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Stomoxys calcitrans (Diptera: Muscidae) outbreaks: current situation and future outlook with emphasis on Brazil

Surtos por *Stomoxys calcitrans* (Diptera: Muscidae) no Brasil: situação atual e perspectivas

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Abstract

The stable fly (*Stomoxys calcitrans*) has historically been a pest of dairy cattle and feedlots due to the availability of decaying plant matter mixed with animal excrements in such production systems. In the last few decades, stable fly outbreaks have also been reported in pasture-raised beef cattle, usually associated with wastes accumulated from animal feeding during winter, the introduction of large-scale crop operations near cattle ranches, and/or the inadvertent use of organic fertilizers. Population explosions of *Stomoxys* flies may also have natural causes, affecting not only domestic and/or wild animals but also humans. This article compiles information on stable fly outbreaks in Brazil and abroad and discusses their causes and consequences.

Keywords: Stable fly, cattle ectoparasites, bloodsucking flies.

Resumo

A mosca-dos-estábulos (*Stomoxys calcitrans*) tem sido historicamente uma praga em gado de leite e gado de corte em confinamento devido à disponibilidade de matéria orgânica vegetal em decomposição, misturada a dejetos animais, nestes sistemas de produção. Nas últimas décadas, surtos de infestação por esta mosca passaram a ocorrer também em rebanhos de corte mantidos extensivamente, geralmente associados ao acúmulo de resíduos de suplementação alimentar durante o inverno, introdução de culturas agrícolas em larga escala no entorno de propriedades pecuárias e/ou uso inadvertido de fertilizantes orgânicos. Eventualmente, explosões populacionais de *Stomoxys* podem ter causas naturais, afetando animais domésticos e/ou selvagens, além do próprio homem. Este artigo reúne informações sobre surtos da mosca-dos-estábulos no Brasil e em outros países e discute suas causas e consequências.

Palavras-chave: Mosca-dos-estábulos, ectoparasitos de bovinos, moscas hematófagas.

Introduction

Popularly known as the stable fly, *Stomoxys calcitrans* (Linnaeus, 1758) stands out as a major livestock pest in several countries (TAYLOR et al., 2012a; GRISI et al., 2014). Adult flies are hematophagous and show little host specificity, attacking cattle, horses, sheep, goats, dogs, pigs, poultry and humans (BISHOPP, 1913; HANSENS, 1951). This fly's painful bite causes behavioral changes and consequent losses to production (MULLENS et al., 2006)

In Brazil, annual losses directly caused by this fly may reach up to US$ 335 million (GRISI et al., 2014), excluding the impact caused by recent outbreaks reported in distinct regions of the country (BARROS et al., 2010). In this review, the term "outbreak" is used hereinafter to refer to any situation involving an unusual sudden increase in the stable fly population, affecting livestock, wildlife and/or people, in any particular location.

The immature stable fly can develop in various substrates, usually containing decaying vegetable matter, sometimes mixed with animal excrements such as cow dung and poultry litter (KOLLER et al., 2009, COOK et al., 1999). Other substrates *S. calcitrans* uses for its development include seaweed and waste horticultural products (KING & LENERT, 1936; SIMMONS, 1944; HERRERO et al., 1989). Sugarcane and alcohol production wastes, particularly sugarcane filter cake and mulch mixed with vinasse (a byproduct of the distillation of sugarcane fermented broth), are also suitable for the development of the stable fly (GILLES et al., 2008; BITTENCOURT, 2012; CANÇADO et al., 2013a).

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A close relationship has been observed between sugarcane mill wastes and mass production of *S. calcitrans* due to the large amounts of organic byproducts produced in sugar and alcohol production processes (BURALLI & GUIMARÃES, 1985; BITTENCOURT, 2012; CORRÊA et al., 2013).

The first record of a *S. calcitrans* population explosion associated with sugar cane mill activities in Brazil dates back to the 1970s, in São Paulo (NAKANO et al., 1973). More recently, a significant increase in the frequency of such outbreaks has been associated with the expansion of sugarcane-related activities in livestock production areas (BARROS et al., 2010).

The lack of appropriate management methods for preventing the development of *S. calcitrans* in sugarcane mills, as well as the lack of sanitary management in livestock facilities, has contributed significantly to the multiplication of developmental sites for the stable fly in these areas.

Outbreaks have generally been concentrated in the Mid-west and Southeast regions of the country, mainly in the states of Mato Grosso, Mato Grosso do Sul, Minas Gerais and São Paulo (ODA & ARANTES, 2010; KASSAB et al., 2012; CANÇADO et al., 2013a). In addition, stable fly outbreaks have also been associated with the use of organic fertilizers such as poultry litter in some municipalities of São Paulo (BURALLI & GUIMARÃES, 1985; BURALLI et al., 1987), and coffee husks in the north of the state of Espírito Santo (OFICINA DE NOTÍCIAS, 2014).

In an attempt to control this pest, sugarcane mills have invested in chemical control activities and cultural management of their by-products, with variable results. According to Biosul (2014), annual investments aimed at controlling this fly in municipalities where outbreaks have occurred have been preliminarily estimated at about US$ 32,000 per million tons of harvested sugarcane, representing a cost of US$ 30 to 160 thousand per sugarcane mill. Additional information from other states suggests that the costs attributed to this fly may reach US$ 480,000 due to changes and adjustments in management procedures, mostly carried out in large areas of cultivation, as well as to activities to support affected producers.

Information about stable fly outbreaks in the scientific literature is sketchy and relatively scanty. Records about outbreaks are often available only from non-scientific sources, such as magazines and internet sites of local news. The purpose of this article is to compile information about the occurrence of *S. calcitrans* outbreaks in Brazil and abroad, as well as to characterize the status of such outbreaks in the country and the measures adopted to prevent and control them, with particular emphasis on outbreaks associated with sugarcane ethanol production.

Stable Fly Outbreaks Around the World

The occurrence of *S. calcitrans* population explosions or outbreaks has been recorded in most continents, associated with different predisposing and/or determining factors related to anthropic activities. Regardless of the situation, such events are closely related to the availability of decomposing organic substrates and the nearby presence of domestic or wild animals.

In most cases, the massive development of *S. calcitrans* larvae has been associated with the availability and abundance of developmental substrates (usually organic byproducts or wastes) from agricultural activities, horticultural production systems (COOK et al., 1999) or feeding supplementation (silage, hay, etc.) to pasture or feedlot cattle (BROCE et al., 2005). However, stable fly population explosions may sometimes occur due to natural events (KING & LENERT, 1936; FOSBROOKE, 1963; ELKAN et al., 2009).

According to Cook et al. (1999), problems with *S. calcitrans* in Western Australia have resulted from use of poultry litter as a fertilizer and conditioner of soil physical properties, especially in horticultural production. New regulations on management practices to reduce stable fly developmental sites, particularly in poultry litter and vegetable residues, are expected (ECHO NEWS, 2014). Additional information is available at the site of the "Stable Fly Action Group" which was founded to develop strategies to fight this pest in Australia.

The use of hay bales to feed pasture cattle in winter led stable flies (primarily a problem of dairy cattle and feedlots) to become a major beef cattle pest in the United States. Indeed, decomposing hay mixed with cattle manure spread over the soil resulted in an excellent substrate for development of *S. calcitrans*, enabling the emergence of 1,632-19,600 flies/m^2 (BROCE et al., 2005).

Recognized as a serious pest by the Ministry of Agriculture, the large proliferation of the stable fly in wastes from pineapple monoculture has become a serious problem in various regions of Costa Rica (HERRERO et al., 1989).

Similarly, large-scale reproduction of the stable fly in residues from palm oil processing has caused high cattle infestation issues in Colombia (MORA et al., 1997). Although several measures, including the release of microhymenopteran parasitoids, trapping and adult control, have been adopted to control this pest and prevent it from attacking hosts, the effectiveness of such approaches has so far been insufficient during the rainy season, requiring alternative options (MARTÍNEZ et al., 2013).

Although population explosions of stable flies have usually resulted from man-made situations, *S. calcitrans* outbreaks have actually also been associated with natural events around the world as well.

On the coast of Florida, the development of large numbers of *S. calcitrans* in decaying seaweed led to a severe disturbance and prevented the use of beach recreational areas by tourists for months (KING & LENERT, 1936).

Prolonged droughts followed by exceptionally rainy periods led to *Stomoxys* outbreaks in the Ngorongoro Crater, Tanzania, in 1962 (FOSBROOKE, 1963), and in northern Congo in 1997 (ELKAN et al., 2009). In Ngorongoro, *S. calcitrans* were numerous and larvae developed in mud mixed with animal excrements (FOSBROOKE, 1963); the massive attack on lions resulted in high mortality and reduced the local lion population by more than 80% (FOSBROOKE, 1963; NATIONAL GEOGRAPHIC MAGAZINE, 1992). In the Congo, excessive straw accumulated during a dry season and later soaked by rains became the substrate for development of *S. omega*. The fly attack affected the behavior and spatial distribution of large ungulates, causing progressive weight loss and mortality of antelopes and other deer species (ELKAN et al., 2009). Although other factors may have contributed to wildlife mortality, the exceptional abundance of *S. omega* was considered the major factor (HUCHZERMEYER et al., 2001).

S. calcitrans Outbreaks in Brazil

Despite the long history of the sugarcane industry in Brazil, the implementation of the National Alcohol Program (Proálcool) in the 1970s led the biofuel industry to a new level of development in the country. Population explosions of *S. calcitrans* (and *Musca domestica*) associated with the large-scale production of sugarcane byproducts were first reported in Brazil at that time, in the state of São Paulo (NAKANO et al., 1973). In the following decade, other fly (*M. domestica*) outbreaks associated with vinasse distribution channels and the use of poultry litter as fertilizer were reported in several municipalities of the same state, requiring the implementation of control measures (BURALLI & GUIMARÃES, 1985; BURALLI et al., 1987).

At that time, vinasse – a liquid byproduct, rich in organic matter and nutrients, resulting from the distillation of sugarcane fermented broth – was dumped into water bodies and "sacrifice zones," a practice banned in the late 1970s by Ministerial Act No. 323 of 29 November 1978, due to its widespread environmental impact. This restriction gave rise to the fertigation process, which involved the application of untreated vinasse in areas of sugarcane cultivation (LAIME et al., 2011), aimed at fertilizing and increasing soil moisture. On the other hand, sugarcane mulch was not a significant waste at the time due to the practice of pre-harvest burning. However, for environmental reasons, the practice of sugarcane pre-harvest burning has been restricted in the country since the late 1990s by Brazilian Environmental Legislation through Federal Decree No. 2661 of 8 July 1998 (BRASIL, 1998).

The widespread use of vinasse as a fertilizer and the gradual reduction of sugarcane pre-harvest burning resulted in the accumulation of a moist (and nutrient-rich) mulch on the ground, creating large areas of fermenting plant matter, a suitable substrate for the development of immature *S. calcitrans* (CORRÊA et al., 2013).

Overall, sugarcane production in Brazil increased by about 150% from 2006 to 2011, driven by the expansion in the number of production units (BUNGENSTAB et al., 2012). Despite the slowdown in recent years, the sector continues to expand, with a 3.8% growth (326,400 hectares) of cultivated area in the 2013/14 season, compared to the previous harvest. This growth is concentrated mainly in the states of São Paulo, Mato Grosso do Sul, Goiás and Minas Gerais (CONAB, 2014).

Not coincidentally, stable fly infestations have become more relevant since 2009, with several outbreaks reported on livestock ranches located near sugarcane mills in the states of Sao Paulo (GOMES, 2009; ODA & ARANTES, 2010), Minas Gerais (IMA, 2012; BITTENCOURT, 2012), Mato Grosso do Sul (KOLLER et al., 2009; BARROS et al., 2010) and Mato Grosso (CUIABÁ, 2010). Since then, stable fly outbreaks have become more frequent and intense in most areas of expansion of sugarcane biofuel activity (CANÇADO et al., 2013b).

Recently, several cases of population explosions of *S. calcitrans*, generally related with the activity and expansion of sugarcane mills, have been reported in the southeastern states of São Paulo, Minas Gerais and Espírito Santo (IMA, 2012; GLOBO RURAL, 2014; OFICINA DE NOTÍCIAS, 2014).

In Brazil's central-west region, the yearly occurrence of *S. calcitrans* outbreaks and the resulting serious economic impacts on cattle ranchers have been ascribed to the significant increase in the number of sugarcane mill operations and the large fertigated area they occupy. In the state of Mato Grosso, problems resulting from severe stable fly infestations associated with a local sugarcane mill have been investigated in the municipality of Nova Olímpia since 2002, with legal actions brought by the state public prosecutor (GORETTH, 2010; CUIABÁ, 2010).

In the state of Goiás, stable fly outbreaks have occurred since 2010 in the municipality of Cabeceiras, and there is evidence that outbreaks have also occurred in other southern municipalities such as Gouvelândia, Piracanjuba and Morrinhos (ALVES, 2012). In addition to proximity to sugarcane mills, such population explosions have generally been related to the beginning of the rainy season, which increases moisture in animal feed wastes (accumulated during the dry season) mixed with animal excrements (ALVES, 2012).

Due to the expansion of the sugarcane industry, a high frequency of outbreaks has been observed in the state of Mato Grosso do Sul, which has 22 operating sugarcane units (BIOSUL, 2014). Since 2009, outbreaks have been reported in the municipalities of Angelica, Dourados and Maracajú; followed by outbreaks in Caarapó, Nova Alvorada do Sul, Nova Andradina, Ponta Porã and Rio Brilhante, in 2010 and 2011 (KOLLER et al., 2009; BARROS et al., 2010; KASSAB et al., 2012).

Despite efforts by the sugarcane industry to mitigate the problem, stable fly outbreaks have occurred annually in several locations. In addition to the aforementioned places, in 2014 outbreaks were also recorded in the municipalities of Vicentina, Fátima do Sul and Costa Rica, not necessarily for the first time. Most of the affected municipalities are located in the southern central region of the state, coinciding with the main area of recent expansion of the biofuel industry and the largest number of sugarcane mills in operation.

The geographic distribution of *S. calcitrans* outbreaks since the end of the last decade shows a polygon with a higher incidence of outbreaks located in Brazil's central-west and southeast regions. This polygon comprises the south of Mato Grosso state, south of Goiás state, north and central-south Mato Grosso do Sul state, western Minas Gerais state and northwestern São Paulo state (Figure 1). Not coincidentally, the vast majority of newly established sugarcane mills in Brazil are located in these regions.

S. calcitrans outbreaks on cattle ranches located in the proximities of sugarcane mills have also been relatively frequent in Brazil's southeastern states. In the municipality of Planalto, state of São Paulo, severe stable fly infestations have been reported since mid-2008, commonly associated with vinasse application by the mills and with feed wastes mixed with animal excrements on ranches (ODA & ARANTES, 2010; BITTENCOURT, 2012). As previously observed by Buralli & Guimarães (1985), many *S. calcitrans* immatures can be found on the banks and bottom of open vinasse conducting channels, as well as in areas where vinasse accumulates in the field. Today, the risks posed by these

Figure 1. Polygon of *Stomoxys calcitrans* outbreaks associated with sugarcane mill activities in Brazil.

open channels of vinasse have been minimized by the use of pipelines to transport vinasse to the application sites.

Since 2009, several municipalities of the state of São Paulo have reported problems with the stable fly, including União Paulista (GOMES, 2009), Planalto (ODA & ARANTES, 2010; BITTENCOURT, 2012), Lins (CADIOLI et al., 2012), Borá and Ouroeste (BITTENCOURT, 2012). Although some outbreaks have been recorded, either by the local media or in scientific publications, the number of municipalities affected by stable fly outbreaks is actually much higher, as evidenced throughout 2014 by the authors. Personal information provided by various sources related to both livestock and sugarcane production systems includes reports of population explosions in several municipalities in the central-west and northeast of the state of São Paulo, such as Paulo de Faria, Orindiúva, Narandiba, Irapuru, Junqueirópolis, Alta Paulista, Jose Bonifácio, Iacanga, Reginópolis and Ubarana, all reporting similar problems. In fact, because of several implications, various events are not widely disclosed, so the real number of affected municipalities is virtually unknown.

Also in Minas Gerais, municipalities such as Frutal and Itapagipe, both located in the "Triângulo Mineiro" region, have undergone massive attacks by stable flies, leading the Instituto Mineiro de Agropecuária to monitor the situation (IMA, 2012; BITTENCOURT, 2012).

Thus, since the 1970s, with the first records and reports about stable fly outbreaks in Brazil, a relationship between sugarcane operations and population explosions has been suspected, albeit not proven until recently. Today, there is no doubt that the increased frequency and intensity of outbreaks is associated with the expansion of the sugarcane-alcohol industry and the resulting large-scale production of organic substrates favorable for stable fly development. On the other hand, it is only fair to emphasize that the poor sanitary management carried out at most livestock facilities provides suitable conditions for the maintenance of stable fly populations on ranches, which ultimately serve as centers of dispersion of flies to sugarcane mills, enabling the occurrence of outbreaks under more favorable conditions.

In the scenario of cattle ranches and sugarcane mills, there has been a close relationship between the harvest season and stable fly abundance. Preliminary studies on the population dynamics of *S. calcitrans*, using Alsynite sticky traps (BROCE, 1988) in sugarcane mills and cattle ranches, have shown a consistent pattern, where a sudden increase in the fly population is noticed shortly after the beginning of the sugarcane harvest season, declining after the end of harvesting activities (DOMINGHETTI et al., unpublished data). These results confirm the observations of ranchers that the fly population increases about a month after the beginning of harvesting and declines a month after harvesting ends (BITTENCOURT, 2012).

Studies of the population dynamics of stable flies adjacent to sugarcane mills have shown that the basal population of stable flies maintained on farms between harvesting seasons seems to work as the initial source for colonization of sugarcane areas, starting their massive proliferation in byproducts from the sugarcane industry (BARROS et al., 2010; BITTENCOURT, 2012). After they emerge, adult stable flies return to ranches in search of hosts for blood feeding. Dominghetti et al. (unpublished data) found the occurrence of *S. calcitrans* outbreaks on cattle ranches about four weeks after the beginning of the sugarcane harvest, indicating a direct relationship between fly infestation and sugarcane mill operation (large production of organic byproducts).

Using emergence traps to evaluate the potential production of *S. calcitrans* in distinct organic substrates generated by sugarcane mills, Corrêa et al. (2013) found a higher production of stable flies in filter cake and mulch fertigated with vinasse than in sugarcane bagasse and mulch without vinasse. Despite the potentially higher production of *S. calcitrans* in filter cake than in mulch plus vinasse (55.8 and 24.2 flies/m^2, respectively), the much larger areas fertigated with vinasse result in a massive production of flies, thus making this substrate the most important one associated with the occurrence of outbreaks. However, in *in vitro* studies, vinasse has been found to exert some influence on stable fly development, apparently related to its concentration in the substrate (LEITE et al., 2013; SILVA et al., 2013). Despite the evident relationship between population explosions of stable flies and sugarcane mill operations, not all outbreaks are so related. *S. calcitrans* outbreaks may be associated with other production systems that generate relatively large amounts of organic wastes which, in a decomposing/fermentation process, provide an adequate environment for the development of immatures of this fly, such as wet grains, fruit and crop production wastes and poultry litter (KOLLER et al., 2009). Indeed, the large-scale development of immature stable flies and consequent heavy infestations caused by the non-judicious use of organic fertilizers have been relatively frequent in several regions of the country.

In March and April 2014, the wastes accumulated from cattle supplementation as well as the organic fertilization of pastures with effluents from a commercial pig farm resulted in stable fly outbreaks in the municipalities of Amambai and Rondonópolis, in the state of Mato Grosso do Sul. Sugarcane activities were not involved in either of these cases (author's information). In the municipality of Eunápolis, in southern Bahia, high infestations of this pest were recorded following the use of raw fertilizers, mostly poultry litter and coffee husks, by producers of papaya, banana, and coffee, causing serious problems to local ranchers (SULBAHIA NEWS, 2009). In the state of São Paulo, *S. calcitrans* immatures were found on 42.3% of the coffee farms in the municipality of Espírito Santo do Pinhal, and were attributed to the use of coffee husks, cattle manure and poultry litter as fertilizers in coffee tree cultivation (BITTENCOURT, 1998). Buralli et al. (1987) also found a high production of flies, including *S. calcitrans*, on farms using poultry litter as organic fertilizer in the same state.

Similar problems in the southeastern municipalities of the state of Espírito Santo led the state's Department of Agriculture, through Ordinance No. 23-R of 02 December 2003, to ban the use of organic fertilizers in the state, such as coffee husks, poultry litter and animal feed wastes, without the previous adoption of adequate measures for stable fly control (ESPÍRITO SANTO, 2003).

In addition to the problems caused to other production systems, the development of stable flies on poultry farms can affect the production system itself. According to Gonçalves & Veiga (1994), cited by Gonçalves & Veiga (1998), a 22% reduction observed in the weight of poultry and of 25% in egg laying was attributed to stable fly attacks. However, poultry are not usually blood hosts for stable flies; in fact, *S. calcitrans* feeds on chickens only in the absence of other hosts (GONÇALVES & VEIGA, 1998).

Despite the advantages of organic fertilizers, care should be taken in specific situations since most of these fertilizers, e.g., poultry litter, tend to be highly favorable for the proliferation of flies, including *S. calcitrans*. Thus, the use of untreated fertilizers surrounding ethanol plants markedly increases the risk of fly population explosions, contributing to the occurrence of stable fly outbreaks. In Angélica, state of Mato Grosso do Sul, the source of an outbreak that occurred in July 2012 was attributed to poultry litter applied on a sugarcane plantation adjacent to a sugarcane mill (author's information).

Prevention and Control Measures

Several recommendations have been put forward to prevent and control stable flies at sugarcane mills and ranches. Most of them involve environmental management practices aimed at eliminating developmental sites or making them less favorable for the development of immatures.

Some measures proposed for sugarcane mills include raising the pH in soils fertigated with vinasse (BURALLI & GUIMARÃES, 1985; KASSAB et al., 2012), incorporation of sugarcane mulch in the soil, management of filter cake piles (KOLLER et al., 2009; BITTENCOURT, 2012), fractionation of vinasse application (KOLLER et al., 2009; KASSAB et al., 2012), cleaning of open vinasse canals and use of vinasse distribution pipes (BITTENCOURT, 2012), prophylactic post-harvest mulch burning (CANÇADO et al., 2013b), and suppression of the use of poultry litter as an organic fertilizer (BURALLI et al., 1987).

Albeit relevant and underpinned by a scientific rationale, most of the current recommendations lack not only scientific studies to give them a more consistent basis but also adequate methodological details for their implementation, as well as confirmation of their real effectiveness in field conditions.

The successful control of stable flies on livestock properties depends on the adequate sanitary management practices to eliminate or properly treat animal excrements and supplemental feed wastes, particularly in feedlots and dairy systems (SKODA et al., 1991; FOIL & HOGSETTE, 1994; BROCE et al., 2005).

Although insecticides are the first option of most producers to control cattle ectoparasites, this method is neither effective nor sustainable against *S. calcitrans*, and is recommended only in emergency situations (FOIL & HOGSETTE, 1994; BARROS et al., 2010). Regardless of the insecticide formulation or class, the low efficacy of insecticide treatments for controlling adult *S. calcitrans* has been empirically observed by producers and confirmed in field studies (CAMPBELL & HERMANUSSEN, 1971; GUGLIELMONE et al., 2004). Thus, control measures should primarily target immature stable flies and their sites of development, improving the overall effectiveness of stable fly control strategies.

The action of insecticides, either neurotoxic or growth regulator (IGRs), on immature *S. calcitrans* has been demonstrated *in vitro* and in field studies. The preventive treatment of cattle with avermectin insecticides (eprinomectin, abamectin, ivermectin, and doramectin) reduced the viability of neo-larvae to adult stable flies in manure by over 84% (MACEDO et al., 2005). Similarly, a significant inhibitory effect on the development of stable fly immatures was achieved by treating cattle dung with the IGRs pyriproxyfen and buprofezin diluted in water (LIU et al., 2012), and with a granular formulation of novaluron (LOHMEYER & POUND, 2012). In the field, a single application of granular cyromazine at hay feeding sites resulted in a 97% reduction in the emergence of *S. calcitrans* (TAYLOR et al., 2012b). Owing to the efficacy, as well as animal and environmental safety, the use of IGRs seems to be particularly promising in integrated stable fly management strategies.

Increase of the pH of substrates used for larval development has been considered a promising approach for the control of *Musca domestica*, including areas where vinasse is applied (BURALLI & GUIMARÃES, 1985; CALVO et al., 2010). However, more detailed studies are needed to support its large-scale application to control *S. calcitrans* in field conditions.

The lack of efficient methods of chemical control of *S. calcitrans* in extensive cattle raising areas (BROCE et al., 2005) is a serious limitation to control this parasite, particularly during outbreaks. Currently available commercial products, as well as their formulations and application methods, need a more comprehensive evaluation to support their safer and more efficient use in this particular epidemiological situation.

Challenges and Outlook

Although sugarcane is one of the oldest crops under cultivation in Brazil and the stable fly has long been widely distributed in the country, the problem of sugarcane-related stable fly outbreaks is a relatively recent one, especially considering their current frequency and intensity. This situation, which involves the expansion of the industry and the gradual ban on pre-harvest burning of sugarcane by the Federal Decree Nº. 2661 of 8 July 1998 (BRASIL, 1998), has introduced a new epidemiological scenario involving the stable fly. Therefore, few studies have so far been conducted to address this new epidemiological context, and scientific information about the bioecology of *S. calcitrans* in Brazil is still scant. This lack of baseline studies makes it difficult to develop specific integrated management programs to address the current situation of expanding sugarcane activity and its emerging risks.

In recent years, however, Brazilian research groups have made advances on the subject, shedding some light on this highly complex problem. Initial studies were limited to recording and describing the basic characteristics of sudden stable fly outbreaks occurring in the country, seeking to compile baseline information to allow for a better understanding of the situation and its geographic occurrence, and proposing some practical measures to mitigate the problem (KOLLER et al., 2009; BARROS et al., 2010; BITTENCOURT, 2012; KASSAB et al., 2012; CANÇADO et al., 2013b). More recently, some field studies have provided additional information, contributing to a more in-depth understanding of the epidemiology of the stable fly, mainly at sugarcane mills, and the dynamics of outbreaks (CORRÊA et al., 2013; CANÇADO et al., 2013a).

This initial knowledge is of paramount importance because it provides baseline support for more applicable research. Running applied research, which includes biological control (MORAES et al., 2008, 2010), population monitoring, and chemical control, should lead to the identification of potentially useful alternatives for controlling the parasite and preventing outbreaks. Unfortunately, such alternatives are not yet available and more time is required for their development before they can be applied in practice.

The low efficacy of commercially available chemical formulations for controlling *S. calcitrans* on pasture cattle (BROCE et al., 2005) clearly reveals the need for a wider range of options to enable efficient and sustainable integrated approaches for the control of adults and immatures. The use of biological insecticides at larval development sites, either separately or combined with chemical insecticides, may be a promising approach.

There is a consensus that the successful control of *S. calcitrans* depends mostly on sanitary management (FOIL & HOGSETTE, 1994; KOLLER et al., 2009; BITTENCOURT, 2012). However, despite the simplicity and economic viability of sanitary management actions recommended for the control of *S. calcitrans* on ranches, such actions are poorly adopted in practice. Lack of information, knowledge and environmental responsibility, as well as cultural issues and labor-related constraints, are among the factors responsible for the paucity of hygiene actions at cattle facilities.

Regardless of the real cause, any increase in stable fly infestations is immediately associated with sugarcane operations when there is a mill located nearby. Thus, in a generally tense situation of mutual accusations, substantial economic losses and daily frustration, dialogue between the parties becomes increasingly difficult, making it even more difficult to achieve advances in prevention, mitigation or solutions.

There is a noteworthy difference in the temporal and proportional participation of the two productive sectors – livestock and sugarcane industries – in the dynamics of population explosions. Cattle ranches keep a relatively small stable fly population between sugarcane harvest seasons, since the fly is practically absent from older and exhausted substrates after the end of the harvest. Such a basal population is essential for the fly's subsequent dispersion and massive reproduction in sugarcane plantations after the harvest begins, ultimately culminating in the occurrence of fly outbreaks.

Ultimately, the ranch-mill-ranch triad is a corridor that offers easy access of the fly to feeding (animals) and reproduction sites (organic wastes at the mill) throughout most of the year, enabling outbreaks whenever environmental conditions are favorable (heavy rains, use of organic fertilizers, etc.). Although the dynamics of fly outbreaks in the livestock and sugarcane sectors may differ, it stands to reason that these sectors should work together in the joint and integrated adoption of actions aimed at preventing, mitigating or solving this problem.

With its industrial park optimized for large-scale low cost production and high productivity, Brazil stands out as the world's largest sugarcane and ethanol producer (ABREU et al., 2011). However, some side effects of this large-scale production system have been identified, such as the massive production of a livestock pest (*S. calcitrans*) that strongly affects another production system. Despite the noticeable efforts of the sugarcane sector, in practice, the adoption of new technologies for stable fly control and prevention of outbreaks is neither simple nor cheap. Therefore, one of the main challenges the sugarcane industry faces in finding a solution to the stable fly problem is the development and validation of techniques to manage the organic byproduct generated by the operation itself. The expansion of the sugarcane industry onto lands traditionally occupied by livestock has generated conflicts, which tend to worsen and require adjustments in both production chains.

Given the responsibility of the sugarcane and livestock production systems in the epidemiology of *S. calcitrans* outbreaks (KOLLER et al., 2009; BARROS et al., 2010; CANÇADO et al., 2013a), it is essential that the two sectors participate jointly in the search for a solution to the problem. Also needed is the formulation and execution of public policies that provide tools for the proper implementation of management actions.

Some possibilities regarding new agronomic techniques with potential benefits for the control of *S. calcitrans* at sugarcane mills have been discussed. One of these possibilities is to concentrate vinasse by means of a technology that significantly reduces the amount of water in the byproduct (CRUZ et al., 2013). Reducing the water content of vinasse and applying it directly on sugarcane cultivation rows tends to render harvested areas less favorable for the fly's development. An additional advantage of this technology is the expansion of fertigation when compared to the current use of channels or pipes. However, this technique is expensive and has so far been employed only by a few mills around the world, and its effectiveness in preventing stable fly outbreaks has not yet been confirmed, particularly when it rains after application.

Another technology under discussion is the anaerobic digestion of vinasse, resulting in the production of biogas (CRUZ et al., 2013). Like other possibilities, the adoption of this technology also depends on the prior assessment of its technical, environmental and economic aspects. Once digested, vinasse would no longer be applied on mulch, thereby eliminating large areas of *S. calcitrans* reproduction. However, the use of fertilizers in place of vinasse may increase, thus raising production costs. Like the previous technology, the potential efficiency of this technology in preventing the fly reproduction at sugarcane mills needs to be carefully assessed before it is recommended and adopted as a fly control measure.

Regardless of their use by sugarcane mills or livestock ranches, a path to be considered is the adaptation of existing technologies to this new situation. An example may be the use of insect growth regulators (IGRs), which are known to be effective in some conditions. However, their use requires field evaluations to determine their efficacy as well as their environmental and economic viability before they are largely adopted. The same applies to other insecticides available on the market, whose formulations and application methods may require adjustments for use in specific situations or even on a large scale.

Biological control agents have also been considered as an option, emphasizing the use of entomopathogenic fungi (MORAES et al., 2008; ALVES et al., 2012) and bacterial isolates, such as *Bacillus thuringiensis* (LYSYK & SELINGER, 2012). However, their use is not a short-term option. Because of the critical importance of the problem, and the greater ability of the sugarcane and alcohol industry to respond to production system-related demands, this sector should keep an eye out for new possibilities, since several lines of research and innovative technologies are currently under development around the world.

Final Remarks

Preliminary research results and empirical experience based on approaches applied to both livestock and sugarcane production systems have contributed to a better understanding of the dynamics of stable fly population explosions, and to improved fly control measures, which ultimately help prevent outbreaks, reducing direct and indirect losses. However, the development of more meaningful technological advances and their widespread adoption requires more time and should not be expected in the short term.

In order to contribute to the growth of the sugarcane sector and minimize the severe economic losses resulting from *S. calcitrans* outbreaks among livestock in several regions of the country, it is necessary to implement public policies that can address the real needs of both productive sectors.

Lastly, it is emphasized the need for dialogue and joint work by the sectors involved so that the best possible level of control can be achieved using the current knowledge and technologies. Only coordinated and integrated actions will effectively reduce the frequency and intensity of stable fly outbreaks until effective solutions can be devised.

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