21.82 a	22.30 a	89.74 a	91.53 a	0.41 a	0.22 a
	Untreated	67.71 b	68.20 b	15.93 b	13.13 b	11.87 b	11.98 b	20.91 b	18.76 b	88.60 b	82.60 b	0.52 b	1.51 b
Yingyu91-59	Treated	69.36 a	69.81 a	16.02 a	15.54 a	10.86 a	10.71 a	20.03 a	20.66 a	85.94 a	85.33 a	0.41 a	0.53 a
	Untreated	67.54 b	66.53 b	14.99 b	14.22 b	11.08 b	11.69 b	19.33 b	19.8 b	84.62 b	83.37 b	0.68 b	0.82 b

The means with different letters (a, b) between treated area and untreated area are significantly different at P=0.05 by Tukey's HSD test.

Data analysis

The differences between treated area and untreated area were analyzed with one-way ANOVA followed by Tukey's HSD test (SAS, 2001). The arcsine transformation was performed on percentages prior to analysis. We set the level of significance to $P < 0.05$ for all statistical tests.

RESULTS

The influence of T. schistaceana *and* C. sacchariphagus-*damage on yield*

T. schistaceana and *C. sacchariphagus* have caused severe damage in cane-growing regions of China that were showed from Figure 1 and Table I. The occurrence and degree of damage by sugarcane borer in different sugarcane planting areas varied. In the newly planted field, the average percent dead-heart, the average percent stalk damaged and the average percent internodes bored in the untreated area were increased by 12.31%, 26.13%, 6.85%, respectively significantly higher than those in the treated areas, and the average effective stems number and average yield of sugarcane in the untreated areas were reduced by 10895 stalk/ ha and 15.59 T/ha, respectively significantly less than those in the treated areas. In the ratoon field, the average percent dead-heart, the average percent stalk damaged and the average percent internodes bored in the untreated area were increased by 37.49%, 67.80%, 14.53%, respectively significantly higher than those in the treated areas, and the average effective stems number and average yield of sugarcane in the untreated areas were reduced by 19967 stalk/ ha and 38.59 T/ha, respectively significantly less than those in the treated areas.

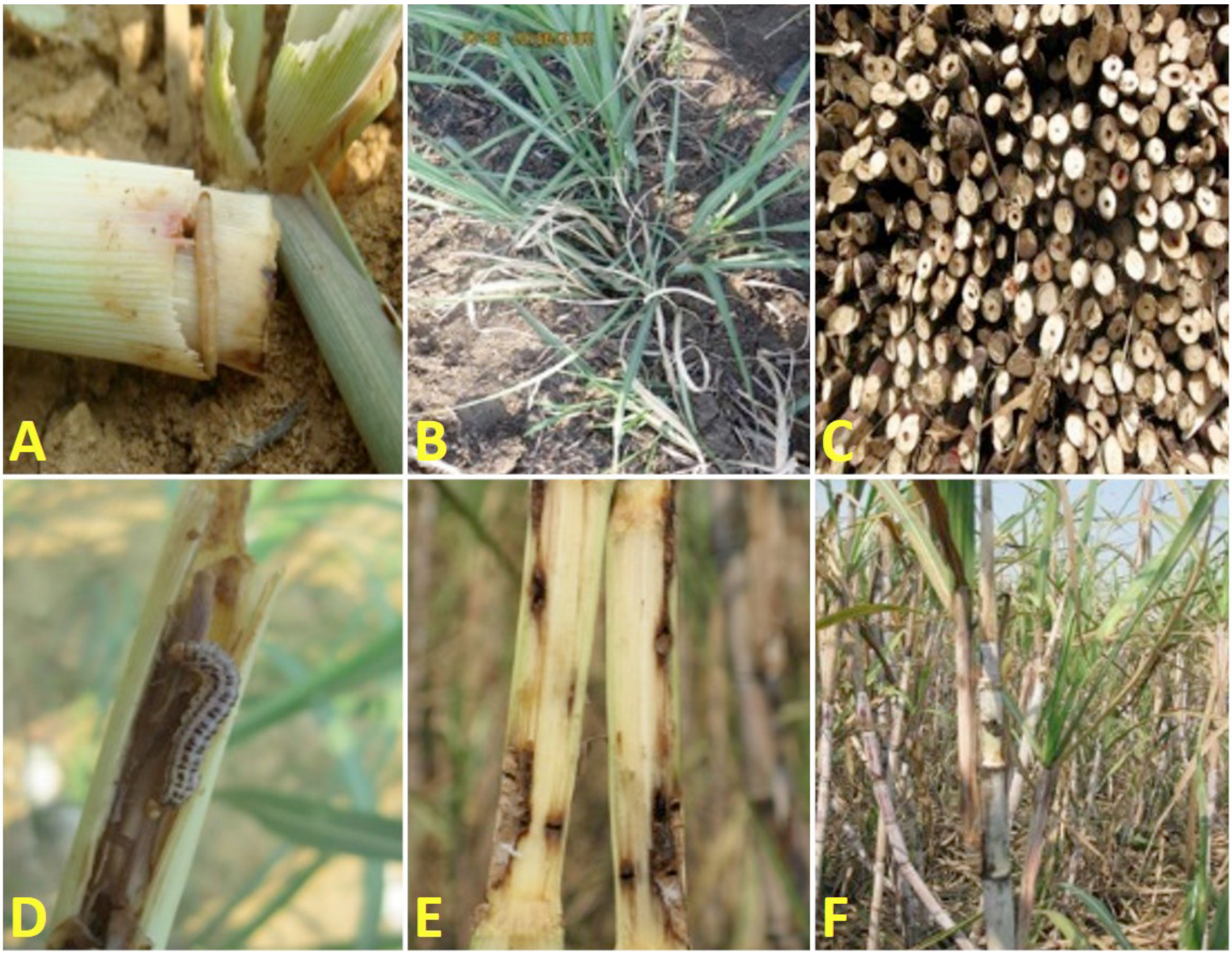

Fig. 1. Injuries caused by *T. schistaceana* and *C. sacchariphagus*. A, *T. schistaceana* larva and its damage; B, dead hearts from borer damage; C, sugarcane stalk damaged by *T. schistaceana*; D, *C. sacchariphagus* larva and its damage; E, stalks damaged by borers; F, plants of *C. sacchariphagus* damage (dead cane top).

The influence of damage by T. schistaceana *and* C. sacchariphagus *on sugarcane quality*

The results of the sugarcane quality analyzes are listed in Table II. In the newly planted field, the average sugarcane juice yield, average sucrose content, average juice brix and average juice gravity purity of damaged sugarcane in the untreated areas were reduced by 2.73%, 1.04%, 1.43 and 1.40%, respectively significantly less than those in the treated areas, but the fibre and reducing sugar content of damaged sugarcane in the untreated area were increased by 0.48% and 0.29% respectively significantly higher than those in the treated areas. In the ratoon field, the average sugarcane juice yield, average sucrose content, average juice brix and average juice gravity purity of damaged sugarcane in the untreated areas were reduced by 2.58%, 2.62%, 2.57 and 5.52%, respectively significantly less than those in the treated areas, but the fibre and reducing sugar content of damaged sugarcane in the untreated area were increased by 0.69% and 0.73%, respectively significantly higher than those in the treated areas.

Thus, the quality of sugarcane was affected by the damage by *T. schistaceana* and *C. sacchariphagus* in varying degrees, which resulted in a reduction of sugar yield.

DISCUSSION

T. schistaceana and *C. sacchariphagus* are major stalk borers which are widely distributed in sugarcane planting fields in China, causing severe damage to the plant and easily transmitted by vegetative propagation of sugarcane (Huang and Li, 2011; Leul and Thangavel, 2013). Climate change could alter patterns of disturbance from pest insects through direct effects on their development and survival, adaptation capability, availability of host plants and physiological changes in host defenses, and indirect effects from changes in the abundance of natural enemies, mutualists, and competitors (Bergant *et al*., 2005). In recent years, the global climate warming and the exchange of sugarcane cultivars between different areas have led to changes in the species, occurrence and extent of damage caused by *T. schistaceana* and *C. sacchariphagus* in main cane-growing areas, such as, Guangxi, Yunnan, Guangdong, and Hainan in China (Yao *et al*., 2006; Xiong *et al*., 2010; Xie *et al*., 2012; Li *et al*., 2014). The infestation of sugarcane borers has become increasingly severe causing great economic loss. It is therefore important to correctly understand the effect of *T. schistaceana* and *C. sacchariphagus* on sugarcane and sugar yield loss that they cause. Many previous studies have shown that the species, their population structure and dominant population of sugarcane borers varied by planting field and growth period, and that could cause the different impacts on sugarcane production, and different loss of cane and sugar yield (White and Hesley, 1987; Milligan *et al*., 2003; Li *et al*., 2007; White *et al*., 2008; Tan *et al*., 2011; Raza *et al*., 2012; Goebel *et al*., 2014). Thus, studying and ascertaining the sugarcane yield and sugar yield loss under natural field conditions when *T. schistaceana* and *C. sacchariphagus* occur in mixed populations is important. It can provide detailed data and contribute to effective control of *T. schistaceana* and *C. sacchariphagus.*

T. schistaceana and *C. sacchariphagus* damage in the main sugarcane production area of Yunnan was severe. These results are consistent with previous studies on other borers such as *Chilo sacchariphagus* and *Scirpophaga excerptalis* (Rajabalee *et al*., 1990; Goebel *et al*., 2014), *Diatraea saccharalis* (Ogunwolu *et al*., 1991; White *et al*., 2008; Rossato *et al*., 2013), *Eoreuma loftini* (Legaspi *et al*., 1999; Reay-Jones *et al*., 2005) and *Eldana saccharina* (Goebel and Way, 2003). Previous studies have shown that the mean percent of yield reduction was 14.4%, up to 27.6%, sugar yield loss percent reached 0.7% on average, up as high as 0.8% due to the sugarcane borers in the main production area of Guangxi (Tan *et al*., 2011); compared with no internodes bored, the sucrose content of internodes bored was reduced by 1.5%–2.9% and gravity purity was reduced by 1.7%–4.3% (Li *et al*., 2007), and the loss of cane yield caused by sugarcane borer was accounted for 5%~20%, sucrose content was reduced by 0.9% in the main sugarcane production area of Guangdong (Yang, 2003). Thus it can be seen that *T. schistaceana* and *C. sacchariphagus* have occurred in combination, leading to considerable damage in the main sugarcane production area of Yunnan recently, the loss of cane and sugar yield caused by *T. schistaceana* and *C. sacchariphagus* notably increased, and the main sugarcane cultivars were severely damaged by *T. schistaceana* and *C. sacchariphagus*. The damage from *T. schistaceana* and *C. sacchariphagus* has become a major challenge that severely impacts on high yield, stable yield and quality of sugarcane. Therefore, the primary task for improving quality, increasing profits, and ensuring the sustainable and stable development of the Chinese sugarcane industry will be the development of an effective control of *T. schistaceana* and *C. sacchariphagus*.

Sugarcane plants may be damaged by *T. schistaceana* and *C. sacchariphagus* during the whole growing period. Dead heart caused by borers occurred in the seedling stage; the number of seedlings and stalks were reduced which could cause yield reduction. During the middle and later growing stage, the borer damaged stalks and destroyed the internal tissue which had severe impact on the sugarcane quality. In the current study, there was mixed occurrence of *T. schistaceana* and *C. sacchariphagus* in the sugarcane planting field in Yunnan that could caused severe damage, and therefore the plant was vulnerable to injury throughout the whole growing season. To control *T. schistaceana* and *C. sacchariphagus* effort should be directed towards prevention and integrated control with a focus on both early warning and surveillance. Controlling the first and second generation of *T. schistaceana* and *C. sacchariphagus* are likely to be key measures, adopting such practices as, for example, light trapping and biological control to reduce the pest source. At the same time, applying 3.6% Bisultap GR in the seedling phase, the middle and later growing stage should be undertaken.

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Statement of conflict of interest

The authors declare no conflicts of interest.

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