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Sugarcane stem borers of the Colombian Cauca River Valley: current pest status, biology, and control

Germán Vargas[1,], Luis A. Gómez[1], and J. P. Michaud[2]*

Abstract

Sugarcane stem borers of the genus of *Diatraea* (Lepidoptera: Crambidae) form a species complex that causes serious economic losses to sugarcane production in the Cauca River Valley and other regions of Colombia. Two primary species, *Diatraea saccharalis* (F.) and *D. indigenella* Dyar and Heinrich, have been effectively managed for more than 4 decades through augmentative releases of the tachinid flies *Lydella minense* (Townsend) and *Billaea claripalpis* (Wulp) (Diptera: Tachinidae) and the egg parasitoid *Trichogramma exiguum* Pinto & Platner (Hymenoptera: Trichogrammatidae). Here we review the current pest status of *Diatraea* species, damage assessment protocols, management tactics, and the environmental factors and cultural practices that can affect biological control outcomes. Recent changes in the cultivars grown have the potential to increase pest populations and diminish biological control efficacy. Additionally, recent outbreaks of new *Diatraea* species may further increase overall pest pressure. Thus, there is a need to develop supplementary tactics for the management of these pests that will be compatible with biological control, as well as more reliable protocols for assessing host plant resistance against the increase in infestation intensity.

Key Words: augmentative release; *Billaea claripalpis*; *Diatraea*; *Lydella minense*; Tachinidae; *Trichogramma exiguum*

Resumen

Los barrenadores del género *Diatraea* (Lepidóptera: Crambidae) constituyen un complejo de especies que causan pérdidas económicas importantes en la producción de caña de azúcar en el valle del río Cauca y otras regiones de Colombia. Dos especies principales, *Diatraea saccharalis* (F.) y *D. indigenella* Dyar y Heinrich han sido manejadas de forma satisfactoria, durante más de cuatro décadas, mediante liberaciones de las moscas taquínidas *Lydella minense* (Townsend) y *Billaea claripalpis* (Wulp) (Diptera: Tachinidae), y el parasitoide de huevos *Trichogramma exiguum* Pinto & Platner (Hymenoptera: Trichogrammatidae). En este documento se revisa el estatus actual de las especies de *Diatraea*, los métodos de evaluación, las alternativas de manejo, los factores ambientales y las prácticas del cultivo que interactúan con la acción del control biológico. Sin embargo, cambios recientes en el uso de nuevas variedades de caña, tienen el potencial de incrementar la presión por la plaga y disminuir la eficacia de las prácticas de manejo utilizadas hasta ahora. Adicionalmente, reportes recientes de brotes por la plaga debido al registro de nuevas especies, como *Diatraea tabernella*, tienen el potencial de incrementar la presión por la plaga a nivel regional. De acuerdo con lo anterior, existe la necesidad de desarrollar alternativas adicionales para el manejo, que sean compatibles con el control biológico, así como protocolos que permitan caracterizar la resistencia varietal, que en conjunto permitan contrarrestar el incremento en la intensidad de infestación.

Palabras Clave: control biológico por aumento; *Billaea claripalpis*; *Diatraea*; *Lydella minense*; Tachinidae; *Trichogramma exiguum*

Lepidopteran stalk borers are among the most damaging pests in sugarcane production. Close to 50 species of Lepidoptera have been reported boring sugarcane stalks (Long & Hensley 1972), most belonging to the family Crambidae. The genus *Diatraea* is confined to the New World, whereas the genus *Chilo* is distributed throughout Africa and Asia (Bleszynski 1969). The economic impact of *Diatraea* species results from reductions in both cane weight (field losses) and sugar content (factory losses) (Metcalfe 1969; White et al. 2008). *Diatraea saccharalis* (F.) is distributed in sugarcane growing areas from the southern USA through Central America to Argentina (Bleszynski 1969). In addition to *D. saccharalis*, 5 other species are found on sugarcane in Colombia including: *Diatraea indigenella* Dyar & Heinrich, *D. lineolata* (Walker), *D. tabernella* Dyar, *D. busckella* Dyar & Heinrich (Bleszynski 1969), and *D. rosa* Heinrich (Gaviria 1990). Recently, a notable outbreak of *D. tabernella* occurred in the Cauca River Valley (CRV) (Vargas et al. 2013).

Management of *Diatraea* spp. in many sugarcane regions has largely focused on biological control. Even though the introduction of the tachinid fly *Lixophaga diatraeae* (Townsend) (Diptera: Tachinidae) from Cuba to Louisiana in 1915 was unsuccessful, other introductions of this species in the Americas resulted in establishment (Bennett 1971). Efforts to improve biological control of *Diatraea* in Colombia began in the early 1970s with releases of *Trichogramma* spp. parasitoids (Hymenoptera: Trichogrammatidae), followed by *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) that proved unsuited to conditions in the CRV thus far (Gómez & Lastra 1995). Release programs of *Trichogramma* spp. in sugarcane did not appear to increase levels of borer egg parasitism (Gómez 1990). Later, Gómez et al. (1996) reported that only *Trichogramma exiguum* Pinto & Platner was recovered from eggs of 3 primary *Diatraea* species (*D. saccharalis, D. indigenella*, and *D. rosa*) and the augmented species, *Trichogramma pretiosum*

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Riley, was not. Henceforth, all efforts to augment egg parasitoids of sugarcane stem borers in the CRV employed *T. exiguum*. Releases of *Trichogramma* have become a component of *D. saccharalis* management in Brazil also, as combined releases of *Trichogramma galloi* Zucchi and *C. flavipes* have reduced infestations by *Diatraea* spp. up to 60% (Postali et al. 2010).

Intriguingly, *C. flavipes* became established in other areas of the continent (e.g., Brazil) and constitutes a major agent in *D. saccharalis* management there (Postali et al. 2010). In addition, *C. flavipes* is an important control agent of *D. saccharalis* in South Texas (Fuchs et al. 1979) and Florida (Capinera 2009), but not in Louisiana (White et al. 2004). Importations of tachinid flies followed in the CRV; although *L. diatraea* never adapted to Colombian conditions (Gaviria 1990), particularly in the CRV, the most industrialized sugarcane growing region, others such as *Lydella minense* (Townsend) and *Billaea claripalpis* (Wulp) became established (Smith & Belloti 1996). Between the 1980s and the 1990s, integrated pest management (IPM) programs were developed that incorporated the economic impact of the pests, their population dynamics, improved sampling procedures, and alternative methods of control, such as use of the native egg parasitoids *T. exiguum* (Gómez et al. 1996). Collectively, these efforts contributed to improved management of stem borers and reductions in their economic impact (Gaviria 1990; Vargas et al. 2005; Bustillo 2009). Here we present an overview of sugarcane stem borer biology and life history, impact on sugarcane production, and control tactics in the CRV of Colombia and review the lessons learned over 4 decades of implementing biological control as the primary tactic within an IPM program for these pests. In addition, we provide a perspective on the current situation and developing problems associated with the advent of new, susceptible cultivars that may have area-wide consequences for overall pest pressure.

DIATRAEA BIOLOGY, LIFE HISTORY, AND DISTRIBUTION

Bleszynski (1969) reported *D. indigenella* as present in western Colombia and northern Ecuador, *D. lineolata* in the Tolima, Magdalena, and Choco regions, *D. tabernella* in western parts of Colombia, including Chocó (Box 1931) and the CRV (Vargas et al. 2013), and *D. busckella* throughout Colombia (Box 1931), whereas Gaviria (1990) located *D. rosa* in eastern Colombia and along the Venezuelan border. It is notable that the taxonomic status of *Diatraea* species in the western hemisphere is uncertain and that a modernized study of these species is required (Vargas et al. 2013).

Although it may be difficult to distinguish among adults of *Diatraea* species (Fig. 1A–D), certain peculiarities are evident in larval stages (Fig. 2A–D). However, the coloration and shape of dorsal stripes are not reliable features for distinguishing *Diatraea* species in larval stages, and features of the male genitalia are more reliable features for species identification (Riley & Solis 2005).

Diatraea saccharalis and *D. indigenella* deposit eggs in clusters (Pastrana et al. 1993; Lima Filho & De Lima 2001), usually on the lower surface of leaves (Peairs & Saunders 1980). Egg masses of *D. saccharalis* and *D. indigenella* vary in size, but average 30 and 16 eggs per cluster, respectively (Pastrana et al. 1993). Under laboratory conditions, female *D. saccharalis* may oviposit for 4 nights (Holloway et al. 1928). Linares (1987) found that a *D. saccharalis* female would usually mate

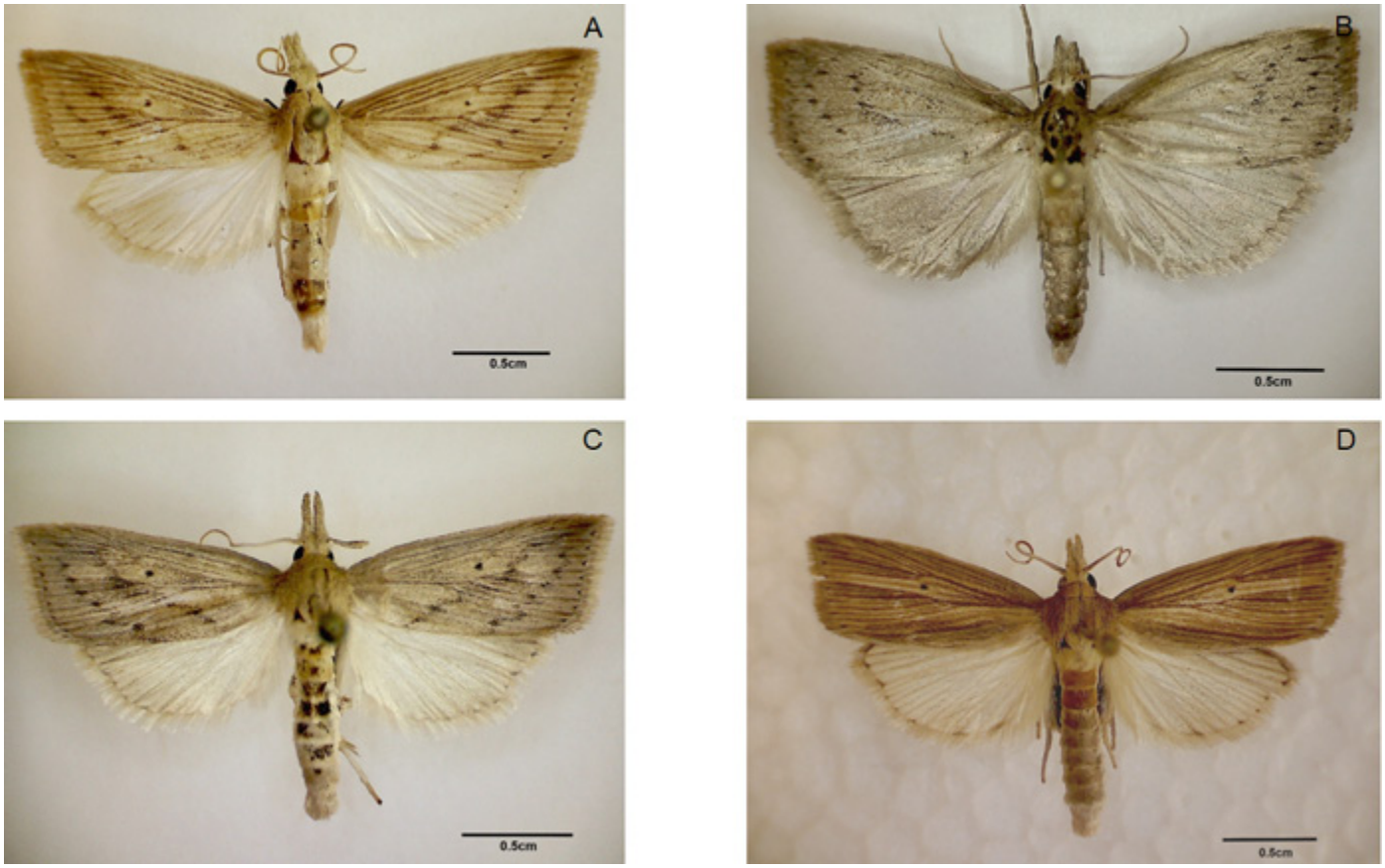


Fig. 1. Male adults of 4 *Diatraea* species present in Colombia. A. *D. saccharalis*; B. *D. indigenella*; C. *D. tabernella*; D. *D. busckella.* In general, moths are difficult to distinguish, and clear species identification requires the dissection of male genitalia (photos L. A. Lastra).

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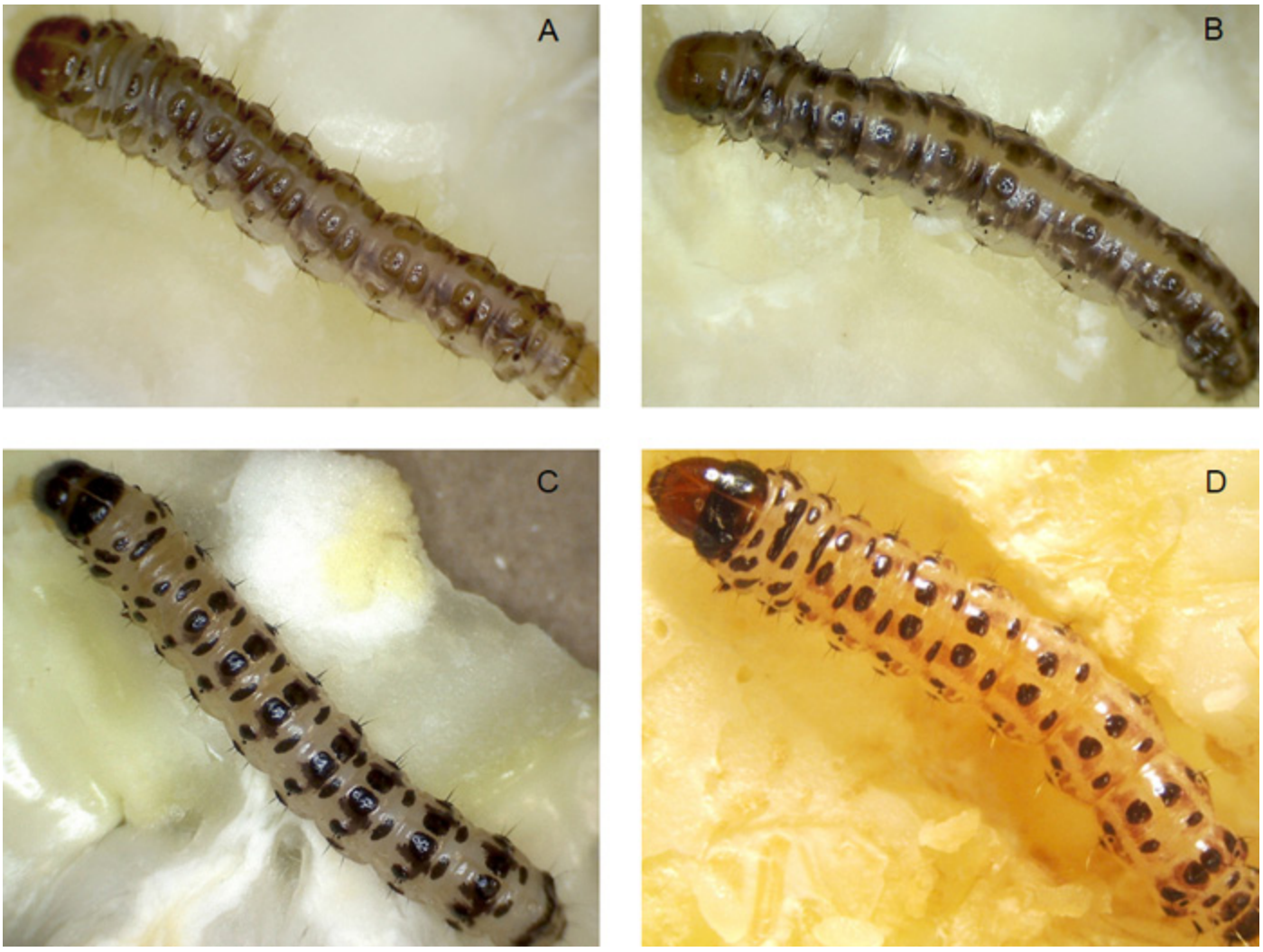


Fig. 2. Larvae of 4 *Diatraea* species present in Colombia. A. *D. saccharalis*; B. *D. indigenella*; C. *D. tabernella*; D. *D. busckella.* In general, larvae of *D. saccharalis* exhibit a well-sclerotized set of setal plates along their length, whereas the setal plates are often less distinguishable in *D. indigenella* due to dark, longitudinal dorsal stripes. Larvae of *D. tabernella* possess a distinctive set of blackish setal plates and adjacent purple spots that resemble transverse lines, which are absent in *D. busckella* (photos L. A. Lastra).

only once in her reproductive life, but could sometimes mate several times in a period of 48 hours. Batista-Pereira et al. (2002) observed that all mating in *D. saccharalis* occurred in darkness between the 3rd and the 8th hour of scotophase with a peak of almost 40% of total activity during the 5th hour. Adult feeding is not required for egg maturation in *D. saccharalis*, but moths do have a moisture requirement to achieve maximum fecundity (Parra et al. 1999), which ranges from 250 to 700 eggs per female (Guagliumi 1962; Bessin & Reagan 1990). Adult longevity is about 3 d for *D. indigenella* when reared on corn (Gómez & Vargas 2014), and ranges from 5–10 d for *D. saccharalis* (Walker & Alemany 1965). *Diatraea* spp. typically produce 6–11 generations per year in the tropics (Guagliumi 1962). Oviposition by *D. indigenella* is sparse in plants less than 6 mo old, but increases in plants of 7 mo and older (Gómez & Vargas 2014).

Eclosion requires about 6 d in *D. saccharalis* and 7 d in *D. indigenella* (Pastrana et al. 1993). In general, neonate larvae feed on leaf tissues and tunnel through leaf sheaths. Later, 3rd to 5th instars bore into the stalk, where they continue to develop (Peairs & Saunders 1980; White 1993). Stalk penetration usually occurs through an immature internode, but different points of entry may be tested, often resulting in multiple entrance holes caused by a single larva (Bessin et al. 1990a; White 1993). *Diatraea saccharalis* usually bores through more than one internode during development, then enlarges the tunnel, prepares an exit hole (wider than the entry hole), and pupates nearby (Guagliumi 1962). Normally, evaluations of bored internodes at harvest show injury concentrated in basal internodes (Gómez & Vargas 2014); because *D. saccharalis* prefers new internodes near the top of the plant (White 1993), most basal injury present at harvest reflects damage sustained at earlier crop stages without further injury in later internodes. The number of instars is variable; 5–10 have been reported for larvae of *D. saccharalis* on sugarcane (Taylor 1944; King et al. 1975; Pastrana et al. 1993), whereas *D. indigenella* may pass through 5–11 instars to complete development on corn (Pastrana et al. 1993). Total development requires 23 and 38 d in *D. saccharalis* and *D. indigenella*, respectively, at 24 °C and 67.5% RH (Pastrana et al. 1993). No information is available yet on the development of *D. tabernella*. Duration of the pupal stage can require 6–11 d in *D. saccharalis* (Taylor 1944; Pastrana et al. 1993) and around 11 d for *D. indigenella* (Pastrana et al. 1993).

The distribution of *Diatraea* species varies along the CRV. *Diatraea saccharalis* is found throughout the valley but was historically predominant in the north (Vargas et al. 2006). Other species are more restricted in distribution: *Diatraea indigenella* seems restricted to central

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and southern regions, whereas *D. tabernella* is now the predominant species in the north (Gómez & Lastra 1995; Vargas et al. 2006; Vargas et al. 2013). Observations from the central region, where *D. saccharalis* and *D. indigenella* have long coexisted, show that species abundance varies with crop phenology, suggesting some niche partitioning. During early stages of the crop, *D. saccharalis* is predominant, whereas *D. indigenella* becomes increasingly abundant from about 6 mo after planting until harvest (Gómez & Vargas 2014).

INJURY AND ECONOMIC DAMAGE

Attack by sugarcane stem borers on young plants may compromise meristematic tissues and result in "dead heart" (Fig. 3A). However, such early damage will only result in a reduction of cane weight at harvest if a large percentage of shoots are affected and feeding damage is sustained for at least 30 d (Pantoja et al. 1994). Natural mortality of shoots can reach 50–75% during the tillering phase (Matsuoka & Stolf 2012), so there is considerable opportunity for plants to compensate for early injury. However, insect tunneling in stalks can interfere with the movement of nutrients and photosynthates in later crop stages, increase the level of fiber in the stalk, and decrease its value (Milligan et al. 2003; White et al. 2008). Stalk injury can disrupt apical dominance and promote the growth of multiple lateral shoots and thereby divert resources from sucrose synthesis to vegetative growth (Metcalfe 1969). Furthermore, multiple entry and exit holes in stalks provide points of entry for microorganisms that can further degrade cane quality and sugar content (Metcalfe 1969; White & Hensley 1987; White et al. 2008) (Fig. 3B). The percentage of bored internodes is conventionally used as an index of infestation intensity and reliably correlates with yield losses (Metcalfe 1969; Milligan et al. 2003; Gómez et al. 2009). Yield studies in the CRV indicate a reduction in cane weight of 0.83% for each percentage unit of internodes bored, and a further loss of 0.26% of sugar yield at milling (Gomez et al. 2009). In Louisiana, damage by *D. saccharalis* was estimated to cause losses of up to 28% of cane weight per acre in a susceptible cultivar ('CP 44-101') (Hensley & Long 1969), whereas damage by *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae) has caused up to 14% yield loss of sugar per ha (Wilson et al. 2012). In Florida, Capinera (2009) reported losses in sucrose of 10–20%.

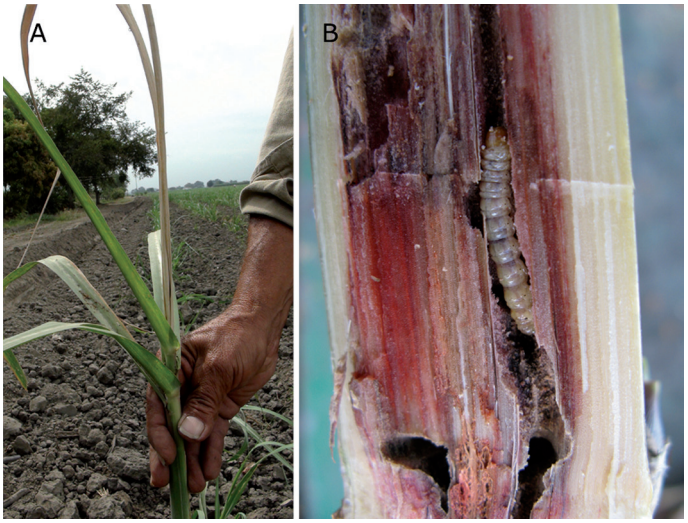


Fig. 3. A. "Dead heart" in sugarcane caused by *Diatraea* sp. (photo M. Rodríguez), and B. bored internode by *Diatraea* sp. can disrupt apical dominance and promote growth of multiple lateral shoots, diverting resources from sucrose synthesis to vegetative growth (photo AE Bustillo).

Farmers or private consultants measured the percentage of bored internodes in a sample of 100 stalks from each field when stalks were piled post-harvest, and they obtained an estimate with 90% precision and a sampling error of ± 1.0% (Garcia et al. 2006). The percentage of bored internodes was measured by counting the number of internodes bored in each of 100 stalks; the number of bored internodes in a given field was then estimated by multiplying the fraction of bored internodes times the estimated total number of internodes in the field. In Florida, fields are scouted every 2–3 wk from Mar through Nov by taking 5 stalks from 5 plants 3 m apart; if 2–3 larvae were recovered from 100 stalks, corrective action was considered necessary. However, if larval parasitism was 50% or higher, insecticide applications were not advised (Hall 1986; Cherry & Nuessly 2011). In Louisiana, scouting for *E. loftini* was done on a regular basis once the first internodes formed. Pheromone traps may assist scouting for the Mexican rice borer, which should begin when the rate of capture reaches 20 moths per trap in a 1 wk period (Hummel et al. 2008). Schexnayder et al. (2001) proposed a sequential sampling plan in Louisiana where 20 stalk samples were required to make management decisions. The accepted economic injury level for *D. saccharalis* in Louisiana was 10% of internodes bored (White el al. 2011).

Some farmers sampled earlier when there were indications of heavy stem borer infestation, or when fields were planted with susceptible cultivars (Ranjel et al. 2003; Vargas et al. 2005). However, early sampling did not substitute for an evaluation at harvest because of the changes in the internode number with crop development. Moreover, the evaluation at harvest facilitated a more random sampling of the field, which reduced the coefficient of variation in estimated damage compared with sampling at earlier stages, and provided a more accurate estimation of yield loss (Gómez & Lastra 1995). The damage estimate obtained in one field usually reflected regional borer populations and pest pressure in surrounding fields (Gómez & Vargas 2014). Sequential sampling could also be used to time releases of tachinid flies in subsequent crop cycles (Gómez & Moreno 1987). Escobar & Raigosa (1982) suggested a nominal damage threshold for sugarcane borers of 5% of internodes bored, and sequential sampling was proposed as a quick means of deciding if the field was above that level, and to schedule releases of 30 tachinid flies per ha in the following crop cycle when plants were between 2 and 5 mo old (Gómez & Moreno 1987). However, sequential sampling was not popular among farmers as it only provided information on the nominal threshold of 5% of bored internodes, did not give precise information on infestation intensity, and required increased sampling effort. Furthermore, Gómez et al. (2009) found significant yield reductions at infestation intensities below 5%, suggesting the need for a lower economic threshold. Nevertheless, estimates of the percentage of bored internodes in the field could be derived by regression of post-harvest estimates of percentage of stalks infested, made either in the field or in the mill (García et al. 2006). Estimates obtained at the mill required less sampling effort and eliminated costs associated with transportation of the scouting teams. Even though end-of-crop sampling has been used to manage sugarcane stem borers for decades in the CRV, there is a need to develop season-long monitoring to prevent damage in the current crop cycle, not just for the following one.

BIOLOGICAL CONTROL

Sugarcane is grown in a continuous, year-long cycle of harvest and planting in the CRV, in crop cycles that may take from 13 to 16 mo from establishment to harvest. Many fields are in close proximity to others, creating a continuous supply of different vegetative crop stages that facilitate overlapping pest generations, but also a continuous supply of host life stages for egg and larval parasitoids (Gómez & Lastra 1995).

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Pest management of *Diatraea* in the CRV has been tailored to the biology and ecology of the 2 primary species present, *D. sacharalis* and *D. indigenella*. However, a pest outbreak in the northern CRV in 2012 was associated with the detection of *D. tabernella*, an important sugarcane pest in Panama and Costa Rica that is managed mainly with releases of *C. flavipes* (Badilla 2002; Rodriguez et al. 2004). Management of stem borers in the CRV focuses on periodic releases of the tachinids *L. minense* and *B. claripalpis*, and the egg parasitoid *T. exiguum*. *Genea jaynesi* could potentially provide better biological control than the other 2 tachinid species, but mass-rearing of this species is not yet possible, so its conservation in the agroecosystem is recommended. For example, Vargas et al. (2006) recommended the establishment of strips of wild flowering plants and hedgerows, composed mainly of mango (*Mangifera indica* L.; Sapindales: Anacardiaceae), whose flowers are very attractive to this tachinid. The detection of *D. tabernella* in northern CRV should incentivize new biological control alternatives, e.g., use of *C. flavipes*, given less larval parasitism of *D. tabernella*, by *L. minense*, in comparison to *D. saccharalis* (Vargas et al. 2013).

Augmentative releases of tachinid flies throughout the CRV hinge on a continuous supply of *D. saccharalis* host larvae for parasitoid rearing. Infection of cultures with *Nosema* sp., a microsporidium causing "white larvae" disease is a significant impediment to large-scale production (Inglis et al. 2003). Lastra & Gomez (2006) proposed screening for the presence of *Nosema* in source material taken from the field to establish stock colonies. These screening efforts are effective in producing disease-free colonies and, consequently, continuous production of healthy parasitoids.

Data on parasitoid releases and economic thresholds have been difficult to obtain. Confounding factors include fluctuations in naturally occurring pest and parasitoid populations, difficulties employing exclusion cages to isolate infested plants for a 12–14 mo crop cycle, and gaps in our understanding of tachinid fly ecology, i.e., flight range (Stireman et al. 2006). For many years, a nominal damage threshold of 5% of internodes bored at time of harvest has been used to trigger a parasitoid release program in the following crop cycle (Escobar & Raigosa 1982). Considering that economic losses occur at levels below 5% (Gómez et al. 2009) and often exceed $50 per ha, whereas biological control agents cost around $10 dollars per ha per release, a threshold of 2.5% of internodes bored has been proposed to justify at least one release of parasitoids in the next crop cycle (Bustillo 2009). Currently, the recommended release rate is 30 tachinid flies (using either *L. minense* or *B. claripalpis*) plus 50 square inches of *T. exiguum* cards per ha (~ 85,000 adults) when 2.5% of internodes are bored in the previous crop. Even though *T. exiguum* prefers eggs of *D. indigenella* over those of *D. saccharalis* under laboratory conditions (Gómez et al. 1994), the egg parasitoid is released wherever the 2 species co-occur. For damage above 4%, the recommendation is 50 square inches of *T. exiguum* cards and 2 releases of 30 tachinid flies per ha in the following crop cycle (Bustillo 2009). This pre-emptive approach of releasing natural enemies in the following crop cycle, after the threshold is exceeded in the previous one, hinges on the assumption that the pest population will increase without corrective measures (Gómez & Vargas 2014).

Farmers in the CRV are confident that augmentation biological control of *Diatraea* spp. is a reliable management tool. Vargas & Posada (2013) found that releases of approximately 30 flies per ha prevented damage in approximately 3.3% of internodes, corresponding to a 65% reduction in infestation relative to the previous crop cycle. The latter analysis is not robust, due to considerable variation in environmental conditions across the CRV, but the apparent economic returns, combined with the low cost of parasitoids, indicate economic feasibility.

CULTURAL CONTROL

Burning may inflict significant mortality on various pest populations, including sugarcane stem borers (Charpentier & Mathes 1969). The implementation of mechanical harvesting in the CRV in the 1970s led to the pre-harvest burning of fields to facilitate the process (Guardiola 1995), and this wide-spread practice may have afforded a certain level of stem borer control. However, pre-harvest burning is being discontinued for environmental reasons, and there are no clear indications that green harvesting is leading to increased levels of damage by sugarcane borers thus far (Gómez & Vargas 2014).

CHEMICAL CONTROL

Until the mid-1950s, some farmers in the CRV were using insecticides to manage sugarcane stem borers (no reliable records of the products used are available), but control efficacy was never adequate, so the practice was abandoned at the beginning of 1970s when biological control programs started showing positive results (Guardiola 1995). Due to a bimodal rainfall pattern in the region, and relatively constant temperatures throughout the year, vegetative stages of the crop are continuously present, facilitating overlapping generations of pests and the simultaneous presence of all developmental stages. These factors significantly hinder the efficacy of insecticide applications, as later instars and pupa are invulnerable within stalks and foliar applications cannot be timed coincide with any peak periods of adult emergence or oviposition (Bennett 1971; Gómez & Lastra 1995). In response to the need for a more sustainable management strategy, efforts shifted to a focus on biological control beginning in the early 1960s. The use of biological control against sugarcane stem borers is now traditional in the CRV, and is favored by public appreciation of sugar produced without insecticides. However, the sustainability of this system is now being debated, given the pressure of pest populations developing on more susceptible cultivars and outbreaks of new *Diatraea* species. Thus, there is a need to develop a more integrated strategy that incorporates novel tactics such as transgenic varieties or systemic insecticides.

HOST PLANT RESISTANCE

Since the advent of biological control programs against *Diatraea* spp., there have been few efforts to explore additional management tactics such as host plant resistance. Plant breeders have not screened releases for resistance to sugarcane stem borers, as this would encumber the plant breeding program and delay the production of new commercial cultivars, while many consider that pest management can be achieved by biological control alone. Selection for borer resistance was not considered in Louisiana either, due to a focus on chemical control in that region (Hensley & Long 1969). However, even though direct selection for borer resistance was not carried out, a recurrent selection program was initiated in Louisiana in 1986 to develop resistant germplasm to incorporate in the crosses of the commercial breeding programs (White et al. 2011). Suppression of *D. saccharalis* in Louisiana was achieved largely through a combination of insecticides and resistant cultivars before the arrival of *E. loftini*, a species that now represents more than 95% of the total stem borer population (Wilson et al. 2012). Different resistance mechanisms have been recognized against *D. saccharalis*; leaf sheath appression coupled with rind hardness in younger internodes are forms of mechanical antibiosis that delay larval entry, increase the mortality of young larvae, and reduce injury to stalks (Martin et al. 1975; White 1993). However, stalk injury levels do not necessarily correlate with larval survival. Bessin et al. (1990a) found a weak correlation between percent of bored internodes and final adult survival and suggested the incorporation of a measure of

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area-wide cultivar impact on the population of the pest (Bessin et al. 1991). The use of a "moth production index" obtained by counting exit holes in stalks (i.e., pupal gates) indicates successful larval development and the cultivar's contribution to the area-wide pest population (Bessin et al. 1990a; Reay-Jones et al. 2003, 2005; White et al. 2011). Unfortunately, many stem borer resistance traits are agronomically undesirable. These include high fiber content, pith, tight leaf sheaths, and hard rind in the immature internodes (White et al. 2011). Compounds biologically active in sugarcane borer resistance were first explored by Meagher et al. (1996), who observed *E. loftini* larval survival and development on artificial diets containing various concentrations of different sugarcane leaf sheath tissues. The use of such antibiosis bioassays in varietal selection programs requires novel approaches to screening and testing new cultivars (White et al. 2011), and avoids the problems associated with characterizing varietal resistance in natural pest infestations that may have variation in both pest pressure and plant performance under field conditions, and which may include nontarget arthropods causing similar symptoms as the target pest (Mihm 1985; Smith 2005).

Because current commercial cultivars exhibit a wide range of variation in susceptibility to borer attack in Colombia (Ranjel et al. 2003), the development and release of varieties with good levels of resistance to borers could make an important contribution to IPM programs in the country (White et al. 2001; Reay-Jones et al. 2003, 2005; Wilson et al. 2012). Gómez & Vargas (2014) used oviposition choice tests to assess varietal resistance under greenhouse conditions and did not find any indication of antixenosis in the varieties tested, but the development and survival of larvae was affected by cultivar, suggesting antibiotic factors were present. Similarly, Vercambre et al. (2001) found no significant differences between susceptible and resistant sugarcane cultivars in oviposition preference tests with *Chilo sacchariphagus* (Bojer), nor has ovipositional preference been observed among commercial cultivars grown in the United States (Bessin et al. 1991)

A balance of control tactics is usually necessary to maintain a sustainable IPM program (Reay-Jones et al. 2005). More effort is needed in the CRV and in all Colombia to develop standardized field, laboratory, and greenhouse protocols that will accurately help identify resistance mechanisms so that host plant resistance can be integrated as a component of sugarcane stem borer management in the CRV.

FUTURE DIRECTIONS OF STEM BORER MANAGEMENT IN COLOMBIA

The IPM program against sugarcane borers in the Cauca River Valley represents a relatively unique example of successful biological control of a complex of stalk-boring lepidopteran pests through augmentation of a combination of egg and larval parasitoids in open field conditions. However, pest populations are dynamic and evolve in response to cultural changes in the crop (e.g., changes in the cultivars grown) and changes in the composition of the pest complex itself (e.g., detection of *D. tabernella*). More efforts should be directed at testing new biological control alternatives (e.g., *Cotesia flavipes*) and developing long season monitoring systems that can predict injury levels based on pest populations, so management decisions can prevent further damage. Although biological control has been effective historically, it will not necessarily be impervious to significant changes in the agroecosystem. Supplementary control tactics inherently compatible with biological control should be sought, evaluated, and integrated into the management program to complement augmentative releases and ensure their continued efficacy. Host plant resistance has been an effective component of sugarcane borer IPM in other production regions (Bessin et al. 1990b; White et al. 2008) and should be explored in the CRV as part of a continuing effort to ensure that pest management practices remain sustainable as cultural and ecological changes gradually alter the agroecosystem.

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