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Review

Triatomine Bugs: History, Control, and Citizen Surveillance

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How To Cite: Galvão, C. Triatomine Bugs: History, Control, and Citizen Surveillance. *Disease Biology, Genetics, and Socioecology* **2025**, *1*(3), 8. https://doi.org/10.53941/dbgs.2025.100008.

Received: 11 June 2025
Revised: 13 July 2025
Accepted: 16 July 2025
Published: 25 July 2025

Abstract: Triatomine bugs (Hemiptera: Reduviidae: Triatominae) are vectors of *Trypanosoma cruzi*, the causative agent of Chagas disease, a neglected tropical disease endemic to the Americas. This review presents a historical overview of triatomine discovery, their biological and ecological characteristics, and the evolution of vector control strategies. It discusses the success and challenges of multinational initiatives that reduced transmission in several countries, while highlighting emerging issues such as species hybridization, insecticide resistance, urbanization of vectors, and oral transmission routes. A key focus is placed on the role of citizen science in enhancing surveillance and control, especially in regions with limited institutional capacity. The use of mobile applications, digital platforms, and participatory campaigns has proven valuable in improving vector detection, engaging communities, and generating epidemiologically relevant data. Additionally, recent technological advances, such as ecological niche modeling and automated image recognition, have the potential to strengthen integrated vector management. Given the dynamic epidemiological landscape, the article emphasizes the importance of intersectoral collaboration, health education, and the incorporation of One Health principles to ensure sustainable control of Chagas disease.

Keywords: Chagas disease; vector control; citizen Science; *Trypanosoma cruzi;* triatomine bugs

1. Introduction

The recognition of triatomine bugs and their habits dates to 1590 when the priest Reginaldo de Lizárraga during his travels to convents in Peru and Chile, observed large hematophagous insects that attacked at night [1]. Subsequent reports from other travelers and naturalists further documented the presence of these insects in South America. One of the most notable accounts comes from Charles Darwin during his voyage aboard the HMS Beagle in 1835 [2]. It has been suggested that Darwin may have contracted Chagas disease after being bitten by a triatomine bug, most likely *Triatoma infestans* (Klug, 1834) or *Mepraia spinolai* (Porter, 1934). Although the exact cause of his illness remains unresolved, recent evidence suggests he was exposed to triatomine vectors during his travels, supporting the hypothesis of Chagas disease [3–5]. Although triatomines have been known since the 16th century, the first formally described species, *Triatoma rubrofasciata*, was identified by De Geer in 1773.

Classified within the subfamily Triatominae (Hemiptera, Reduviidae), are hemimetabolous insects, meaning that their five nymphal stages share many biological characteristics with adults. Triatomines are unique within the Reduviidae family, as all other subfamilies consist exclusively of predatory species. It is hypothesized that triatomines evolved from a predatory ancestor, with insect feeding representing a primitive trait, possibly explaining why some species retain the ability to feed on other invertebrates. Triatominae are characterized by their obligate hematophagous behavior and exhibit morphological adaptations for detecting and feeding on vertebrate hosts. Their feeding behavior has been investigated from multiple perspectives, including physiological and behavioral aspects, its effects on survival and reproduction (i.e., fitness), and host-use patterns in both field and laboratory settings [6–10].

These insects exhibit considerable interspecific size variation, ranging from just a few millimeters in species of *Alberprosenia* Martínez & Carcavallo, 1977; *Belminus* Stål, 1859; and *Microtriatoma* Prosen & Martínez, 1952, to up to 45 mm in *Dipetalogaster maxima* (Uhler, 1894). Their coloration is diverse: the body is generally dark, with spots on the connexivum (the lateral region of the abdomen) that may be yellow, orange, red, or brownish. Moreover, coloration can vary between species and even within the same species (Figures 1–6). Since the first formal description of triatomine species in the late 18th century, their classification has primarily relied on traditional morphological characteristics. Overall, the current classification of Triatominae recognizes 158 species grouped into 19 genera (Table 1), with three genera, *Triatoma*, *Rhodnius*, and *Panstrongylus* considered epidemiologically significant in the transmission of *T. cruzi* to the humans [11]. Over time, advanced techniques such as morphometrics [12] and molecular approaches have been employed to refine the systematics of these vectors. Despite these advancements, the comprehensive integration of diverse methodologies under the framework of integrative taxonomy has gained prominence only in the past decade, substantially enhancing the study of triatomine systematics [13]. However, important topics such as hybridization among vector species pose significant challenges to taxonomy and species identification, and are therefore increasingly relevant, given their direct implications for surveillance and vector control [14,15].

Table 1. Updated list of the 158 valid Triatomine species (including three fossil taxa).

Genus	Species
Alberprosenia	(1) *A. goyovargasi* Martínez & Carcavallo, 1977 (2) *A. malheiroi* Serra, Atzingen & Serra, 1980
Belminus	(1) *B. costaricencis* Herrer, Lent & Wygodzinsky, 1954 (2) *B. herreri* Lent & Wygodzinsky, 1979 (3) *B. laportei* Lent, Jurberg & Carcavallo, 1995 (4) *B. peruvianus* Herrer, Lent & Wygodzinsky, 1954 (5) *B. pittieri* Osuna & Ayala, 1993 (6) *B. rugulosus* Stål, 1859 (7) *B. ferroae* Sandoval, Pabón, Jurberg & Galvão, 2007 (8) *B. corredori* Galvão & Angulo, 2006 (9) *B. santosmalletae* Dale, Justi & Galvão, 2021
Bolbodera	(1) *B. scabrosa* Valdés, 1910
Cavernicola	(1) *C. lenti* Barrett & Arias, 1985 (2) *C. pilosa* Barber, 1937
Dipetalogaster	(1) *D. maxima* (Uhler, 1894)
Eratyrus	(1) *E. cuspidatus* Stål, 1859 (2) *E. mucronatus* Stål, 1859
Hermanlentia	(1) *H. matsunoi* (Fernández-Loayza, 1989)
Hospesneotomae	(1) *H. protracta* (Uhler, 1894) (2) *H. sinaloensis* (Ryckman, 1962) (3) *H. peninsularis* (Usinger, 1940) (4) *H. incrassata* (Usinger, 1939) (5) *H. barberi* (Usinger, 1939) (6) *H. neotomae* (Neiva, 1911) (7) *H. nitida* (Usinger, 1939)

Table 1. *Cont.*

Genus	Species
Linshcosteus	(1) *L. carnifex* Distant, 1904 (2) *L. chota* Lent & Wygodzinsky, 1979 (3) *L. confumus* Ghauri, 1976 (4) *L. costalis* Ghauri, 1976 (5) *L. kali* Lent & Wygodzinsky, 1979 (6) *L. karupus* Galvão, Patterson, Rocha & Jurberg, 2002
Mepraia	(1) *M. gajardoi* Frias, Henry & Gonzalez, 1998 (2) *M. spinolai* (Porter, 1934) (3) *M. parapatrica* Frías-Lasserre, 2010
Microtriatoma	(1) *M. borbai* Lent & Wygodzinsky, 1979 (2) *M. trinidadensis* (Lent, 1951)
Nesotriatoma	(1) *N. flavida* (Neiva, 1911) (2) *N. obscura* Maldonado & Farr, 1962 (3) *N. confusa* Oliveira et al., 2018
Paleotriatoma †	(1) *P. metaxytaxa* Ponair Jr., 2019 †
Panstrongylus	(1) *P. chinai* (Del Ponte, 1929) (2) *P. diasi* Pinto & Lent, 1946 (3) *P. geniculatus* (Latreille, 1811) (4) *P. guentheri* Berg, 1879 (5) *P. hispaniolae* Ponair Jr., 2013 † (6) *P. howardi* (Neiva, 1911) (7) *P. humeralis* (Usinger, 1939) (8) *P. lenti* Galvão & Palma, 1968 (9) *P. lignarius* (Walker, 1873) (10) *P. lutzi* (Neiva & Pinto, 1923) (11) *P. martinezorum* Ayala, 2009 (12) *P. megistus* (Burmeister, 1835) (13) *P. mitarakaensis* Bérenger & Blanchet, 2007 (14) *P. rufotuberculatus* (Champion, 1899) (15) *P. tibiamaculatus* (Pinto, 1926) (16) *P. tupynambai* Lent, 1942 (17) *P. noireaui* Gil-Santana et al., 2022
Parabelminus	(1) *P. carioca* Lent, 1943 (2) *P. yurupucu* Lent & Wygodzinsky, 1979
Paratriatoma	(1) *P. hirsuta* Barber, 1938 (2) *P. lecticularia* (Stål, 1859)
Psammolestes	(1) *P. arthuri* (Pinto, 1926) (2) *P. coreodes* Bergroth, 1911 (3) *P. tertius* Lent & Jurberg, 1965
Rhodnius	(1) *R. amazonicus* Almeida, Santos & Sposina, 1973 (2) *R. barretti* Abad-Franch et al., 2013 (3) *R. brethesi* Matta, 1919 (4) *R. colombiensis* Mejia, Galvão & Jurberg, 1999 (5) *R. dalessandroi* Carcavallo & Barreto, 1976 (6) *R. domesticus* Neiva & Pinto, 1923 (7) *R. ecuadoriensis* Lent & León, 1958

Table 1. *Cont.*

Genus	Species
Rhodnius	(8) *R. marabaensis* Souza et al., 2016 (9) *R. montenegrensis* Rosa et al., 2012 (10) *R. nasutus* Stål, 1859 (11) *R. micki* Zhao, Galvão & Cai, 2021 (12) *R. neglectus* Lent, 1954 (13) *R. neivai* Lent, 1953 (14) *R. pallescens* Barber, 1932 (15) *R. paraensis* Sherlock, Guitton & Miles, 1977 (16) *R. pictipes* Stål, 1872 (17) *R. prolixus* Stål, 1859 (18) *R. robustus* Larrousse, 1927 (19) *R. stali* Lent, Jurberg & Galvão, 1993
Triatoma	(1) *T. amicitiae* Lent, 1952 (2) *T. arthurneivai* Lent & Martins, 1940 (3) *T. atrata* Zhao & Cai, 2023 (4) *T. bahiensis* Sherlock & Serafim, 1967 (5) *T. baratai* Carcavallo & Jurberg, 2000 (6) *T. bassolsae* Alejandre Aguilar et al., 1999 (7) *T. bolivari* Carcavallo, Martínez & Pelaez, 1987 (8) *T. boliviana* Martinez et al., 2007 (9) *T. bouvieri* Larrousse, 1924 (10) *T. brailovskyi* Martínez, Carcavallo & Pelaez, 1984 (11) *T. brasiliensis brasiliensis* Neiva, 1911 and *T. b. macromelasoma* Galvão, 1956 (12) *T. breyeri* Del Ponte, 1929 (13) *T. carcavalloi* Jurberg, Rocha & Lent, 1998 (14) *T. carrioni* Larrousse, 1926 (15) *T. cavernicola* Else & Cheong, 1977 (16) *T. circummaculata* (Stål, 1859) (17) *T. costalimai* Verano & Galvão, 1958 (18) *T. deaneorum* Galvão, Souza & Lima, 1967 (19) *T. delpontei* Romaña & Abalos, 1947 (20) *T. dimidiata* (Latreille, 1811) (21) *T. dispar* Lent, 1950 (22) *T. dominicana* Ponair G Jr., 2005 † (23) *T. eratyrusiformis* Del Ponte, 1929 (24) *T. garciabesi* Carcavallo et al., 1967 (25) *T. gerstaeckeri* (Stål, 1859) (26) *T. gomeznunezi* Martínez, Carcavallo & Jurberg, 1994 (27) *T. guasayana* Wygodzinsky & Abalos, 1949 (28) *T. hegneri* Mazzotti, 1940 (29) *T. huehuetenanguensis* Lima-Cordón & Justi, 2019 (30) *T. indictiva* Neiva, 1912 (31) *T. infestans* (Klug, 1834) (32) *T. jatai* Gonçalves et al., 2013 (33) *T. juazeirensis* Costa & Felix, 2007 (34) *T. jurbergi* Carcavallo, Galvão & Lent, 1998 (35) *T. klugi* Carcavallo et al., 2001 (36) *T. lenti* Sherlock & Serafim, 1967 (37) *T. leopoldi* (Schoudeten, 1933) (38) *T. limai* Del Ponte, 1929 (39) *T. longipennis* Usinger, 1939 (40) *T. maculata* (Erichson, 1848) (41) *T. matogrossensis* Leite & Barbosa, 1953 (42) *T. mazzottii* Usinger, 1941 (43) *T. melanica* Neiva & Lent, 1941 (44) *T. melanocephala* Neiva & Pinto, 1923

Table 1. *Cont*.

Genus	Species
Triatoma	(45) *T. mexicana* (Herrich-Schaeffer, 1848) (46) *T. migrans* Breddin, 1903 (47) *T. mopan* Dorn et al., 2018 (48) *T. nigromaculata* (Stål, 1872) (49) *T. oliveirai* (Neiva, Pinto & Lent, 1939) (50) *T. pallidipennis* (Stål, 1872) (51) *T. patagonica* Del Ponte, 1929 (52) *T. petrocchiae* Pinto & Barreto, 1925 (53) *T. picta* Zhao & Cai, 2023 (54) *T. picturata* Usinger, 1939 (55) *T. pintodiasi* Jurberg, Cunha & Rocha, 2013 (56) *T. phyllosoma* (Burmeister, 1835) (57) *T. platensis* Neiva, 1913 (58) *T. pseudomaculata* Corrêa & Espínola, 1964 (59) *T. pugasi* Lent, 1953 (60) *T. recurva* (Stål, 1868) (61) *T. rosai* Alevi et al., 2020 (62) *T. rubida* (Uhler, 1894) (63) *T. rubrofasciata* (De Geer, 1773) (64) *T. rubrovaria* (Blanchard, 1843) (65) *T. ryckmani* Zeledón & Ponce, 1972 (66) *T. sanguisuga* (Leconte, 1855) (67) *T. sherlocki* Papa et al., 2002 (68) *T. sinica* Hsiao, 1965 (69) *T. sordida* (Stål, 1859) (70) *T. vandae* Carcavallo et al., 2002 (71) *T. venosa* (Stål, 1872) (72) *T. vitticeps* (Stål, 1859) (73) *T. williami* Galvão, Souza & Lima, 1965 (74) *T. wygodzinskyi* Lent, 1951 (75) *T. yelapensis* Téllez-Rendón et al., 2023

† = fossil taxa.

Figure 1. Dorsal view of a live *Rhodnius brethesi* specimen.

Figure 2. Dorsal view of a live *Rhodnius nasutus* specimen.

Figure 3. Dorsal view of a live *Triatoma longipennis* specimen.

American trypanosomiasis, also known as Chagas disease, is a parasitic infection caused by the protozoan *Trypanosoma cruzi*. The disease is endemic in the Americas, being present in 21 countries, where it affects about six million people and places approximately 70 million individuals at risk for living in endemic areas [16]. Named in honor of its discoverer, Carlos Chagas, the disease affects a wide range of wild vertebrate hosts and is primarily transmitted to humans through the vectorial contaminative route. This occurs when triatomines shed the parasite in their feces or urine, which can then enter the human body through the orifice caused by the bite, mucous membranes, or open wounds. Additionally, some animals (or humans) may become infected by consuming triatomines, or fruit contaminated with infected triatomines or their feces, which serves as an efficient vectorial-oral transmission route. Other routes of transmission include the oral route by ingestion of undercooked meat from wild animals, congenital transmission, blood transfusion, and laboratory accidents [17–19].

Figure 4. Dorsal view of a live *Panstrongylus megistus* specimen, showing typical morphological characteristics.

Figure 5. Dorsal view of a live *Panstrongylus megistus* specimen, showing atypical coloration on the pronotum.

Figure 6. Dorsal view of a live *Panstrongylus tibiamaculatus* specimen.

Although triatomines are also found in parts of Asia and Oceania, *Trypanosoma cruzi* has never been detected in these regions, indicating that vector-borne transmission does not occur there. In contrast, reported cases have increased in non-endemic areas such as North America and Europe, primarily due to migration from endemic countries. Congenital transmission has also contributed to the global spread of the disease, reinforcing its status as an emerging public health concern. Sustained efforts are essential to maintain current progress and prevent further expansion [20]. However, from an epidemiological perspective, vector-borne transmission remains a major concern in Mexico and in countries across Central and South America, where dozens of triatomine species have been reported [21–36] (Figure 7).

Figure 7. Number of Triatominae species by country. Sources: [21–37].

While all triatomine species in the Americas are potential vectors of *T. cruzi*, only a few species play significant epidemiological roles due to their domiciliary habits. However, species previously considered less relevant can become more important due to factors such as deforestation, environmental anthropization, and climate change. Given these dynamic shifts, understanding the geographic distribution and habitat preferences of triatomines is essential for guiding surveillance and control strategies for Chagas disease. Galvão and Justi [38] provided a comprehensive overview of triatomine ecology, ecological niches, and their association with humans, noting that approximately 70 species have been found naturally infected with *T. cruzi*.

Since the discovery of Chagas disease in 1909, triatomine bugs have remained a central focus of scientific research. Both biotic and abiotic factors influence their development and phenotypic variation. Their ability to adapt to synanthropic and urban environments further enhances their epidemiological relevance by facilitating increased contact with human populations. Research on their life cycle dynamics and behavioral ecology continues to advance, alongside numerous studies addressing their systematics, biology, biogeography, evolution, and vector control strategies. [39–41].

Vector control: historical background. The control of Chagas disease has emerged as a major success story over the past two decades, driven by regional and multinational initiatives focused on eliminating domestic vectors, improving blood donor screening, and providing supportive treatment for infected individuals. With the support of the Pan American Health Organization (PAHO) and the World Health Organization (WHO), numerous multinational efforts for vector control and surveillance in endemic countries have led to a significant decline in house-infesting triatomine bug populations [42].

Historically, vector control has been the primary strategy for preventing Chagas disease transmission. This approach has largely relied on indoor residual spraying (IRS) campaigns, which, when properly executed, have a long-lasting impact. During the implementation period, vector mortality gradually increased, while their carrying capacity simultaneously decreased. By the end of this period, the vector density stabilized at a new, lower level, considered to be under control. The duration of the implementation period reflects the initial effort invested in vector control, while the final reduction in vector density indicates the efficacy and coverage of the control measures [43,44].

The Southern Cone Initiative (INCOSUR), launched in 1991, was the first major multinational effort to combat Chagas disease. It focused on blood screening and insecticide-based elimination of *T. infestans*, the primary domiciliary vector in the southern cone region of South America. The initiative achieved significant success, drastically reducing *T. infestans* populations in Uruguay, Chile, Brazil, Argentina, and Paraguay. Building on this example, the Central American Initiative (IPCA) was launched in 1996, aiming to eliminate *Rhodnius prolixus* Stål, 1859 a South American species with exclusively domiciliary populations in Central America, and to reduce infestations of *Triatoma dimidiata* (Latreille, 1811) a native species found in sylvatic, intra and peridomiciliary environments [45]. Inspired by this success, additional regional initiatives were later established in the Andean Region (1997), Mexico (2003), and the Amazon Initiative (AMCHA) in 2004. To date, Brazil, Chile, Uruguay, and Guatemala have been declared free of Chagas disease transmission by their main vectors, alongside certain areas in Argentina and Paraguay [46]. These initiatives highlight the effectiveness of coordinated, region-specific strategies in reducing transmission of Chagas disease. Despite the success of these initiatives, active intradomiciliary transmission remains a persistent challenge, particularly in hard-to-reach rural communities across Latin America. In Brazil, for instance, the control of secondary triatomine species remains difficult, as the country harbors 64 species with diverse and often unpredictable vectorial capacities (i.e., their potential to acquire, maintain, and transmit the parasite to humans) [37]. Another critical issue in endemic countries is the financial and managerial challenges faced by national vector control programs in maintaining long-term surveillance across vast areas. In regions with decentralized health systems, these programs often struggle with inadequate funding and disorganization, further impeding effective disease control [47].

Housing improvement is a strategy with the potential to significantly reduce infestations; however, its long-term nature and high costs have restricted its integration into vector control programs, except for Venezuela and a few small-scale initiatives in other countries [48–51].

2. Methodology

This review aims to synthesize key aspects of the historical vector's discovery, control strategies, and citizen-based surveillance related to triatomine bugs. A narrative approach was adopted, focusing primarily on scientific literature published between 2000 and 2025. Articles were identified through searches in databases such as BibTri, PubMed, and SciELO, using combinations of keywords including "triatomine bugs", "Chagas disease control," "triatomine vector control", "community surveillance", and "citizen participation". Priority was given to review articles, field studies, and public health policy papers relevant to Latin America, with particular emphasis on Brazil. Additionally, publications and historical references published prior to 2000 were included when they provided foundational context or detailed the early development of vector control initiatives and surveillance systems. The extraction of information was guided by three central themes: the historical evolution of triatomine control programs; current strategies, achievements, and challenges in vector control; and the role and effectiveness of community-based and citizen-led surveillance. No formal quality assessment was conducted, given the descriptive nature of this review.

3. Discussion

Despite significant multinational initiatives, the long-term sustainability of control programs remains uncertain. The decentralization of public health systems, particularly in countries like Brazil, has resulted in disparities in surveillance capacity, funding, and technical infrastructure, hindering cohesive national responses. The fragmentation of surveillance efforts following decentralization has left many municipalities without permanent teams, led to high turnover among health agents, and contributed to low political prioritization. These factors directly result in limited household visit coverage, failures in data entry into the government data systems, and ultimately, ineffective passive surveillance. A more critical reflection on these systemic weaknesses and potential solutions, such as reinvestment in centralized coordination and cross-sector collaboration, is necessary to strengthen Chagas disease control efforts.

Rojas de Arias et al. [42] highlight the significant challenges in interrupting *T. cruzi* transmission via vectors, primarily due to its zoonotic nature and the involvement of over a hundred vector species widely distributed across the Americas. Compounding these difficulties is the increasing urbanization of triatomines, certain species, due to their biological and behavioral adaptability, are becoming more capable of surviving and thriving in urban environments. Over the past three decades, Latin America has seen a notable rise in recorded cases. Species from the genera *Triatoma* and *Panstrongylus* have been predominantly found in dwellings and exhibit the highest levels of parasite infection. Infected triatomine species have been documented from Argentina to the USA. Some species have even become intrusive, frequently entering homes and establishing colonies in urban areas [52–54] contributing to the increasing number of reported encounters in recent years. This evolving epidemiological scenario highlights the urgent need to adapt control strategies for urban vector populations to effectively mitigate the spread of Chagas disease [55]. Numerous studies have highlighted emerging challenges in the surveillance and control of triatomine vectors. Key concerns include hybridization among vector species, which complicates taxonomic classification and the evaluation of vector competence [14,15], as well as the growing issue of insecticide resistance, which compromises the effectiveness of conventional spraying strategies [44]. Addressing these challenges requires the continuous development and implementation of novel methodologies and technologies. In this regard, ecological niche modeling (ENM) has proven to be a valuable tool for predicting areas at risk and for optimizing the allocation of public health resources. Understanding the potential geographic distribution of key vector species is fundamental to assessing the spatial dimensions of disease transmission risk. ENM enables the analysis of geographic and ecological patterns based on verified species occurrence data. This approach has been widely employed to investigate Chagas disease transmission dynamics, including the delineation of ecological niches of vector species and the spatial associations between vectors and reservoir hosts [56].

More recently, the integration of advanced tools, such as machine learning algorithms, has demonstrated considerable potential to enhance entomological surveillance, particularly through the automation of vector image classification [57].

Challenges of vector control in a new epidemiological scenario: vectorial-oral transmission of Chagas disease. The emergence of oral transmission routes for Chagas disease presents new challenges for vector control in changing epidemiological landscapes. Two distinct pathways have been documented since the 1930s. Oral transmission occurs through the direct consumption of undercooked meat from infected reservoir hosts, while vectorial-oral transmission happens when food or beverages are contaminated with triatomine insects, their parasite-laden feces, or secretions from reservoir hosts. These transmission routes have been documented across Latin America, including Brazil, Colombia, Venezuela, Bolivia, Ecuador, Argentina, and French Guiana, with most cases arising from large-scale outbreaks linked to contaminated consumables. Such outbreaks underscore the growing public health significance of foodborne Chagas disease and the need for adapted control strategies beyond traditional vector-focused approaches. In their review, Velásquez-Ortiz & Ramirez [58] present a comprehensive overview of the current epidemiological landscape surrounding oral transmission of Chagas disease, compiling all available data to highlight its growing significance as a foodborne zoonosis with both veterinary and medical implications. Their work systematically examines the documented cases, transmission routes, and public health challenges associated with this alternative infection pathway.

In Brazil, vectorial-oral transmission has become an increasing concern, particularly in the Amazon region, where various palm species serve as the primary habitat for triatomine insects of the genus *Rhodnius* [59]. These palms provide ideal conditions for the development of triatomines and play a significant role in the epidemiology of Chagas disease, especially when located close to human dwellings. The insects often come into contact with harvested açaí, posing a risk of contamination either through their feces or by being inadvertently crushed during processing. This is especially concerning given that the consumption of fresh açaí is deeply rooted in local culture. These environments are characterized by high humidity, warm temperatures, dense vegetation, and precarious infrastructure.

Between 2012 and 2018, 1340 cases of orally transmitted acute Chagas disease were reported, with 1172 occurring in the state of Pará, the country's largest producer and consumer of açaí [60]. Since triatomine species in the Amazon region do not colonize homes but rather enter residences by flying in, insecticide-based control measures are ineffective. Additionally, installing protective window screens is challenging due to local environmental conditions. Therefore, the most viable approach is to promote good practices in food handling and preparation, a strategy that must be continuously reinforced by government authorities.

Citizen Science: A powerful tool for triatomine surveillance. Historically, triatomine species have been identified by experts using dichotomous keys based on morphological characteristics [61]. Over time, technological advancements have led to the development of electronic keys that can be used on computers or smartphones. Currently, two electronic keys for triatomine identification are available: TriatoKey, which includes 42 triatomine species recorded in Brazil [62] and TriatoDex, which includes 150 triatomine species described worldwide [63]. These applications have the potential to enhance routine entomological activities conducted by professionals, improve the accuracy and efficiency of triatomine monitoring, and support broader public health initiatives related to Chagas disease (CD). However, their use still requires a certain degree of knowledge about the morphology of these vectors, which limits accessibility for non-experts.

In this context, citizen science has emerged as a powerful and innovative tool to enhance triatomine surveillance. By engaging the public in data collection and reporting, citizen science initiatives can enhance triatomine monitoring, especially in regions with limited professional resources. This collaborative approach not only increases public awareness about Chagas disease and its vectors but also fosters community involvement in vector control efforts. Citizen science systems can be organized through specialized education programs, various social networks, websites, and text messaging applications. Successful examples of citizen science in triatomine surveillance have been documented in several Latin American countries, where community participation has complemented traditional surveillance methods, leading to more effective detection of infestations and timely interventions.

Abad-Franch et al. [64] emphasized the efficiency of community-based vector tracking methods over traditional active-search approaches, demonstrating that community-driven initiatives have historically been more successful in interrupting the household re-infestation cycle of vector species. Similarly, Curtis-Robles et al. [65] highlighted the effectiveness of citizen science approaches in the southern United States, showing that they not only generate essential data on vector phenology and infection prevalence but also play a crucial role in educating the public about the observable aspects of the disease. These tracking and reporting methods have gained traction, proving particularly valuable in communities heavily affected by neglected tropical diseases [66].

Gonçalves-Oliveira et al. [67] organized science fairs in two municipalities in the northern region of Minas Gerais, Brazil, both of which are endemic for Chagas disease in rural and urban areas. The study evaluated participants' prior knowledge through a series of questions and involved them in voluntary educational sessions facilitated by mediators. The results revealed that critical aspects of Chagas disease prevention and control, such as host and vector diversity, as well as household risks, were either overlooked in local education initiatives or unknown to the populations in both municipalities. This underscores significant gaps in public awareness and education regarding the vector-borne transmission of the disease. The study concludes that zoonoses, particularly CD, should be incorporated into basic education and health professional training programs.

Yoshioka [68] implemented a successful community-based bug-hunting campaign in Guatemala. The campaign effectively detected vectors within a short period, provided valuable data to update the vector infestation map, and increased both community and political awareness regarding Chagas disease.

Delgado-Noguera et al. [69] conducted the named Trae Tu Chipo (BringYour Kissing Bug) campaign in Venezuela, a pilot initiative that collected data through online surveys, social media platforms, and telephone text messages. This campaign served as a strategic effort relying on community engagement to define the current ecological distribution of triatomines, despite the absence of a functional national surveillance program.

More recently, Amaral et al. [70] conducted a study on community-based surveillance for Chagas disease in a high-risk region of Latin America, focusing on the role of Triatomine Information Posts (TIPs), designated locations where community members can submit suspected vector insects to support public health efforts. The study revealed a heterogeneous pattern in the implementation and functioning of TIPs, accompanied by low levels of public engagement and utilization. The findings underscore an urgent need for health systems to be structured in a way that supports regulated surveillance with active community participation, alongside awareness campaigns aimed at preventing future household reinfestations by triatomines and the resurgence of Chagas disease transmission in endemic areas.

One notable initiative is the Chagas disease Portal (https://chagas.fiocruz.br/, accessed on 10 June 2025), launched by the Oswaldo Cruz Foundation (Fiocruz), Brazil, to popularize knowledge about Chagas disease and extend entomological surveillance to the general population. Through this platform, citizens can contribute by submitting photos of insects, which are then reviewed by experts who identify the species and assess its medical significance. Another important example is GeoVin (http://geovin.com.ar/ accessed on 10 June 2025), a platform that collects geographic data on Argentinean triatomines by enabling citizens to report bug sightings. Users can submit photos and geographic coordinates online, which are automatically stored and integrated into the GeoVin occurrence database [71].

A more recent initiative is the "WhatsBarb" tool, developed by Paz et al. [72], which leverages the widely used WhatsApp application to allow users to submit photographs of suspected triatomine insects for expert identification. By utilizing a platform already familiar to most users, WhatsBarb facilitates seamless communication and data collection without the need for additional app downloads, thereby streamlining the process of reporting observations and resolving inquiries.

On a global scale and dedicated to biodiversity more broadly, the iNaturalist platform (https://www.inaturalist.org/ accessed on 10 June 2025) stands out. iNaturalist allows users worldwide to record observations of living organisms by uploading photos and location data through a web interface or mobile app. These observations are then verified collaboratively by the community and experts, contributing to a large, open-access database. The platform supports biodiversity monitoring, species distribution mapping, and public engagement in science. Its major advantages include fostering citizen participation, providing high-quality data for researchers, and promoting environmental awareness and education.

These initiatives demonstrate the significant potential of citizen science to enhance triatomine surveillance by engaging communities and leveraging accessible, user-friendly technologies. Citizen science initiatives are often supported by mobile applications and online platforms designed to be intuitive and easy to use, enabling non-experts to participate effectively. However, challenges remain in ensuring the accuracy of species identification, maintaining long-term participant engagement, and effectively integrating citizen-collected data with formal surveillance systems. Addressing these challenges is critical to optimizing the impact of citizen science initiatives and ensuring their sustainability. Overall, by leveraging the collective efforts of communities, citizen science represents a promising strategy for strengthening triatomine surveillance, raising public awareness, and contributing to the prevention and control of Chagas disease.

4. Conclusions

In summary, significant strides have been made in the control of triatomines and Chagas disease through coordinated multinational programs, community-based strategies, and the application of innovative technologies. However, emerging challenges, such as urban expansion, ecological changes, and the increasing relevance of oral transmission underscore the need for dynamic, context-specific responses. To ensure long-term impact, it is imperative to strengthen intersectoral coordination under the One Health framework, reinforce community participation in surveillance systems, and institutionalize health education initiatives. The incorporation of digital tools and real-time data platforms into surveillance networks will be critical for improving responsiveness, optimizing resource allocation, and preventing the reestablishment of transmission cycles in both rural and urban endemic areas. In this context, digital platforms and citizen science initiatives offer the added advantage of being low-cost alternatives, an especially important consideration amid ongoing budgetary constraints faced by public health programs. Furthermore, connecting these initiatives with the One Health framework, acknowledging the interconnectedness of human, animal, and environmental health, can foster integrated strategies that are more resilient to ecological and social shifts

Funding

The author gratefully acknowledges financial support from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ).

Acknowledgments

The author sincerely thanks the two anonymous reviewers for their valuable comments and suggestions, which significantly contributed to improving the original version of this manuscript.

Conflicts of Interest

There is no conflict of interest.

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