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Loss of cane and sugar yield resulting from *Ceratovacuna lanigera* Zehntner damage in cane-growing regions in China

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Abstract

Ceratovacuna lanigera Zehntner is a major leaf pest of sugarcane. Widely distributed, it affects both the yield and quality of sugarcane in China. This study aimed to assess real yield and sugar yield losses, and the effect of *C. lanigera* damage on emergence of newly planted and ratoon cane under current production levels. Field experiments were carried out from 2014 to 2016 in Yunnan Province China. At maturity, plants were harvested and weighed to determine yield, and the effect on sugarcane quality and sucrose content analyzed. Real yield decreased by average of 46,185 kg hm^{-2} (range: 37,545–61,845 kg hm^{-2}) in damaged versus undamaged areas, with an average yield loss rate of 35.9% (28.5–45.7%). Juice yield decreased by an average of 3.01% (2.4–4.13%) and sucrose content by 6.38% (5.48–8.16%). Juice brix decreased by an average of 7.66°BX (6.95–9.05°BX) and juice gravity purity by 12.35% (8.43–19.97%). In contrast, the reducing sugar content increased by an average of 1.21% (1.01–1.3%). Emergence rates of newly planted cane decreased by an average of 26.0% (24.7–27.3%). The emergence number of ratoon cane decreased by 66,834 hm^2 (57,429–76,238 hm^{-2}) and relative emergence loss rates of ratoon cane decreased by an average of 57.8% (57.6–58.0%). These findings confirm that *C. lanigera* damage severely affects sugarcane yield and quality in Yunnan Province. The results will help the implementation of effective control measures, thereby supporting sustainable development of the Chinese sugar industry.

Keywords: Sugarcane, China, *Ceratovacuna lanigera* Zehntner, yield, sucrose content, loss evaluation

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Introduction

The sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner (Hemiptera: Aphididae) is a major pest of sugarcane. Now widely distributed, *C. lanigera* damage affects more than 80% of the total sugarcane growing area in China (Li & Huang, 2004; An & Guan, 2009; Huang & Li, 2011). The recent introduction of a complex culture system of spring- and autumn-sugarcane planting has supplemented the *C. lanigera* diet, increasing migration and resulting in widespread damage. In addition, hot dry weather in successive years has also benefited rapid propagation and population growth. *C. lanigera* damage trend has increased year by year. In China, virginoparous *C. lanigera* produce 18–20 overlapping generations every year. From June to July, Winged adults move into the sugarcane fields, reproducing and dispersing. From July to August, populations of *C. lanigera* develop rapidly, reaching a peak in September and October. In late November, a large number of winged adults move to wild sugarcane, reeds and weeds for overwintering. In China, the biological control agents of *C. lanigera* are *Synonycha grandis* (Thunberg) (Coleoptera: Coccinellidae), *Lemnia biplagiata* (Swartz) (Coleoptera: Coccinellidae) and *Thiallela* sp. (Lepidoptera: Pyralidae) (Li &

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Huang, 2004). In early June, the biological control agents begin to appear; however, these species reproduce slowly and is therefore unable to effectively prohibit the population growth of *C. lanigera*. Because the timing and methods of *C. lanigera* control are often insufficient, serious losses in overall cane and sugar yield have resulted in considerable economic losses in major sugarcane planting areas (Huang & Li, 2011; Li *et al.*, 2013).

Both nymphs and adults of *C. lanigera* gather and suck sap from both sides of the veins on lower leaf surfaces, causing leaf wilting and yellowing. In addition, honeydew secreted by *C. lanigera* is left on the upper surface of lower leaves, resulting in the formation of 'sooty mold'. Sooty mold interferes with plant photosynthesis, affecting overall growth, decreasing production and reducing sugar quality. *C. lanigera* damages both seed and ratoon cane, severely reducing the rate of emergence, quantity of seedlings and overall production (Huang & Li, 2011; Li *et al.*, 2013). A number of studies have documented the biological and ecological characteristics of *C. lanigera*; however, few have examined the resulting losses in sugarcane yield and sugar (Arakaki, 1992; Feng, 1998; Chen, 1999; Joshi & Viraktamath, 2004; Kumarasinghe & Basnayake, 2009; Tiwari *et al.*, 2014). In this study, losses in real yield and sugar yield caused by *C. lanigera* damage were assessed under natural field conditions and existing production levels with the aim of providing detailed data for effective control measures.

Materials and methods

Analysis of losses in yield and sugar caused by C. lanigera *damage*

In 2014–2015, field experiments of newly planted and ratoon cane were carried out for two times and one time, respectively. The ROC22 cultivar, which accounts for more than 60% of the total sugarcane grown in China, was used. Experimental fields were irrigated fields located in Kaiyuan, Yunnan Province, China. Sugarcane is planted perennially in the area. Fields were irrigable and flat, and soil conditions including fertility were comparable between sites: clay loam with a pH of 6.0 and organic matter content of 2.05%.

C. lanigera damaged and undamaged areas within the same field were examined in triplicate across a total of six experimental plots, respectively. Each plot was 50 m^2 and consisted of ten rows, each 5 m long and spaced 1 m apart. The cultivation density was 300 two-bud seedlings per plot. Plots were arranged in a random block design.

In early June, before *C. lanigera* migration, breeding and damage, 600 g hm^{-2} of 70% Thiamethoxam ZF mixed with the regular fertilizer (dosage per hm^2) was spread evenly across base of stalks and covered with soil in areas designated 'undamaged'. Pesticide was applied in undamage area onetime when the soil was 'hilled up'. In 'damaged' areas, fertilizer only was applied. All other cultivation measures were conducted according to local conventional methods and were the same in both damaged and undamaged areas.

In October, at the peak of *C. lanigera* occurrence, total numbers of seedlings and numbers of damaged plants were surveyed and recorded, and the rate of *C. lanigera* damage (%) was calculated as follows:

$$\frac{\text{Number of } C.\textit{lanigera}-\text{damaged plants}}{\text{Total number of surveyed seedlings}} \times 100$$

In February, when plants reached maturity, plant height, stem diameter, stalk brix and the effective number of stems were recorded in damaged and undamaged areas. Height, stem diameter and stalk brix were determined using a three-point sampling method, with 20 stalks selected sequentially at each point. The effective stem number was calculated as the effective number of stems per hm^2 as follows:

$$\frac{\text{Number of effective stems per plot}}{50\ (\text{m}^2)} \times 10\,005\ (\text{m}^2)$$

Real yield in the damaged and undamaged areas was measured after cutting and weighing, and the relative yield loss rate was calculated as follows:

$$\frac{\text{Real yield in undamaged areas} - \text{Real yield in damaged areas}}{\text{Real yield in undamaged areas}} \times 100$$

In February, when crops were harvested, sucrose content was determined in damaged and undamaged areas. In each plot, ten sugarcane stalks were selected randomly and using the two rotatory analysis method established by the National Sugar Industry Standardization and Quality Detection Center analyzed for juice yield (%), sucrose content (%), gravity purity (%) and the reducing sugar content (%). A fully automatic sugar analysis system (Rudolph, Autopol 880 + J257; USA) was used, and the loss of each index calculated as:

$$\text{Loss in undamaged areas} - \text{Loss in damaged areas}$$

Analysis of emergence rates of newly planted C. lanigera*-damaged seed cane*

In 2015–2016, rates of emergence of newly planted damaged and undamaged seed cane were surveyed. Experiments were carried out in triplicate in a total of six experimental plots, respectively. Plots and cultivation measures were as described above. After full emergence, emergence number was recorded in each plot and the rate of emergence (%) was calculated as follows:

$$\frac{\text{Emergence number in a plot}}{\text{Bud number in a plot}} \times 100$$

Analysis of emergence rates of C. lanigera*-damaged ratoon cane*

In 2015–2016, ratoon cane grown from the newly planted sugarcane planted in 2014 and 2015 was examined for emergence rates of *C. lanigera* damage. The plots and cultivation methods were as described above. After full emergence, emergence number was recorded in each plot, and emergence number (hm^2) was calculated as follows:

$$\frac{\text{Emergence number per plot}}{50\ (\text{m}^2)} \times 10\,005\ (\text{m}^2)$$

The relative loss rates calculated as follows:

$$\frac{\text{Emergence number in undamaged areas} - \text{Emergence number in damaged areas}}{\text{Emergence number in undamaged areas}} \times 100$$

Results

Effect of C. lanigera *damage on agronomic characters and yield*

As shown in fig. 1 and table 1, *C. lanigera* caused serious damage, with a damaged plant rate of as high as 100%.

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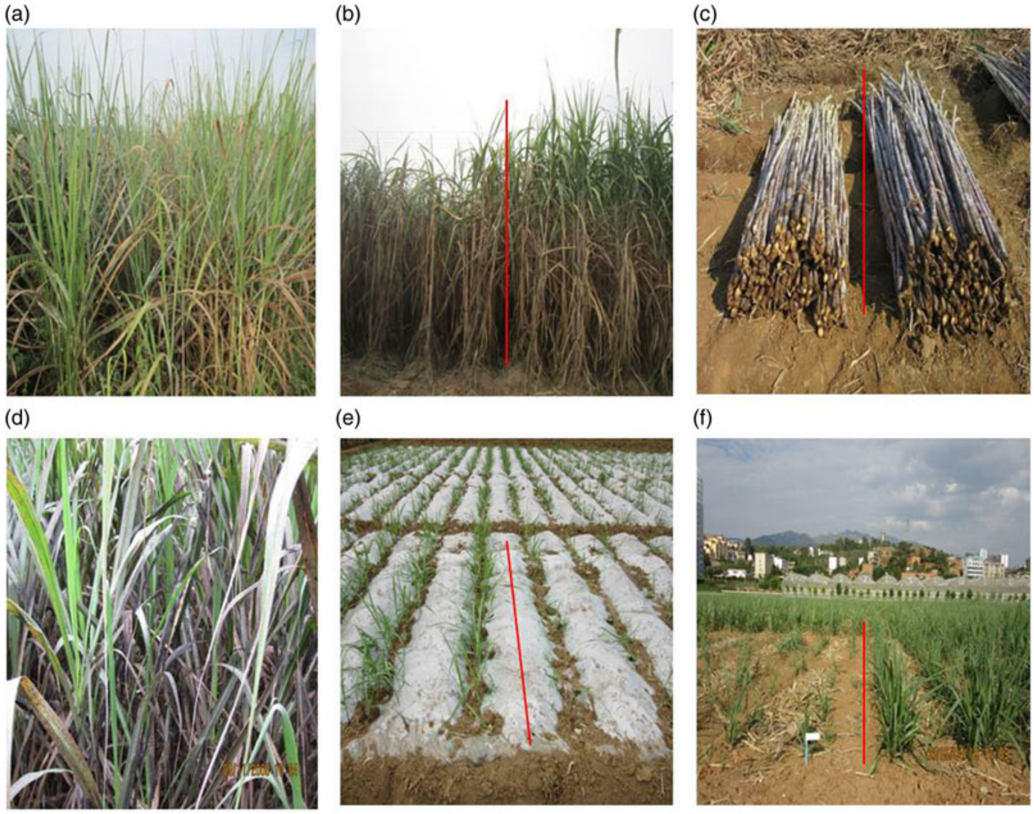

Fig. 1. Symptoms of *Ceratovacuna lanigera* Zehntner damage (a) Symptoms of *C. lanigera* damage in the field. (b) Sugarcane growth atrophy caused by *C. lanigera* damage. (c) Severe yield losses caused by *C. lanigera* damage. (d) Sooty mold caused by *C. lanigera* damage. (e) The low emergence rates of *C. lanigera*-damaged seed cane and (f) ratoon cane.

Table 1. Effect of *Ceratovacuna lanigera* Zehntner damage on agronomic characters and yield.

Year	Cane type	Area	Pests plant rate (%)	Plant height (cm)	Stem diameter (cm)	Brix (°BX)	Effective stem number (stalks hm^{-2})	Measured yield (kg hm^{-2})	Relative yield loss rate (%)
2014	Newly planted	Undamaged	0.0	274.4 a	2.67 a	21.9 a	93375 a	131940 a	
		Damaged	100.0	216.9 b	2.06 b	12.9 b	91155 b	94395 b	28.5
		Losses		57.5	0.61	9	2220	37545	
2015	Newly planted	Undamaged	0.0	273.7 a	2.54 a	21 a	82545 a	117435 a	
		Damaged	100.0	186.6 b	2.01 b	12.9 b	80040 b	78270 b	33.4
		Losses		87.1	0.53	8.1	2505	39165	
	Ratoon	Undamaged	0.0	283.7 a	2.51 a	22.3 a	90045 a	135375 a	
		Damaged	100.0	179.1 b	1.72 b	10.9 b	85050 b	73530 b	45.7
		Losses		104.6	0.79	11.4	4995	61845	
		Average losses		83.1	0.64	9.5	3240	46185	35.9

Different letters in the same column represent a significant difference at 0.05.

C. lanigera-damaged leaves were yellow and wilting, and covered with sooty mold. Damaged plants showed growth atrophy and a significant reduction in height, stem diameter, stalk brix and effective stem number compared with healthy sugarcane. Height was reduced by an average of 83.1 cm (range: 57.5–104.6 cm), stem diameter by an average of 0.64 cm (0.53–0.79 cm), stalk brix by an average of 9.5°BX (8.1–11.4°BX), and effective stem number by an average of 3240 stalks hm^{-2} (2220–4995 stalk hm^{-2}). Yield was also significantly affected, with an average reduction in real yield of 46,185 kg hm^{-2} (37,545–61,845 kg hm^{-2}), representing a relative real yield loss rate by an average of 35.9% (28.5–45.7%)

Effect of C. lanigera *damage on sugarcane quality*

The results of sugarcane quality analysis are presented in table 2. As shown, the juice yield, sucrose content, juice brix and juice gravity purity of damaged sugarcane in damaged areas was lower than that of healthy sugarcane in undamaged areas. Juice yield decreased by an average of 3.01% (range: 2.4–

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Table 2. Effect of *Ceratovacuna lanigera* Zehntner damage on sugarcane quality.

Year	Cane type	Area	Juice yield (%)	Sucrose content (%)	Brix (°BX)	Gravity purity (%)	Reducing sugar content (%)
2014	Newly planted	Undamaged	71.04 a	16.42 a	22.44 a	87.18 a	0.3
		Damaged	68.64 b	10.94 b	15.49 b	78.75 b	1.6
		Losses	2.4	5.48	6.95	8.43	−1.3
2015	Newly planted	Undamaged	70.65 a	16.05 a	21.91 a	86.18 a	0.27
		Damaged	68.14 b	10.54 b	14.94 b	77.52 b	1.6
		Losses	2.51	5.51	6.97	8.66	−1.33
	Ratoon	Undamaged	74.78 a	16.15 a	22.11 a	86.58 a	0.24
		Damaged	70.65 b	7.99 b	13.06 b	66.61 b	1.25
		Losses	4.13	8.16	9.05	19.97	−1.01
		Average losses	3.01	6.38	7.66	12.35	−1.21

Different letters in the same column represent a significant difference at 0.05.

Table 3. Effect of *Ceratovacuna lanigera* Zehntner damage on emergence for newly planted cane and ratoon cane.

		Newly planted		Ratoon		
Year	Area	Emergence number of experimental plot	Emergence rate (%)	Emergence number of experimental plot	Emergence number (hm^2)	Relative emergence loss rate (%)
2015	Undamaged	416	69.3 a	498	99650 a	
	Damaged	252	42.0 b	211	42221 b	57.6
	Losses	208	27.3	287	57429	
2016	Undamaged	403	67.2 a	657	131466 a	
	Damaged	255	42.5 b	276	55228 b	58.0
	Losses	148	24.7	381	76238	
	Average losses	178	26.0	334	66834	57.8

Different letters in the same column mean significant difference at 0.05 level.

4.13%), sucrose content by an average of 6.38% (5.48–8.16%), juice brix by an average of 7.66°BX (6.95–9.05°BX) and juice gravity purity by an average of 12.35% (8.43–19.97%). In contrast, the reducing sugar content increased by an average of 1.21% (1.01–1.3%) in damaged areas. Thus, *C. lanigera* seriously affected sugarcane quality and reduced the sugar production rate.

Effect of C. lanigera *damage on the emergence rate of newly planted cane and ratoon cane*

As shown in fig. 1 and table 3, *C. lanigera* damage seriously affected the emergence of newly planted and ratoon cane, severely decreasing the emergence rate and quantity of seedlings. The *emergence rates of newly planted C. lanigera*-damaged seed cane decreased by an average of 26.0% (24.7–27.3%). The emergence number of *C. lanigera*-damaged ratoon cane was also severely reduced by an average of 66,834 hm^2 (57,429–76,238 hm^2). This represented an average relative emergence loss rate of 57.8% (57.6–58.0%).

Discussion

C. lanigera is the most harmful of all sugarcane leaf pests in the grand period of sugarcane growth. Now widely distributed in sugarcane planting areas, *C. lanigera* damage affects more than 80% of the total sugarcane area in China. Recent changes in sugarcane planting systems along with global warming have provided favorable wintering conditions for *C. lanigera*, conducive to migration, reproduction and population development. Moreover, because of insufficient management, sugarcane damage caused by *C. lanigera* is increasing annually, resulting in considerable economic loss (Li & Huang, 2004; An & Guan, 2009; Huang & Li. 2011; Li *et al.*, 2013). Understanding the effect of *C. lanigera* damage on losses in cane yield and sugar content is therefore important. Previous research suggests variation in the dynamics of *C. lanigera*, and therefore, the damage intensity and cane yield and sugar content losses at different times, under different planting systems and different production levels (Gupta & Goswami, 1995; Patil *et al.*, 2004; Mukunthan *et al.*, 2008; Padul *et al.*, 2008; Tatagar & MohanKumar, 2010). Researching the losses in real cane yield and sugar yield as well as the effect on emergence of newly planted and ratoon cane under existing production levels will therefore provide a theoretical basis and detailed data for scientifically-based control of *C. lanigera.*

The results of yield and sugar losses as well as the emergence rates of newly planted and ratoon cane obtained here closely represent actual production rates seen in the field under natural conditions. That is, they objectively reflect actual conditions of pest damage in the field and are therefore highly applicable. Moreover, the results show the serious effect of *C. lanigera* on cane yield and sugar content in Yunnan Province. The negative effect on rates of emergence of newly planted and ratoon cane and on the quantity of seedlings and overall production was also confirmed. Yield was reduced by an average of 46,185 kg hm^{-2}, with a maximum finding of 61,845 kg hm^{-2}. Moreover, the relative loss rate in yield was an average of 35.9%, with a maximum of 45.7%. Sugar content was reduced by an average of 6.38%, with a maximum of 8.16%, and gravity purity by 12.35%, with a maximum of 19.97%. The rates of emergence of newly planted cane were reduced by 26.0%, with maximum of 27.3%. Moreover, the emergence number of ratoon cane per hectare was reduced by an average of 66,834, with a maximum of 76,238, this represented an average relative emergence loss rate of 57.8%, with a maximum of 58.0%. Gupta and Goswami revealed a loss in cane yield with *C. lanigera* damage of 16.6% (Gupta & Goswami, 1995), while in Maharashtra, India, cane yield and the recovery rate of sugar content caused by *C. lanigera* damage decreased by 7–39 and 1.2–3.43%, respectively(Patil *et al.*, 2004). Losses in cane yield and sugar content of 26 and 24%, respectively, were also reported in Karnataka, India (Tatagar &MohanKumar, 2010). Thus, cane yield and sugar content losses caused by *C. lanigera* damage are very serious, making it a major challenge for high and stable yield and good quality of sugarcane. Ensuring safe sugarcane production and sustainable development of the sugar industry by strengthening *C. lanigera* control measures and reducing the losses resulting from damage is therefore important.

July to September is the key period of sugarcane jointing as well as an important yield accumulation stage. It is also the peak period of *C. lanigera* occurrence and subsequent damage. The occurrence of *C. lanigera* in sugarcane fields can be divided into the following stages: migration of winged aphids to sugarcane fields and the formation of spread center, which become the base of *C. lanigera* from June to July. Rapid spread of *C. lanigera* across entire fields from July to August, causing large outbreaks from September to October, with serious effects on growth, cane yield and sugar content (Li & Huang, 2004; An & Guan, 2009; Huang & Li, 2011). The grand period of sugarcane growth should therefore be considered when tackling damage caused by *C. lanigera*.

Based on the above characteristics of *C. lanigera*, as well as the findings of this study, the following is suggested as an effective control method. A single dose of 600 g hm^{-2} of 70% Thiamethoxam ZF should be applied to the sugarcane planting and management between February and June, prior to migration of *C. lanigera* and subsequent breeding and damage. The pesticide should be mixed with regular fertilizer at a per hm^2 dosage and spread evenly across sugarcane ditches, stumps or the base of stalks before being covered with soil.

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