**ENTOMOLOGICAL
SOCIETY OF AMERICA**
SHARING INSECT SCIENCE GLOBALLY

OXFORD

Review

A scoping review of triatomine control for Chagas disease prevention: current and developing tools in Latin America and the United States

Yuexun Tian[1], Cassandra Durden[2], Gabriel L. Hamer[1,*]

[1]Department of Entomology, Texas A&M University, College Station, TX, USA, [2]Department of Veterinary Integrative Biosciences, Texas A&M University, College Station, TX, USA *Corresponding author, mail: gabe.hamer@ag.tamu.edu

Subject Editor: Juan Carlos Navarro

Chagas disease is an infectious disease of human and animal health concern, with 6–8 million chronic human infections and over 50,000 deaths throughout the Americas annually. Hematophagous insects of the subfamily Triatominae, also called kissing bugs, vector the protozoan parasite, *Trypanosoma cruzi* Chagas (Trypanosomatida: Trypanosomatidae), that causes Chagas disease. Despite the large human health burden, Chagas disease is a neglected tropical disease with inadequate funding for research and preventive practices. Given the resource-poor environment of most agencies trying to protect public health, it is critical to consider all control options for reducing vector populations and the risk of human exposure to *T. cruzi* to identify the most appropriate tools for each context. While numerous triatomine control methods exist, the literature lacks a compilation of the strategies used, a critical examination of their efficiency, and a particular focus on triatomine control in the United States compared to elsewhere in the Americas. Here, we present a review of the literature to assess historical intervention strategies of existing and developing triatomine control methods. For each method, we discuss progress in the field, future research to further advance the method, and limitations. While we found that pyrethroid insecticide is still the most commonly used method of triatomine and Chagas disease control, we suggest that complementing these techniques with alternative control methods in development will help to achieve Chagas disease reduction goals.

Key words: pyrethroid, xenointoxication, environmental control, biological control

Introduction

Vector-borne disease is increasing in human incidence in both the United States and the rest of the world. Due to factors such as climate change, globalization, and persistent poverty, vectors are shifting their geographic distribution and now occupy habitats that were once unsuitable (Gonzalez-Salazar et al. 2022). A vector-borne and neglected tropical disease resulting in one of the largest human disease burdens is American trypanosomiasis, or Chagas disease, which is spread by insect vectors of the subfamily Triatominae (Hemiptera: Reduviidae). These vectors, also known as "kissing bugs," "conenose bugs," or other names used locally such as barbeiro or bicudo in Brazil, bush chinche in Belize, or chipo in Venezuela, harbor the flagellate protozoan parasite, *T. cruzi*, which causes Chagas disease in many mammalian hosts, such as humans and canines.

Chagas disease is a debilitating infection endemic to Latin America that affects 6–10 million people worldwide, with an estimate of 65–100 million people residing in regions at infection risk (Manne-Goehler et al. 2016, Lidani et al. 2019). Of these infections, approximately 50,000 per year result in mortality, and others often leave those infected with lifelong health complications. Chagas disease is reported as a neglected tropical disease by WHO, and it primarily affects low-income populations with limited healthcare (Lidani et al. 2019). This leads to significant underreporting of Chagas disease cases, as well as a significant number of chronic infections, which can occur when the acute infection is untreated. Most mortality, morbidity, and economic burden are caused by chronic Chagas disease infections, which are responsible for an estimated $627.5 million per year in healthcare costs globally (Lidani et al. 2019). Notably, the WHO has outlined a goal of eliminating Chagas disease in 15 countries (34% of the current distribution) by 2030 (World Health Organization 2021).

Transmission of *T. cruzi* is mostly facilitated by triatomine vectors in a fecal-oral route of transmission (Monteiro et al. 2018).

Triatomines shed the parasite in feces, which may then enter the body through ingestion, mucous membranes, or an open wound (Lidani et al. 2019). Some animals may also ingest infected triatomines or fruit contaminated with infected triatomine or their feces, which is an efficient route of transmission (Shikanai-Yasuda and Carvalho 2012). Other routes of transmission include congenital transmission, blood transfusions, and consumption of contaminated food (Pereira et al. 2009).

Vector transmission of *T. cruzi* is limited to the Americas, predominantly in rural areas of Latin America, where housing conditions promote the colonization of homes by domestic triatomine species (Sommerfeld and Kroeger 2015). While over 150 triatomine species have been documented and are potential vectors of *T. cruzi* (Lent and Wygodzinsky 1979, Galvão 2021), only a subset are considered intrusive with higher levels of domiciliation and thus responsible for the majority of human risk of exposure to *T. cruzi* (Waleckx et al. 2015a). These domestic triatomines thrive in and around homes, which increases contact between humans and domestic animals with infected vectors. Domestic triatomine populations are the major contributor to human infection of *T. cruzi* (Cahan et al. 2019). However, the epidemiology of Chagas disease is changing as urban sprawl encroaches on sylvatic habitat and is predicted to change further in response to projected climate change (Medone et al. 2015). Spillover of triatomines and *T. cruzi* from sylvatic cycles in natural habitats that enter the domestic or peridomestic habitat may also occur (Waleckx et al. 2015a), although the extent to which these sylvatic vectors contribute to human infection is not well established (Stevens et al. 2013).

There is a long history of intervention strategies aimed at controlling triatomine vectors, yet Chagas disease remains a significant burden in the Americas in both endemic and nonendemic regions. Here, we compile triatomine control methods currently in use and in development to discuss the advantages and disadvantages of each (Fig. 1). We further highlight unique aspects of triatomine control in the United States as it relates to Latin America (Table 1). The goal of this review is to comprehensively cover the diverse approaches that have been evaluated in lab and small-scale trials, as well as others that have reached area-wide interventions coordinated by local ministries of health. Each control method covered by this review may not be feasible or appropriate for all contexts and all triatomine species, given the diverse ecological and social contexts across the Americas. Therefore, this review does not serve as guidelines or provide specific suggestions for triatomine control to professionals and public health officials. Instead, this comprehensive review provides a broad compilation of control approaches that have been considered for triatomines.

Vector-Targeted Intervention

Environmental Insecticides

In the past 40 years, the control of Chagas disease has primarily relied on vector control using insecticides, with the most common class being pyrethroids (Gürtler and Cecere 2021). Insecticides sprayed in indoor and outdoor environments have made great progress in controlling domestic triatomines as well as other domestic insect pests (Dias and Schofield 1999). Different pyrethroids, such as deltamethrin, lambda-cyhalothrin, beta-cyfluthrin, and alpha-cypermethrin, have been used as wettable powder and suspension concentrate and applied by indoor and outdoor residual spray (Rozendaal 1997, Hashimoto et al. 2006, Gurevitz et al. 2013, Goncalves et al. 2021a). Other formulations, such as microencapsulated pyrethroids and ultra-low volume spraying, have been tried but were not as effective and cost-efficient as traditional indoor spraying (Dias and Schofield 1999). However, newer developed insecticide delivery methods, such as insecticide-impregnated paints and curtains, provide additional options for triatomine
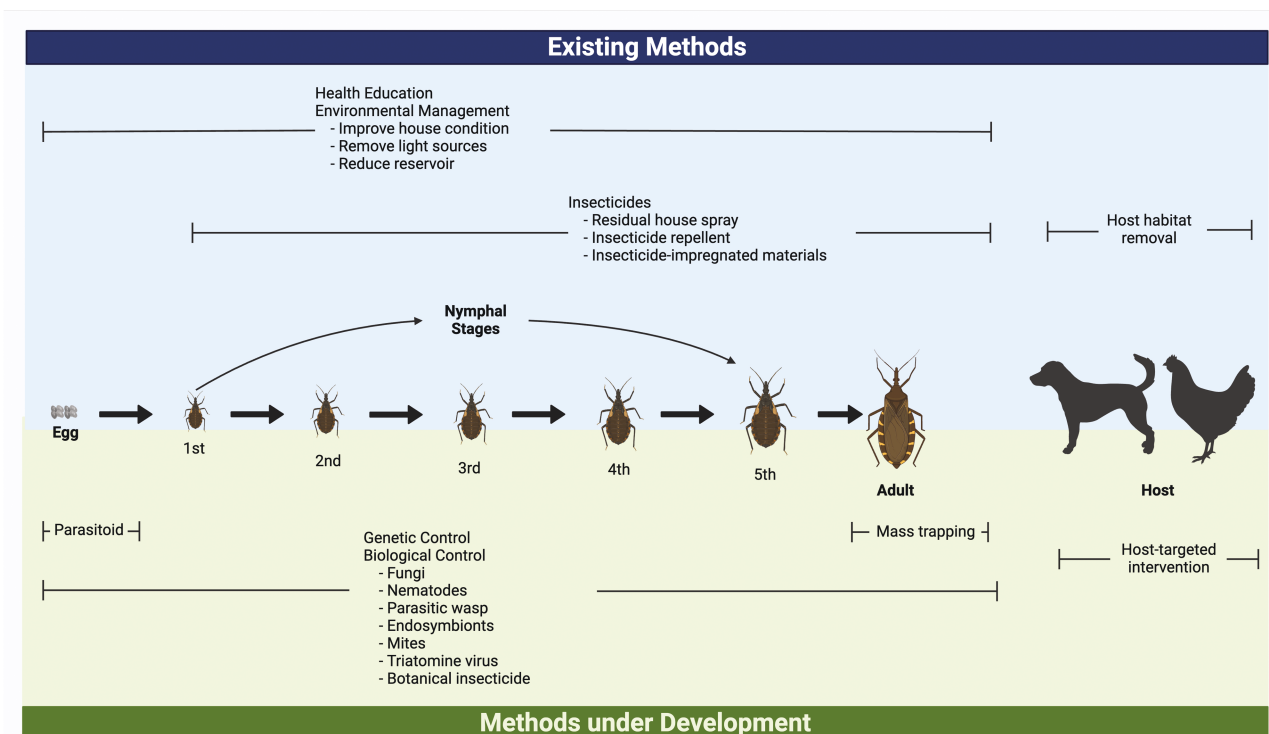
Fig. 1. Existing and developing methods of triatomine control for Chagas disease prevention. Figure design adapted from Achee et al. (2015).

Table 1. Control methods against triatomines that currently exist (E) with area-wide application or are under development (D) in the United States and Latin America. Control methods not receiving active research to our knowledge or are performed sporadically are classified as under development

Category	Subcategory	United States	Latin America
Environmental insecticide[a]	House spraying (Spraying insecticides, mainly pyrethroids, on house walls)	D	E
	Insecticide-impregnated materials (Insecticide-treated curtains, paints, and other materials that are used in the household)	D	E
	Repellent (Chemicals that can be used to repel triatomines to prevent infestation and contact with humans)	D	D
Biological control	Entomopathogenic fungi (Fungi that can infect and kill triatomines)	D	D
	Nematodes (Nematodes that can infect and kill triatomines)	D	D
	Parasitic wasps (Wasps that live on, obtain resources from, and eventually kill triatomines)	D	D
	Mites (Mites parasitize triatomines and reduce their fitness)	D	D
	Triatoma virus (Virus that can infect triatomines and increase their mortality)	D	D
	Botanical insecticides (Products extracted from plants that exhibit insecticidal properties)	D	D
Genetic control	Paratransgenesis (Engineered symbionts delivered to triatomines to make refractory to *T. cruzi*)	D	D
Mass trapping	Traps (Deployment of a large number of traps to suppress triatomine populations)	D	D
Host-targeted intervention	Xenointoxication (Treatment of triatomine hosts with systematic insecticide to produce toxic bloodmeals for triatomines)	D	D
Environmental management	Household improvement (Improve household conditions, such as house wall material, house hygiene, the removal of firewood piles, host habitat, and lights to reduce triatomine habitat suitability)	E	E
	Reduction of artificial lights (Reduce light attraction to dispersing triatomines to reduce infestation)	E	E
	Reservoir control (Reduce *Trypanosoma cruzi* prevalence in triatomines or triatomine populations by reducing populations of important hosts such as rats or chickens)	E	E
	Health education (Increase the public awareness of triatomines and Chagas disease and their control tools)	E	E

[a]Currently, no insecticide is labeled to control triatomines.

control using insecticide, although these methods are currently limited in use.

Despite the efficiency and wide usage of insecticides, adverse effects of pyrethroid insecticide exposure in aquatic wildlife are well documented (Antwi and Reddy 2015), and adverse effects in humans are still under investigation, with some studies suggesting high human exposure is linked to behavioral problems in children (Oulhote and Bouchard 2013, Burns and Pastoor 2018). This is especially problematic as domestic species of triatomine are commonly found in and around homes, with pesticides sprayed indoors, creating a high likelihood of human insecticide exposure. However, exposure to insecticides is relative to the dosage of the product and frequency of application. Where some endemic areas may undergo periodic treatments, which may risk increased human exposure, other areas may rarely undergo insecticide treatments. Ultimately, the hazards of insecticide use are dependent on the appropriate application of products, as outlined by vector control professionals. In addition to the exposure risk, some areas may struggle with the increasing resistance to pyrethroid insecticides with widely used and high application frequency of pyrethroids (Mougabure-Cueto and Picollo 2015).

House spraying. House spraying with pyrethroids has been used widely in controlling triatomines in rural and urban areas due to its high efficiency (Dias 2007). Successful reductions of triatomines after pyrethroids house spray have been reported in many countries and areas. In Guatemala, the triatomine *Rhodnius prolixus* (Stål) (Hemiptera: Reduviidae) and *Triatoma dimidiata* Latreille (Hemiptera: Reduviidae) infestation index (number of houses infested by triatomines/number of houses examined × 100) reduced from 14% (2000) to 0.8% (2001) including cases of complete elimination in Zacapa (Nakagawa et al. 2003) and from 20.8% (July 2000–April 2001) to 1.4% (April 2002–August 2003) in Jutiapa (Hashimoto et al. 2006) after a single house spraying with deltamethrin, beta-cyfluthrin, lambda-cyhalothrin, or beta-cyfluthrin. Higher infestation index reductions of 46%–96.7% (6–12 months post spray) were achieved against *T. pallidipennis*

(Stål) (Hemiptera: Reduviidae) and *T. barberi* (Usinger) (Hemiptera: Reduviidae) in a village in Mexico that was sprayed with bifenthrin, cyfluthrin, or deltamethrin (Ramsey et al. 2003). Similar high effectiveness was also observed in other countries such as Paraguay (de Arias et al. 2004), Nicaragua (Yoshioka et al. 2015), Bolivia (Guillen et al. 1997), and Argentina (Bezerra et al. 2014, Gaspe et al. 2015). However, reinfestation often occurs after pyrethroid house spraying (Gürtler et al. 1994, Dumonteil et al. 2013, Bezerra et al. 2014), which may be related to households not participating in the control campaign (Barbu et al. 2014) or from recolonization from sylvatic habitat (Bezerra et al. 2020).

The efficacy of pyrethroid house spraying is affected by multiple factors, including house structure and material, the peridomestic (outdoor) structures used by domestic or synanthropic animals, the accuracy of pyrethroid dilutions, the level of education, and rodent control (Ramsey et al. 2003, Pojo De Rego et al. 2006, Walter et al. 2007, De Urioste-Stone et al. 2015, Goncalves et al. 2021b). de Arias et al. (2004) reported high variability of pyrethroid deposition in roof treatment samples, where some areas remained untouched. In addition, the highest reduction of pyrethroid toxicity occurred on the porous surface due to its strong absorption (de Arias et al. 2004). Therefore, household improvement can enhance the efficiency of house spraying (Goncalves et al. 2021b). Although following the same insecticide preparation formulas, variable alpha-cypermethrin concentrations were reported between houses and independent spray tanks by Goncalves et al. (2021a). In addition, De Urioste-Stone et al. (2015) demonstrated the transmission risk can be reduced by insecticide application accompanied by education and rodent control. Besides the technical difficulties, the intense labor requirement of house spraying will not only increase the cost but also decrease the feasibility of house spraying in certain areas. However, motorized vehicle-mounted sprayer provides a potential solution to reduce the labor cost as it had similar performance to manual compression sprayers, which reduced house infestation from 100% to 21%, 0%, and 8% at 0, 1, 4, and 12 months postintervention without significant difference between the 2 methods (Carbajal-de-la-Fuente et al. 2017).

Insecticide-impregnated materials and paints. In addition to house spraying, newer insecticide delivery methods have shown high control efficiency. Insecticide paint was proposed in the 1980s (Dias and Jemmio 2008) and has now been commercialized to control multiple vectors such as mosquitoes, flies, cockroaches, bedbugs, and ticks. Commercial paints with pyriproxyfen, pyrethroids (Inesfly 5A IGR NG), and organophosphates (Inesfly 5A IGR) were evaluated against *T. infestans* Klug (Hemiptera: Reduviidae) nymphs at multiple days postpainting (DPP) under laboratory conditions (Amelotti et al. 2009). High mortalities of 100% and 99% of *T. infestans* nymphs were observed at 1 and 365 DPP with the organophosphates paint; respectively, 100% and 83% were observed with the pyrethroid paint. At 80 DPP, the mortality of *T. infestans* exposed to the pyrethroid paint dropped to 73%–80%, which may be due to the reduced nymphal motility from the low temperature (around 0 °C). In addition, Maloney et al. (2013) compared the organophosphate paint to standard deltamethrin against *T. infestans* nymphs and revealed that the paint caused higher mortalities (>90%), but had more host-seeking nymphs cross the paint than standard deltamethrin up to 9 months. The commercial product with organophosphates was evaluated in Camiri, Bolivia, and similarly demonstrated high control efficiency for up to 72 months with highlights of good house appearance and high acceptance by the local population and authorities (Dias and Jemmio 2008). In 1999, insecticidal paint containing malathion and polyvinyl acetate was evaluated for its effectiveness and community acceptance (Ávila Montes et al. 1999). The acceptance by the community and field operators was low (28.8%) due to its low effectiveness compared to traditional insecticide spray, transport and application difficulty, and unpleasant smell. However, with the improvement of the paint formulation and active ingredients, insecticidal paints now have excellent acceptance given the high efficiency, easy handling, and good appearance of homes in the community in Bolivian Chaco (Dias and Jemmio 2008).

Insecticide-treated bed nets are another common addition to households in areas with endemic vector-borne diseases such as malaria (Robert 2020) and leishmaniasis (Kroeger et al. 1999, Chowdhury et al. 2019). Similarly, insecticide-treated bed nets have been evaluated as randomized controlled trials in Columbia (Kroeger et al. 2003) and as protection of sentinel peridomestic animals in Peru (Levy et al. 2008), reporting evidence of killing triatomines and protecting humans from vector bites. Bed nets are most commonly treated with pyrethroids, including deltamethrin (Kroeger et al. 1999) and lambda-cyhalothrin (Kroeger et al. 2003). In addition to inducing mortality in vectors, studies show insecticide-treated bed nets protect humans from triatomine bites and subsequent infection with *T. cruzi* (Schwarz et al. 2011). While traditionally reserved for areas of high *T. cruzi* endemicity, treated bed nets may also provide a protective effect in the United States, where populations may experience allergic reactions to triatomine bites (Klotz et al. 2014). Despite the potential utility of bed nets for triatomine use in Chagas endemic regions, one factor that limits the use is reduced air circulation and excessive heat, which are common in many tropical areas (Pulford et al. 2011, Pooseesod et al. 2021).

Repellent. In addition to reducing triatomine vector populations using insecticide, repellents can also reduce contact between triatomine and humans and other animal hosts. Some repellent ingredients in commercial products labeled against mosquitoes and ticks and other chemicals have been studied to repel triatomines, such as DEET, IR3535, and picaridin (Alzogaray et al. 2000, Terriquez et al. 2013, Reynoso et al. 2017). N-ethylmaleimide, a sulfhydryl reagent, was demonstrated to have a feeding deterrent effect on *T. infestans* nymphs (Picollo et al. 1993). Alzogaray et al. (2000) documented a significantly higher repellency effect of DEET for *T. infestans* nymphs than the control treatment within 60 min. The repellency index (area occupied by nymphs in acetone treated arena/area occupied by nymphs in DEET treated arena) ranged approximately from 1.25 to 190 depending on the experiment design and DEET dose. Reynoso et al. (2017) reported minimum effective concentrations of 1.15 ug/cm^2 for both DEET and IR3535 to produce repellency against *T. infestans* nymphs, while Terriquez et al. (2013) documented the lowest concentrations of 10% and 7% for DEET and picaridin, respectively, to significantly reducing *T. rubida* (Uhler) (Hemiptera: Reduviidae) feeding. Besides the synthetic insecticides, plant essential oils and their compounds have been studied widely as repellents against triatomines due to their volatile properties (see *Botanical insecticides* section). Spatial repellents have been successful in disrupting mosquito–human contact (Achee et al. 2012, Revay et al. 2013, Dame et al. 2014, Mannino et al. 2019, Morrison et al. 2022). However, we were unable to find studies evaluating spatial repellents for triatomines. The closest such example is irritants, such as pyrethroids, used in the standard flush-out method for surveillance by spraying in crevices in homes to encourage triatomines to escape the crevices, which aids in the detection and collection (Gürtler et al. 1993, 2001, Reynoso et al. 2017). Exploring spatial repellents for reducing triatomine colonization of households is warranted.

Although repellents may have great effects on interrupting contacts between triatomine and host, it is highly dose-dependent to achieve, especially for long-lasting effects. For example, 15% DEET shows repellency of mosquitoes for 6 h (Colucci and Müller 2018), which indicates the need for reapplication. The need to reapply repellants in Chagas endemic contexts could be a barrier to use and the commercializing of products labeled specifically for triatomines. Exploring more insecticides and formulations that are safe and long-lasting would be beneficial. We also highlight that repellants could be effective when the risk of exposure to triatomines is ephemeral, such as deployed warfighters.

Pyrethroid resistance. Although few studies have reported low resistance to fipronil in triatomine populations (Toloza et al. 2008, Germano et al. 2010, 2012), resistance to pyrethroids is a major problem in triatomine control resulting in failures in different regions with persistent or rapid recovery of infestations (Gurevitz et al. 2012, 2013, Bezerra et al. 2014, Mougabure-Cueto and Picollo 2015, 2021). The major mechanisms of pyrethroid resistance are target site insensitivity, metabolic detoxification, and reduced penetration, which have been summarized and explained in Mougabure-Cueto and Picollo (2015, 2021). Pyrethroid resistance was reported in triatomines collected in Brazil and Venezuela, where *T. infestans* from Brazil demonstrated resistance to deltamethrin, beta-cyfluthrin, and cypermethrin, while *R. prolixus* from Venezuela were resistant to lambda-cyhalothrin and cypermethrin (Vassena et al. 2000). However, the resistance was not considered as a contributing factor to the control failures in 1998 where fast recovery of high-level infestation was observed after pyrethroid sprays (Picollo et al. 2005, Zaidemberg 2012, Gürtler and Cecere 2021). However, subsequent research revealed high resistance to deltamethrin (resistance ratio = 50.5–133.1) was reported in 2005 in Salta, Argentina, along with resistance to beta-cypermethrin, beta-cyfluthrin, and lambda-cyhalothrin, resulting in ineffective control in the field (Picollo et al. 2005). In addition, Gurevitz et al. (2012) reported persistent infestations in 28.4% of the deltamethrin-treated houses in the Gran Chaco region of Argentina due to resistance with a resistance ratio range of 4.47–11.50. Likewise, pyrethroid resistance has been recorded in Mexico (Davila-Barboza et al. 2019), Bolivia (Lardeux et al. 2010, Depickere et al. 2012), and Colombia (Torres et al. 2013). Therefore, alternative control strategies to complement insecticides are needed for effectively controlling vectors of Chagas disease in the affected areas (Fig. 1).

Biological Control

Biological control involves the introduction of a natural enemy or predator to control a pest (Waage and Greathead 1988). In the past, this method has demonstrated success in controlling vector populations such as mosquitos, where predatory larvae and mosquitofish have been used to reduce populations (Benelli et al. 2016). Similarly, we will discuss below several types of biological control that have been evaluated as potential candidates for triatomine vector control. Biological control can target vectors with reduced nontarget effects and environmental impact and, in some cases, may target populations that demonstrate resistance to traditional insecticides. Further, biological control often involves a delayed action, allowing the reproduction of part of the adult population before they are killed, thereby preventing the evolution of resistance (Benelli et al. 2016).

While biological control has many successes and benefits, there are multiple barriers to applying it to large-scale interventions. As agents of biological control are live organisms, the acceptance of applying them in a domestic environment where humans and other animals reside may be low due to multiple factors, including differences in culture, value, and regions, and knowledge of pest management and biological control (Barratt et al. 2021). In addition, pesticides, including biological control agents, have been heavily regulated with lengthy and expensive testing and documentation (Messing and Brodeur 2018). Nontarget effects are one of the concerns of using biological controls, which extends the regulatory process and necessitates agency approval in each country or region (Messing and Brodeur 2018). These challenges can significantly impede the transition from laboratory evaluation to large-scale application of innovative biological control methods.

Fungi. The effects of entomopathogenic fungi on triatomines were evaluated as early as 1987, and high mortality was demonstrated in *R. prolixus* that was sprayed with *Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales: Cordycipitaceae) (Romana et al. 1987). Thereafter, more studies have been conducted to explore its mechanisms (Forlani et al. 2015, Lobo et al. 2015), effects on triatomine oviposition (Forlani et al. 2015), immune response (Lobo et al. 2015, Mannino et al. 2019), fungal formulations (Luz et al. 1999, Luz and Batagin 2005, Forlani et al. 2011), and strains (Lecuona et al. 2001). *Beauveria bassiana* has shown a significant effect in *T. infestans* mortality up to 100% under both field and laboratory conditions (Forlani et al. 2011, 2015). Field studies have distributed the fungus through boxes baited with carbon dioxide (Pedrini et al. 2009) or triatomine pheromones (Forlani et al. 2015). The fungus is then transmitted horizontally to exposed insects, similar to autodissemination traps used to treat tsetse flies with entomopathogenic fungus (Maniania et al. 2006). *Beauveria bassiana* has been shown not only to increase vector mortality but also to significantly affect *T. infestans* oviposition, where the infected females produce significantly fewer eggs than uninfected females (Forlani et al. 2015). However, there was no significant difference in fertility. Triatomines also showed a measurable attractiveness to the fungi, compared to repulsion from some chemical insecticides (Forlani et al. 2015). The use of *B. bassiana* provides a potential effective control for pyrethroid-resistant triatomines given that *B. bassiana* degrades the thickened cuticle (Napolitano and Juarez 1997, Pedrini et al. 2009), which is a pyrethroid resistance mechanism (Pedrini et al. 2009). Pedrini et al. (2009) reported 52.4% mortality in pyrethroid-resistant insects exposed to entomopathogenic fungi in experimental houses and rural human dwellings. However, the use of entomopathogenic fungi, especially in the indoor environment, will require regulatory approval, public acceptance, and minimal nontarget impacts.

Nematodes. Entomopathogenic nematodes are widely used as biological control to target agricultural pests and can be applied using traditional spraying equipment. Entomopathogenic nematodes form symbiotic relationships with enteric bacteria, which create virulent bacteria-nematode complexes that can kill insects (Stock and Blair 2008). The third juvenile stage is the infective stage of the parasite, which leaves the insect, traveling in the soil to seek a new host. Entomopathogenic nematodes are mainly found in 2 families, Steinernematidae and Heterorhabditidae, which have been developed as biological control agents and used to control agricultural pests (Campos-Herrera 2015). In addition, it has been evaluated extensively against the aquatic mosquito larval stage with high mortality (Cagnolo and Almirón 2010, Peschiutta et al. 2014, Dilipkumar et al. 2019) as well as against ticks (Kocan et al. 1998, Samish and Glazer 2001, Goolsby and Shapiro-Ilan 2020, Filgueiras et al. 2023).

While entomopathogenic nematodes have been studied against other vectors, the research on their effects against triatomines is limited. Two genera of nematodes, *Heterorhabditis* and *Steinernema*, have

demonstrated the ability to kill *T. infestans* and *R. prolixus* under laboratory conditions (Eliceche et al. 2022). Laboratory experiments found that *T. infestans* parasitized by the nematodes had mortalities of up to 90% in as little as 3 days postexposure, and the experiment was equally successful in both insecticide-resistant and nonresistant triatomines (Eliceche et al. 2022). In addition, Martins et al. (2020) reported the parasitism of mermithid nematodes (Mermithidae) on *T. sordida* (Stål) (Hemiptera: Reduviidae) collected from Brazil, which provided another candidate for triatomine biological control. While field studies of the mermithids have not been evaluated for triatomine control, boxes containing pheromones used in experiments to attract triatomes to traps containing entomopathogenic fungi (Forlani et al. 2015) may also be used to attract the insects to be treated with entomopathogenic nematodes. Although entomopathogenic nematodes seem to be promising candidates for triatomine control, there are still challenges to overcome before implementation in the field and communities. For example, field evaluations need to confirm the interaction between nematodes and triatomines as well as the efficacy of control. The mass production of nematodes could also be a prohibiting factor to consider, as well as the formulation and application technology (Askary and Abd-Elgawad 2021) and transport challenges to remote Chagas endemic locations. In addition, contact between nematodes and human and companion animals may be a concern.

Parasitic wasps. Parasitoids are organisms that live on and obtain resources from their hosts, which often eventually cause death in hosts. Most parasitoids are insects in the orders of Hymenoptera and Diptera that lay eggs in other insects, where they develop and emerge as an adult. Parasitoids have been an important biological control tool in integrated pest management and have been used to control multiple economically and medically important pests, such as filth flies (Machtinger et al. 2015, Smith et al. 2022) and fruit flies (Garcia et al. 2020). Multiple parasitoid species of triatomines have been reported, such as *Telenomus fariai* Costa Lima (Hymenoptera: Scelionidae), *T. costalimai*, *Megaselia scalaris*, and *Aprostocetus asthenogmus*, which parasitize different triatomine species (Feliciangeli and Rabinovich 1985, Costa et al. 2007, dos Santos et al. 2014, Ramirez-Ahuja et al. 2021).

Telenomus fariai was proposed as a biological control of triatomines as early as 1957 (Zeledón 1957) and was widely studied (Rabinovich 1970). Gorla and Schofield (1985) documented that *Te. fariai* appeared at the end of summer and attacked up to 37% of *T. infestans* eggs, which then decreased to zero in winter due to the low triatomine egg production. Fernandes et al. (1990) found 70.9% parasitism in eggs of *Panstrongylus megistus* (Burmeister) and *T. vitticeps* (Stål) and observed an average of 10 parasitoids per *T. infestans* egg in the laboratory. However, the triatomine egg age influences the parasitism of *Te. fariai*, which was reduced as the egg matured (Rabinovich 1970). However, egg parasitism resulted in high mortality, high egg production in a limited period, and the low effectiveness of *Te. fariai* under natural conditions limit the potential for using parasitoids as biological control field settings (Gorla and Schofield 1985, Noya et al. 2019, Gorla 2020).

The parasitoid *M. scalaris*, was documented infesting a *T. brasiliensis* colony in the laboratory in Brazil. Costa et al. (2007) reported that *M. scalaris* larvae were discovered feeding inside *T. brasiliensis* nymphs and adults and the fly pupa was found in the colony container. dos Santos et al. (2014) observed *A. asthenogmus* near the *T. infestans* and *T. vitticeps* colonies and subsequently demonstrated the wasp's ability to parasitize *T. infestans* and *T. vitticeps* eggs with rates of 56.8% and 45.5%, respectively. With more parasitoid species of triatomines being discovered, using parasitoids remains a viable biological control option for triatomines.

Endosymbionts. Endosymbionts have been playing an important role in vector and vector-borne diseases, especially in mosquitoes. *Wolbachia* is one of them that has been widely studied in mosquito management as it can not only suppress pathogen replication, such as Dengue virus, yellow fever virus, and Zika virus, but also negatively affect mosquito reproduction, resulting in population reduction (Yen and Failloux 2020). It is favored and considered a more acceptable tool as it can be vertically transmitted and does not involve gene editing. *Wolbachia* infection in insects is high, with an estimated 66% of insect species being infected (Hilgenboecker et al. 2008), including triatomines (Espino et al. 2009, Kieran et al. 2019, Waltmann et al. 2019). However, it is unclear how *Wolbachia* affects triatomines as there are no observed beneficial or negative effects (Kieran et al. 2019, Salcedo-Porras et al. 2020). Unlike *Wolbachia*, *Serratia marcescens* is a common bacteria found in some triatomine species and regulates the population of *T. cruzi* in triatomine by producing prodigiosin that hinders *T. cruzi* establishment. From the in vitro experiments, 2 strains of *S. marcescens* reduced *T. curzi* population in triatomine at 30 °C and killed flagellates at 0 °C (Azambuja et al. 2004). More studies further explored the effects of *S. marcescens* on the humoral immunity of *R. prolixus* (Batista et al. 2021) and as a potential antagonist of *T. cruzi* (da Mota et al. 2018). While *S. marcescens* has the ability to regulate *T. cruzi* population in triatomines, it remains unknown whether *S. marcescens* can be used as a biological tool to control *T. cruzi* transmission. Additional endosymbiont bacteria are being isolated and evaluated for advancing the utility of using symbiotic bacteria to create populations of triatomines refractory to *T. cruzi* (Cambronero-Heinrichs et al. 2024).

Mites. Mites have been found parasitizing on triatomine head, thorax, abdomen, and legs (Anderson 1968, Dye-Braumuller et al. 2021) with different preferences of triatomine species. Marti et al. (2017a) summarized the literature and their laboratory data and reported 8 mite species in the genus *Pimeliaphilus* parasitizing 12 *Triatoma* species in North and South America. In addition to those species, mites in the genus *Leptus* were found on *Mepraia spinolai*, an endemic triatomine vector for *T. cruzi* in Chile (Gonzalez-Moraga et al. 2015). *Archegozetes magnus* was also reported to parasitize *T. dimidiata* in Mexico (Waleckx et al. 2018). Dye-Braumuller et al. (2020) reported a 25% mite prevalence in *T. rubida* collected from Texas.

Besides the high prevalence in some triatomine colonies, mite infection can reduce triatomine fecundity and nymphal molting rate, as well as increase triatomine mortality (Anderson 1968, Martinez-Sanchez et al. 2007). Anderson (1968) reported that in the laboratory, triatomine molting success reduced as the number of attached female mites increased. The high parasitism produced in the laboratory study also caused death in early triatomine instars. Martinez-Sanchez et al. (2007) also demonstrated the effects of mite parasitism on triatomine biology by exposing different stages of *Meccus pallidipennis* to 40 *P. plumifer*. The survival times of the triatomines infested with mites were significantly shorter than those without mite infestation. In addition, mite infestation also had effects on reproductive capacity by significantly reducing eggs and hatching rates, similar to another study (Zumaquero et al. 2004). These findings indicated the potential of using mites as biological control of triatomines by interrupting molting, reducing survival and reproduction, which may subsequently reduce triatomine populations and Chagas disease risk. However, there are barriers that hinder the use of mites to control populations of field triatomines. The effects of mites on triatomines were observed with high intensity under confined conditions, which may not be the same in the field. Mite prevalence in field-collected triatomines varied greatly. For example,

Anderson (1968) collected 507 triatomines from the field with an average mite: triatomine ratio of 1:3.1 (0.32 mite/triatomine), while in the 408 triatomines collected from Arizona and New Mexico, 13.2% of them had mites attached with an average of 1.56 and 1.71 mites per *T. rubida* and *T. protracta* Uhler (Hemiptera: Reduviidae), respectively (Dye-Braumuller et al. 2021). In addition, mites as a biological control tool may be less accepted for use in the indoor environment given nontarget impacts such as human allergies. There have been many successful cases of using mites to control other pests, such as whiteflies, and many of them have been commercialized and play a leading role in biological control (Knapp et al. 2018). Therefore, more research, especially field evaluations and application strategies, are needed to explore and develop the use of mites as a biological control for triatomines.

Triatoma virus. Triatoma virus (TrV) is a nonenveloped virus in the family Dicistroviridae (Czibener et al. 2000, Squires et al. 2013). It was first isolated from *T. infestans* and has been found in 15 species of triatomine (Muscio et al. 1988, Ceccarelli et al. 2015), such as *T. patagonica* (Rozas-Dennis et al. 2002), *T. delpontei*, *Psammolestes coreodes* (Susevich et al. 2012), and *T. sordida* (Marti et al. 2009). It is the only documented pathogenic virus of triatomines (Querido et al. 2015) and has only been found infecting triatomines (Marti et al. 2020). The primary transmission route of TrV is the fecal-oral route in triatomines, while other routes, such as feeding on infected chickens and transovarial infection, may also occur (Muscio et al. 2000). TrV replicates in the triatomine's intestinal epithelium cells after infection. Beyond TrV, Brito et al. (2021) described 7 single-strand RNA viruses isolated from *R. prolixus* and named RpV1-7. However, current evidence suggests these viruses are not pathogenic to triatomines.

Muscio et al. (1997) found 10% of wild *T. infestans* in Argentina harbor TrV, while the virus has also found its way into triatomine laboratory colonies in Argentina and Brazil, causing significant problems within insectaries (Marti et al. 2013, 2015). Marti et al. (2017b) explored the interaction between TrV and *T. cruzi* and concluded that TrV infection could assist *T. cruzi* in invading triatomines' intestinal cells but not vice versa. On the other hand, TrV infection affects the development and mortality of triatomines. The survival time of *T. infestans* nymphs displayed a negative relationship with the amount of virus ingested (Marti et al. 2015). Muscio et al. (1997) reported a 97.6% mortality of nymphal *T. infestans* and inhibitions of nymphal molting with TrV infection, while Rozas-Dennis and Cazzaniga (2000) reported a shorter longevity and lower fecundity of infected females compared to those of uninfected *T. infestans*. These results indicated that TrV is a strong candidate for biological control of triatomines, especially for *T. infestans*, the major vector of *T. cruzi* in South America, in addition to its high host specificity (Marti et al. 2020).

Insect-specific viruses have previously been proposed to be used as a biological control for vectors and vector-borne diseases (Bolling et al. 2015, Carvalho and Long 2021), inspired by the success of *Wolbachia* controlling mosquitoes, which can reduce vector competence of mosquitoes by shortening mosquito lifespan and blocking pathogen replication (Xue et al. 2018). Similar concepts can be applied using insect-specific viruses. Multiple mosquito-borne viruses, such as West Nile virus, Zika virus, dengue virus, and chikungunya virus, have been documented to be suppressed by insect-specific viruses (Bolling et al. 2012, Romo et al. 2018, Baidaliuk et al. 2019). Although no evidence suggests TrV suppresses *T. cruzi* in triatomines, it can induce high mortality in *T. infestans* and subsequently reduce populations, which is promising to be used as a biological control for triatomines and Chagas disease. In addition to being a biological control tool, virus-like particles from TrV also have the potential to be used as an adjuvant to develop vaccines against Chagas disease (Queiroz et al. 2021). Similar ideas have been proposed and further explored in other vector-borne diseases, such as diseases caused by the Zika virus and West Nile virus (Porier et al. 2021, Zhang et al. 2023).

Botanical insecticide. Due to the development of pyrethroid resistance, alternative insecticides are needed to replace or facilitate the traditional pyrethroids. Botanical products have a long history of being used as insecticides, which was recorded 3,000 years ago (Pavela 2016). The botanical insecticide has attracted a lot of attention to be used as an alternative to synthetic insecticides, such as pyrethroids, for more efficient control of vectors and low toxicity to mammals. Some essential oils are currently used in commercial products (Luiz de Oliveira et al. 2018, Isman 2020). Multiple insecticidal properties of botanical insecticides against pests have been reported, including repellents, antifeedants, toxicants, growth regulators, and attractants (Ahmed et al. 2021). In 1997, essential oils extracted from 63 Bolivian plants were tested against *T. infestans*, and most of them exhibited insecticidal activities (Laurent et al. 1997). Moretti et al. (2013) evaluated 10 botanical monoterpenes from plants against *T. infestans* and *R. prolixus*, revealing significant effects on the locomotion of both species as well as repellency that was comparative to DEET (positive control). The monoterpenes also exhibited knock-down effects but were not as strong as dichlorvos (positive control). For *T. rubida*, *T. protracta*, and *T. recurva* collected in Arizona, citronella oil (Terriquez et al. 2013) and its major components, geraniol and citronellol (Zamora et al. 2015), demonstrated significant inhibition of feeding. Besides the direct effects on triatomines, botanical monoterpenes also act as synergists to synthetic insecticides. For example, the toxicity of azamethiphos was significantly increased against *T. infestans* when applied with eugenol, menthol, or menthyl acetate (Reynoso et al. 2020), with similar effects on bed bugs (*Cimex lectularius*) (Gaire et al. 2020). With multiple modes of action (Jankowska et al. 2017), using essential oils as insecticides will potentially slow down the resistance development as essential oils are a mix of many compounds.

Due to the volatile property of essential oil, they may have poor environmental stability, which leads to a short effective control period and subsequently increases the cost of triatomine control. However, the development of nanotechnology may contribute to essential oil formulation as pesticides and provide a long-lasting efficacy and cost-friendly delivery method (Luiz de Oliveira et al. 2018). One limitation of commercializing botanical products as pesticides is the plant availability and standard extraction techniques to ensure consistent product quality. In addition, the regulatory process may hinder the application and commercialization of essential oils as pesticides in different regions (Luiz de Oliveira et al. 2018).

Genetic Control

The modification of symbionts in the arthropod is another way to achieve vector population control or make populations refractory to the transmission of disease-causing agents (Coutinho-Abreu et al. 2010). Symbiotic bacteria can be engineered and delivered to populations of insects, which may harbor the symbiont throughout their life (Hurwitz et al. 2011). Triatomine vectors, including *R. prolixus* and *T. infestans*, have been the subject of successful paratransgenesis experiments (Beard et al. 1992, Durvasula et al. 1999, 2008, Hurwitz et al. 2011). *Rhodococcus rhodnii* is a soil-associated actinomycete that lives in *R. prolixus* gut lumen and can be transferred from adult to offspring through coprophagy (Hurwitz et al. 2011). This bacterium plays a vital role in *R. prolixus*

development and sexual maturation (Durvasula et al. 2003). Early studies of paratransgenesis in triatomines found that introducing genetically modified bacteria *Rh. rhodnii* into *R. prolixus* can produce a trypanolytic antimicrobial peptide (AMP) called cecropin A, which targets *T. cruzi* in *R. prolixus* (Durvasula et al. 1997, 1999). Durvasula et al. (1997) reported that out of 7 *R. prolixus* from the genetically transformed *R. prolixus*-carrying group, 5 had no detectable metacyclic trypomastigotes (Durvasula et al. 1997). Several subsequent studies have examined ways to improve the lethality of *T. cruzi*, finding that combined AMPs can achieve up to 100% lethal concentration levels (Fieck et al. 2010). Additional AMPs that are effective against *T. cruzi* include apidaecin, Magainin II, and melittin (Fieck et al. 2010). *Rhodococcus rhodnii* has been the subject of other experiments assessing antitrypanosomal molecules, such as β-1,3-glucanase (Hurwitz et al. 2012, Jose et al. 2013). Besides *Rh. rhodnii*, *Corynebacterium* sp. is necessary for triatomine development and has been engineered to secrete an immunologically active antibody fragment against *T. cruzi* (Durvasula et al. 2008).

Despite the success of laboratory studies, there are barriers to the successful implementation of paratransgenesis strategies, including their ability to be transferred to wild triatomine populations. CRUZIGARD, a product containing modified *Rh. rhodnii* designed to simulate triatomine feces, was developed as a delivery medium (Beard et al. 2001). Durvasula et al. (1999) conducted a laboratory and field-simulation study of *R. prolixus*, allowing eggs from wild-caught triatomines to emerge inside cages impregnated with CRUZIGARD. The results indicated that 100% and 56% of the triatomines carried the bacteria under laboratory and simulated field conditions (Durvasula et al. 1999), indicating that CRUZIGARD is effective in delivering genetically transformed *Rh. rhodnii* into the field *R. prolixus* populations, which could be part of the integrated pest management and supplement of insecticide applications (Beard et al. 2001).

Still, the field release of engineered bacteria is risky. An additional barrier to the implementation of this intervention is the possibility of unintended environmental impacts. Paratransgenesis may threaten microbiome diversity and influence horizontal gene transfer (Hurwitz et al. 2011). Mathematical models and simulations may provide more insight into the possible ramifications and safety of such an intervention (Hurwitz et al. 2011, Matthews et al. 2011). In addition, human health and safety concerns may rise as paratransgenesis develops. However, the engineered bacteria that target *T. cruzi* are not pathogenic to mammals (Beard et al. 2001).

Mass Trapping

While traps for arthropod vectors are primarily utilized for surveillance, the deployment of large numbers can kill sufficient numbers that can result in vector population suppression (Day and Sjogren 1994). Several success stories exist with mass trapping and population control of mosquitoes (Johnson et al. 2017). In Caguas City, Puerto Rico, applications of 78,126 autocidal gravid ovitraps in 60%–80% of buildings successfully reduced *Aedes aegypti* populations by about 75%, as well as the infection with dengue, chikungunya, and Zika viruses (Barrera et al. 2019). Significant reduction or elimination of *Culex quinquefasciatus* and *Aedes albopictus* were observed in Maldivian islands with the deployment of baited mosquito traps and oviposition traps, as well as larval source management (Jahir et al. 2022).

Similar mass trapping concepts can be applied to triatomine control, and several traps have been developed to capture a large number of triatomines. In 1964, 3 light traps around a rural residence in Arizona captured 398 *T. protracta* (Sjogren and Ryckman 1966). This trap was a fluorescent black light placed next to a white wall surrounded by an insecticide (Malathion)-treated gutter that trapped and killed all triatomines that arrived at the light. Three of these light traps around a rural residence captured and killed 398 *T. protracta*, with the homeowners noticing fewer triatomines around the home compared to typical years (Sjogren and Ryckman 1966). This observation suggested the potential for mass trapping to control populations of triatomines and reduce the risk of human and animal exposure to *T. cruzi*. In Argentina, 3 light traps consisting of a cross panel with diode lights captured 39 triatomines containing 4 species during 270 trap nights (Abrahan et al. 2011). More recently, Updyke and Allan (2018) deployed cross-vane traps baited with UV lights, which autonomously captured 24 adult *R. pallescens* during 85 trap nights in Panama. A different light trap design was also used, which contained a vertical white cloth with fluorescent light and required manual collection. Although it requires more labor, a total of 101 triatomines were collected within 14 days of trapping from 1982 to 1984 (Wisnivesky-Colli et al. 1993). Similar traps were used in Mexico, and a total of 544 adult *T. dimidiata* were caught within 8 sampling nights (Rebollar-Tellez et al. 2009). While these light traps are efficient for flying triatomines that are attracted by light sources, other traps, such as baited traps and sticky traps, can target both flying and walking triatomines. In artificial chicken coops, yeast-baited traps captured significantly more *T. infestans* than nonbaited traps, with a peak capture of 39 in one trap overnight (Lorenzo et al. 1998). Abrahan et al. (2011) used sticky traps as dispersal barriers around chicken coops and goat corrals and caught 32 triatomines over 270 trap nights in Argentina. Mouse-baited sticky traps (Noireau traps) have been a gold standard trap for triatomines in nidicolous and domiciliary environments (Noireau et al. 1999, 2002).

With the high capture rate, the deployment of a large number of mixed traps that target different triatomine behaviors can potentially reduce triatomine numbers as well as slow down the infestation and reinfestation in residences by capturing dispersing adults. However, to achieve high capture rates, it is important to understand the seasonal phenology of triatomine dispersal, as well as the effects of the environment on triatomine behaviors. Given the large number of traps needed, labor requirements may be intense for deployment and maintenance. Therefore, the development of traps that require minimal maintenance and autonomously capture triatomines would be beneficial for developing mass trapping as a control tool.

Host-Targeted Intervention

Triatomines are obligatory hematophagous insects, and many species require multiple bloodmeals to advance from one nymphal life stage to another (Guarneri et al. 2000). This biology necessitates frequent contact with vertebrates to obtain blood. Systemic insecticides or insecticide-treated collars given to the vertebrate hosts can result in toxic bloodmeals able to kill triatomines, a control strategy known as xenointoxication (Rocha E Silva et al. 1969). This strategy is more efficient when the vertebrate species responsible for the majority of triatomine bloodmeals are targeted, for example, domestic dogs in the peridomestic environment, which have been shown to account for a large number of triatomine bloodmeals (Gürtler and Cardinal 2015).

Xenointoxication for the control of triatomines builds on companion animal products targeting protection from ectoparasites such as ticks and fleas but also has broad spectrum control of other arthropods (Rokhsar et al. 2023). Deltamethrin dog collars have been shown to reduce triatomine feeding success in dogs, although

it did not affect bug mortality (Reithinger et al. 2005). Similarly, the evaluation of insecticides with topical application of fipronil on dogs showed no significant effect on *T. infestans* mortality (Gürtler et al. 2009). However, a later study found a topical application of the combination of fipronil and permethrin resulted in 100% mortality of *R. prolixus* within 24 h after feeding on dogs that were 0–5 wk posttreatment (Ucan-Mezquita et al. 2019). Topical formulations of cypermethrin have also shown effectiveness against *T. infestans* when applied to chickens, and a topical formulation of imidacloprid was effective against pyrethroid-resistant *T. infestans* populations when applied to pigeons (Amelotti et al. 2010, Carvajal et al. 2014). Although the topical formulations tested on chicken and pigeons were designed as contact insecticides instead of systemic insecticides used on dogs, it is also possible that some of the active ingredients reached the blood and became systemic. Topical formulations can exhibit variability in the ability to disperse through the skin or enter blood becoming systemic and in some cases, insufficient active ingredient reaches feeding arthropods (Amelotti et al. 2010).

Insecticides given as oral formulations improve the systemic treatment of the animal, creating toxic bloodmeals for feeding arthropods. Several active ingredients have been tested and are labeled for use in animals to target internal parasites (e.g., endoparasiticides) or ectoparasites (e.g., ectoparasiticides). Ivermectin is a commonly used endectocide, a drug with endoparasitocidal and ectoparasitocidal activity on endoparasites and ectoparasites in humans and other animals (Chaccour et al. 2013, Sharun et al. 2019). Ivermectin-treated blood from in vitro blood feeding or direct feeding on vertebrates had high efficiency in killing or controlling multiple pests and vectors such as *C. lectularius* (Sheele and Ridge 2016), *Anopheles* mosquitoes (Chaccour et al. 2013), *Culex* mosquitoes (Holcomb et al. 2022), and *Rhipicephalus microplus* (Davey et al. 2010). In addition, consuming ivermectin-treated blood can also reduce fecundity, feeding success, and development in those surviving individuals (Sheele and Ridge 2016). Dogs treated with ivermectin injections caused high mortality of *T. infestans* after blood feeding with a peak occurring at 24 h posttreatment (Dias et al. 2005). Dadé et al. (2014) evaluated the xenointoxication effects of ivermectin in chickens against *T. infestans* by feeding the 5th instar nymphs directly on the chickens treated with a spot-on formulation. Mortality of the nymphs was observed when feeding occurred 24–336 h posttreatment, with a peak (47.5%) observed at 120 h posttreatment. The mortality generally matched the ivermectin concentration in plasma, where the peak concentration was observed at 48 h posttreatment. However, Durden et al. (2023) did not observe any mortality from *T. gerstaeckeri* nymphs that fed on chickens treated with ivermectin orally, which may be because the first feeding occurred at the 3 days posttreatment and missed the ivermectin concentration peak. Similar results were documented by Busselman et al. (2023), who found no mortality in triatomines that fed on blood from dogs treated with ivermectin; the first evaluation of toxic bloodmeals posttreatment was 7 days. However, cypermethrin-treated chickens also produced higher mortality in *T. infestans* nymphs (Amelotti et al. 2014), which was not the case with fipronil-treated dogs (Gürtler et al. 2009).

In addition to ivermectin, other active ingredients have been tested as systemic insecticides to manage triatomines. Fluralaner is a member of the isoxazoline drug class. It is commercially available in the United States as Bravecto to treat ticks and fleas on dogs and cats. Although triatomines are not labeled as the targeted parasites, fluralaner has been reported to be effective against triatomines that feed on dogs orally treated with Bravecto, with up to 100% mortality of *R. prolixus*, *T. brasillensis*, and *T. infestans* (Laino et al. 2019, 2022, Queiroga et al. 2021, Ortega-Pacheco et al. 2022).

Field studies of fluralaner-treated dogs reported a significant reduction in human-triatomine contact, *T. cruzi* infections, and overall *T. infestans* populations (Gürtler et al. 2022). Fluralaner has also been reported to be effective in chickens to kill other pests, such as bed bugs and mites, without safety issues in chicken health and egg production (Huyghe et al. 2017, Thomas et al. 2017, Gonzalez-Morales et al. 2023). Durden et al. (2023) confirmed the treatment of poultry with fluralaner killed *T. gerstaeckeri* for up to 14 days posttreatment. Therefore, fluralaner may be promising in terms of treating multiple key host species in the Chagas disease system.

Although xenointoxication had promising effects in killing triatomines, there are other aspects to be considered when applying this method community-wide. As *T. cruzi* can be transmitted not only by triatomine feces but also by consuming infected triatomines. While xenointoxication could potentially reduce triatomine populations by killing the feeding triatomines, the dead triatomines could increase the chance of being consumed by dogs and subsequently facilitating *T. cruzi* transmission in dogs (Fiatsonu et al. 2023, Rokhsar et al. 2023). Rokhsar et al. (2023) developed a simulation model to evaluate the impact of xenointoxication in dogs for *T. cruzi* transmission. The simulation indicated that in the low prevalence area, *T. cruzi* prevalence in dogs increased after one fluralaner treatment, while it generally stayed stable in the endemic area. Therefore, xenointoxication must be carefully evaluated before being applied in communities.

Environmental Management

Besides using chemical and biological control agents, environmental control has been playing a critical role in pest management, especially for triatomines, as reinfestation often occurs after chemical control (Monroy et al. 2009). To prevent reinfestation and achieve long-term effectiveness, environmental modifications, such as household improvements, light reduction, and reservoir control, have been used. In addition, community participation, which is promoted by health education, is a key factor in successful triatomine management (Curtis-Robles et al. 2015, Lardeux et al. 2015).

Triatomine reinfestation could occur due to the residual populations in a refuge that are not treated with pesticides and the dispersal of triatomines from other infested areas (Monroy et al. 2009). Household conditions, such as house wall material, house hygiene, the presence of firewood piles, host habitat, and lights, are related to triatomine habitat suitability (Dumonteil et al. 2013, Zamora et al. 2015). Household improvements such as removing or reducing objects or materials that serve as a refuge for triatomines or hosts and outdoor lights that attract dispersing adult triatomines reduce the risk of Chagas disease (Cecere et al. 2003). Multiple control programs that include household improvements, such as Healthy Living Initiative (Bates et al. 2023), Ecohealth intervention (Monroy et al. 2012, Lucero et al. 2013), and ecosystem approach to health (Waleckx et al. 2015b), have been implemented with successful results. Zeledon and Rojas (2006) reported that in Costa Rica, removing objects or materials and modifying artificial ecotopes that serve as hiding and breeding sites in houses can greatly reduce or eliminate *T. dimidiata* populations. Those houses remained triatomine-free for at least 4–5 years except for 2 houses that had a chicken coop and inappropriate use of storage space (Zeledón et al. 2008). This result indicates that household improvement has a sustainable effect of successfully reducing and even eliminating triatomine populations, while artificial ecotopes like chicken coops may provide habitat and blood sources for triatomine and result in reinfestation. A different result was observed in Jutiapa, Guatemala,

where ecosystemic interventions, including health education, wall plastering, insecticide application, backyard reforestation, and traditional interventions (health education and insecticide application) were implemented in villages (Monroy et al. 2009). Both interventions resulted in lower *T. dimidiata* infestations (number of infested houses) and colonization (number of houses with nymphs) and higher crowding (average of collected bugs from infested houses). However, a spatial shift of triatomine distribution from domestic to the peridomestic environment was observed in all villages, which likely reduced disease transmission by reducing human–vector contacts (Monroy et al. 2012). Similar studies using ecohealth interventions were also conducted in Bolivia (Lardeux et al. 2015). However, Horstick and Runge-Ranzinger (2018) concluded after a systematic review that although waste management and cleanup campaigns can reduce vector populations, the results were not consistent, and house structure modification had no effects on Chagas disease. Therefore, more research and evidence are needed to clarify the effects of household improvement and environmental modification for reducing Chagas disease to ensure these are economically feasible solutions for large-scale implementation

Besides household conditions, artificial lights can facilitate triatomine reinfestation and spread. Minoli and Lazzari (2006) revealed that both *T. infestans* and *R. prolixus* tended to fly toward white light compared to UV light, although the light presence did not increase the take-off rate at night. Similar results were also observed in *T. dimidiata* (Pacheco-Tucuch et al. 2012). Therefore, artificial lights can serve as an attractant for dispersing adults and subsequently allow sylvatic triatomines to arrive in the domestic and peridomestic environment (Minoli and Lazzari 2006, Castro et al. 2010). Di Iorio and Gürtler (2017) reported the capture of 288 triatomines over 425 daily collections using 29 mercury-vapor lamps as an attractant, with most of them caught nearly sunset with temperature >20 °C and sex ratio varied by species. Pacheco-Tucuch et al. (2012) evaluated the relationships between houses infested with *T. dimidiata* and artificial light distributions in the Yucatan peninsula, Mexico. The results indicate that the infested houses had significantly shorter distances to street light sources than the noninfested houses. However, the domestic light sources did not have significant effects on the infestations, which may be due to the lights normally being turned on for a short period after dusk. Therefore, increasing the distance between houses and lights or reducing lights at night around homes may help prevent triatomines infestations and reinfestations. In addition, triatomines are more attractive to the spectrum of 397–555 nm (Reisenman and Lazzari 2006), which provided another potential solution to reduce the light attractiveness by using long wavelengths (Pacheco-Tucuch et al. 2012).

Another important element in environment modification is reducing *T. cruzi* reservoirs and triatomine blood sources, such as chicken and rats, to interrupt the transmission cycle. Studies have reported that triatomine spatial distribution was affected by local host abundance and density of semisylvatic habitats (Vazquez-Prokopec et al. 2008, Rossi et al. 2015). Chickens serve as a great blood source for triatomines but are not a reservoir of *T. cruzi*. Bustamante et al. (2014) reported 64% *T. dimidiata* fed on chickens. In Brazil, *T. sordida* mainly occurs in peridomestic environments with chicken coops (Rossi et al. 2015). A study has reported that chicken coops can lead to reinfestations, while houses without chicken coops remained triatomine-free for at least a couple of years (Zeledón et al. 2008). Unlike chickens, rodents serve as both a blood source and a *T. cruzi* reservoir, which makes them important in maintaining the *T. cruzi* transmission cycle (Cortez et al. 2006). In addition, wild animals, such as raccoons, canine species, and opossums, are reservoirs

for *T. cruzi* (Gunter et al. 2017). Integrated vector management, including insecticide application, education, and rodent and chicken control, can result in lower triatomine nymph and rat infestations compared to the communities without interventions (De Urioste-Stone et al. 2015). Therefore, reservoir control, such as removing wild animal nests and trash and avoiding living in rural areas, is an important element in Chagas disease control in areas with persistent triatomine infestation.

Triatomine Control in the United States

Although human Chagas disease is not considered endemic in the United States (World Health Organization 2021, 2023a, 2023b), 11 triatomine species have been reported in the United States, primarily distributed in the southern United States, and the detections of triatomine have been reported in 28 states from 1939 to 2010 (Bern et al. 2011). All 11 species have also been documented to occur in Mexico except *T. sanguisuga* (LeConte) and *T. rubrofasciata* (De Geer) (Hemiptera: Reduviidae) (Bern et al. 2011). The *T. cruzi* infection rates in triatomines collected in the United States varied, where infection rates of 56% ($n = 18$), 41.5% ($n = 164$), 21.1% ($n = 161$), and 78% ($n = 153$) were reported in Louisiana (Dorn et al. 2007), Arizona (Reisenman et al. 2010), California (Hwang et al. 2010), and Texas (Kjos et al. 2013). With 1,510 triatomines acquired from 17 states in the United States, Curtis-Robles et al. (2018) reported an average *T. cruzi* infection prevalence of 54.4%, which varied among species. Although it is rare for triatomines to colonize in houses in the United States, the urbanization of habitat with sylvatic cycles of triatomines and *T. cruzi* is increasing the risk of human exposure (Bern et al. 2011). In addition, migration from endemic areas increases the US burden of Chagas disease. In 2005, more than 300,000 cases of *T. cruzi* infection were estimated in the United States by applying the seroprevalence figures to immigrant populations by country (Bern and Montgomery 2009). In 2012, this estimate was reduced to 238,091, with over 10,000 cases in California, Texas, Florida, and New York (Manne-Goehler et al. 2016).

Chagas disease also occurs in other animals and presents a notable burden to domestic animals, especially canines (Busselman and Hamer 2022). Besides vector transmission, oral transmission by consuming infected triatomine, their faces, or infected animals through predation is likely to be the major transmission route for veterinary Chagas disease (Hamer and Saunders 2022). Canine Chagas disease has been reported in at least 8 states with varied prevalence despite the lack of standardized surveillance (Hamer and Saunders 2022). Dogs can serve as reservoirs for *T. cruzi* and facilitate the transmission cycle, which makes canine kennels with triatomines a high-risk environment (Curtis-Robles et al. 2017). Busselman et al. (2021) reported that 29.4% of the *T. cruzi*-negative dogs converted to positive over a 1-year observation period with *T. cruzi*-positive dogs in the same kennel. A thorough review of veterinary Chagas disease can be found in Hamer and Saunders (2022).

The control of triatomines and Chagas disease in the United States presents a unique context compared to many regions in Latin America where Chagas is endemic, and only a subset of control approaches are suitable in the United States (Table 1; Klotz et al. 2014). While triatomine and Chagas control in many Latin American contexts are managed by local ministries of health agencies, this is not the case in the United States. Only mosquito control has historically received area-wide control by local public health agencies in at least some regions. Triatomine control is similar to tick control in the United States, where the reduction of exposure to tick-borne diseases falls on the individual responsibility, although initiatives are

encouraging a shift towards a professionally staffed integrated tick management (Eisen 2020).

Triatomine colonization of homes in the United States is rare, partly because of higher housing quality. As a result, indoor residual spraying, which is common in Latin America, is not justified in most scenarios in the United States. Much of the risk in the United States of human and animal contact with triatomines involves dispersing adults from sylvatic to peridomestic habitat. In addition, triatomines are able to colonize the peridomestic environment, which often involves dogs, chickens, or other animals as bloodmeal hosts. Residual insecticides used around dog kennels, chicken coops, and household perimeters are a common practice, although we are not aware of studies confirming efficacy. There are no insecticides specifically labeled for use against triatomines in the United States, although several active ingredients have been shown to be effective based on work in the lab or in Latin America (Beatty et al. 2023; Table 1). Active ingredients of products found in the United States used for structural pest control that are known to kill triatomines include deltamethrin and cypermethrin.

The most common form of triatomine control in the United States that is alternative to insecticides is environmental control. The same methods performed in Latin America can apply to the United States. For example, reducing household permeability to triatomines with the use of screens and other mechanical methods can mitigate triatomines entering the home. Reducing triatomine habitat suitability around the home and peridomestic environment is recommended, such as minimizing natural or artificial harborage or refuse that can create habitat for triatomines or hosts. This is similar to the control of ticks and Lyme disease in the northeastern United States through yard management, such as the removal of wood piles of trash and separating the lawn from adjacent forest (Fischhoff et al. 2019). This is especially important with urban sprawl and as homes are built in sylvatic habitats that increase the opportunity for contact with infected vectors. Outdoor safety lights are common in the United States, but these can attract kissing bugs, so removing these lights or using longer wavelengths in the yellow-red spectrum (>550 nm) that are less attractive to insects is recommended. Reducing wild or domestic vertebrate hosts that provide bloodmeals to triatomines around the peridomestic environment can help reduce environmental suitability for triatomines. Rats, opossums, and other wild animals that nest near homes can be removed by trapping to block their ability to nest in structures. Domestic animals that are desired, such as dogs and chickens, can receive the systemic insecticides discussed above to create toxic bloodmeals for triatomines.

In combination with environmental control, the mass capture of dispersing adult triatomines from the sylvatic habitat arriving at the peridomestic habitat was first acknowledged as a control option in the United States in 1966 (Sjogren and Ryckman 1966). Advancements in technology will facilitate newer trap designs that autonomously capture triatomines with minimal maintenance, which will provide future options for triatomine control in the United States. Options for biological control in the United States have received minimal attention compared to areas in Latin America.

Conclusions

In the past 40 years, pyrethroid insecticides targeting the triatomine vector have been the primary control tool for triatomine vectors of *T. cruzi* (Gürtler and Cecere 2021). However, insecticide resistance, global climate change, lack of sustained control effort, and globalization have all contributed to the emergence or reemergence of triatomines and the persistent Chagas disease burden (Medone et al. 2015). Despite long-term interventions and changes in health policy in endemic countries, *T. cruzi* continues to cause new infections, and new interventions are needed now more than ever (Hotez et al. 2020).

Alternative insecticides, such as botanicals, should also be further investigated as a potential for insecticide-resistant triatomine populations (Moretti et al. 2013). Treating dogs, chickens, cats, wildlife, or other hosts with commercially available systemic insecticides may be especially effective at targeting triatomines in peridomestic habitats, and many products can be easily given to animals by their owners (Gürtler et al. 2022, 2009). Similarly, biological control in the form of mites, fungi, wasps, and other predators may be especially effective in endemic areas with extremely high triatomine burdens or areas with insecticide-resistant triatomines (Forlani et al. 2015). However, biological control has limitations, such as the potential for nontarget effects and an extensive regulatory process, which could be a barrier to area-wide use. Mass trapping may also be a useful addition to triatomine control to intercept dispersing adults flying from sylvatic to domestic habitats (Sjogren and Ryckman 1966). The goal of reducing human and animal infection with *T. cruzi* can be achieved by having fewer infected triatomines and breaking transmission cycles. Therefore, control of *T. cruzi* reservoirs, such as rodents, can aid in the reduction of *T. cruzi* circulating in triatomine and host populations. All the control tools covered in this review require community engagement and partnerships (Juarez et al. 2022). Education and engagement are vital for successful triatomine interventions (Curtis-Robles et al. 2015, De Urioste-Stone et al. 2015, Lardeux et al. 2015, Rivera et al. 2023), and it is possible that strategies can be implemented at the household level to prevent colonization and reinfestation of triatomine vectors (Cecere et al. 2003).

To effectively control triatomine vectors, it is vital that we update our understanding of both current and developing control interventions. Rigorous investigations into new control tools and their epidemiological and entomological outcomes are needed in order to advance the scale-up of intervention evaluations. This review captures the diverse control tools that have been evaluated over the last century for triatomines and offers options to consider for local public health agencies. Ultimately, it will take the collaboration between researchers, public health officials, and community members to translate control tools into sustainable initiatives that can protect human and animal health.

Author Contributions

Yuexun Tian (Conceptualization [equal], Writing—original draft [equal], Writing—review & editing [equal]), Cassandra Durden (Conceptualization [equal], Writing—original draft [equal], Writing—review & editing [equal]), and Gabriel Hamer (Conceptualization [equal], Writing—review & editing [equal])

References

Abrahan LB, Gorla DE, Catala SS. Dispersal of *Triatoma infestans* and other triatominae species in the arid Chaco of Argentina – flying, walking or passive carriage? The importance of walking females. Mem Inst Oswaldo Cruz. 2011;106(2):232–239. https://doi.org/10.1590/S0074-02762011000200019

Achee NL, Bangs MJ, Farlow R, Killeen GF, Lindsay S, Logan JG, Moore SJ, Rowland M, Sweeney K, Torr SJ, et al. Spatial repellents: from discovery and development to evidence-based validation. Malar J. 2012;11:164. https://doi.org/10.1186/1475-2875-11-164

Achee NL, Gould F, Perkins TA, Reiner RC Jr, Morrison AC, Ritchie SA, Gubler DJ, Teyssou R, Scott TW. A critical assessment of vector control

for dengue prevention. PLoS Negl Trop Dis. 2015:9(5):e0003655. https://doi.org/10.1371/journal.pntd.0003655

Ahmed N, Alam M, Saeed M, Ullah H, Iqbal T, Al-Mutairi KA, Shahjeer K, Ullah R, Ahmed S, Ahmed NAAH. Botanical insecticides are a non-toxic alternative to conventional pesticides in the control of insects and pests. In: El-Shafie HAF, editor. Global decline of insects. London (UK): IntechOpen; 2021.

Alzogaray RA, Fontan A, Zerba EN. Repellency of deet to nymphs of *Triatoma infestans*. Med Vet Entomol. 2000:14(1):6–10. https://doi.org/10.1046/j.1365-2915.2000.00213.x

Amelotti I, Catala SS, Gorla DE. Experimental evaluation of insecticidal paints against *Triatoma infestans* (Hemiptera: Reduviidae), under natural climatic conditions. Parasit Vectors. 2009:2(1):30. https://doi.org/10.1186/1756-3305-2-30

Amelotti I, Catala SS, Gorla DE. The effects of cypermethrin pour-on and piperonyl butoxide on *Triatoma infestans* under laboratory conditions. J Med Entomol. 2010:47(6):1135–1140. https://doi.org/10.1603/me10116

Amelotti I, Catala SS, Gorla DE. Control of experimental *Triatoma infestans* populations: effect of pour-on cypermethrin applied to chickens under natural conditions in the Argentinean Chaco region. Med Vet Entomol. 2014:28(2):210–216. https://doi.org/10.1111/mve.12034

Anderson RC. Ecological observations on three species of *Pimeliaphilus* parasites of Triatominae in the United States (Acarina: Pterygosomidae) (Hemiptera: Reduviidae). J Med Entomol. 1968:5(4):459–464. https://doi.org/10.1093/jmedent/5.4.459

Antwi FB, Reddy GVP. Toxicological effects of pyrethroids on non-target aquatic insects. Environ Toxicol Pharmacol. 2015:40(3):915–923. https://doi.org/10.1016/j.etap.2015.09.023

Askary TH, Abd-Elgawad MMM. Opportunities and challenges of entomopathogenic nematodes as biocontrol agents in their tripartite interactions. Egypt J Biol Pest Control. 2021:31(1):1–10. https://doi.org/10.1186/s41938-021-00391-9

Ávila Montes GA, Ponce C, Ponce E, Martínez Hernández M, Flores M. Insecticidal paint and fumigant canisters for Chagas' disease control: community acceptance in Honduras. Rev Panam Salud Publ = Pan Am J Public Health. 1999:6(5):311–320. https://doi.org/10.1590/s1020-49891999001000003

Azambuja P, Feder D, Garcia ES. Isolation of *Serratia marcescens* in the midgut of *Rhodnius prolixus*: impact on the establishment of the parasite *Trypanosoma cruzi* in the vector. Exp Parasitol. 2004:107(1–2):89–96. https://doi.org/10.1016/j.exppara.2004.04.007

Baidaliuk A, Miot EF, Lequime S, Moltini-Conclois I, Delaigue F, Dabo S, Dickson LB, Aubry F, Merkling SH, Cao-Lormeau VM, et al. Cell-fusing agent virus reduces arbovirus dissemination in *Aedes aegypti* mosquitoes in vivo. J Virol. 2019:93(18):e00705–e00719. https://doi.org/10.1128/JVI.00705-19

Barbu CM, Buttenheim AM, Pumahuanca ML, Calderon JE, Salazar R, Carrion M, Rospigliossi AC, Chavez FS, Alvarez KO, Cornejo del Carpio J, et al. Residual infestation and recolonization during urban *Triatoma infestans* bug control campaign, Peru. Emerg Infect Dis. 2014:20(12):2055–2063. https://doi.org/10.3201/eid2012.131820

Barratt BI, Colmenarez YC, Day MD, Ivey P, Klapwijk JN, Loomans AJ, Mason PG, Palmer WA, Sankaran K, Zhang F. Regulatory challenges for biological control. In: Mason PG, editor. Biological control: global impacts, challenges and future directions of pest management. Victoria (Australia): CSIRO Publishing; 2021. p. 166–196.

Barrera R, Harris A, Hemme RR, Felix G, Nazario N, Munoz-Jordan JL, Rodriguez D, Miranda J, Soto E, Martinez S, et al. Citywide control of *Aedes aegypti* (Diptera: Culicidae) during the 2016 Zika epidemic by integrating community awareness, education, source reduction, larvicides, and mass mosquito trapping. J Med Entomol. 2019:56(4):1033–1046. https://doi.org/10.1093/jme/tjz009

Bates BR, Carrasco-Tenezaca M, Mendez-Trivino AM, Mendoza LE, Nieto-Sanchez C, Baus EG, Grijalva MJ. Identifying barriers and facilitators for home reconstruction for prevention of Chagas disease: an interview study in rural Loja Province, Ecuador. Trop Med Infect Dis. 2023:8(4):228. https://doi.org/10.3390/tropicalmed8040228

Batista KKS, Vieira CS, Figueiredo MB, Costa-Latge SG, Azambuja P, Genta FA, Castro DP. Influence of *Serratia marcescens* and *Rhodococcus rhodnii* on the humoral immunity of *Rhodnius prolixus*. Int J Mol Sci. 2021:22(20):10901. https://doi.org/10.3390/ijms222010901

Beard CB, Dotson EM, Pennington PM, Eichler S, Cordon-Rosales C, Durvasula RV. Bacterial symbiosis and paratransgenic control of vector-borne Chagas disease. Int J Parasitol. 2001:31(5–6):621–627. https://doi.org/10.1016/s0020-7519(01)00165-5

Beard CB, Mason PW, Aksoy S, Tesh RB, Richards FF. Transformation of an insect symbiont and expression of a foreign gene in the Chagas' disease vector *Rhodnius prolixus*. Am J Trop Med Hyg. 1992:46(2):195–200. https://doi.org/10.4269/ajtmh.1992.46.195

Beatty NL, Bhosale CR, Torhorst CW, Burkett-Cadena ND, Oi FM, Forsyth CJ, Wisely SM. Integrated pest management strategies targeting the Florida kissing bug, *Triatoma sanguisuga*: preventing this vector of Chagas disease from invading your home. Curr Res Parasitol Vector-Borne Dis. 2023:4:100144. https://doi.org/10.1016/j.crpvbd.2023.100144

Benelli G, Jeffries CL, Walker T. Biological control of mosquito vectors: past, present, and future. Insects. 2016:7(4):52. https://doi.org/10.3390/insects7040052

Bern C, Kjos S, Yabsley MJ, Montgomery SP. *Trypanosoma cruzi* and Chagas disease in the United States. Clin Microbiol Rev. 2011:24(4):655–681. https://doi.org/10.1128/CMR.00005-11

Bern C, Montgomery SP. An estimate of the burden of Chagas disease in the United States. Clin Infect Dis. 2009:49(5):e52–e54. https://doi.org/10.1086/605091

Bezerra CM, Barbosa SE, Souza RCM, Feijão LX, Gürtler RE, Ramos AN Jr, Diotaiuti L. Fast recovery of house infestation with *Triatoma brasiliensis* after residual insecticide spraying in a semiarid region of Northeastern Brazil. Plos Negl Trop Dis. 2020:14(7):e0008404. https://doi.org/10.1371/journal.pntd.0008404

Bezerra CM, Cavalcanti LP, Souza Rde C, Barbosa SE, Xavier SC, Jansen AM, Ramalho RD, Diotaiut L. Domestic, peridomestic and wild hosts in the transmission of *Trypanosoma cruzi* in the Caatinga area colonised by *Triatoma brasiliensis*. Mem Inst Oswaldo Cruz. 2014:109(7):887–898. https://doi.org/10.1590/0074-0276140048

Bolling BG, Olea-Popelka FJ, Eisen L, Moore CG, Blair CD. Transmission dynamics of an insect-specific flavivirus in a naturally infected *Culex pipiens* laboratory colony and effects of co-infection on vector competence for West Nile virus. Virology. 2012:427(2):90–97. https://doi.org/10.1016/j.virol.2012.02.016

Bolling BG, Weaver SC, Tesh RB, Vasilakis N. Insect-specific virus discovery: significance for the arbovirus community. Viruses. 2015:7(9):4911–4928. https://doi.org/10.3390/v7092851

Brito TF, Coelho VL, Cardoso MA, Brito IAA, Berni MA, Zenk FL, Iovino N, Pane A. Transovarial transmission of a core virome in the Chagas disease vector *Rhodnius prolixus*. PLoS Pathog. 2021:17(8):e1009780. https://doi.org/10.1371/journal.ppat.1009780

Burns CJ, Pastoor TP. Pyrethroid epidemiology: a quality-based review. Crit Rev Toxicol. 2018:48(4):297–311. https://doi.org/10.1080/10408444.2017.1423463

Busselman RE, Hamer SA. Chagas disease ecology in the United States: recent advances in understanding *Trypanosoma cruzi* transmission among triatomines, wildlife, and domestic animals and a quantitative synthesis of vector-host interactions. Annu Rev Anim Biosci. 2022:10:325–348. https://doi.org/10.1146/annurev-animal-013120-043949

Busselman RE, Meyers AC, Zecca IB, Auckland LD, Castro AH, Dowd RE, Curtis-Robles R, Hodo CL, Saunders AB, Hamer SA. High incidence of *Trypanosoma cruzi* infections in dogs directly detected through longitudinal tracking at 10 multi-dog kennels, Texas, USA. Plos Negl Trop Dis. 2021:15(11):e0009935. https://doi.org/10.1371/journal.pntd.0009935

Busselman RE, Zecca IB, Hamer GL, Hamer SA. Canine systemic insecticides fluralaner and lotilaner induce acute mortality of Triatoma gerstaeckeri, North American vector of the Chagas disease parasite. Am J Trop Med Hyg. 2023:109(5):1012–1021. https://doi.org/10.4269/ajtmh.23-0300

Bustamante DM, De Urioste-Stone SM, Juarez JG, Pennington PM. Ecological, social and biological risk factors for continued *Trypanosoma*

cruzi transmission by *Triatoma dimidiata* in Guatemala. PLoS One. 2014:9(8):e104599. https://doi.org/10.1371/journal.pone.0104599

Cagnolo SR, Almirón WR. Capacity of the terrestrial entomopathogenic nematode *Steinernema rarum* (Rhabditida: Steinernematidae) to parasite *Culex apicinus* larvae (Diptera: Culicidae). Rev Soc Entomol Argent. 2010:69(1):141–145.

Cahan SH, Orantes LC, Wallin KF, Hanley JP, Rizzo DM, Stevens L, Dorn PL, Rodas A, Monroy C. Residual survival and local dispersal drive reinfestation by *Triatoma dimidiata* following insecticide application in Guatemala. Infect Genet Evol. 2019:74:104000. https://doi.org/10.1016/j.meegid.2019.104000

Cambronero-Heinrichs JC, Rojas-Gätjens D, Baizán M, lvarado-Ocampo J, Rojas-Jimenez K, Loaiza R, Calderón-Arguedas O, Troyo A. Highly abundant bacteria in the gut of *Triatoma dimidiata* (Hemiptera: Reduviidae) can inhibit the growth of *Trypanosoma cruzi*. J Med Entomol. 2024:In press. https://doi.org/10.1093/jme/tjae012

Campos-Herrera R. Nematode pathogenesis of insects and other pests: ecology and applied technologies for sustainable plant and crop protection. Switzerland: Springer International Publishing; 2015. https://doi.org/10.1007

Carbajal-de-la-Fuente AL, Lencina P, Spillmann C, Gurtler RE. A motorized vehicle-mounted sprayer as a new tool for Chagas disease vector control. Cad Saude Publica. 2017:33(1):e00099115. https://doi.org/10.1590/0102-311X00099115

Carvajal G, Picollo MI, Toloza AC. Is imidacloprid an effective alternative for controlling pyrethroid-resistant populations of *Triatoma infestans* (Hemiptera: Reduviidae) in the Gran Chaco ecoregion? Mem Inst Oswaldo Cruz. 2014:109(6):761–766. https://doi.org/10.1590/0074-0276140100

Carvalho VL, Long MT. Insect-specific viruses: an overview and their relationship to arboviruses of concern to humans and animals. Virology. 2021:557:34–43. https://doi.org/10.1016/j.virol.2021.01.007

Castro MC, Barrett TV, Santos WS, Abad-Franch F, Rafael JA. Attraction of Chagas disease vectors (Triatominae) to artificial light sources in the canopy of primary Amazon rainforest. Mem Inst Oswaldo Cruz. 2010:105(8):1061–1064. https://doi.org/10.1590/s0074-02762010000800019

Ceccarelli S, Balsalobre A, Susevich ML, Echeverria MG, Gorla DE, Marti GA. Modelling the potential geographic distribution of triatomines infected by *Triatoma* virus in the southern cone of South America. Parasit Vectors. 2015:8:153. https://doi.org/10.1186/s13071-015-0761-1

Cecere MC, Canale DM, Gürtler RE. Effects of refuge availability on the population dynamics of *Triatoma infestans* in central Argentina. J Appl Ecol. 2003:40(4):742–756. https://doi.org/10.1046/j.1365-2664.2003.00825.x

Chaccour CJ, Kobylinski KC, Bassat Q, Bousema T, Drakeley C, Alonso P, Foy BD. Ivermectin to reduce malaria transmission: a research agenda for a promising new tool for elimination. Malar J. 2013:12:153. https://doi.org/10.1186/1475-2875-12-153

Chowdhury R, Chowdhury V, Faria S, Akter S, Dash AP, Bhattacharya SK, Maheswary NP, Bern C, Akhter S, Alvar J, et al. Effect of insecticide-treated bed nets on visceral leishmaniasis incidence in Bangladesh. A retrospective cohort analysis. PLoS NeglTrop Dis. 2019:13(9):e0007724. https://doi.org/10.1371/journal.pntd.0007724

Colucci B, Müller P. Evaluation of standard field and laboratory methods to compare protection times of the topical repellents PMD and DEET. Sci Rep. 2018:8(1):12578. https://doi.org/10.1038/s41598-018-30998-2

Cortez MR, Pinho AP, Cuervo P, Alfaro F, Solano M, Xavier SCC, D'Andrea PS, Fernandes O, Torrico F, Noireau F, et al. *Trypanosoma cruzi* (Kinetoplastida Trypanosomatidae): ecology of the transmission cycle in the wild environment of the Andean valley of Cochabamba, Bolivia. Exp Parasitol. 2006:114(4):305–313. https://doi.org/10.1016/j.exppara.2006.04.010

Costa J, AlmeidA CE, Esperanca GM, Morales N, Mallet JRDS, Goncalves TCM, Do Prado AP. First record of *Megaselia scalaris* (Loew) (Diptera: Phoridae) infesting laboratory colonies of *Triatoma brasiliensis* Neiva (Hemiptera: Reduviidae). Neotrop Entomol. 2007:36(6):987–989. https://doi.org/10.1590/S1519-566x2007000600026

Coutinho-Abreu IV, Zhu KY, Ramalho-Ortigao M. Transgenesis and paratransgenesis to control insect-borne diseases: current status and future challenges. Parasitol Int. 2010:59(1):1–8. https://doi.org/10.1016/j.parint.2009.10.002

Curtis-Robles R, Auckland LD, Snowden KF, Hamer GL, Hamer SA. Analysis of over 1500 triatomine vectors from across the US, predominantly Texas, for *Trypanosoma cruzi* infection and discrete typing units. Infect Genet Evol. 2018:58:171–180. https://doi.org/10.1016/j.meegid.2017.12.016

Curtis-Robles R, Wozniak EJ, Auckland LD, Hamer GL, Hamer SA. Combining public health education and disease ecology research: using citizen science to assess Chagas disease entomological risk in Texas. PLoS NeglTrop Dis. 2015:9(12):e0004235. https://doi.org/10.1371/journal.pntd.0004235

Curtis-Robles R, Zecca IB, Roman-Cruz V, Carbajal ES, Auckland LD, Flores I, Millard AV, Hamer SA. *Trypanosoma cruzi* (agent of Chagas disease) in sympatric human and dog populations in "colonias" of the Lower Rio Grande Valley of Texas. Am J Trop Med Hyg. 2017:96(4):805–814. https://doi.org/10.4269/ajtmh.16-0789

Czibener C, La Torre JL, Muscio OA, Ugalde RA, Scodeller EA. Nucleotide sequence analysis of *Triatoma* virus shows that it is a member of a novel group of insect RNA viruses. J Gen Virol. 2000:81(Pt 4):1149–1154. https://doi.org/10.1099/0022-1317-81-4-1149

da Mota FF, Castro DP, Vieira CS, Gumiel M, de Albuquerque JP, Carels N, Azambuja P. In vitro trypanocidal activity, genomic analysis of isolates, and in vivo transcription of type vi secretion system of *Serratia marcescens* belonging to the microbiota of *Rhodnius prolixus* digestive tract. Front Microbiol. 2018:9:3205. https://doi.org/10.3389/fmicb.2018.03205

Dadé MM, Daniele MR, Marín GH, Silvestrini M, Mestorino N. Ivermectin efficacy against *Triatoma infestans* in vivo using hen model. J Pharm Pharmacol. 2014:2:353–358.

Dame DA, Meisch MV, Lewis CN, Kline DL, Clark GG. Field evaluation of four spatial repellent devices against Arkansas rice-land mosquitoes. J Am Mosq Control Assoc. 2014:30(1):31–36. https://doi.org/10.2987/13-6379.1

Davey RB, Pound JM, Miller JA, Klavons JA. Therapeutic and persistent efficacy of a long-acting (LA) formulation of ivermectin against *Rhipicephalus* (*Boophilus*) *microplus* (Acari: Ixodidae) and sera concentration through time in treated cattle. Vet Parasitol. 2010:169(1–2):149–156. https://doi.org/10.1016/j.vetpar.2009.12.040

Davila-Barboza J, Villanueva-Segura OK, Lopez-Monroy B, Ponce-Garcia G, Bobadilla-Utrera C, Montes-Rincon M, Molina-Garza ZJ, Arredondo-Jimenez JI, Rodriguez-Sanchez IP, Manrique-Saide PC, et al. Novel Kdr mutations (K964R and A943V) in pyrethroid-resistant populations of *Triatoma mazzottii* and *Triatoma longipennis* from Mexico and detoxifying enzymes. Insect Sci. 2019:26(5):809–820. https://doi.org/10.1111/1744-7917.12594

Day JF, Sjogren RD. Vector control by removal trapping. Am J Trop Med Hyg. 1994:50(6 Suppl):126–133. https://doi.org/10.4269/ajtmh.1994.50.126

de Arias AR, Lehane MJ, Schofield CJ, Maldonado M. Pyrethroid insecticide evaluation on different house structures in a Chagas disease endemic area of the Paraguayan Chaco. Mem Inst Oswaldo Cruz. 2004:99(6):657–662. https://doi.org/10.1590/S0074-02762004000600022

De Urioste-Stone SM, Pennington PM, Pellecer E, Aguilar TM, Samayoa G, Perdomo HD, Enriquez H, Juarez JG. Development of a community-based intervention for the control of Chagas disease based on peridomestic animal management: an eco-bio-social perspective. Trans R Soc Trop Med Hyg. 2015:109(2):159–167. https://doi.org/10.1093/trstmh/tru202

Depickere S, Buitrago R, Sinani E, Baune M, Monje M, Lopez R, Waleckx E, Chavez T, Breniere SF. Susceptibility and resistance to deltamethrin of wild and domestic populations of *Triatoma infestans* (Reduviidae: Triatominae) in Bolivia: new discoveries. Mem Inst Oswaldo Cruz. 2012:107(8):1042–1047. https://doi.org/10.1590/s0074-02762012000800013

Dias JC, Schofield CJ, Machado EM, Fernandes AJ. Ticks, ivermectin, and experimental Chagas disease. Mem Inst Oswaldo Cruz. 2005:100(8):829–832. https://doi.org/10.1590/s0074-02762005000800002

Dias JCP. Southern cone initiative for the elimination of domestic populations of *Triatoma infestans* and the interruption of transfusion Chagas disease: historical aspects, present situation, and perspectives. Mem Inst Oswaldo Cruz. 2007:102(suppl 1):11–18. https://doi.org/10.1590/s0074-02762007005000092

Dias JCP, Jemmio A. Sobre uma pintura inseticida para o controle de *Triatoma infestans*, na Bolívia. Rev Soc Bras Med Trop. 2008:41(1):79–81. https://doi.org/10.1590/s0037-86822008000100016

Dias JCP, Schofield CJ. The evolution of Chagas disease (American trypanosomiasis) control after 90 years since Carlos Chagas discovery. Mem

Inst Oswaldo Cruz. 1999:94(suppl 1):103–121. https://doi.org/10.1590/s0074-02761999000700011

Dilipkumar A, Raja Ramalingam K, Chinnaperumal K, Govindasamy B, Paramasivam D, Dhayalan A, Pachiappan P. Isolation and growth inhibition potential of entomopathogenic nematodes against three public health important mosquito vectors. Exp Parasitol. 2019:197:76–84. https://doi.org/10.1016/j.exppara.2018.11.001

Di lorio O, Gurtler RE. Seasonality and temperature-dependent flight dispersal of Triatoma infestans (Hemiptera: Reduviidae) and other vectors of Chagas disease in western Argentina. J Med Entomol. 2017:54(5):1285–1292. https://doi.org/10.1093/jme/tjx109

Dorn PL, Perniciaro L, Yabsley MJ, Roellig DM, Balsamo G, Diaz J, Wesson D. Autochthonous transmission of *Trypanosoma cruzi*, Louisiana. Emerg Infect Dis. 2007:13(4):605–607. https://doi.org/10.3201/eid1304.061002

dos Santos CB, Tavares MT, Leite GR, Ferreira AL, de Souza Rocha L, Falqueto A. Research article first report of *Aprostocetus asthenogmus* (Hymenoptera: Eulophidae) in South America and parasitizing eggs of triatominae vectors of Chagas disease. J Parasitol Res. 2014:2014:547439 https://doi.org/10.1155/2014/547439

Dumonteil E, Nouvellet P, Rosecrans K, Ramirez-Sierra MJ, Gamboa-Leon R, Cruz-Chan V, Rosado-Vallado M, Gourbiere S. Eco-bio-social determinants for house infestation by non-domiciliated *Triatoma dimidiata* in the Yucatan Peninsula, Mexico. PLoS NeglTrop Dis. 2013:7(9):e2466. https://doi.org/10.1371/journal.pntd.0002466

Durden C, Tian Y, Knape K, Klemashevich C, Norman KN, Carey JB, Hamer SA, Hamer GL. Fluralaner systemic treatment of chickens results in mortality in *Triatoma gerstaeckeri*, vector of the agent of Chagas disease. Parasite Vector. 2023:16(1):1–10. https://doi.org/10.1186/s13071-023-05805-1

Durvasula R, Gumbs A, Panackal A, Kruglov O, Taneja J, Kang AS, Cordon-Rosales C, Richards F, Whitham R, Beard C. Expression of a functional antibody fragment in the gut of *Rhodnius prolixus* via transgenic bacterial symbiont *Rhodococcus rhodnii*. Med Vet Entomol. 1999:13(2):115–119. https://doi.org/10.1046/j.1365-2915.1999.00175.x

Durvasula RV, Gumbs A, Panackal A, Kruglov O, Aksoy S, Merrifield RB, Richards FF, Beard CB. Prevention of insect-borne disease: an approach using transgenic symbiotic bacteria. Proc Natl Acad Sci U S A. 1997:94(7):3274–3278. https://doi.org/10.1073/pnas.94.7.3274

Durvasula RV, Sundaram RK, Cordon-Rosales C, Pennington P, Beard B. *Rhodnius prolixus* and its symbiont, *Rhodococcus rhodnii*: a model for paratransgenic control of disease transmission. In: Bourtzis K, Miller TA, editors. *Insect Symbiosis*. Florida (USA): CRC Press; 2003. https://doi.org/10.1201/9780203009918.ch6

Durvasula RV, Sundaram RK, Kirsch P, Hurwitz I, Crawford CV, Dotson E, Beard CB. Genetic transformation of a Corynebacterial symbiont from the Chagas disease vector *Triatoma infestans*. Exp Parasitol. 2008:119(1):94–98. https://doi.org/10.1016/j.exppara.2007.12.020

Dye-Braumuller KC, Lynn MK, Gorchakov R, Gunter SM, Berry RM, Murray KO, Nolan MS. Low *Trypanosoma cruzi* transmission risk to humans in the Trans-Pecos region of Texas. Parasite Epidemiol Control. 2020:11:e00180. https://doi.org/10.1016/j.parepi.2020.e00180

Dye-Braumuller KC, Waltz H, Lynn MK, Klotz SA, Schmidt JO, Romero A, Rodriguez Aquino MS, Palacios Valladares JR, Cornejo Rivas PM, Nolan MS. A Southwestern United States pilot investigation of triatomine-mite prevalence. Insects. 2021:12(9):811. https://doi.org/10.3390/insects12090811

Eisen L. Stemming the rising tide of human-biting ticks and tickborne diseases, United States. Emerg Infect Dis. 2020:26(4):641–647. https://doi.org/10.3201/eid2604.191629

Eliceche DP, Achinelly MF, Silvestre C, Micieli MV, Marti GA. Entomopathogenic nematodes (Heterorhabditidae and Steinernematidae), to control *Triatoma infestans* populations (Hemiptera: Reduviidae), Chagas disease vector. Biol Control. 2022:165:104814. https://doi.org/10.1016/j.biocontrol.2021.104814

Espino CI, Gomez T, Gonzalez G, do Santos MF, Solano J, Sousa O, Moreno N, Windsor D, Ying A, Vilchez S, et al. Detection of *Wolbachia* bacteria in multiple organs and feces of the triatomine insect *Rhodnius pallescens* (Hemiptera, Reduviidae). Appl Environ Microbiol. 2009:75(2):547–550. https://doi.org/10.1128/AEM.01665-08

Feliciangeli D, Rabinovich JE. Parasitism of *Telenomus costalimai* (Hymenoptera: Scelionidae) on *Rhodnius prolixus* (Hemiptera: Reduviidae) under laboratory conditions: effects of density. J Med Entomol. 1985:22(6):654–657. https://doi.org/10.1093/jmedent/22.6.654

Fernandes AJ, da Silva JC, Diotaiuti L. Natural parasitism of triatominae eggs by *Telenomus fariai* Lima, 1927 in the laboratory. Rev Soc Bras Med Trop. 1990:23(3):149–151. https://doi.org/10.1590/s0037-86821990000300003

Fiatsonu E, Busselman RE, Hamer GL, Hamer SA, Ndeffo-Mbah ML. Effectiveness of fluralaner treatment regimens for the control of canine Chagas disease: a mathematical modeling study. PLoS NeglTrop Dis. 2023:17(1):e0011084. https://doi.org/10.1371/journal.pntd.0011084

Fieck A, Hurwitz I, Kang AS, Durvasula R. *Trypanosoma cruzi*: synergistic cytotoxicity of multiple amphipathic anti-microbial peptides to *T. cruzi* and potential bacterial hosts. Exp Parasitol. 2010:125(4):342–347. https://doi.org/10.1016/j.exppara.2010.02.016

Filgueiras MDG, Matos RS, Barreto LP, Mascarin GM, Rizzo PV, Freitas FMC, de Azevedo Prata MC, Monteiro C, Fernandes EKK. From the laboratory to the field: efficacy of entomopathogenic nematodes to control the cattle tick. Pest Manag Sci. 2023:79(1):216–225. https://doi.org/10.1002/ps.7190

Fischhoff IR, Keesing F, Pendleton J, DePietro D, Teator M, Duerr STK, Mowry S, Pfister A, LaDeau SL, Ostfeld RS. Assessing effectiveness of recommended residential yard management measures against ticks. J Med Entomol. 2019:56(5):1420–1427. https://doi.org/10.1093/jme/tjz077

Forlani L, Pedrini N, Girotti JR, Mijailovsky SJ, Cardozo RM, Gentile AG, Hernandez-Suarez CM, Rabinovich JE, Juarez MP. Biological control of the Chagas disease cector *Triatoma infestans* with the entomopathogenic fungus *Beauveria bassiana* combined with an aggregation cue: field, laboratory and mathematical modeling assessment. PLoS Negl Trop Dis. 2015:9(5):e0003778. https://doi.org/10.1371/journal.pntd.0003778

Forlani L, Pedrini N, Juarez MP. Contribution of the horizontal transmission of the entomopathogenic fungus *Beauveria bassiana* to the overall performance of a fungal powder formulation against *Triatoma infestans*. Res Rep Trop Med. 2011:2(2011):135–140. https://doi.org/10.2147/RRTM.S22961

Gaire S, Lewis CD, Booth W, Scharf ME, Zheng W, Ginzel MD, Gondhalekar AD. Bed bugs, *Cimex lectularius* L., exhibiting metabolic and target site deltamethrin resistance are susceptible to plant essential oils. Pestic Biochem Physiol. 2020:169(2020):104667. https://doi.org/10.1016/j.pestbp.2020.104667

Galvão C. Taxonomy. In: Guarneri A, Lorenzo M, editors. Triatominae – the biology of Chagas disease vectors. Cham: Springer International Publishing; 2021. p. 15–38. https://doi.org/10.1007/978-3-030-64548-9_2

Garcia FRM, Ovruski SM, Suarez L, Cancino J, Liburd OE. Biological control of tephritid fruit flies in the Americas and Hawaii: a review of the use of parasitoids and predators. Insects. 2020:11(10):662. https://doi.org/10.3390/insects11100662

Gaspe MS, Provecho YM, Piccinali RV, Gürtler RE. Where do these bugs come from? Phenotypic structure of *Triatoma infestans* populations after control interventions in the Argentine Chaco. Mem Inst Oswaldo Cruz. 2015:110(3):310–318. https://doi.org/10.1590/0074-02760140376

Germano MD, Roca Acevedo G, Mougabure Cueto GA, Toloza AC, Vassena CV, Picollo MI. New findings of insecticide resistance in *Triatoma infestans* (Heteroptera: Reduviidae) from the Gran Chaco. J Med Entomol. 2010:47(6):1077–1081. https://doi.org/10.1603/me10069

Germano MD, Santo-Orihuela P, Roca-Acevedo G, Toloza AC, Vassena C, Picollo MI, Mougabure-Cueto G. Scientific evidence of three different insecticide-resistant profiles in *Triatoma infestans* (Hemiptera: Reduviidae) populations from Argentina and Bolivia. J Med Entomol. 2012:49(6):1355–1360. https://doi.org/10.1603/me12070

Goncalves R, Landivar D, Liendo EGS, Fernandez JM, Ismail HM, Paine MJI, Courtenay O, Bern C. Improving houses in the Bolivian Chaco increases effectiveness of residual insecticide spraying against infestation with *Triatoma infestans*, vector of Chagas disease. Trop Med Int Health. 2021b:26(9):1127–1138. https://doi.org/10.1111/tmi.13640

Goncalves R, Logan RAE, Ismail HM, Paine MJI, Bern C, Courtenay O. Indoor residual spraying practices against *Triatoma infestans* in the Bolivian

Chaco: contributing factors to suboptimal insecticide delivery to treated households. Parasite Vector. 2021a:14(1):327. https://doi.org/10.1186/s13071-021-04831-1

Gonzalez-Moraga MF, Yanez-Meza A, Cares RA, Welbourn C, Botto-Mahan C. First report of mites of the genus *Leptus* (Trombidiformes: Erythraeidae) on the endemic kissing bug *Mepraia spinolai* (Hemiptera: Reduviidae). Int J Acarol. 2015:41(5):393–394. https://doi.org/10.1080/01647954.2015.1047404

Gonzalez-Morales MA, Thomson AE, Yeatts J, Enomoto H, Haija A, Santangelo RG, Petritz OA, Crespo R, Schal C, Baynes R. Pharmacokinetics of fluralaner as a systemic drug to control infestations of the common bed bug, *Cimex lectularius*, in poultry facilities. Parasit Vectors. 2023:16(1):333. https://doi.org/10.1186/s13071-023-05962-3

Gonzalez-Salazar C, Meneses-Mosquera AK, Aguirre-Pena A, Fernandez-Castel KPJ, Stephens CR, Mendoza-Ponce A, Velasco JA, Calderon-Bustamante O, Estrada F. Toward new epidemiological landscapes of *Trypanosoma cruzi* (Kinetoplastida, Trypanosomatidae) transmission under future human-modified land cover and climatic change in Mexico. Trop Med Infect Dis. 2022:7(9):221. https://doi.org/10.3390/tropicalmed7090221

Goolsby JA, Shapiro-Ilan DI. Passive transfer of *Steinernema riobrave* entomopathogenic nematodes with potential implications for treatment of cattle fever tick-infested nilgai. Biocontrol Sci Technol. 2020:30(12):1330–1339. https://doi.org/10.1080/09583157.2020.1817332

Gorla D, Schofield C. Analysis of egg mortality in experimental populations of *Triatoma infestans* under natural climatic conditions in Argentina. Bull Soc Vector Ecol. 1985:10(2):107–117.

Gorla DE. Telenomus fariai (Hymenoptera: Scelionidae) is not a good choice for the control of domestic populations of *Triatoma infestans* (Hemiptera: Reduviidae). Rev Soc Entomol Arg. 2020:79(1):31–33. https://doi.org/10.25085/rsea.790105

Guarneri AA, Pereira MH, Diotaiuti L. Influence of the blood meal source on the development of *Triatoma infestans*, *Triatoma brasiliensis, Triatoma sordida*, and T*riatoma* pseudomaculata (Heteroptera, Reduviidae). J Med Entomol. 2000:37(3):373–379. https://doi.org/10.1093/jmedent/37.3.373

Guillen G, Diaz R, Jemio A, Cassab JA, Pinto CT, Schofield CJ. Chagas disease vector control in Tupiza, southern Bolivia. Mem Inst Oswaldo Cruz. 1997:92(1):1–8. https://doi.org/10.1590/s0074-02761997000100001

Gunter SM, Brown EL, Gorchakov R, Murray KO, Garcia MN. Sylvatic transmission of *Trypanosoma cruzi* among domestic and wildlife reservoirs in Texas, USA: a review of the historical literature. Zoonoses Public Health. 2017:64(5):313–327. https://doi.org/10.1111/zph.12330

Gurevitz JM, Gaspe MS, Enriquez GF, Provecho YM, Kitron U, Gurtler RE. Intensified surveillance and insecticide-based control of the Chagas disease vector *Triatoma infestans* in the Argentinean Chaco. Plos Negl Trop Dis. 2013:7(4):e2158. https://doi.org/10.1371/journal.pntd.0002158

Gurevitz JM, Gaspe MS, Enriquez GF, Vassena CV, Alvarado-Otegui JA, Provecho YM, Cueto GAM, Picollo MI, Kitron U, Gurtler RE. Unexpected failures to control Chagas disease vectors with pyrethroid spraying in northern Argentina. J Med Entomol. 2012:49(6):1379–1386. https://doi.org/10.1603/me11157

Gürtler R, Prokopec GV, Ceballos L, Petersen CL, Salomón O. Comparison between two artificial shelter units and timed manual collections for detecting peridomestic *Triatoma infestans* (Hemiptera: Reduviidae) in rural northwestern Argentina. J Med Entomol. 2001:38(3):429–436. https://doi.org/10.1603/0022-2585-38.3.429

Gürtler RE, Cardinal MV. Reservoir host competence and the role of domestic and commensal hosts in the transmission of *Trypanosoma cruzi*. Acta Trop. 2015:151:32–50. https://doi.org/10.1016/j.actatropica.2015.05.029

Gürtler RE, Ceballos LA, Stariolo R, Kitron U, Reithinger R. Effects of topical application of fipronil spot-on on dogs against the Chagas disease vector *Triatoma infestans*. Trans R Soc Trop Med Hyg. 2009:103(3):298–304. https://doi.org/10.1016/j.trstmh.2008.09.018

Gürtler RE, Cecere MC. Chagas disease vector control. In: Guarneri A, Lorenzo M, editors. Triatominae – the biology of Chagas disease vectors. New York City (NY, USA): Springer; 2021. p. 491–535.

Gürtler RE, Laino MA, Alvedro A, Enriquez GF, Macchiaverna NP, Gaspe MS, Cardinal MV. Treatment of dogs with fluralaner reduced

pyrethroid-resistant *Triatoma infestans* abundance, *Trypanosoma cruzi* infection and human-triatomine contact in the Argentine Chaco. Parasite Vector. 2022:15(1):257. https://doi.org/10.1186/s13071-022-05343-2

Gürtler RE, Petersen RM, Cecere MC, Schweigmann NJ, Chuit R, Gualtieri JM, Wisnivesky-Colli C. Chagas disease in north-west Argentina: risk of domestic reinfestation by *Triatoma infestans* after a single community-wide application of deltamethrin. Trans R Soc Trop Med Hyg. 1994:88(1):27–30. https://doi.org/10.1016/0035-9203(94)90483-9

Gürtler RE, Schweigmann NJ, Cecere MC, Chuit R, Wisnivesky-Colli C. Comparison of two sampling methods for domestic populations of *Triatoma infestans* in north-west Argentina. Med Vet Entomol. 1993:7(3):238–242. https://doi.org/10.1111/j.1365-2915.1993.tb00683.x

Hamer SA, Saunders AB. Veterinary Chagas disease (American trypanosomiasis) in the United States. Vet Clin North Am Small Anim Pract. 2022:52(6):1267–1281. https://doi.org/10.1016/j.cvsm.2022.06.008

Hashimoto K, Cordon-Rosales C, Trampe R, Kawabata M. Impact of single and multiple residual sprayings of pyrethroid insecticides against *Triatoma dimidiata* (Reduviiade; Triatominae), the principal vector of Chagas disease in Jutiapa, Guatemala. Am J Trop Med Hyg. 2006:75(2):226–230. https://doi.org/10.4269/ajtmh.2006.75.2.0750226

Hilgenboecker K, Hammerstein P, Schlattmann P, Telschow A, Werren JH. How many species are infected with *Wolbachia*? – A statistical analysis of current data. FEMS Microbiol Lett. 2008:281(2):215–220. https://doi.org/10.1111/j.1574-6968.2008.01110.x

Holcomb KM, Nguyen C, Foy BD, Ahn M, Cramer K, Lonstrup ET, Mete A, Tell LA, Barker CM. Effects of ivermectin treatment of backyard chickens on mosquito dynamics and West Nile virus transmission. Plos Negl Trop Dis. 2022:16(3):e0010260. https://doi.org/10.1371/journal.pntd.0010260

Horstick O, Runge-Ranzinger S. Protection of the house against Chagas disease, dengue, leishmaniasis, and lymphatic filariasis: a systematic review. Lancet Infect Dis. 2018:18(5):e147–e158. https://doi.org/10.1016/S1473-3099(17)30422-X

Hotez P, Bottazzi ME, Strub-Wourgaft N, Sosa-Estani S, Torrico F, Pajin L, Abril M, Sancho J. A new patient registry for Chagas disease. PLoS NeglTrop Dis. 2020:14(10):e0008418. https://doi.org/10.1371/journal.pntd.0008418

Hurwitz I, Fieck A, Durvasula R. Antimicrobial peptide delivery strategies: use of recombinant antimicrobial peptides in paratransgenic control systems. Curr Drug Targets. 2012:13(9):1173–1180. https://doi.org/10.2174/138945012802002366

Hurwitz I, Fieck A, Read A, Hillesland H, Klein N, Kang A, Durvasula R. Paratransgenic control of vector borne diseases. Int J Biol Sci. 2011:7(9):1334–1344. https://doi.org/10.7150/ijbs.7.1334

Huyghe B, Le Traon G, Flochlay-Sigognault A. Safety of fluralaner oral solution, a novel systemic poultry red mite treatment, for chicken breeders' reproductive performances. Parasite Vector. 2017:10(1):17. https://doi.org/10.1186/s13071-017-2480-2

Hwang WS, Zhang G, Maslov D, Weirauch C. Infection rates of *Triatoma protracta* (Uhler) with *Trypanosoma cruzi* in Southern California and molecular identification of trypanosomes. Am J Trop Med Hyg. 2010:83(5):1020–1022. https://doi.org/10.4269/ajtmh.2010.10-0167

Isman MB. Commercial development of plant essential oils and their constituents as active ingredients in bioinsecticides. Phytochem Rev. 2020:19(3):741–741. https://doi.org/10.1007/s11101-020-09696-3

Jahir A, Kahamba NF, Knols TO, Jackson G, Patty NFA, Shivdasani S, Okumu FO, Knols BGJ. Mass trapping and larval source management for mosquito elimination on small Maldivian islands. Insects. 2022:13(9):805. https://doi.org/10.3390/insects13090805

Jankowska M, Rogalska J, Wyszkowska J, Stankiewicz M. Molecular targets for components of essential oils in the insect nervous system – a review. Molecules. 2017:23(1):34. https://doi.org/10.3390/molecules23010034

Johnson BJ, Ritchie SA, Fonseca DM. The state of the art of lethal oviposition trap-based mass interventions for arboviral control. Insects. 2017:8(1):5. https://doi.org/10.3390/insects8010005

Jose C, Klein N, Wyss S, Fieck A, Hurwitz I, Durvasula R. Recombinant Arthrobacter β-1, 3-glucanase as a potential effector molecule for paratransgenic control of Chagas disease. Parasite Vector. 2013:6:1–8. https://doi.org/10.1186/1756-3305-6-65

Juarez JG, Carbajal E, Dickinson KL, Garcia-Luna S, Vuong N, Mutebi JP, Hemme RR, Badillo-Vargas I, Hamer GL. The unreachable doorbells of South Texas: community engagement in colonias on the US-Mexico border for mosquito control. BMC Public Health. 2022:22(1):1176. https://doi.org/10.1186/s12889-022-13426-z

Kieran TJ, Arnold KMH, Thomas JC, Varian CP, Saldana A, Calzada JE, Glenn TC, Gottdenker NL. Regional biogeography of microbiota composition in the Chagas disease vector *Rhodnius pallescens*. Parasit Vectors. 2019:12(1):504. https://doi.org/10.1186/s13071-019-3761-8

Kjos SA, Marcet PL, Yabsley MJ, Kitron U, Snowden KF, Logan KS, Barnes JC, Dotson EM. Identification of bloodmeal sources and *Trypanosoma cruzi* infection in triatomine bugs (Hemiptera: Reduviidae) from residential settings in Texas, the United States. J Med Entomol. 2013:50(5):1126–1139. https://doi.org/10.1603/me12242

Klotz SA, Dorn PL, Mosbacher M, Schmidt JO. Kissing bugs in the United States: risk for vector-borne disease in humans. Environ Health Insights. 2014:8(Suppl 2):49–59. https://doi.org/10.4137/EHI.S16003

Knapp M, van Houten Y, van Baala E, Groot T. Use of predatory mites in commercial biocontrol: current status and future prospects. Acarologia. 2018:58(Suppl):72–82. https://doi.org/10.24349/acarologia/20184275

Kocan KM, Blouin EF, Pidherney MS, Claypool P, Samish M, Glazer I. Entomopathogenic nematodes as a potential biological control method for ticks. Ann N Y Acad Sci. 1998:849(1):355–364.

Kroeger A, OrdoÃ±ez-Gonzalez J, Behrend M, Alvarez G. Bednet impregnation for Chagas disease control: a new perspective. Trop Med Int Health. 1999:4(3):194–198. https://doi.org/10.1046/j.1365-3156.1999.43370.x

Kroeger A, Villegas E, Ordonez-Gonzalez J, Pabon E, Scorza JV. Prevention of the transmission of Chagas' disease with pyrethroid-impregnated materials. Am J Trop Med Hyg. 2003:68(3):307–311. https://doi.org/10.4269/ajtmh.2003.68.307

Laino MA, Cardinal MV, Enriquez GF, Alvedro A, Gaspe MS, Gurtler RE. An oral dose of fluralaner administered to dogs kills pyrethroid-resistant and susceptible Chagas disease vectors for at least four months. Vet Parasitol. 2019:268:98–104. https://doi.org/10.1016/j.vetpar.2019.03.005

Laino MA, Cardinal MV, Gaspe MS, Enriquez GF, Alvedro A, Macchiaverna NP, Gurtler RE. Control of pyrethroid-resistant populations of *Triatoma infestans*, the main vector of *Trypanosoma cruzi*, by treating dogs with fluralaner in the Argentine Chaco. Med Vet Entomol. 2022:36(2):149–158. https://doi.org/10.1111/mve.12561

Lardeux F, Depickere S, Aliaga C, Chavez T, Zambrana L. Experimental control of *Triatoma infestans* in poor rural villages of Bolivia through community participation. Trans R Soc Trop Med Hyg. 2015:109(2):150–158. https://doi.org/10.1093/trstmh/tru205

Lardeux F, Depickere S, Duchon S, Chavez T. Insecticide resistance of *Triatoma infestans* (Hemiptera, Reduviidae) vector of Chagas disease in Bolivia. Trop Med Int Health. 2010:15(9):1037–1048. https://doi.org/10.1111/j.1365-3156.2010.02573.x

Laurent D, Vilaseca LA, Chantraine JM, Ballivian C, Saavedra G, Ibanez R. Insecticidal activity of essential oils on *Triatoma infestans*. Phytother Res. 1997:11:285–290. https://doi.org/10.1002/(Sici)1099-1573(199706)11:4<285::Aid-Ptr95>3.0.Co;2-T

Lecuona RE, Edelstein JD, Berretta MF, Rossa FRL, Arcas JA. Evaluation of *Beauveria bassiana* (Hyphomycetes) strains as potential agents for control of *Triatoma infestans* (Hemiptera: Reduviidae). J Med Entomol. 2001:38(2):172–179. https://doi.org/10.1603/0022-2585-38.2.172

Lent H, Wygodzinsky P. Revision of the Triatominae (Hemiptera, Reduviidae), and their significance as vectors of Chagas' disease. Bull AMNH. 1979:163(3):123–520.

Levy MZ, Quispe-Machaca VR, Ylla-Velasquez JL, Waller LA, Richards JM, Rath B, Borrini-Mayori K, del Carpio JG, Cordova-Benzaquen E, McKenzie FE, et al. Impregnated netting slows infestation by *Triatoma infestans*. Am J Trop Med Hyg. 2008:79(4):528–534.

Lidani KCF, Andrade FA, Bavia L, Damasceno FS, Beltrame MH, Messias-Reason IJ, Sandri TL. Chagas disease: from discovery to a worldwide health problem. Front Public Health. 2019:7:166. https://doi.org/10.3389/fpubh.2019.00166

Lobo LS, Luz C, Fernandes EK, Juarez MP, Pedrini N. Assessing gene expression during pathogenesis: use of qRT-PCR to follow toxin production in the entomopathogenic fungus *Beauveria bassiana* during infection and immune response of the insect host *Triatoma infestans*. J Invertebr Pathol. 2015:128:14–21. https://doi.org/10.1016/j.jip.2015.04.004

Lorenzo MG, Reisenman CE, Lazzari CR. *Triatoma infestans* can be captured under natural climatic conditions using yeast-baited traps. Acta Trop. 1998:70(3):277–284. https://doi.org/10.1016/s0001-706x(98)00042-4

Lucero DE, Morrissey LA, Rizzo DM, Rodas A, Garnica R, Stevens L, Bustamante DM, Monroy MC. Ecohealth interventions limit triatomine reinfestation following insecticide spraying in La Brea, Guatemala. Am J Trop Med Hyg. 2013:88(4):630–637. https://doi.org/10.4269/ajtmh.12-0448

Luiz de Oliveira J, Ramos Campos EV, Fraceto LF. Recent developments and challenges for nanoscale formulation of botanical pesticides for use in sustainable agriculture. J Agric Food Chem. 2018:66(34):8898–8913. https://doi.org/10.1021/acs.jafc.8b03183

Luz C, Batagin I. Potential of oil-based formulations of *Beauveria bassiana* to control *Triatoma infestans*. Mycopathologia. 2005:160(1):51–62. https://doi.org/10.1007/s11046-005-0210-3

Luz C, Silva IG, Magalhães BP, Cordeiro CM, Tigano MS. Control of *Triatoma infestans* (Klug) (Reduviidae: Triatominae) with *Beauveria bassiana* (Bals.) Vuill.: preliminary assays on formulation and application in the field. An Soc Entomol Brasil. 1999:28(1):101–110.

Machtinger ET, Geden CJ, Kaufman PE, House AM. Use of pupal parasitoids as biological control agents of filth flies on equine facilities. J Integr Pest Manag. 2015:6(1):16. https://doi.org/10.1093/jipm/pmv015

Maloney KM, Ancca-Juarez J, Salazar R, Borrini-Mayori K, Niemierko M, Yukich JO, Naquira C, Keating JA, Levy MZ. Comparison of insecticidal paint and deltamethrin against *Triatoma infestans* (Hemiptera: Reduviidae) feeding and mortality in simulated natural conditions. J Vector Ecol. 2013:38(1):6–11. https://doi.org/10.1111/j.1948-7134.2013.12003.x

Maniania NK, Ekesi S, Odulaja A, Okech MA, Nadel DJ. Prospects of a fungus-contamination device for the control of tsetse fly. Biocontrol Sci Technol. 2006:16(2):129–139. https://doi.org/10.1080/09583150500258503

Manne-Goehler J, Umeh CA, Montgomery SP, Wirtz VJ. Estimating the burden of Chagas disease in the United States. Plos Negl Trop Dis. 2016:10(11):e0005033. https://doi.org/10.1371/journal.pntd.0005033

Mannino MC, Paixao FRS, Pedrini N. The limpet transcription factors of *Triatoma infestans* regulate the response to fungal infection and modulate the expression pattern of defensin genes. Insect Biochem Mol Biol. 2019:108:53–60. https://doi.org/10.1016/j.ibmb.2019.03.010

Marti GA, Balsalobre A, Pazos RS, Ceccarelli S, Martinez PA. Geographical distribution of the genus *Pimellaphilus Tragardh* (Acari: Prostigmata) associated with triatomines (Hemiptera: Reduviidae). Rev Soc Entomol Arg. 2017a:76(1-2):41–45. https://doi.org/10.25085/rsea.761205

Marti GA, Balsalobre A, Susevich ML, Rabinovich JE, Echeverria MG. Detection of triatomine infection by Triatoma virus and horizontal transmission: protecting insectaries and prospects for biological control. J Invertebr Pathol. 2015:124:57–60. https://doi.org/10.1016/j.jip.2014.10.008

Marti GA, Bonica MB, Susevich ML, Reynaldi F, Micieli MV, Echeverría MG. Host range of Triatoma virus does not extend to *Aedes aegypti* and *Apis mellifera*. J Invertebr Pathol. 2020:173:107383. https://doi.org/10.1016/j.jip.2020.107383

Marti GA, Echeverria MG, Susevich ML, Becnel JJ, Pelizza SA, Garcia JJ. Prevalence and distribution of parasites and pathogens of Triatominae from Argentina, with emphasis on *Triatoma infestans* and *Triatoma* virus TrV. J Invertebr Pathol. 2009:102(3):233–237. https://doi.org/10.1016/j.jip.2009.06.010

Marti GA, Echeverria MG, Susevich ML, Ceccarelli S, Balsalobre A, Rabinovich JE, Diotaiuti L, Guerin DMA. Exploration for *Triatoma* virus (TrV) infection in laboratory-reared triatomines of Latin America: a collaborative study. Int J Trop Insect Sci. 2013:33(4):294–304. https://doi.org/10.1017/S1742758413000337

Marti GA, Ragone P, Balsalobre A, Ceccarelli S, Susevich ML, Diosque P, Echeverria MG, Rabinovich JE. Can *Triatoma* virus inhibit infection of *Trypanosoma cruzi* (Chagas, 1909) in *Triatoma infestans* (Klug)? A cross infection and co-infection study. J Invertebr Pathol. 2017b:150:101–105. https://doi.org/10.1016/j.jip.2017.09.014

Martinez-Sanchez A, Camacho AD, Quintero-Martinez MT, Alejandre-Aguilar R. Effect of ectoparasitic *Pimeliaphilus plumifer* mites (Acari: Pterygosomatidae) on *Meccus pallidipennis* (Hemiptera: Reduviidae) and several other Chagas' disease vectors under laboratory conditions. Exp Appl Acarol. 2007:42(2):139–149. https://doi.org/10.1007/s10493-007-9079-9

Martins MF, de Moraes SC, Cohen SC, Cardenas MQ, Galvao C. First record of a mermithid worm (Nematoda, Mermithidae) parasitizing a third instar nymph of *Triatoma sordida* (Stal, 1859) (Hemiptera, Reduviidae, Triatominae) from Mato Grosso, Brazil. Zookeys. 2020:980:79–91. https://doi.org/10.3897/zookeys.980.55865

Matthews S, Rao VS, Durvasula RV. Modeling horizontal gene transfer (HGT) in the gut of the Chagas disease vector *Rhodnius prolixus*. Parasit Vectors. 2011:4:77. https://doi.org/10.1186/1756-3305-4-77

Medone P, Ceccarelli S, Parham PE, Figuera A, Rabinovich JE. The impact of climate change on the geographical distribution of two vectors of Chagas disease: implications for the force of infection. Philos Trans R Soc Lond B. 2015:370(1665):20130560. https://doi.org/10.1098/rstb.2013.0560

Messing R, Brodeur J. Current challenges to the implementation of classical biological control. BioControl. 2018:63(1):1–9. https://doi.org/10.1007/s10526-017-9862-4

Minoli SA, Lazzari CR. Take-off activity and orientation of triatomines (Heteroptera: Reduviidae) in relation to the presence of artificial lights. Acta Trop. 2006:97(3):324–330. https://doi.org/10.1016/j.actatropica.2005.12.005

Monroy C, Bustamante DM, Pineda S, Rodas A, Castro X, Ayala V, Quinones J, Moguel B. House improvements and community participation in the control of *Triatoma dimidiata* re-infestation in Jutiapa, Guatemala. Cad Saude Publica. 2009:25(Suppl 1):S168–S178. https://doi.org/10.1590/s0102-311x2009001300016

Monroy C, Castro X, Bustamante DM, Pineda SS, Rodas A, Moguel B, Ayala V, Quiñonez J. An ecosystem approach for the prevention of Chagas disease in rural Guatemala. In: Charron D, editor. Ecohealth research in practice: innovative applications of an ecosystem approach to health. New York (NY, USA): Springer; 2012. p. 153–162. https://doi.org/10.1590/s0102-311x2009001300016

Monteiro FA, Weirauch C, Felix M, Lazoski C, Abad-Franch F. Evolution, systematics, and biogeography of the Triatominae, vectors of Chagas disease. Adv Parasitol. 2018:99:265–344. https://doi.org/10.1016/bs.apar.2017.12.002

Moretti AN, Zerba EN, Alzogaray RA. Behavioral and toxicological responses of *Rhodnius prolixus* and T*riatoma* infestans (Hemiptera: Reduviidae) to 10 monoterpene alcohols. J Med Entomol. 2013:50(5):1046–1054. https://doi.org/10.1603/me12248

Morrison AC, Reiner RC Jr, Elson WH, Astete H, Guevara C, Del Aguila C, Bazan I, Siles C, Barrera P, Kawiecki AB, et al. Efficacy of a spatial repellent for control of *Aedes*-borne virus transmission: a cluster-randomized trial in Iquitos, Peru. Proc Natl Acad Sci U S A. 2022:119(26):e2118283119. https://doi.org/10.1073/pnas.2118283119

Mougabure-Cueto G, Picollo MI. Insecticide resistance in vector Chagas disease: evolution, mechanisms and management. Acta Trop. 2015:149:70–85. https://doi.org/10.1016/j.actatropica.2015.05.014

Mougabure-Cueto G, Picollo MI. Insecticide resistance in triatomines. In: Guarneri A, Lorenzo M, editors. Triatominae—The biology of Chagas disease vectors. Cham (Switzerland): Springer; 2021. p. 537–555.

Muscio O, Bonder MA, La Torre JL, Scodeller EA. Horizontal transmission of *Triatoma* virus through the fecal-oral route in *Triatoma infestans* (Hemiptera: Triatomidae). J Med Entomol. 2000:37(2):271–275. https://doi.org/10.1603/0022-2585-37.2.271

Muscio OA, La Torre JL, Scodeller EA. Characterization of *Triatoma* virus, a picorna-like virus isolated from the triatomine bug *Triatoma infestans*. J Gen Virol. 1988:69 (Pt 11)(Pt 11):2929–2934. https://doi.org/10.1099/0022-1317-69-11-2929

Muscio OA, LaTorre JL, Bonder MA, Scodeller EA. *Triatoma* virus pathogenicity in laboratory colonies of *Triatoma infestans* (Hemiptera: Reduviidae). J Med Entomol. 1997:34(3):253–256. https://doi.org/10.1093/jmedent/34.3.253

Nakagawa J, Cordon-Rosales C, Juarez J, Itzep C, Nonami T. Impact of residual spraying on *Rhodnius prolixus* and *Triatoma dimidiata* in the department

of Zacapa in Guatemala. Mem Inst Oswaldo Cruz. 2003:98(2):277–281. https://doi.org/10.1590/s0074-02762003000200019

Napolitano R, Juarez MP. Entomopathogenous fungi degrade epicuticular hydrocarbons of *Triatoma infestans*. Arch Biochem Biophys. 1997:344(1):208–214. https://doi.org/10.1006/abbi.1997.0163

Noireau F, Abad-Franch F, Valente SA, Dias-Lima A, Lopes CM, Cunha V, Valente VC, Palomeque FS, de Carvalho-Pinto CJ, Sherlock I, et al. Trapping Triatominae in silvatic habitats. Mem Inst Oswaldo Cruz. 2002:97(1):61–63. https://doi.org/10.1590/s0074-02762002000100009

Noireau F, Flores R, Vargas F. Trapping sylvatic Triatominae (Reduviidae) in hollow trees. Trans R Soc Trop Med Hyg. 1999:93(1):13–14. https://doi.org/10.1016/s0035-9203(99)90161-x

Noya Y, Jimenes F, Lopez J, Aliaga W, Colque B, Martinez L, Callapa G. Biological control of vectors of Chagas disease with Microhymenoptera (Micro Wasps). Rev Con-Ciencia. 2019:7(2):85–94.

Ortega-Pacheco A, Poot-Ramos A, Chan-Perez JI, Gutierrez-Blanco E, Acevedo-Arcique CM, Baak-Baak CM, Jimenez-Coello M. Evaluation of the effectiveness of fluralaner against adult stages of *Rhodnius prolixus* in dogs. Parasitol Int. 2022:87:102508. https://doi.org/10.1016/j.parint.2021.102508

Oulhote Y, Bouchard MF. Urinary metabolites of organophosphate and pyrethroid pesticides and behavioral problems in Canadian children. Environ Health Perspect. 2013:121(11-12):1378–1384. https://doi.org/10.1289/ehp.1306667

Pacheco-Tucuch FS, Ramirez-Sierra MJ, Gourbiere S, Dumonteil E. Public street lights increase house infestation by the Chagas disease vector *Triatoma dimidiata*. PLoS One. 2012:7(4):e36207. https://doi.org/10.1371/journal.pone.0036207

Pavela R. History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects – a review. Plant Prot Sci. 2016:52(4):229–241. https://doi.org/10.17221/31/2016-pps

Pedrini N, Mijailovsky SJ, Girotti JR, Stariolo R, Cardozo RM, Gentile A, Juarez MP. Control of pyrethroid-resistant Chagas disease vectors with entomopathogenic fungi. Plos Neglect Trop Dis. 2009:3(5):e434. https://doi.org/10.1371/journal.pntd.0000434

Pereira KS, Sciimidt FL, Guaraldo AMA, Franco RMB, Dias VL, Passos LAC. Chagas disease as a foodborne illness. J Food Prot. 2009:72(2):441–446. https://doi.org/10.4315/0362-028x-72.2.441

Peschiutta ML, Cagnolo SR, Almirón WR. Susceptibilidad de larvas de *Aedes aegypti* (Linnaeus) (Diptera: Culicidae) al nematodo entomopatógeno *Heterorhabditis bacteriophora* (Poinar) (Rhabditida: Heterorhabditidae). Rev Soc Entomol Arg. 2014:73(3-4):99–108.

Picollo MI, Seccacini E, Vassena C, Zerba E. Feeding and mating deterrency by sulfhydryl-reagents in *Triatoma Infestans*. Acta Trop. 1993:52(4):297–307. https://doi.org/10.1016/0001-706x(93)90014-3

Picollo MI, Vassena C, Orihuela PS, Barrios S, Zaidemberg M, Zerba E. High resistance to pyrethroid insecticides associated with ineffective field treatments in *Triatoma infestans* (Hemiptera: Reduviidae) from northern Argentina. J Med Entomol. 2005:42(4):637–642. https://doi.org/10.1093/jmedent/42.4.637

Pojo De Rego I, Walter A, Ferreira AJ, Rangel M, Girard-Ferreira E, Noireau F. Peridomestic structure, farming activity and triatomine infestation. Parasite. 2006:13(3):237–243. https://doi.org/10.1051/parasite/2006133237

Pooseesod K, Parker DM, Meemon N, Lawpoolsri S, Singhasivanon P, Sattabongkot J, Cui L, Phuanukoonnon S. Ownership and utilization of bed nets and reasons for use or non-use of bed nets among community members at risk of malaria along the Thai-Myanmar border. Malar J. 2021:20(1):1–12. https://doi.org/10.1186/s12936-021-03837-5

Porier DL, Wilson SN, Auguste DI, Leber A, Coutermarsh-Ott S, Allen IC, Caswell CC, Budnick JA, Bassaganya-Riera J, Hontecillas R, et al. Enemy of my enemy: a novel insect-specific flavivirus offers a promising platform for a Zika Virus vaccine. Vaccines (Basel). 2021:9(10):1142. https://doi.org/10.3390/vaccines9101142

Pulford J, Hetzel MW, Bryant M, Siba PM, Mueller I. Reported reasons for not using a mosquito net when one is available: a review of the published literature. Malar J. 2011:10(1):1–10. https://doi.org/10.1186/1475-2875-10-83

Queiroga TBD, Gomez LCP, de Sena ER, dos Santos WV, Ferreira HRP, de Araujo-Neto VT, Barbosa-Silva AN, Brito CRD, Lima RKD, Fagundes-Neto

JC, et al. Insecticidal efficacy of fluralaner (Bravecto(R)) against *Triatoma brasiliensis*, a major vector of *Trypanosoma cruzi* in Brazil. Parasite Vector. 2021:14(1):456. https://doi.org/10.1186/s13071-021-04978-x

Queiroz AMV, Yanshina YA, Rodrigues ETD, Santos FLN, Celedon PAF, Maheshwari S, Gabelli SB, Rubio CSP, Durana A, Guerin DMA, et al. Antibodies response induced by recombinant virus-like particles from *Triatoma virus* and chimeric antigens from *Trypanosoma cruzi*. Vaccine. 2021:39(33):4723–4732. https://doi.org/10.1016/j.vaccine.2021.05.039

Querido JFB, Echeverria MG, Marti GA, Costa RM, Susevich ML, Rabinovich JE, Copa A, Montano NA, Garcia L, Cordova M, et al. Seroprevalence of *Triatoma virus* (Dicistroviridae: Cripaviridae) antibodies in Chagas disease patients. Parasite Vector. 2015:8:29. https://doi.org/10.1186/s13071-015-0632-9

Rabinovich JE. Population dynamics of Telenomus fariai (Hymenoptera: Scelionidae), a parasite of Chagas' disease vectors. II. Effect of host-egg age. J Med Entomol. 1970:7(4):477–481.

Ramirez-Ahuja MD, Davila-Barboza JA, Talamas EJ, Moore MR, Bobadilla-Utrera C, Ponce-Garcia G, Rodriguez-Sanchez IP, Flores AE. First record of *Telenomus fariai* Costa Lima, 1927 (Hymenoptera, Scelionidae, Telenominae) as a parasitoid of *Triatoma dimidiata* (Latreille, 1811) (Hemiptera, Reduviidae, Triatominae) eggs in Mexico. J Hymenopt Res. 2021:87:309–322. https://doi.org/10.3897/jhr.87.73546

Ramsey JM, Cruz-Celis A, Salgado L, Espinosa L, Ordonez R, Lopez R, Schofield CJ. Efficacy of pyrethroid insecticides against domestic and peridomestic populations of *Triatoma pallidipennis* and *Triatoma barberi* (Reduviidae: Triatominae) vectors of Chagas' disease in Mexico. J Med Entomol. 2003:40(6):912–920. https://doi.org/10.1603/0022-2585-40.6.912

Rebollar-Tellez EA, Reyes-Villanueva F, Escobedo-Ortegon J, Balam-Briceno P, May-Concha I. Abundance and nightly activity behavior of a sylvan population of *Triatoma dimidiata* (Hemiptera: Reduviidae: Triatominae) from the Yucatan, Mexico. J Vector Ecol. 2009:34(2):304–310. https://doi.org/10.1111/j.1948-7134.2009.00038.x

Reisenman CE, Lawrence G, Guerenstein PG, Gregory T, Dotson E, Hildebrand JG. Infection of kissing bugs with *Trypanosoma cruzi*, Tucson, Arizona, USA. Emerg Infect Dis. 2010:16(3):400–405. https://doi.org/10.3201/eid1603.090648

Reisenman CE, Lazzari C. Spectral sensitivity of the photonegative reaction of the blood-sucking bug *Triatoma infestans* (Heteroptera: Reduviidae). J Comp Physiol A Neuroethol Sens Neural Behav Physiol. 2006:192(1):39–44. https://doi.org/10.1007/s00359-005-0045-x

Reithinger R, Ceballos L, Stariolo R, Davies CR, Gurtler RE. Chagas disease control: deltamethrin-treated collars reduce *Triatoma infestans* feeding success on dogs. Trans R Soc Trop Med Hyg. 2005:99(7):502–508. https://doi.org/10.1016/j.trstmh.2004.11.013

Revay EE, Kline DL, Xue RD, Qualls WA, Bernier UR, Kravchenko VD, Ghattas N, Pstygo I, Muller GC. Reduction of mosquito biting-pressure: spatial repellents or mosquito traps? A field comparison of seven commercially available products in Israel. Acta Trop. 2013:127(1):63–68. https://doi.org/10.1016/j.actatropica.2013.03.011

Reynoso MMN, Seccacini EA, Calcagno JA, Zerba EN, Alzogaray RA. Toxicity, repellency and flushing out in *Triatoma infestans* (Hemiptera: Reduviidae) exposed to the repellents DEET and IR3535. PeerJ. 2017:5:e3292. https://doi.org/10.7717/peerj.3292

Reynoso MMN, Seccacini EA, Zerba EN, Alzogaray RA. Botanical monoterpenes synergise the toxicity of azamethiphos in the vector of Chagas disease, *Triatoma infestans* (Hemiptera: Reduviidae). Trop Med Int Health. 2020:25(12):1480–1485. https://doi.org/10.1111/tmi.13488

Rivera EP, Arrivillaga MR, Juarez JG, De Urioste-Stone SM, Berganza E, Pennington PM. Adoption of community-based strategies for sustainable vector control and prevention. BMC Public Health. 2023:23(1):1834. https://doi.org/10.1186/s12889-023-16516-8

Robert V. Brief history of insecticide-treated bed nets in the fight against malaria: a testimony on the crucial 1980's decade. Bull Soc Pathol Exot. 2020:113(2):88–103. https://doi.org/10.3166/bspe-2020-0128

Rocha E Silva E, Reis U, Correa R, Lima A. Xeno-intoxication in the control of Triatomidae. Arch Fac Hig Saude Publ Univ S Paulo. 1969:34(119-120):25–42.

Rokhsar JL, Raynor B, Sheen J, Goldstein ND, Levy MZ, Castillo-Neyra R. Modeling the impact of xenointoxication in dogs to halt *Trypanosoma cruzi* transmission. medRxiv. 2023:19(5):e1011115. https://doi.org/10.1371/journal.pcbi.1011115

Romana CA, Fargues J, Pays JF. Method of biological control of Triatominae, vectors of Chagas disease, using entomopathogenic Hyphomycetes. Preliminary study. Bull Soc Pathol Exot Filiales. 1987:80(1):105–111.

Romo H, Kenney JL, Blitvich BJ, Brault AC. Restriction of Zika virus infection and transmission in *Aedes aegypti* mediated by an insect-specific flavivirus. Emerg Microbes Infect. 2018:7(1):181. https://doi.org/10.1038/s41426-018-0180-4

Rossi JC, Duarte EC, Gurgel-Goncalves R. Factors associated with the occurrence of *Triatoma sordida* (Hemiptera: Reduviidae) in rural localities of Central-West Brazil. Mem Inst Oswaldo Cruz. 2015:110(2):192–200. https://doi.org/10.1590/0074-02760140395

Rozas-Dennis GS, Cazzaniga NJ. Effects of *Triatoma* virus (TrV) on the fecundity and moulting of *Triatoma infestans* (Hemiptera: Reduviidae). Ann Trop Med Parasitol. 2000:94(6):633–641. https://doi.org/10.1080/00034983.2000.11813586

Rozas-Dennis GS, Cazzaniga NJ, Guerin DMA. *Triatoma patagonica* (Hemiptera, Reduviidae), a new host for *Triatoma* virus. Mem Inst Oswaldo Cruz. 2002:97(3):427–429. https://doi.org/10.1590/s0074-02762002000300028

Rozendaal JA. Vector control: methods for use by individuals and communities. Geneva (Switzerland): World Health Organization; 1997.

Salcedo-Porras N, Umana-Diaz C, Bitencourt ROB, Lowenberger C. The role of bacterial symbionts in triatomines: an evolutionary perspective. Microorganisms. 2020:8(9):1438. https://doi.org/10.3390/microorganisms8091438

Samish M, Glazer I. Entomopathogenic nematodes for the biocontrol of ticks. Trends Parasitol. 2001:17(8):368–371. https://doi.org/10.1016/s1471-4922(01)01985-7

Schwarz A, Juarez JA, Richards J, Rath B, Machaca VQ, Castro YE, Malaga ES, Levy K, Gilman RH, Bern C, et al. Anti-triatomine saliva immunoassays for the evaluation of impregnated netting trials against Chagas disease transmission. Int J Parasitol. 2011:41(6):591–594. https://doi.org/10.1016/j.ijpara.2011.02.001

Sharun K, Shyamkumar T, Aneesha V, Dhama K, Pawde AM, Pal A. Current therapeutic applications and pharmacokinetic modulations of ivermectin. Vet World. 2019:12(8):1204. https://doi.org/10.14202/vetworld.2019.1204-1211

Sheele JM, Ridge GE. Toxicity and potential utility of ivermectin and moxidectin as xenointoxicants against the common bed bug, *Cimex lectularius* L. Parasitol Res. 2016:115(8):3071–3081. https://doi.org/10.1007/s00436-016-5062-x

Shikanai-Yasuda MA, Carvalho NB. Oral transmission of Chagas disease. Clin Infect Dis. 2012:54(6):845–852. https://doi.org/10.1093/cid/cir956

Sjogren RD, Ryckman RE. Epizootiology of trypanosoma cruzi in Southwestern North America. Part VIII: Nocturnal flights of triatoma protracta (Uhler) as indicated by collections at black light traps (Hemiptera: Reduviidae: Triatominae). J Med Entomol. 1966:3(1):81–92. https://doi.org/10.1093/jmedent/3.1.81

Smith KV, DeLong KL, Boyer CN, Thompson JM, Lenhart SM, Strickland WC, Burgess ER, Tian Y, Talley J, Machtinger ET, et al. A call for the development of a sustainable pest management program for the economically omportant pest flies of livestock: a beef cattle perspective. J Integr Pest Manag. 2022:13(1):1–18. https://doi.org/10.1093/jipm/pmac010

Sommerfeld J, Kroeger A. Innovative community-based vector control interventions for improved dengue and Chagas disease prevention in Latin America: introduction to the special issue. Trans R Soc Trop Med Hyg. 2015:109(2):85–88. https://doi.org/10.1093/trstmh/tru176

Squires G, Pous J, Agirre J, Rozas-Dennis GS, Costabel MD, Marti GA, Navaza J, Bressanelli S, Guerin DMA, Rey FA. Structure of the *Triatoma* virus capsid. Acta Crystallogr Sect D Biol Crystallogr. 2013:69(Pt 6):1026–1037. https://doi.org/10.1107/S0907444913004617

Stevens L, Rizzo DM, Lucero DE, Pizarro JC. Household model of Chagas disease vectors (Hemiptera: Reduviidae) considering domestic, peridomestic, and sylvatic vector populations. J Med Entomol. 2013:50(4):907–915. https://doi.org/10.1603/me12096

Stock SP, Blair HG. Entomopathogenic nematodes and their bacterial symbionts: the inside out of a mutualistic association. Symbiosis. 2008:46(2):65–75.

Susevich ML, Marti GA, Serena MS, Echeverria MG. New *Triatoma* virus hosts in wild habitats of Argentina. J Invertebr Pathol. 2012:110(3):405–407. https://doi.org/10.1016/j.jip.2012.03.023

Terriquez JA, Klotz SA, Meister EA, Klotz JH, Schmidt JO. Repellency of DEET, picaridin, and three essential oils to *Triatoma rubida* (Hemiptera: Reduviidae: Triatominae). J Med Entomol. 2013:50(3):664–667. https://doi.org/10.1603/me12282

Thomas E, Chiquet M, Sander B, Zschiesche E, Flochlay AS. Field efficacy and safety of fluralaner solution for administration in drinking water for the treatment of poultry red mite (Dermanyssus gallinae) infestations in commercial flocks in Europe. Parasit Vectors. 2017:10(1):457. https://doi.org/10.1186/s13071-017-2390-3

Toloza AC, Germano M, Cueto GM, Vassena C, Zerba E, Picollo MI. Differential patterns of insecticide resistance in eggs and first instars of *Triatoma infestans* (Hemiptera: Reduviidae) from Argentina and Bolivia. J Med Entomol. 2008:45(3):421–426. https://doi.org/10.1603/0022-2585(2008)45[421:dpoiri]2.0.co;2

Torres FA, Angulo VM, Reyes M. Resistencia a lambdacihalotrina y fenitrotión en una población de campo de *Panstrongylus geniculatus* (Hemiptera: Reduviidae: Triatominae). Salud UIS. 2013:45(3):19–24.

Ucan-Mezquita A, Jimenez-Coello M, Guzman-Marin E, Gutierrez-Blanco E, Chan-Perez JI, Travi BL, Hernandez-Cortazar I, Ortega-Pacheco A. Efficacy of a topical combination of fipronil-permethrin against *Rhodnius prolixus* on dogs. Vet Parasitol. 2019:276:108978. https://doi.org/10.1016/j.vetpar.2019.108978

Updyke EA, Allan BF. An experimental evaluation of cross-vane panel traps for the collection of sylvatic triatomines (Hemiptera: Reduviidae). J Med Entomol. 2018:55(2):485–489. https://doi.org/10.1093/jme/tjx224

Vassena CV, Picollo MI, Zerba EN. Insecticide resistance in Brazilian *Triatoma infestans* and Venezuelan *Rhodnius prolixus*. Med Vet Entomol. 2000:14(1):51–55. https://doi.org/10.1046/j.1365-2915.2000.00203.x

Vazquez-Prokopec GM, Cecere MC, Kitron U, Gurtler RE. Environmental and demographic factors determining the spatial distribution of *Triatoma guasayana* in peridomestic and semi-sylvatic habitats of rural northwestern Argentina. Med Vet Entomol. 2008:22(3):273–282. https://doi.org/10.1111/j.1365-2915.2008.00746.x

Waage J, Greathead D. Biological control: challenges and opportunities. Philos Trans R Soc Lond B Biol Sci. 1988:318(1189):111–128. https://doi.org/10.1098/rstb.1988.0001

Waleckx E, Camara-Mejia J, Ramirez-Sierra MJ, Cruz-Chan V, Rosado-Vallado M, Vazquez-Narvaez S, Najera-Vazquez R, Gourbiere S, Dumonteil E. An innovative ecohealth intervention for Chagas disease vector control in Yucatan, Mexico. Trans R Soc Trop Med Hyg. 2015b:109(2):143–149. https://doi.org/10.1093/trstmh/tru200

Waleckx E, Gourbiere S, Dumonteil E. Intrusive versus domiciliated triatomines and the challenge of adapting vector control practices against Chagas disease. Mem Inst Oswaldo Cruz. 2015a:110(3):324–338. https://doi.org/10.1590/0074-02760140409

Waleckx E, Montalvo-Balam TD, Pinzon-Canul A, Arnal A, Marti G, Martinez PA. First report of phoresy by an oribatid mite (Acari: Oribatida) on a triatomine bug (Hemiptera: Reduviidae). Int J Acarol. 2018:44(4-5):210–211. https://doi.org/10.1080/01647954.2018.1487467

Walter A, Lozano-Kasten F, Bosseno MF, Ruvalcaba EG, Gutierrez MS, Luna CE, Baunaure F, Phelinas P, Magallon-Gastelum E, Breniere SF. Peridomicilary habitat and risk factors for Triatoma infestation in a rural community of the Mexican occident. Am J Trop Med Hyg. 2007:76(3):508–515.

Waltmann A, Willcox AC, Balasubramanian S, Borrini Mayori K, Mendoza Guerrero S, Salazar Sanchez RS, Roach J, Condori Pino C, Gilman RH, Bern C, et al. Hindgut microbiota in laboratory-reared and wild *Triatoma infestans*. PLoS Negl Trop Dis. 2019:13(5):e0007383. https://doi.org/10.1371/journal.pntd.0007383

Wisnivesky-Colli C, Gurtler RE, Solarz ND, Schweigmann NJ, Pietrokovsky SM, Alberti A, Flo J. Dispersive flight and house invasion by *Triatoma guasayana* and *Triatoma sordida* in Argentina. Mem Inst Oswaldo Cruz. 1993:88(1):27–32. https://doi.org/10.1590/s0074-02761993000100006

World Health Organization. Ending the neglect to attain the sustainable development goals: a sustainability framework for action against neglected tropical diseases 2021-2030. Geneva (Switzerland): World Health Organization; 2021.

World Health Organization. Chagas disease; 2023b [accessed 2024 March]. https://www.paho.org/en/topics/chagas-disease.

World Health Organization. Chagas disease (American trypanosomiasis); 2023a [accessed 2024 March 25]. https://www.who.int/health-topics/chagas-disease#tab=tab_1.

Xue L, Fang X, Hyman JM. Comparing the effectiveness of different strains of Wolbachia for controlling chikungunya, dengue fever, and zika. PLoS Negl Trop Dis. 2018:12(7):e0006666. https://doi.org/10.1371/journal.pntd.0006666

Yen PS, Failloux AB. A review: *Wolbachia*-based population replacement for mosquito control shares common points with genetically modified control approaches. Pathogens. 2020:9(5):404. https://doi.org/10.3390/pathogens9050404

Yoshioka K, Nakamura J, Perez B, Tercero D, Perez L, Tabaru Y. Effectiveness of large-scale Chagas disease vector control program in Nicaragua by residual insecticide spraying against *Triatoma dimidiata*. Am J Trop Med Hyg. 2015:93(6):1231–1239. https://doi.org/10.4269/ajtmh.15-0403

Zaidemberg M. Evolución de la infestación en un área de triatominos resistentes a piretroides, Salvador Mazza, Salta, Argentina. Revista Argentina de Zoonosis y Enfermedades Infecciosas Emergentes. 2012:7:3–13.

Zamora D, Klotz SA, Meister EA, Schmidt JO. Repellency of the components of the essential oil, citronella, to *Triatoma rubida*, *Triatoma protracta*, and *Triatoma recurva* (Hemiptera: Reduviidae: Triatominae). J Med Entomol. 2015:52(4):719–721. https://doi.org/10.1093/jme/tjv039

Zeledón R. Sobre la biología del *Telenomus fariai* Lima, 1927 (Hymenoptera: Scelionidae), parásito endófago de huevos de algunos Triatominae. Rev Biol Trop. 1957:5(1):1–17.

Zeledón R, Rojas JC. Environmental management for the control of *Triatoma dimidiata* (Latreille, 1811), (Hemiptera: Reduviidae) in Costa Rica: a pilot project. Mem Inst Oswaldo Cruz. 2006:101(4):379–386. https://doi.org/10.1590/s0074-02762006000400006

Zeledón R, Rojas JC, Urbina A, Cordero M, Gamboa SH, Lorosa ES, Alfaro S. Ecological control of *Triatoma dimidiata* (Latreille, 1811): five years after a Costa Rican pilot project. Mem Inst Oswaldo Cruz. 2008:103(6):619–621. https://doi.org/10.1590/s0074-02762008000600020

Zhang HQ, Li N, Zhang ZR, Deng CL, Xia H, Ye HQ, Yuan ZM, Zhang B. A chimeric classical insect-specific flavivirus provides complete protection against West Nile virus lethal challenge in mice. J Infect Dis. 2023:229(1):43–53. https://doi.org/10.1093/infdis/jiad238

Zumaquero JL, Alejandre R, Linares G, Cedillo ML, Lopez JF, Caicedo R. *Pimeliaphilus triatomae* (Acari: Pteregosomidae) utilizado como control biológico de *Meccus pallidipennis* (Hemiptera: Keduviidae) en condiciones de laboratorio. Rev Colomb Entomol. 2004:30(2):131–135. https://doi.org/10.25100/socolen.v30i2.9541