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Review Article

Natural Enemies of Sugarcane Pests and Their Roles in Natural Control in Yunnan, China

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Sugarcane, Natural enemies, Natural control.

ABSTRACT

This paper summarizes the natural enemies of major sugarcane pests and their roles in natural control in sugarcane growing regions in Yunnan. In general, these natural enemies can be divided into two groups: parasites and predators. The dominant species include *Apanteles flavipes* (Cameron), *Sturmiopsis inferens* Townsend and *Trichogramma* sp., which parasitize the sugarcane borer; *Synonycha grandis* (Thunberg), *Lemnia biplagiata* (Swartz), *Cheilomenes sexmaculata* (Fabricius) and *Thiallela* sp., which prey on *Ceratovacuna lanigera* Zehntner; and *Euborellia pallipes* Shiraki, *Orius* (*Heterorius*) *minutus* (Linnaeus) and *Scymnus* (*Neopullus*) *hoffmanni* Weise which preys on *Saccharicoccus sacchari* (Cocherell), *Baliothrips serratus* Kobus and *Trochorhopalus humeralis* Chevrolat. Protecting these natural enemies will encourage natural control of pest species while protecting the environment and maintaining ecological balance. Moreover, through enhanced comprehensive pest control, sustainable development of the sugar industry will be promoted.

Yunnan province is the second largest sugarcane growing area in China as well as the main area of distribution and the most potential development area of future production. As a result, sugarcane is a major economic crop, and the sugar industry the main source of regional economic development and farmers' income in frontier minority areas in Yunnan. Moreover, since the implementation of reform policies aimed at national industrial development aided by Yunnan provincial party and provincial government support, the sugar sector in Yunnan has experienced rapid development (Zhang, 2011). In 2013-2014, the sugarcane planting area reached 333,333 ha, with a yield of refined sugar exceeding 2.3 million tons (Zhang, 2015). However, the long-term control and treatment of sugarcane pests currently relies on highly toxic chemicals and broad-spectrum pesticides such as methamidophos, omethoate and terbufos. As a result, many natural enemy species are also targeted, with some having experienced a rapid decline, therefore, the pest resistance to insecticide is higher than before, upsetting the dynamic relationship between pests and their natural enemies. Moreover, this has a direct effect on pest control, further encouraging successive long-term application of pesticides, and thereby increasing residual toxicity and pollution, which poses a threat to human health (Huang and Li, 2011, 1995b, 1997; Liang *et al*., 2010). To avoid the negative effects of pesticide application, several avenues of research and novel control strategies have demonstrated potential in controlling insect pests. For example, the use of silicon based fertilizers can enhance sugarcane resistance to pests (Frew *et al*., 2016), light-trapping is widely used for trapping a variety of insect pests (Wu *et al*., 2009) and biological control agents such as *Beauveria bassiana* and *Metarhizium anisopliae* have good effect to control sugarcane borers (Ashok and Tandan, 1996). A new task facing plant protection management from a comprehensive and environmental standpoint is therefore the control of pest insects.

Biological prevention has recently become a comprehensive method of pest control in China, achieving wide-spread attention due to the social and ecological benefits. Research on the use of natural enemies in sugarcane growing areas will therefore help effective control of the damage caused by pests, thereby increasing

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raw cane production, reducing environment pollution, maintaining ecological balance and reducing production costs. Moreover, since entering the World Trade Organization (WTO), which demands strict regulation of agricultural products, the protection and utilization of natural enemies rather than pesticides has become of even greater importance. Recent research reported that nectar-producing plants grown around rice fields could attract natural enemies, significantly reduced populations of two key pests, reduced insecticide applications by 70%, increased grain yields by 5% and delivered an economic advantage of 7.5% (Gurr *et al*., 2016).

Yunnan province, which is located on a low-latitude plateau, is the main distribution area and most potential development area of sugarcane production in China. In these sugarcane growing areas, the climate and environment is both complex and variable, and while pests are numerous, natural enemy resources are also very rich. A total of 283 natural enemies exist in Yunnan province alone. Dominant species with conservation use value and research significance include *Apanteles flavipes* (Cameron), *Sturmiopsis inferens* Townsend and *Trichogramma* sp., which parasitize sugarcane borer; *Synonycha grandis* (Thunberg), *Lemnia biplagiata* (Swartz), *Chilomenes sexmaculata* (Fabricius) and *Thiallela* sp., which prey on *Ceratovacuna lanigera* Zehntner; and *Euborellia pallipes* Shiraki, which preys on *Saccharicocus sacchari* (Cocherell) and *Trochorhopalus humeralis* Chevrolat (Huang and Li, 1995a).

To help promote the role of biological control in integrated management of sugarcane pests in China, this paper summarizes the natural enemy resources and their roles in biological control in sugarcane planting regions in Yunnan.

GEOGRAPHIC LOCATIONS AND OCCURRENCE OF SUGARCANE PESTS IN YUNNAN

Yunnan province is situated on the southwest of Yunnan-Guizhou plateau, which lies between north latitude 21°9′~29°15′ and east longitude 97°39′~102°12′. Geographically, Yunnan province is situated in a low-latitude area that includes high altitudes and mountainous terrain. Accordingly, because of these differences in elevation and the complex and variable landform types, Yunnan possesses characteristics of "three-dimensional agriculture". This is further complicated by the climate, which varies from cold to temperate to tropical, even within a small area, because of the differences in altitude. As a result, the structure and distribution of biocoenosis is both variable and complex.

Table I.- Natural enemies of sugarcane pests across Yunnan Province, China.

Class (Number)	Order (Number)	Family (Number)
Insecta (201)	Odonata (2)	Libellulidae (2)
	Mantodea (2)	Mantidae (2)
	Dermaptera (1)	Psalididae (1)
	Hemiptera (22)	Reduviidae (12) Pentatomidae (2) Miridae (1) Lygaeidae (2) Anthocoridae (4) Nabidae (1)
	Neuroptera (5)	Chrysopidae (3) Hemerobiidae (1) Ascalaphidae (1)
	Lepidoptera (1)	Pyralidae (1)
	Coleoptera (56)	Coccinellidae (35) Cicindelidae (8) Carabidae (11) Staphylinidae (1) Meloidae (1)
	Diptera (23)	Asilidae (1) Syrphidae (7) Dexiidae (1) Larvaevovidae (13) Pipunculidae (1)
	Hymenoptera (88)	Eumenidae (10) Polistidae (8) Ropalidiidae (2) Polybiidae (2) Vespidae (2) Sphecoidae (1) Scoliidae (1) Chrysididae (1) Mutillidae (1) Dryinidae (1) Ichneumonidae (23) Braconidae (14) Aphidiidae (1) Chalcididae (5) Pteromalidae (1) Eulophidae (2) Torymidae (1) Encyrtidae (4) Trichogrammatidae (2) Elasmidae (1) Scelionidae (1) Gasteruptionidae (1) Evaniidae (1) Formicidae (1) Pompilidae (1)
	Strepsiptera (1)	Halictophagidae (1)
Arachnoidea (82)	Araneida (82)	Erigonidae (1) Theridiidae (5) Tetragnathidae (8) Araneidae (19) Lycosidae (7) Clubionidae (3) Thomisidae (6) Oxyopidae (3) Salticidae (10) Sicariidae (2) Amaurobiidae (1) Dictynidae (1) Linyphiidae (1) Uloboridae (2) Eresidae (1) Gnaphosidae (5) Hahniidae (2) Pisauridae (2) Pholcidae (1) Heteropodidae (1) Oecobiidae (1)

Sugarcane planting has a very long history in Yunnan and is widely distributed, largely within tropical to semitropical regions. Because of the varying climate and landforms, and the complex methods of sugarcane cultivation, many kinds of pest are encountered. Statistics from sugarcane regions throughout Yunnan suggest 124 pest species in the classes Insecta (7 orders, 31 families, 122 species) and Arachnoidae (1 order, 2 families, 2 species), some of which have a serious effect on sugarcane growth and frequently cause disasters during cultivation. Such species include *Sesamia inferens* Walker, *Chilo infuscatellus* Snellen,, *Chilo auricilia* Dudgeon, *Chilo suppressalis* (Walker), *Argyroploce schistaceana* (Snellen), *C. lanigera*, *Baliothrips serratus* Kobus, *S. sacchari*, *Exolontha serrulata* (Gyllenhal), *Alissonotum impressicolle* Arrow, *Alissonotum pauper* Burmeister,, *T. humeralis*, *Otidognathus rubriceps* Chevrolat, *Odontotermes formosanus* (Shiraki), *Macrotermes barneyi* Light, *Coptotermes formosanus* Shiraki and *Tetraneura hivsuta* Baker etc. (Huang and Li, 2011).

CLASSIFICATION AND DISTRIBUTION OF NATURAL ENEMIES OF SUGARCANE PESTS IN YUNNAN

There are an abundance of natural enemies of sugarcane pests in sugarcane growing regions in Yunnan. Statistics suggest a total of 283 natural enemy species in the classes Insecta (10 orders, 50 families, 201 species) and Arachnoidae (1 order, 21 families, 82 species; Table I) (Huang and Li, 2014). These species can be divided into two groups: predators and parasites, the former of which includes predacious insects and spiders, while the latter includes parasitic insects. The distribution of predominant natural enemies differs among districts due to the differences in climates, ecosystems and dominant pests across Yunnan (Table II).

FLUCTUATIONS IN NATURAL ENEMIES AND NATURAL CONTROL OF SUGARCANE PESTS IN YUNNAN

Of the 124 pest species in Yunnan province, only 10 to 12 % occur frequently, the remainder being largely influenced by the environment. Of all environmental factors, natural enemies play the most important role in the spread of these pests. Fluctuations in the frequency of these pest insects are also largely affected by the roles of their natural enemies. Various natural enemies which inhabit sugarcane fields appear sequentially along with pest occurrence, which can effectively control pest proliferation.

From March to May, two species of pest begin to emerge: the cane borer and cane beetle, subsequently becoming the major pests of sugarcane seedling growth. At the same time, natural parasitic enemies of the cane borer such as the parasitoid wasp Tachinidae and predators such as *Cosmolestes annulipes* Distant, spiders, *Paederus fuscipes* Curtis, Carabidae species, and *Euborellia pallipes* Shiraki begin to prey on or parasitize these pests. The subsequent increase in natural enemies thereby helps prevent the spread of these two pests, causing a decrease in numbers.

From June to July, sugarcane growth enters the tiller and elongation stages. During this time, pests such as *C. lanigera* and *B. serratus* move into the sugarcane fields, reproducing and dispersing, and eventually becoming the predominant species. At the same time, predators such as Syrphidae, ladybirds, *Chrysopa perla*, mantis, spiders, *Thiallela* sp., Carabidae species, predatory stinkbugs, and *Orius (Heterorius) minutus* (Linnaeus) also begin to appear. Although reproduction rates of these natural enemies do not surpass those of the above pests, numbers increase as a result of increasing numbers of pests. Overall, however, these enemy species cannot control the harmful effects of the above two pests at this time.

From August to October, Yunnan province enters the rainy season, and the sugarcane begins to elongate and broaden. Various environmental factors benefit natural enemies during this time, rather than *C. lanigera* and *B. serratus*. Consequently, populations of these enemy species develop rapidly, reaching a peak in November. As a result, they are able to effectively restrain reproduction of *C. lanigera* and *B. serratus*. Although *S. sacchari* reproduces all year round, numbers of corresponding natural predators such as *O. minutus*, *Scymnus* (*Neopullus*) *hoffmanni* Weise, and *E. pallipes* are sufficiently high to control proliferation, thereby helping avoid large-scale loss of sugarcane output.

Four species of sugarcane pest occur frequently: *S. inferens* Walker, *C. infuscatellus, C. auricilia*, *C. suppressalis*, *A. schistaceana*, *C. lanigera*, *S. sacchari* and *B. serratus*, seriously impacting cane growth and often having disastrous effects on the sugarcane industry. The major natural enemies of these important pests are listed in the following sections.

Natural enemies of the sugarcane borer and their roles in natural control

Most natural enemies of the sugarcane borer are parasitic, the dominant species of which are *A. flavipes*, *S. inferens*, and *Trichogramma* sp., *A. flavipes* is the dominant natural enemy of *S. inferens* Walker and *C. infuscatellus*, playing an effective role in their control. This species is widely distributed throughout Yunnan, its larva producing

upto 4 -5 generations inside the bodies of both borer species each year. Moreover, larvae of *A. flavipes* are found in the bodies of first to fifth generations of these borer species. The natural parasitic rate of each generation in the borer body is 25-40%, with a peak from May to June. As many as 80 to 100 infants of *A. flavipes* can be found in a single host body, causing tardiness along with a decrease in appetite, and often complete refusal to eat, thereby reducing movement and damage between plants and preventing subsequent damage to sugarcane crops (Li, 1995).

S. inferens is mainly distributed in the tropical and humid Dehong autonomous region, where it is the major natural enemy of four pest species: *Sesamia inferens* Walker, *C. infuscatellus*, *C. auricilius* Dudgeon and *C. suppressalis* Walker. It parasitizes the post larva body, each host infected by a parasite. The incidence of natural autoeciousness can reach 20~35%, playing a significant role in inhibition of the sugarcane borer in Dehong area.

Trichogramma sp. is mainly distributed in arid and semiarid regions of tropical south Asia where it parasitizes the ovum of *Argyroploce schistaceana* (Snellen). The incidence of natural autoeciousness can reach 25-38% if an adequate number of ova are laid during the first 10 days of July. Under such favorable conditions, *Trichogramma* can therefore help control the economic losses resulting from *A. schistaceana* damage.

Table II.- The dominant species of natural enemies of sugarcane pests in different climatic and geographical regions across Yunnan Province, China.

Region	Geographical and climatic characteristics	Dominant species	
		Parasitic	**Predatory**
Tropical and humid	Altitude: 400-700 m Annual rainfall: 1200-1800 mm Vaporization capacity ≤rainfall Annual average temperature: ≥20°C	*Apanteles flavipes* (Cameron)	*Cosmolestes annulipes* Distant, *Polididus armatissimus* Stal, *Euagoras plagiatus* Burmeiter, *Coelophora biplagiata* (Swartz), *Synonycha grandis* (Thunberg), *Scymnus (Neopullus) hoffmanni* Weise, *Paederus fuscipes* Curtis, *Thiallela* Sp.
Tropical, subtropical and arid	Altitude: 300-1000 m Annual rainfall: 600-900 mm Relative humidity: 60-70%, Vaporization capacity is greater than rainfall, Annual average temperature: ≥20°C	*Apanteles flavipes* (Cameron), *Tomosvaryella oryzaetora* (Koizumi)	*Scymnus (Neopullus) hoffmanni* Weise, *Chilomenes sexmaculata* (Fabricius), *Leis axyridis* (Pallas), *Stethorus* Sp., *Orius (Heterorius) minutus* (Linnaeus), *Cyrtorrhinus lividipennis* Bedt
Subtropical and humid	Altitude: 700-1000 m Annual rainfall: 1100-1700 mm Vaporization capacity approximately equal to rainfall, Annual average temperature:≥18-20°C	*Sturmiopsis inferens* Townsend, *Servillia planiforceps* Chao	*Sirthenea flavipes* Stal, *Scymnus (Neopullus) hoffmanni* Weise, *Synonycha grandis* (Thunberg), *Coelophora biplagiata* (Swartz), *Paederus fuscipes* Curtis, *Cicindela chinensis* DeGeer
Tropical and humid, south Asia	Altitude: 900-1300 m Annual rainfall: 1200-1800 mm Vaporization capacity approximately equal to rainfall, Annual average temperature: ≥18-20°C	*Sturmiopsis inferens* Townsend, *Servillia Planiforceps* Chao, *Linnaemya vulpinoides* Baranoff	*Synonycha grandis* (Thunberg), *Coelophora biplagiata* (Swartz), *Synharmonia octomaculata* (Fabricius), *Calosoma chinense* Kirby
Tropical, arid and subarid, south Asia	Altitude: 1000-1500 m Annual rainfall: 700-1000 mm Vaporization capacity is greater than rainfall, Annual average temperature: ≥18-20°C	*Apanteles flavipes* (Cameron), *Trichogramma* Sp.	*Synonycha grandis* (Thunberg), *Chilomenes sexmaculata* (Fabricius), *Leis axyridis* (Pallas), *Scymnus (Neopullus) hoffmanni* Weise, *Propylaea japonica* (Thungberg), *Thiallela* Sp., *Micromus timidus* Hagen, *Orius (Heterorius) minutus* (Linnaeus), *Paederus fuscipes* Curtis, *Euborellia pallipes* Shiraki
Tropical and humid, central Asia	Altitude: 1200-1400 m Annual rainfall: 1200 mm Vaporization capacity > rainfall Annual average temperature: ≥16-18°C		*Coelophora biplagiata* (Swartz), *Chilomenes sexmaculata* (Fabricius), *Verania discolor* (Fabricius), *Coelophora bissellata*(Mulsant), *Epistrophe balteata* De Geer

Natural enemies of sugarcane C. lanigera *and their roles in natural control*

Most natural enemies of *C. lanigera* are predators, the predominant species of which are *S. grandis* (Thunberg), *L. biplagiata* (Swartz), *Cheilomenes sexmaculata* (Fabricius) and *Thiallela* sp., which frequently inhabit sugarcane fields. *S. grandis* not only forms substantial populations widely distributed throughout Yunnan, but also has the highest predatory capacity of all species of ladybug (Huang and Li, 2006). Both its imago and larva are able to catch *C. lanigera.* Statistics suggest that in its lifetime, one *S. grandis* is able to catch 32,000 *C. lanigera*, thereby significantly inhibiting proliferation. In early June, *S. grandis* imago begin to; however, this species reproduces slowly and is therefore unable to effectively prohibit the occurrence of the initial peak of *C. lanigera* in June and July. Between August and October, however, *S. grandis* populations expand rapidly, reaching a peak in November. Up to 2 to 3 imagines, 6 to 8 larvae, 30 to 50 ova and even a few pupa of *S. grandis* can occupy a single sugarcane leaf, thereby having a significant effect on the second and third peaks of *C. lanigera* (Li *et al*., 2001, 2009).

L. biplagiata is also widely distributed across Yunnan and has the second largest predation capacity after *S. grandis*. Both its imago and larva are able to feed on *C. lanigera.* In general, *L. biplagiata* starts to appear at the beginning of June, after which it increases with reproduction of *C. lanigera.* It subsequently gains its first peak in July, before decreasing again between August and September. A second peak is then reached in October to November during which time it plays an effective role in controlling early and late *C. lanigera* proliferation and damage.

C. sexmaculata is widely distributed throughout much of Yunnan province. Both its imago and infants are able to hunt *C. lanigera*. When *C. lanigera* occurred in the early, there are a large number of *C. sexmaculata* in the field. Numbers of *C. sexmaculata* start to increase in the last 10 days of June, reaching a peak in July to August. However, numbers begin to decline from the middle of September. It therefore has an important effect on the occurrence of early *C. lanigera*.

Thiallela sp., which belongs to the Lepidoptera Pyralidae family, is distributed throughout all major sugarcane planting regions in Yunnan. The larvae prey on *C. lanigera* by weaving a net from which they hunt, capturing up to 100 *C. lanigera* a day. When *C. lanigera* occurred in the late, there are a large number of *Thiallela* sp. in the field. Numbers of *Thiallela* sp. reach a peak from September to December, during which time they play an important role in controlling the occurrence of late *C. lanigera* populations.

Natural enemies of S. sacchari *and* B. serratus *and their roles in natural control*

Several natural enemies of *S. sacchari* and *B. serratus* inhabit sugarcane fields; for example, *E. pallipes*, *O. minutus*, *Orius* sp., *S.* (*Neopullus*) *hoffmanni* Weise, and *Pseudoscymnus kurohime* (Miyatake). Of these, the dominant species are *E. pallipes*, *O. minutus* and *S. hoffman*ni, all of which are distributed widely throughout sugarcane growing regions in Yunnan. They emerge all year round and pray on both *S. sacchari* and *B. serratus*, thereby effectively helping control proliferation of these two pests.

CONCLUSIONS

A number of natural enemies of sugarcane pests exist in the cane field ecosystem, playing an important role in preventing crop damage. However, many farmers lack scientific knowledge about the roles of these natural enemies, and as a result, do not know how to protect and exploit them. To make matters worse, many natural enemies are killed by abuse of chemical pesticides used to control pests. As a result, this is destroying the dynamic balance between pests and their enemies, increasing the number of pests, while poisoning the ecological environment and leading to environmental degradation. To improve the currently passive situation, an improved understanding of the roles of natural enemies in natural control is required to help the conservation and utilization of such species over pesticides.

In line with this, pesticides should be used sparingly with scientific backing to help reduce the effect on natural enemies, allowing them to play a role in controlling pests. In addition, farmers should be encouraged to make use of other crops such as maize, soybean, peanut, vegetable and green manure crops, inter-planting them with sugarcane in order to alter the microclimate and create an ideal ecosystem for natural enemies, helping increase the number of species. If conditions permit, artificial breeding or introduction of natural enemies should also be encouraged to increase population numbers. That is, methods should be employed to fully exploit the effectiveness of natural enemies in sugarcane fields. This will have an important significant effect on biological control, improving pest management, maintaining the dynamic balance in farmland ecosystems and reducing environmental pollution. In turn, this will further protect the environment and promote sustainable development of the sugar industry.

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Statement of conflict of interest

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