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Integrated pest management of the sugarcane stemborers *Diatraea* spp., *Elasmopalpus lignosellus* and *Telchin licus*

Manejo integrado de los barrenadores *Diatraea* spp., *Elasmopalpus lignosellus* y *Telchin licus* en caña de azúcar

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Abstract

This work reviews the Integrated Pest Management (IPM) of three sugarcane stemborers of economic importance in Panama: *Diatraea* spp. (Lepidoptera: Crambidae), *Elasmopalpus lignosellus* (Zeller, 1848) (Lepidoptera: Pyralidae) and *Telchin licus* (Drury, 1773) (Lepidoptera: Castniidae). An overview of the use of chemical insecticides against these borer species is included, along with the main results and achievements obtained with different agricultural practices and alternative pest management methods such as pheromones bioinsecticides and biological control. This study supports the necessity of developing alternative solutions based on agroecological approaches in the context of more sustainable and climate-smart agriculture interventions in sugarcane and other vital industrial crops in the country.

Keywords: Alternative control, stemborers, biological control, chemical control, IPM, industrial crops

Resumen

La presente revisión se centra en el manejo de tres barrenadores de la caña de azúcar de importancia económica en Panamá: *Diatraea* spp. (Lepidoptera: Crambidae), *Elasmopalpus lignosellus*

(Zeller, 1848) (Lepidoptera: Pyralidae) and *Telchin licus* (Drury, 1773) (Lepidoptera: Castniidae). Se presenta una visión general sobre el uso de insecticidas químicos contra estas especies de barrenadores, acompañada de los principales resultados y logros obtenidos con diferentes prácticas agrícolas, así como del uso de métodos alternativos de manejo de plagas como feromonas, bioinsecticidas y control biológico. Este estudio respalda la necesidad de implementar soluciones alternativas, basadas en enfoques agroecológicos en el contexto de intervenciones agrícolas más sostenibles y climáticamente inteligentes en la caña de azúcar y otros cultivos industriales estratégicos para el país.

Palabras clave: Barrenadores, caña de azúcar, control alternativo, control químico, MIP

INTRODUCTION

In Panama private sugarcane mills as Compañía Azucarera La Estrella Sociedad Anónima (CALESA) in Cocle; Azucarera Nacional Sociedad Anónima (ANSA) in Coclé; Central Azucarera La Victoria Sociedad Anónima (CALVISA) in Veraguas and Central Azucarera de Alanje Sociedad Anónima (CADASA) in Chiriqui (Atencio et al., 2020a) represent the sugarcane (*Saccharum officinarum* L.) industry that produces sugar and alcohol (medical and beverages).

Sugar production has been consolidated as one of the leading export industries in Panama. Sugarcane crops for industrial processing occupy more than 29 000 hectares; data reported in 2019-2020 (MIDA, 2020). Field production required the use of varieties such as RAGNAR, B74125, DB7160, CP742005, SP74-8355, and RB73-9735 (Rossi, 2001); also planting in the last years' other options such as B0072, E07-11, E07-14, CP89-2143, CT-14 and CT-41 (Jorge et al., 2018). This industry has a series of production limitations that include dry areas, pests, pathogens, and weeds, to mention a few (Atencio et al., 2020a).

Lepidoptera stemborers are an essential key pest in Panama, including *Diatraea* spp. (Lepidoptera: Crambidae), *Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae) and *Telchin licus* (Drury) (Lepidoptera: Castniidae) (Esquivel, 1980; Narvaéz, 1989; Atencio et al., 2019a). In Panama, seven species of the genus *Diatraea* have been reported, including *Diatreae bellifactella* Dyar, *Diatraea busckella* Dyar & Heinrich, *Diatraea* gaga Dyar, *Diatraea lineolate* (Walker), *Diatraea lisseta* (Dyar), *Diatraea saccharalis* (F.) and *Diatraea tabernella* Dyar (the most prevalent in sugarcane in Panama) (Solis & Metz, 2016; Atencio & Goebel, 2018). These species cause serious internal damage to the stalk and degradation of the sugar juice (Chaves et al., 2008; Atencio et al., 2017).

In North America (United States of America USA: Lousiana and Florida mainly), Central and South America, Sugarcane is attacked by the same stemborer species complex (*Diatraea* spp. (Figure 1, larva), *Elasmopalpus lignosellus* (Zeller) (Figure 2 (Photo by José Daniel Salazar, DIECA-LAICA)) and *Telchin licus* (Drury) (Figure 3) (Narvaéz, 1989; Beuzelin et al., 2010; Gill et al., 2011). The use of chemical insecticides has never been sustainable neither an efficient option

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for stemborer management because of the internal development of these insects in the sugar stalk, problems of insecticide resistance, and the negative impacts on humans, biodiversity, and the environment (Lenteren & Bueno, 2003; Aktar et al., 2009).



Figure 1. Diatraea spp. larva. *Figure 2. E. lignosellus* larva. *Figure 2. T. licus* larva.

Integrated Pest Management (IPM) strategies seek the combination of chemical and biological control as an alternative to control pests without relying solely on pesticides. Historically, one of the reasons for implementing IPM programs was the lethal and sublethal impact of insecticides on natural enemies, which altered their performance, affecting their ability to control pests (Bale et al., 2008; Goebel & Sallam, 2011).

Interestingly, some successful IPM programs that were implemented in sugarcane were focused exclusively on non-chemical control. For example, the Entomology Program for Sugarcane Management, Research, and Development (DIECA), shows the successful implementation of a biological control program for sugarcane borers in Costa Rica. This program combined the use of several species of natural enemies. Among these are the larval parasitoid *Cotesia flavipes*, the entomopathogenic fungus *Metarhizium anisopliae*, *Beauveria bassiana*, and the employment of adhesive and light traps to control sugarcane borers *Diatraea* spp, *E. lignosellus*, and *T. licus* (Badilla-Fernández, 2000). Favorable results of these control tactics show how alternative strategies led to successful control.

In Panama, the sugarcane industry has gradually implemented IPM programs for stemborers and initial research in this regard (Atencio et al., 2020a). This review focused on IPM strategies to control three stemborers of economic importance in America, mainly in Panama.

MATERIALS AND METHODS

To prepare this review, a total of 100 technical and scientific documents published over 62 years, from 1959 to the present, were consulted. Due to the relevance of the contributions on the matter addressed in this work. Additionally, the document contains unpublished images to illustrate pests and damage caused in the sugar cane crop.

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RESULTS AND DISCUSSION

Use of pesticides in sugarcane

The term pesticide covers a wide range of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant growth regulators, and other types of substances (e.g., organochlorine (OC), organophosphate (OP), carbamates, and pyrethroids insecticides). The most benefits of chemical insecticides are based on the direct crop returns, reduced crop losses and improved crop productivity. Nevertheless, their use often implies an indirect environmental and economic cost (Aktar et al., 2009). The quality of food and the risks from eating residues of pesticides in pesticide-treated crops are costs associated with pesticides (Weisenburger, 1993). Moreover, pesticides contaminate soil, water, turf and other vegetation (Aktar et al., 2009). In addition to killing insects or weeds, pesticides are also toxic to other organisms, including birds, fishes, beneficial insects, and non-target plants (Bale et al., 2008).

Another essential element is the impact of insect resistance that has occurred throughout the world. Wherever insecticides are used in terms of increased disease vectors, pesticide hazards in the environment, crop losses and poorer quality of products, increased production costs, pest resurgences, and rise of secondary pests; These are a few of the various socioeconomic repercussions (Forgash, 1984).

Foliar insecticides are generally avoided to control aboveground sugarcane pests worldwide because of detrimental non-target effects, poor efficacy, costs and restrictive regulations, and the availability of more efficient and sustainable management tactics (Goebel & Sallam, 2011).

In Panama various crops like tomato, pineapple, banana, rice and others frequently use insecticides such as organophosphate, with high consumption of these substances, but the impact on the environment had been a determining factor in finding solutions without reducing production and maintaining pest control (Garcerán & Castillo, 2019). For this reason, the sugar cane industry in Panama has implemented various techniques in sugarcane plantations within the integrated pest management component, especially in the case of stemborers (Atencio et al., 2020a).

Chemical control of *Diatraea* spp.

Chemical control of sugarcane pests started with synthetic chemical insecticides during the 1940s and 1950s (Simon & Arellano, 1959). Among the successful products used to control *Diatraea* spp. References include insecticide growth regulators (Beni et al., 1990), Ecdysone RH-2485 (methoxyfenozide) and Tebufenozide (RH-5992) (against eggs and larvae) (Trisyono & Chippendale, 1998), Novaluron (Beuzelin et al., 2010), Triflumuron, Fipronil, Lambda-cyhalothrin (Mena, 2010) and insecticidal protein of Talisia esculenta Radlk (Freire et al., 2012).

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Chemical control of *E. lignosellus*

Chemical control of *E. lignosellus* in sugarcane in Peru included the use of methomyl (Lannate), Tamaron (O, S-diméthyl phosphoramidothioate), Carbofuran (Furadan), Dicrotophos (Bidrin), Phenthoate (Cidial), Bilobran (Dinocap, Monocrotophos and monoacétate dodécylguanidine), Talcord (S-2-cyanoéthyl N-((méthyl) oxy) thioacétimidate) or Monocrotophos (azodrin) (Campos, 1972). In Florida (USA), chemical control of this species was recommended using Carbofuran (Furadan), Fensulfothion (Dasanit), Diazinon and Parathion (Dixon, 1982).

Chemical control of *T. licus*

For T. *Licus*, sugarcane chemical control includes using Carbofuran, Phoxime, Ethoprophos, Aldicarb, and Methamidophos in Panama (Esquivel, 1981a) and Ethoprop, Trichlorfon, Monocrotophos, Endosulfan, and Oxamyl in Brazil (Lima & Marques, 1984).

Damage and losses due to stemborers

This section discusses the damage due to three species of stemborers of economic importance for sugarcane: *Diatraea* spp., E. *lignosellus*, and T. *licus*. For the two latest species, data are quite scarce on the yield losses and economic impact.

Diatraea spp.

Damage is characterized by holes and internal galleries in the internodes caused by the larvae feeding inside sugarcane stalks (Figure 4). This overall damage cause losses in production. For example, for damage levels from 10% to 20% of internodes bored, the sugar loss is estimated at 2.02 kg/ton, for every 1% of the internodes bored (Gómez et al., 2009). This borer is a major pest in countries such as Costa Rica (Chaves et al., 2008), Argentina (Salvatore et al., 2008), Brazil (Dinardo-Miranda et al., 2012), Colombia (Gómez & Vargas, 2014) and Panama (Narvaéz, 1989).

Figure 4. Stem damage by *Diatraea* spp.

E. lignosellus

This species occurs mainly in the first three months of plant growth, and the damage leads to "Dead Hearts" symptoms following the larvae destroying the young stalk at ground level (Gill et al., 2011) (Figure 5). The distribution of this pest is widespread in America on sugarcane plantations, including Brazil (Busoli et al., 1977), Panama (Narvaéz, 1989), and Argentina (Salvatore et al., 2008).

T. licus

This pest spends most of its life larvae cycle feeding on the bottom of the stalks at the soil level (Figure 6). Studies on yield losses in sugarcane, due to this borer species, are minimal but were mentioned including the following countries: Brazil (Carvalho et al., 2013), Costa Rica (Salazar, 2007), Colombia (Linares et al., 1995), and Panama (Narvaéz, 1989).

Figure 5. Dead-hearts by *E. lignosellus.*

Figure 6. Damage by *T. licus* at the stalk bottom.

Main agricultural practices as control alternatives in borer management

There are several agricultural practices that are known to reduce infestation from stemborers in sugarcane.

***Diatraea* spp.**

Fertilizers and silicon applications. The use of high doses of nitrogen, phosphorus and potassium increase the percentage of infestation by *Diatraea saccharalis* in sugarcane (Alvarez et al., 2014), which is a common observation with other stemborer species, when the use of less amount of nitrogen allow to decrease infestation.

The use of silicon increases the resistance of the sugarcane stalks and is able to significantly reduce *D. saccharalis* infestation (Barrantes et al., 2013). In other crops such as rice, encouraging results have been obtained when silicate fertilization is applied at less than 200 kg / ha -1 which is able to reduce borer damage (Sidhu et al., 2013).

The studies carried out in Panama on sugar cane with the used of silicon-based products reduced internodes borer by 50% and the use of high doses of nitrogen doses resulted in an increase in the damage level from 5.2% (100 kg N/ha) to 6.9% (210 kg N/ha) internodes bored (Atencio et al., 2019b)

Harvesting practices. The green cane harvesting represents a significant change in sugarcane ecosystem due to the presence of straw left on the soil and to the absence of fire. These two factors may affect the populations of pests and their natural enemies (Dinardo-Miranda & Fracasso, 2013). It has been eventually implemented in practice in Panama, but without published studies to demonstrate the results.

Varietal resistance. Proper selection of resistant varieties to *Diatraea* spp. led to the use of several cultivars least preferred by *D. saccharalis* for oviposition, and the most unfavorable for larvae entrance and development (Kimbeng et al., 2006). As an example, varietal resistance programs have been conducted for many years to propose resistance varieties to control *D. saccharalis* in USA (Reay-Jones et al., 2003) and Brazil (Portela et al., 2011).

The studies carried out by Atencio et al. (2017), showed that there are varieties of sugarcane in Panama including E07-09, Na56-42, SP01-2050 and SP81-3250 with less damaged at the internodes (less than 2 borer internodes per stem where found) compared to others varieties (more than 2 attacked internodes per stem where observed) by attacks of the stemborer *Diatraea tabernella* Dyar.

Weed management. The management of alternatives host of stemborers constitutes an alternative within the integrated management pest of stemborers, considering, for example, results in the initial studies of host plant of *Diatraea tabernella* Dyar in sugarcane plantations in Panama with highest borer infestations had been found in *Sorghum halepense* (L.) Pers., *Echinochloa colonum* (L.) Link, *Eleusine indica* (L.) Gaertn., *Cenchrus echinatus* (L.) and *Dactyloctenium aegyptium* (L.) Beav; varying in percentages among 5.8% and 21.6% of borer infestation during sugarcane growth and harvest period (Atencio et al., 2018).

E. lignosellus

Irrigation and green-cane harvesting. Timely irrigation and green-cane harvesting decrease *E. lignosellus* infestation. For example, soil moisture which results from precipitation or irrigation were inversely correlated with *E. lignosellus* attacks. Therefore, damage can be reduced through early implementation of irrigation after harvesting (O'Reilly et al., 1984). It has been eventually implemented in Panama, but without published studies to demonstrate the results.

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Green crop residues. In USA, the use of green crop residues of sugarcane was encouraged to decrease *E. lignosellus* infestation (Sandhu et al., 2011). In Tucumán, Argentina, recent studies were directed towards the adoption of the practice of green-cane harvesting. The study showed that post-harvest crop residue left in sugarcane rows (also known as "trash blanket") is able to reduce the populations of *E. lignosellus* and *Pseudaletia unipuncta* Haworth (Lepidoptera: Noctuidae). Therefore, leaving the crop residue in place seems to be the most appropriate crop management approach (Isas et al., 2016).

T. licus

Manual control and post-harvest irrigation. This practice includes both manual remove and killing of the larvae and pupae and post-harvest irrigation "flooding type"; and is commonly used in Panama and other countries (Esquivel, 1981b; Rodríguez et al., 1999).

Varietal resistance. Selection of resistant varieties to *T.licus* infestation via field experiments was made in Brazil (Peixoto et al., 2008), Guyana (Duke & Eastwood, 1997) and Panama (Esquivel, 1980, 1983).

Drip irrigation. The latest agricultural practices to control *T. licus* include the use of drip irrigation and application of bioinsecticides such as the entomopathogenic fungus *Beauveria bassiana*. This fungus showed good result in controlling this pest with up to 81.8% reduction of the Giant Borer population resulting in an increase of sugarcane yields (Krontal, 2014). It has been eventually implemented in Panama, but without published studies to demonstrate the results.

Pheromones

The use of pheromones for detecting and monitoring adult populations of stemborers using baited traps with synthetic compounds in the field has been shown to be an interesting option for alternative strategies of pest control (Kalinová et al., 2005).

Diatraea **spp.**

Considering that pheromones are specific, each species should be previously tested by using isolated pheromones. For example, electroantennographic gas chromatographic detection with extracts of female pheromone glands has been used for *Diatraea flavipennella*. The identified compounds were (Z)-9-hexadecenal (Z9-16: Ald) et (Z)-11-hexadecenal (Z11-16: Ald) (Kalinová et al., 2012). Identification of possible components of the sexual pheromone was conducted in Brazil for *D. saccharalis* (Kalinová et al. 2005). However, there are no studies related to this issue in Panama.

E. lignosellus

The use of pheromones traps has allowed population studies of *E. lignosellus* in the field (Pires et al., 1992; Gill et al., 2011). In Brazil, a more detailed study in laboratory led to identify acetates

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from gland extracts of females which improved the attractivity of the synthetic pheromones (Jham et al., 2007). Like the previous case, studies about this matter in Panama are needed.

T. licus

There is no commercial pheromone available for population monitoring of this pest, but there are encouraging results of female sex pheromone identification (Rebouças et al., 2000), including gland extracts and the chemical composition of the pheromone of this species (Wadt, 2012).

Biological Control

***Diatraea* spp.**

Biological control is the most effective practice to control sugarcane borers currently in America (Lenteren & Bueno, 2003; Fuentes et al., 2012). The main species of parasitoids produced in laboratory units and used for field releases are: *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on larvae (Rossi & Fowler, 2003), *Trichogramma* spp. on eggs (Hymenoptera: Trichogrammatidae) (Browning & Melton, 1987), *Lixophaga diatraea* (Towns.) on larvae (Cuban fly), *Billaea* (=*Paratheresia*) *claripalpis* Wulp. (Diptera: Tachinidae) (Argentina Fly) on larvae and *Metagonistylum mínense* Tns. (Diptera: Tachinidae) (Amazon Fly) on larvae (Melo et al., 2012). For these species the parasitism rates in *Diatraea* eggs and larvae ranged from 20 to 50%.

In Brazil (The world's largest sugar producer), the sugarcane borer *D. saccharalis* is controlled with the following parasitoids: *C. flavipes* (6000 parasitoids are released per hectare) and *Trichogramma galloi* Zucchi (200 000 adults per hectare) (Parra et al., 2014).

The most important parasitoids of *Diatraea* spp. (mainly *D. tabernella* and *D. saccharalis*) rerported in Panama include *B. claripalpis*; *C. flavipes*, *L. diatraeae*; *Tetrastichus howardi* (Eulophidae); *Trichogramma* sp. (Narvaéz, 1986; Narvaéz, 1989; Rodríguez et al., 2004; Zachrisson, 2014; Atencio et al., 2018; Atencio et al., 2020b; Zachrisson and Barba, 2020).

Studies carried out in sugarcane in Panama demonstrated the importance of functional entomofauna (with 81 species that included phytophagous, predators, parasitoids, coprophagous, florivores and omnivores) (Atencio et al., 2019a); and studies with the sentinel prey *Galleria mellonella* L. to study native enemies associated with *Diatraea tabernella* resulting in the knowledge of the impact mainly of the ants species (*Solenopsis* sp., *Camponotus* spp., *Linepithema* sp. and *Ectatomma* sp. (Hymenoptera: Formicidae)) and spiders (*Leptofreya bifurcata* (F.O. Pickard-Cambridge)) on stemborers populations in stages of eggs, larvae and pupae (+84% predation) (Atencio et al., 2020b).

E. lignosellus

There is a lack of knowledge about parasitoids and predatory species for biocontrol of *E. lignosellus*. Nevertheless, prospective studies of parasitoids that could be used for this purpose are currently conducted. For example, *Orgilus elasmopalpis* Muesebeck (Hymenoptera: Bracondiae) was considered as a good candidate for biological control but has shown limited results (Johnson & Smith, 1980). The egg parasitoid *T. pretiosum* was also tested and showed no effective results (Xavier et al., 2011). Tachinid flies *Stomatomya meridionalis* Townsend (Carbonell, 1978), *Plagiprospherysa trinitatis* Thompson (Beg & Bennett, 1974), *Lixophaga diatraeae* (Tns.) (Pérez, 1978) also showed limited results as biocontrol agents. The latest studies on natural enemies of *E. lignosellus* indicated *Trachagathis rubricincta* (Ashmead) (Hymenoptera: Braconidae), as the main parasitoid of *E. lignosellus larvae* (Sharkey 2006). In Panama, there are no studies related to this issue.

T. licus

Biological control has not yet been developed on this pest. This is due to the lack of studies on natural enemies and particularly on research and identification of parasitoids that can be used in laboratory for mass production for field releases. Potential natural enemies were tested but with limited applications for biocontrol programs. This was particularly the case of the tachinid fly *Palpozenillia palpalis* (Aldr.) (Vignes, 1987), parasitic flies of the tribe Johnsoniini, gender *Emdenimyia* (Diptera: Sarcophaguidae) (Lopes, 1979). Esquivel (1983), mentioned the impact of *Ectatomma tuberculatum* (Ol.), *Euponera cognata* (Emery), *Pheidole flavens* (Roger), *Solenopsis geminata* (F) and *Crematogaster* sp. (Hymenoptera: Formicidae), as predators on *T. licus* eggs and larvae in sugarcane fields in Panama.

Bioinsecticides and Genetically Modified (Gm) sugarcane

Diatraea spp.

One of the most popular microorganisms used as bioinsecticides is the bacteria *Bacillus thuringiensis* (*Bt*). In some cases, *Bt* formulation caused 88% of mortality after seven days on *D. saccharalis* larvae (Rosas-García, 2006). The sprayable formulation at 10% concentration in the field was efficient, but it should be applied to primary larval stages before the larvae can enter in the stalk (Rosas-García, 2006). The studies showed the possibilities of control on *D. saccharalis* with Crystal protein Cry (Cry proteins from *Bt* are insecticidal pore-forming toxins (PFTs) (Gómez et al., 2014)). Several studies have focused on entomopathogenic potential for controlling populations of stemborers with entomopathogenic fungi *Metarhizium anisopliae* (Metsch.) Sorok and *Beauveria bassiana* (Bals.) Vuill. The use of entomopathogenic fungus on stemborers larvae treated with 10^5 conidia mL-1 of *M. anisopliae* showed that adults originated from those larvae presented reduced performance compared to untreated larvae. Results indicate that *B. bassiana* and *M. anisopliae* are pathogenic to *D. saccharalis* larvae and affect its biology (Oliveira et al., 2008).

There are encouraging results for the potential use of the entomopathogenic nematodes as efficient biological control of stemborers agents with the use of applied aqueous formulation with 500 000 infectives juveniles of nematodes (Rhabditida: Steinernematidae and Heterorhabditia) (Bellini & Dolinski, 2012). In the same way among other investigations it is mentioned, promising tests were obtained with the use of the insecticidal protein Vip3Aa20 (Bernardi et al., 2014), biocidal action of piperine plant *Piper tuberculatum* Jacq. (Tavares et al., 2011) and the activity of neem extract (Justiniano et al., 2012).

Transgenic sugarcane plants with improved resistance (Cultivar FN15 using cry1Ac gene) were developed against the sugarcane borer *D. saccharalis*, compared to the non-transgenic control plants. These cultivars had relatively equal or lower sucrose yield but significantly reduced borer damage (Gao et al., 2016). At the moment, no field evaluations have been carried out in Panama with the use of genetically modified varieties (Atencio et al., 2020a).

E. lignosellus

Recent studies focused on the biological potential of Vip and Cry proteins from *Bt* against *D. flavipennella* and *E. lignosellus*. The results suggested that Cry1Ac and Vip3Aa might have potential in future production of transgenic sugarcane for control of *D. flavipennella* and *E. Lignosellus* (Lemes et al., 2017).

There is a high potential for the use of bioinsecticides based on *Bt* and entomopathogenic fungi as *B. bassiana* (McDowell et al., 1990). Larvae control results were obtained in El Salvador using *B. bassiana* and *Bt* (Dipel) (microbiologique) (Romero & Huezo, 2011). In Hawaii, studies showed larval control using *Bt* (Chang et al., 1996) and entomopoxviruses (Mitchell et al., 1983).

T. licus

Bioinsecticides based on *Bt*, entomopathogenic nematodes and entomopathogenic fungi show a potential control option on *T. licus*. In Brazil, studies showed good control on *T. licus* larvae with the use of the *Bt* (Cry1Ia) (Craveiro et al., 2010), *B. bassiana* and *M. anisopliae* (Figueiredo et al., 2002) and *Steinernema* sp. (Rhabditida: Steinernematidae) (Oliveira et al., 2004). In Guyana, entomopathogenic nematodes *Steinernema riobrave* (Cabanillas, Poinar & Raulston), *S. carpocapsae* (Weiser) and *Heterorhabditis bacteriophora* Poinar gave promising results on *T. licus* control (Dasrat, 2001). In Costa Rica, *B. bassiana* showed positive result in larval control (Badilla-Fernández et al., 1994).

The potential development of transgenic plants resistant to *T. licus* was investigated with *Bt* Cry protein Cry1Ia12synth (truncated protein lacking C-terminus with plant codon usage). As a result, there were four genes encoding Cry1Ia12synth variants active against *T. licus* for future development of resistant transgenic sugarcane lines (Craveiro et al., 2010).

In Panama, experiments with the use of entomopatogenic nematodes (*Heterorhabditis bacteriophora* (Poinar) (Rhabditida: Heterorhabditidae)) and entomophagenic fungi (*M. anisopliae* (Hypocreales: Clavicipitaceae) and *B. bassiana* (Hypocreales: Cordycipitaceae)), to control pest in the soil (such as the nymphs in the soil and adults of *Aeneolamia* spp. (Hemiptera: Cercopidae), obtaining mortalities over 70% between 6 and 12 days of application) have yielding promising results (Pérez Milián et al., 2018) and have promoted the beginning of field trials at present for the management of *T. licus* among other soil pests (Atencio et al., 2020a; Candanedo-Lay et al., 2020).

CONCLUSION

This review was needed for a better understanding about the achievements of conventional tactics to control three major sugarcane borers. Future management plans should focus on potential alternatives, like a more efficient pesticides use, cultural practices, pheromones, bioinsecticides and biological control with natural enemies present by geographic region or country.

Current research lines for the control of stemborers in sugarcane mainly focus on the use of bioinsecticides such as formulations based on *Bt*, entomopathogenic fungi and nematode entomopathogens; selection of commercial varieties for their resistance to stemborers and the use of adequate doses of Nitrogen and Silicon application; the production and releases of parasitoids and predatory populations. Today, the molecular tools allow to complement this work with taxonomic classification and factors associated with natural enemies already identified. We also noticed the necessity of ecological studies for pests and natural enemies in relation to landscape and this open a new path for agroecological crop protection.

The integrated management of a complex of sugarcane stemborers in Panama is not limited to an exclusive technique, but to a component of complementary techniques, and in the case of some stemborers, such as *Elasmopalpus lignosellus* and *Telchin licus*, requires further basic and applied investigation. Elements such as applied biotechnology, applied agroecology, the use of drones, among other modern techniques, can lead to improving the integrated management programs for stemborers in Panama.

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