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A multidisciplinary, collaborative, inter-agency and comprehensive approach for the control of Chagas Disease as a public health problem in Guatemala

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A R T I C L E I N F O

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A B S T R A C T

The Pan American Health Organization (PAHO) has defined Chagas Disease hotspots in Central America associated with the vector *Triatoma* spp. *Triatoma dimidiata* is a native vector adapted to multiple environments, including intra-domestic and peri-domestic habitats. A multi-institutional project named "Alliances for the elimination of Chagas in Central America" was created to help reduce the incidence of the disease in the region. Activities performed in the field as part of the project included aspects of vector surveillance and control, improvement of houses, diagnosis and treatment of individuals, health promotion, training of human resources and identification of access barriers to diagnosis and treatment. As a base line study, eleven villages, comprised of 1,572 households, were entomologically evaluated (83.4% overall participation); five were found to have very high infestation rates (>20%), three had high infestation rates (8-20%) and three had low-infestation rates (<8%), coinciding with the category of infestation-risk of the houses within each village. Serological tests were carried out in 812 people (>80% participation) in two of the 11 villages and none of the 128 children tested, less than 5 years of age, were positive for *Trypanosoma cruzi* infection. Community participation in all the activities was high (>70%). The collaboration between several subnational, national, and international institutions, each with specific roles, promoted community participation in the activities of vector control and patient care, thus, establishing a baseline to continue implementing and monitoring project progress.

1. Introduction

Chagas Disease is the leading cause of death associated with heart disease in Latin America (Chatelain, 2015), with more than 8 million people at risk (World Health Organization, 2015). Central America and Mexico have always been endemic areas for Chagas Disease, with the

Abbreviations: CAP, Capacities, Attitudes and Practices; DASJ, Jutiapa Health Area; DC-USAC, Cytohistology department, School of Pharmacy, University of San Carlos of Guatemala; DNDi, Drugs for Neglected Diseases *initiative*; ES, Entomological Survey; ETV-MSPAS, Vector Control Unit, Ministry of Public Health and Social Assistance; FMS, Fundación Mundo Sano; HAI, Hemagglutination; LENAP-USAC, Laboratory of Applied Entomology and Parasitology, University of San Carlos of Guatemala; LNS-MSPAS, National Health Laboratory, Ministry of Public Health and Social Assistance; masl, meters above sea level; MC, Municipality of Comapa; MSPAS, Ministry of Public Health and Social Assistance; RIA, Routes of Care.

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presence of a diversity of native Triatomine species, vectors of *Trypanosoma cruzi*, among which *Triatoma dimidiata* stands out, given its important ability for colonizing domestic and peri-domestic habitats. Additionally, during the 20th century, an accident led to the introduction of an important allochthonous species in the region, originally from the north of South America, *Rhodnius prolixus* (Dujardin et al., 1998). This introduction increased the number of cases, due to the better vector competence and domiciliation of this species, until its control / elimination was achieved during the first decades of the 21st century (Hashimoto and Schofield, 2012) through international programmatic actions and cooperation among countries, within the framework of the Chagas Control Initiative in Central America and Mexico (IPCAM).

Currently, *R. prolixus* has been eliminated as a public health problem in El Salvador, Nicaragua, Guatemala, Honduras, Mexico, Costa Rica, and Belize; however, the native species, *T. dimidiata* is still present and responsible for vector transmission in the area (Hashimoto and Schofield, 2012; OPS, 2011; OPS, 2019). At the XVI Meeting of the IPCAM, the space shared by Guatemala and El Salvador was defined as a high-risk area or "hotspot" which should be prioritized and addressed to achieve control of Chagas Disease in the region (Pons et al., 2015). Based on this scenario, an inter-institutional agreement was signed between different public and private organizations. As part of this agreement, a project under the name “Alliances for the elimination of Chagas in Central America” was elaborated with the objective of contributing to the elimination of Chagas Disease as a public health problem in the area of greatest transmission in Guatemala through the development of tools, methodologies, and transfer of technology suitable for transmission control in Central America. This association of national and international institutions allowed complementary actions, based on the experience and specialization of each organization, which addressed most of the aspects that contribute to the presence of the disease in the region regarding the link between person, vector, environment, habits, and behavior, in a comprehensive approach.

The transmission of *T. cruzi* is complex and it is influenced by ecological and socioeconomic aspects that need to be taken into consideration for its comprehensive control. In the *vector domestic cycle*, which results from the permanence and reproduction of triatomines inside the home and peri-domestic areas, elimination requires vector control mechanisms based on household risk factors, such as the physical characteristics of households and cultural practices within the home (Bustamante et al., 2009), as well as vector dynamics. The characteristics and structure of the community is also important to develop participatory surveillance activities (vector findings, search and follow-up of positive patients), as well as adequate environmental management. In the *mother-to-child transmission cycle*, improvement in access to adequate medical care is required (Ávila Montes et al., 1998; Balouz et al., 2017; Zeledón and Rojas, 2006). Finally, appropriate care of any infected person is needed and may be achieved through early diagnosis, the use of antiparasitic agents and/or appropriate medical treatment that can prevent or delay the progression of complications due to chronic Chagas Disease, significantly mitigating morbidity (Viotti et al., 2006; PAHO, 2018).

Access to diagnosis, treatment and comprehensive care is limited by several factors that need to be identified to proceed in consequence and implement strategic approaches that promote the removal of barriers to health care. The aim of this study is to present the Alliances Project and the preliminary results of the baseline implementation performed in Guatemala, which included aspects of vector control, housing quality, surveillance implementation, diagnosis, identification of barriers for a comprehensive healthcare, community participation promotion, and training of human resources that will serve for the development of tools, methodologies and the intervention evaluation at different points throughout project implementation.

2. Methodology

2.1. Study area

The Municipality of Comapa (Jutiapa Department) is located on the Guatemala-Salvador border (Fig. 1) and is part of the region defined as a "hotspot" of importance for the control of Chagas Disease in the region, shared between Guatemala, El Salvador, and Honduras (Pons et al., 2015). Its geography corresponds to subtropical dry forest, predominantly deforested by the change of land use for productive activities such as monocultures and grasslands for livestock (Griscom and Ashton, 2011; Penados et al., 2020). It has an average elevation from 540 to 1350 meters above sea level and temperatures ranging from 22 °C to 32 °C (14.11328; -89.914811) (INSIVUMEH, 2020).

Jutiapa has been characterized by the Ministry of Public Health and Social Assistance (MSPAS) of Guatemala as a department with high epidemiological risk for Chagas Disease due to the high levels of triatomine infestation documented, including usual re-infestations after vector control with insecticide spraying (Bustamante et al., 2015). Comapa has sociodemographic characteristics that also contribute to its high risk classification, including the highest rate of illiteracy among all the municipalities of Jutiapa, with most of its population living in rural areas under poverty conditions (72%) and more than a quarter of them living in extreme poverty (INE, 2014).

The project's field actions were performed during 2018 and 2019 in 11 villages from the Municipality of Comapa: Anonito, Matochal, San Cristóbal, San Antonio, Ixcanal I, Ixcanal II, San Ramón, El Naranjo, Piedra Pintada, El Pinito and San Miguel (Fig. 1), with a total population of 6,096 people distributed in 1,572 households. The selection of the villages was done based on previous reports of infestation by the Ministry of Health and the area was recommended by IPCAM-PAHO in 2015. The actions included household surveys, vector surveillance and control, house improvements, a seroprevalence study, and a seminar for identification of healthcare access barriers. Given the multidisciplinary and inter-agency collaboration characteristic of the project, secondary information was also gathered through surveys (entomological, social), primary prevention actions (spraying, house improvement, and technical training of local human resources), secondary prevention actions (activities to strengthen local capacities to detect, diagnose and treatment of patients), health promotion and human resources training (community activities, workshops, diplomas, trainings and consultancies). These activities were performed by the project's different participating institutions which coordinated each activity through a Framework Conventions for Technical Cooperation between the MSPAS, national academic institutions, and two non-governmental associations (NGOs): Fundación Mundo Sano (FMS) and Drugs for Neglected Diseases *initiative* (DNDi). The entire list of participants is included in Supplementary Material Table 1.

2.2. Household surveys and risk definition

All the houses in the area were registered and georeferenced by the Laboratory of Applied Entomology and Parasitology from the University of San Carlos of Guatemala (LENAP-USAC). Moreover, the characteristics of the household (sleeping areas, warehouses, kitchen, etc.) were recorded by direct observation. Empty, abandoned, and houses under construction were also recorded during either primary or secondary preventive actions. Individuals who did not wish to participate were excluded from the activities. Additionally, the head of the family or an elderly resident was interviewed to learn about capacities, attitudes, and practices (CAP) related to vector transmission of the disease.

Since 1992, different risk measurements for the presence of triatomine bugs have been evaluated. Results showed that 80% of *T. dimidiata* were found in wall cracks (Monroy et al., 1998), mainly in houses constructed with mud. Over the years, we found other risk factors such as dirt floor, animals sleeping exclusively inside the house,

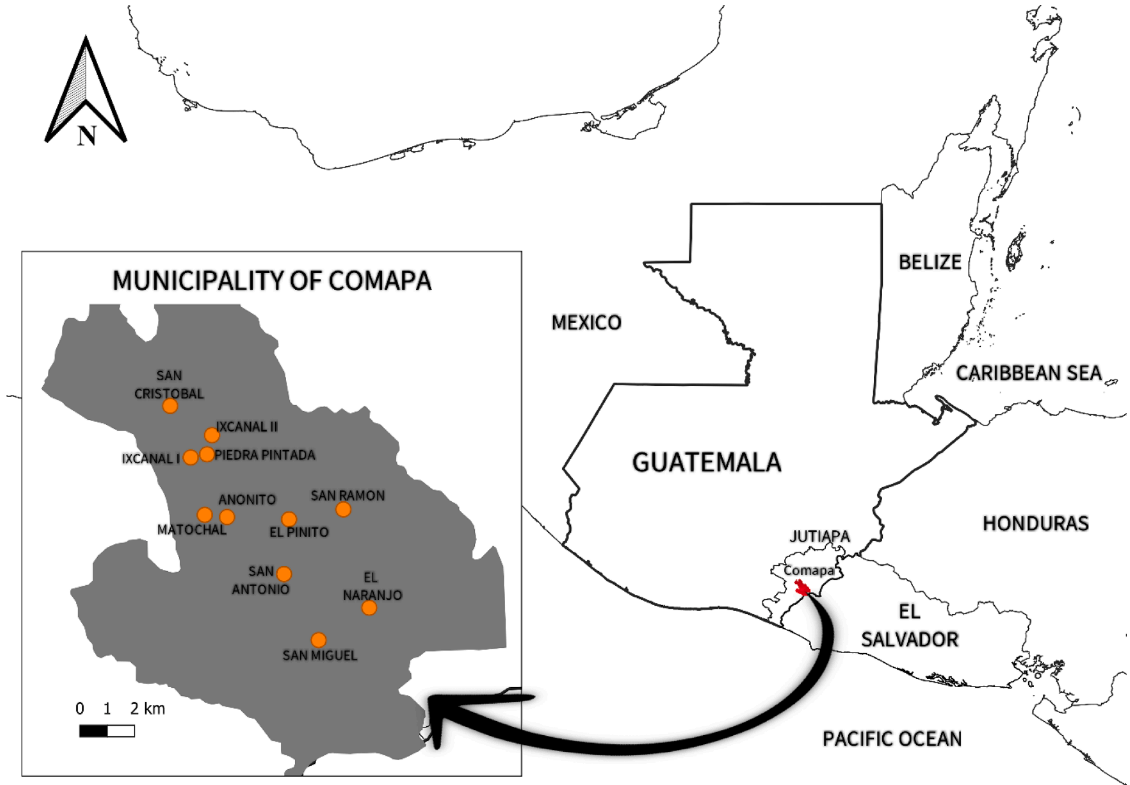

Fig. 1. Study area showing the location of the 11 baseline villages within the Municipality of Comapa in the department of Jutiapa, Guatemala.

presence of chicken coops inside the house, or the accumulation of construction materials. Field experience over the years and detailed studies of risk factors were used to develop a house risk score (Bustamante et al., 2009, 2015). Type A houses are considered at low risk of infestation by *T. dimidiata*, while type B houses are considered to have average risk and C houses are of high risk. The risk categorization facilitated the field control processes. Table 1 details the variables considered as well as the assigned scores for each characteristic to categorize the houses into the three different types.

2.3. Preventive actions in primary and secondary interventions

The different actions performed may be divided as those related to primary prevention and those related to secondary prevention.

Table 1
Risk variables for *Triatoma dimidiata* infestation. Household risks are categorized into three categories: A (low risk) ≤2.5 points; B (average risk) ≤4.4 points; and C high risk ≥4.5 points.

Variable	Points
Walls built with traditional *bajareque* (sticks and straws intertwined with mud) or adobe with the presence of cracks	3.5
Presence of triatomine bugs or any of their traces (i.e., fresh, or old feces, exuviate)	1.5
Presence of animals inside the household	1.0
Chicken coop inside the house or attached to one of the walls of the household	1.5
Presence of wood or firewood inside the household	0.5
Presence of construction materials inside the household	0.5
House constructed more than 6 years ago	0.5
Visible accumulation of objects or clutter	0.5
Presence of a dirt or badly broken floor	0.5

2.3.1. Primary prevention: base line, entomological surveillance and house improvement

2.3.1.1. Base line data and Vector surveillance. An entomological survey (ES) was conducted by the Vector Control Unit (ETV–MSPAS) based in Jutiapa in two different times: in *Time 1,* the man/hour methodology was used for the active search of kissing/triatomine bugs in homes with the help of tweezers and a flashlight (Monroy et al., 1998) and in *Time 2 (flush out),* vectors were searched by one person, 20 min after insecticide application. All the houses were sprayed inside and outside. A house is considered positive if a vector is captured during either *Time*.

Collected live specimens were placed in an appropriately labeled container with the collection date, name of the head of the household, house identification number, place of capture (intra or peridomicile) and number of specimens collected. Approximately 5 to 8 h post field collection, the samples were transferred to individual, properly identified vials with 95% ethanol for their preservation, with capture and demographic information (sex or life stage and whether it appeared engorged or not, indicating if it had fed recently) recorded in a notebook and an electronic database.

The data obtained was digitized in Microsoft Excel sheets and subsequently uploaded to a Data Management Platform, which also allows uploading the geolocation of the households and the associated epidemiological information in a Geographic Information System (GIS).

2.3.1.2. Entomological indexes and vector control. Four entomological indexes were used to evaluate the situation of each village: 1) infestation rate; 2) overcrowding rate; 3) colonization rate; and 4) visitation rate.

Vector control was achieved by spraying with a pyrethroid insecticide in all homes, regardless of the house risk category (A, B or C). Beta Cypermethrin (Sipertrin-Asimethrin 5g, Chemotecnica, Argentina) solution was used at a concentration of 5% of 50 mg per square meter on the wall with a Hudson manual pump. Ten to 20 min after spraying, the triatomines that escaped from their hiding/refuge spots were collected as specified under vector surveillance.

2.3.1.3. House improvement and environmental management. House improvement is based on community participation. It includes covering of walls using local materials (i.e. river sand, lime and volcanic ashes) to avoid the formation of cracks, and replacement of the floor with cement-like material instead of dirt (Monroy et al., 2003; Pellecer et al., 2013). The materials needed were provided in part by the authorities of the Municipality of Comapa; by the project and by the inhabitants of the community themselves. The community members, families and authorities were trained in the different house improvement techniques, while project staff monitored, guided, and recorded the improvements. Weekly monitoring of the improvements was conducted to organize the partial and sequential provision of materials; upon completion of the walls, the floor materials were delivered.

Environmental management was accomplished through community training workshops, as explained by Soto *et. al.* (2019). The community and local authorities received information on the risks of maintaining animals, accumulating objects, firewood, and construction materials inside the households. Individuals were instructed to relocate all materials to the peridomicile, away from the house walls, especially if the walls were made of *bajareque* or *adobe* (Soto et al., 2019).

2.3.2. Secondary prevention

2.3.2.1. Serological study. In June 2018 and January 2019, two villages with the highest rate of vector infestation (Anonito and Matochal) were selected to begin sampling for a total population serological study. Sampling was carried out along with the collaboration of bachelor students from Biological Chemistry (Department of Cytohistology, School of Pharmacy, University of San Carlos of Guatemala - DC-USAC). The community was informed in advance of the benefits and risks of the activity, as well as the objectives of the study, the procedure, and the timing of the sampling. The study was approved by the Ethics Committee of the University of San Carlos (approval AC-010-2018) along with an epidemiological data sheet for each family. Additionally, informed consents were obtained from all those individuals that were interested in participating, including informed assent from children between the ages of 12 and 17 years.

Diagnostic tests were carried out based on PAHO recommendations (PAHO, 2018), and the regular practices of the Ministry of Health in Guatemala. Blood was drawn through venipuncture (5 ml total) and the serum was separated through centrifugation, aliquoted in 1 ml tubes and transported while refrigerated to the USAC laboratory to determine the presence of anti-*T. cruzi* antibodies by indirect hemagglutination (HAI, Wiener Argentina). ELISA lysate (Wiener laboratories) was used as the second test for all the positive samples and 10% of the negative ones. Samples with discordant results were confirmed by recombinant ELISA (Wiener, SAIC, Argentina). An individual was considered positive if two of the tests performed were positive; confirmed positive samples were then processed by a semi-qualitative HAI to determine antibody titles. Since only the patients confirmed as positive by the National Health Laboratory of the Ministry of Health (LNS-MSPAS) could receive the treatment; all positive samples and 10% of negative samples (different form the first ones tested) were submitted to the LNS-MSPAS for evaluation. Once the results were confirmed by the LNS-MSPAS, they were transferred to the Jutiapa Health Area (DASJ-MSPAS) to coordinate the initiation of treatment, if appropriate, and to guarantee comprehensive care of all these patients in the Chagas Clinic located in the Comapa health area. The delivery of both positive and negative results to the communities was carried out by DASJ-MSPAS staff, as well as the monitoring of the treatment.

2.3.2.2. Seminar for the identification of access barriers. To analyze the factors that act as barriers to the access to diagnosis and treatment of Chagas Disease in the area, a seminar was offered to health care officials, (professionals, technicians and support personnel), health authorities, academic referents, municipal authorities, Chagas patients, health promoters, community vector personnel, traditional midwives and a community organized into committees (COCODE - community development councils - COMUDE: municipal development council), from endemic regions/areas of Guatemala. Barriers refer to any factor that limits or inhibits patient access to diagnosis, treatment and/or clinical management of Chagas Disease (Forsyth et al., 2019). The aim of the seminar was to identify barriers to comprehensive people's care based on a participatory technique, specifically on the challenge model (Management Sciences for Health, 2009). Working groups were established and distributed into 4 themes: 1) Diagnosis; 2) Treatment; 3) Epidemiological and entomological surveillance and 4) Congenital transmission. The working groups (each with representatives of the participants' groups) determined the obstacles for each of the discussion components and prioritized and classified them according to four established categories: 1. Guidelines and procedures, 2. Services and Health System, 3. Supplies and infrastructure, 4. Individual and community. Challenge methodology (Management Sciences for Health, 2019) was used in the working groups. Identification of the main access barriers is key for the future elaboration of a comprehensive and effective care roadmap.

3. Results

The results of these first interventions and baseline study correspond to the 11 communities mentioned above, which were used as a pilot to evaluate the methodology and write operational guidelines for both primary and secondary prevention actions.

3.1. Primary prevention actions

3.1.1. Household surveys and risk definition

A total of 1,572 dwellings were registered and 1,311 (83.4%) were assessed. From these 1,311 assessed households, 175 (13.3%) were uninhabited and 67 (5.1%) were closed (Table 2). Only 10 of the visited homes (0.8%) rejected domiciliary inspection. The percent participation in each of the villages varied from one to another, with very high participation in Piedra Pintada (98%), Matochal (90.3%), and San Miguel (89.1%) and lower participation in San Antonio (72.1%), Ixcanal II (73.4%), and San Cristobal (75.0%).

Assessment of the households showed that many of the houses belonged to category B and C, which are at higher risk of infestation. The results of the risk categorization from each village are detailed along with home improvements in Table 4. The villages with the highest percentage of B and C category households were Ixcanal I (78.7%), Piedra Pintada (77.1%) and El Naranjo (76.9%), while the ones with the lowest percentage of B and C category households were San Cristóbal (46.6%), El Pinito (46.8%) and San Ramón (53.8%).

Table 2
Community participation in household surveys conducted in the 11 villages of Comapa, Jutiapa (Guatemala), included in the study.

Village	Surveyed	Closed	Uninhabited	Total	Participation
Anonito	184	4	21	211	87.2%
El Naranjo	52	5	5	62	83.9%
El Pinito	47	8	1	56	83.9%
Ixcanal I	136	5	18	160	86.3%
Ixcanal II	141	4	41	192	73.4%
Matochal	65	2	4	72	90.3%
Piedra Pintada	153	0	2	155	98.7%
San Antonio	75	17	12	104	72.1%
San Cristobal	174	8	43	232	75.0%
San Miguel	180	9	12	202	89.1%
San Ramón	104	5	16	126	82.5%
Total	1311	67	175	1572	83.4%

3.1.2. Vector surveillance and control

During the vector surveillance activities, no *R. prolixus* specimens were found, not even in the villages which had previously reported its presence. The infestation indexes vary among villages, as shown in Table 3. Five of the villages had an infestation rate greater than 20%, which is considered to be a very high infestation rate in this area; these were Anonito, Matochal, San Antonio, Ixcanal II, and Piedra Pintada. The villages identified as having a high infestation rate (8% - 20%) were Ixcanal I, El Pinito, and San Cristóbal, and those identified as having a low-infestation rate (less than 8%) were San Miguel, El Naranjo and San Ramón. More importantly, all the villages included in the study had a colonization rate greater than 50%, most villages even had colonization rates greater than 75%. Moreover, several villages showed important rates of triatomine overcrowding within the household, like El Naranjo (10.7), San Antonio (10.2) and Matochal (8.7). Finally, the highest triatomine visitation rates were found in the villages of San Miguel (50.0%), Piedra Pintada (35.1%), and Ixcanal I (33.3%). All households were controlled by the local health agents with insecticide spraying (inside and outside), independently if they were positive or not.

Fig. 2 shows an altitudinal pattern in the infestation rates. The low infestation villages (<8% infestation index) are located precisely under 500 meters above sea level (masl), and the high infestation villages (>20%) are located between 1000 and 1450 masl. Areas between the 500 and 1000 masl range act like a transition area, with the presence of medium and high infestation villages in this range.

3.1.3. House improvement

Participation in wall and floor improvement activities in the different villages is described in Table 4, along with the results of house risk evaluation. The villages with the greatest participation for home improvement were Piedra Pintada and Matochal, with 78.8% and 78.9% participation, respectively, followed by Ixcanal II (70.4%) and San Miguel (67.9%). The villages with the lowest percentage of participation were El Pinito (45.5%), San Antonio (41.8%) and San Cristóbal (21.0%).

3.2. Secondary prevention actions

3.2.1. Serological study

The serological analysis performed in the villages of Anonito and Matochal (Table 5) showed high participation rates: 71.8% (619 participants/861 inhabitants) in Anonito and 72.8% (193 participants/265 inhabitants) in Matochal. Anonito had a higher percentage of positive individuals, with a total seroprevalence of 7.3%, compared to Matochal which had a seroprevalence of 3.6%. In both villages, the percentage of positive women was higher than that of men: in Anonito, 5.3% of positive individuals were women and 1.9% were men, while in Matochal 2.6% were women and 1.0% were men. Finally, in both villages, none of the participating children under 5 years of age were found to be infected. Nonetheless, Anonito presented positive results in individuals from the age range of 6 to 14 years, while Matochal only presented positive individuals from the age range of 21 to 40 years.

3.2.2. Seminar for the identification of access barriers

The seminar carried out for the identification of access barriers to the diagnosis and treatment of Chagas Disease in the area involved 90% of the units which work with Chagas Disease Care in the country, from both the national (MSPAS) and departmental (DASJ, Chiquimula Health Area) health sectors. Organizations from the civil society (Community Leaders of Comapa, COCODEs, COMUDEs), Chagas patients, other local Institutions (LENAP/USAC) and international partners (FMS, DNDi) also participated.

The barriers identified in the seminar are described in Table 6. According to the participants of the seminar, the main access barriers to diagnosis are process centralization, lack of professional and specific training and the lack of socialization of regulations. Regarding the main barriers to treatment, those identified as most important were outdated protocols, lack of trained personnel, delays in diagnostics and lack of equipment and reagents for clinical evaluation prior to etiological treatment. About epidemiological surveillance, the participants agreed that main barriers included the fact that Chagas Disease did not stand out as a priority for guidelines, the centralization of health services, and the lack of comprehensive information in the community (i.e. effect of deforestation and hygiene). Finally, specifically concerning congenital transmission, the main barriers identified were excessive bureaucracy, lack of information records, lack of parental screening processes, and lack of perception of risk and education in the community.

4. Discussion

Working in the community in an interinstitutional, cross-sectoral, multidisciplinary and collaborative manner produces irrefutable benefits and improvements in the quality of physical, mental and social health (Rosales, 1999). A systemic vision to tackle different problems from various points of view enables the implementation of more effective actions (Molina-Marín et al., 2018).

A threshold was determined after eliminating *R. prolixus*; an infestation rate of *T. dimidiata* of 8% indicated that disease transmission would become unlikely (Aiga et al., 2012). Thus, an infestation lower than 8% could be considered low risk, between 8-20% as high and greater than 20% as very high. Entomological index variations were associated with the rates of vector infestation and coincided with the calculated risk obtained for the households. Very High infestation values (>20%) coincided with a greater than 40% presence of type C dwellings in the villages (Table 4). This is consistent with the presence of risk variables such as cracked walls, animals inside the house, clutter, firewood or construction materials accumulated inside of the household, as well as the presence of dirt floors, increasing the possibility of household triatomine infestation (Bustamante et al., 2009, 2015).

Ixcanal I village had a high percentage of type B and C dwellings (78.7%) and a high infestation rate (15.4%). The visitation rate of

Table 3
Values of the entomological indexes calculated for *Triatoma dimidiata* in the 11 villages from the Municipality of Comapa, Jutiapa (Guatemala), included in the study.

Villages	Homes Surveyed (N)	Infestation rate (%)	Overcrowding rate	Colonization index (%)	Visitation rate (%)
Anonito	184	34.4	4.7	77.8	22.2
El Naranjo	52	5.8	10.7	100.0	0.0
El Pinito	47	10.0	7.6	100.0	0.0
Ixcanal I	136	15.4	3.5	66.7	33.3
Ixcanal II	141	27.0	4.0	76.3	23.7
Matochal	65	33.3	8.7	77.3	22.7
Piedra Pintada	153	24.2	5.9	64.9	35.1
San Antonio	75	29.7	10.2	77.3	22.7
San Cristóbal	174	15.8	8.4	78.6	21.4
San Miguel	180	4.4	1.9	50.0	50.0
San Ramón	104	7.6	2.3	87.5	12.5

Infestation rate = (Infested homes/total homes inspected) x 100. **Overcrowding** rate = Triatomine bugs captured/total infested homes. **Colonization index** = (Houses with nymphs / total infested homes) x 100. **Visitation rate** = (Homes with only adult triatomine bugs/total infested homes) x 100.

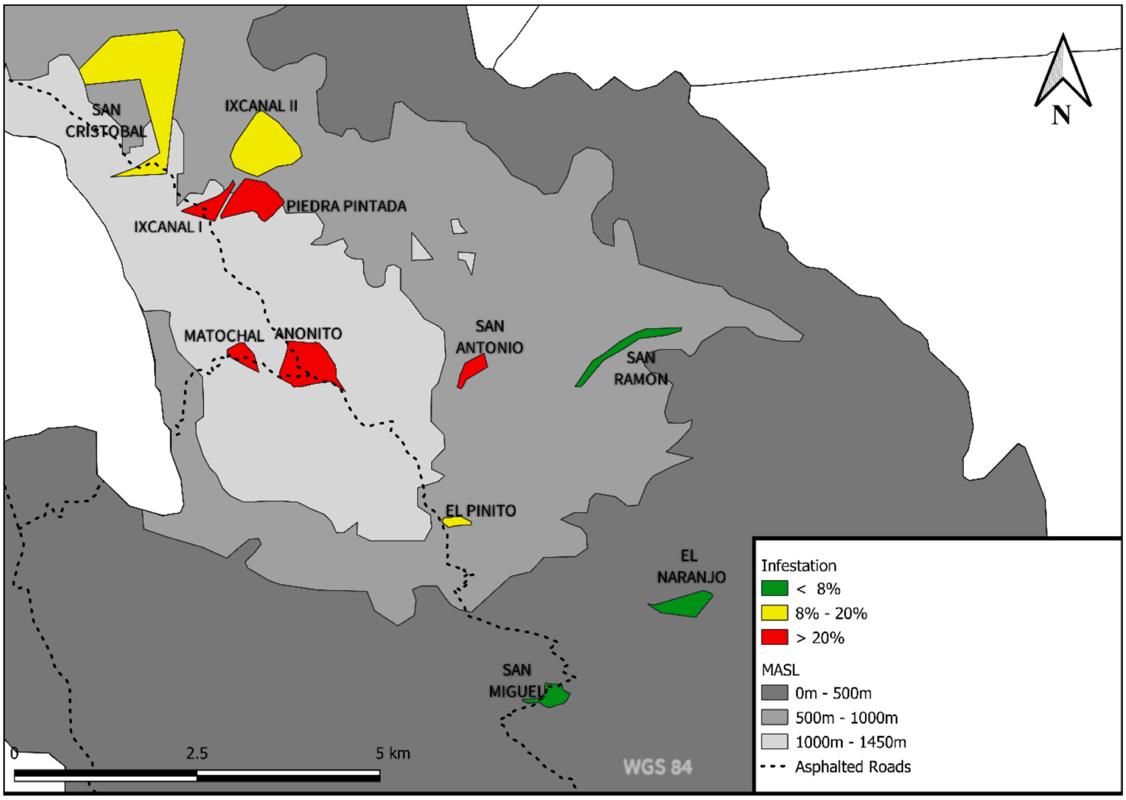

Fig. 2. Infestation range of the 11 villages in Comapa, Jutiapa. The map shows the infestation range, low (<8%), medium (8% – 20%) and High (>20%), of the project's 11 baseline villages.

Table 4
Assessment of homes at risk of *Triatoma dimidiata* infestation in the 11 villages of the Municipality of Comapa and percentage of houses improved by the community.

	Homes at risk (Categories B and C)		Improvement of at-risk housing (B and C)	
Village	N houses	%	N houses	%
Anonito	121	65.7	59	48.8
El Naranjo	40	76.9	22	55.0
El Pinito	22	46.8	10	45.5
Ixcanal I	107	78.7	71	66.4
Ixcanal II	98	69.5	69	70.4
Matochal	38	58.5	30	78.9
Piedra Pintada	118	77.1	93	78.8
San Antonio	55	73.3	23	41.8
San Cristóbal	81	46.6	17	21.0
San Miguel	112	62.2	76	67.9
San Ramón	56	53.8	30	53.6

Category A houses are at low risk of infestation by *T. dimidiata*, category B houses are at average risk and category C houses are at high risk of infestation.

Table 5
Results of the serological tests specific for *Trypanosoma cruzi* carried out in the villages of Anonito and Matochal.

Anonito Village				
Age range (years)	N positive individuals (%)		Total N positives (%)	Total N of individuals tested
	Females	Males		
0-5	0 (0)	0 (0)	0 (0)	99
6-14	3 (1.5)	1 (0.5)	4 (2.0)	202
15-20	1 (1.9)	1 (1.9)	2 (3.7)	54
21-40	11 (7.5)	5 (3.4)	16 (10.9)	147
> 41	18 (15.4)	5 (4.3)	23 (19.7)	117
Totals	33 (5.3)	12 (1.9)	45 (7.3)	619
Matochal Village				
Age range (years)	**N positive individuals (%)**		**Total N positives (%)**	**Total N of individuals tested**
	Females	Males		
0-5	0 (0)	0 (0)	0 (0)	29
6-14	0 (0)	0 (0)	0 (0)	46
15-20	0 (0)	0 (0)	0 (0)	19
21-40	4 (7.8)	1 (2.0)	5 (9.8)	51
> 41	1 (2.1)	1 (2.1)	2 (4.2)	48
Totals	5 (2.6)	2 (1.0)	7 (3.6)	193

N = number

triatomines in Ixcanal I was also among the highest of all villages, representing a highly mobile population of triatomine bugs, possibly from colonized dwellings to other non-infested dwellings. This evidences the important influence of colonized dwellings, with active reproduction processes, on non-infested dwellings, highlighting the high risk that these houses pose for the entire village (Cahan et al., 2019). On the other hand, it is important to note that there are two villages, San Miguel and El Naranjo, which present more than 40% of type C housing, yet their infestation values were less than 10%. This might be due to *T. dimidiata*'s altitude range, since the highest density values are usually found between 1000 to 1400 masl and the lowest between 500 and 700 masl, which is the altitude of both San Miguel and El Naranjo (Fig. 2) (Tabaru et al., 1999). This evidence shows the importance of altitude distribution while evaluating *T. dimidiata* infestation risk. For future studies, not only the domestic risk variables, but also the altitude range could be useful to determine *T. dimidiata* infestation risk in the region.

The presence of high intra-domiciliary infestation, despite constant use of insecticide, is the main pattern for concern in the 11 villages; the colonization rates greater than 50%, which is a measure of an active

Table 6
Barriers to the diagnosis and treatment of Chagas Disease in Guatemala identified through a specific seminar given to health effectors.

Categories/ component	Diagnosis	Treatment	Surveillance	Congenital transmission
Guidelines and Procedures	Centralization	Outdated health care protocols and guidelines	Chagas Disease is not a priority for decision makers	Lack of information records
	Lack of knowledge of national guidelines and international guidelines	Weakness in the information and records system	Lack of interinstitutional coordination and management	Excess bureaucracy
	Lack of records			
	Lack of quality control			
Services/Health System	Lack of training of health personnel	Lack of trained health personnel	Lack of training of health personnel	Lack of trained health teams
	Lack of follow-up on positive cases	Delayed diagnosis	Centralization of health services	Prenatal screening during pregnancy is scarce
	Limited laboratory resolution capacity in endemic areas	Lack of active search for acute infection		Centralization of health services
Inputs / Infrastructure	Lack of validation of a third test for discordant diagnosis	Lack of equipment (ECG) and other medical tests for initiation of treatment	Lack of strategic inputs	Lack of strategic inputs in health centers
	Lack of human resources			
Individual/ community/ society	Lack of awareness and information in the community about the diagnosis of Chagas Disease	Lack of information about Chagas Disease in the community	Lack of comprehensive information in the community (deforestation, hygiene, environmental management, housing, etc.)	Lack of perception of risk and education in the community

reproduction of the vector within the house, represent triatomine bug populations which are highly adapted to the household (Dumonteil et al., 2002; Penados et al., 2020; Sarquis et al., 2004). This high colonization dynamic represents a high risk of vector transmission of *T. cruzi*; therefore, it is necessary to improve the households to make them refractory to infestation, reducing those characteristics that favor colonization and maintenance of the kissing bugs within the house (i.e., presence of cracked walls, animals within the household and dirt floors). Reducing the presence of these household characteristics would allow to reduce the risk of transmission of *T. cruzi* in the region (Monroy et al., 2009; Pellecer et al., 2013). A comprehensive intervention based on education and community work is needed to ensure a long-term solution to diminish and prevent the infestation of *T. dimidiata* (Monroy et al., 2009; Soto et al., 2019). The selective insecticide spraying performed in the last 10 years in Jutiapa by the Ministry of Health must be evaluated and supplemented with the removal of intra domiciliary risk factors. Given the high number of high-risk homes (type C) present in the villages, which strengthens the value of community participation for the improvement, it is important to consider that the time it takes to achieve house improvement differs for each village; depending on the time of the year, the ease of work and the availability of materials in each village need to be evaluated. This is reflected in the varying attitude of the inhabitants towards the entomological control actions and the percentage of houses that were improved in each village. For example, San Cristóbal was the town with the least participation in the house improvement activity; however, it also had the highest proportion of type A households. Type A houses are made mostly of brick blocks, with no cracks in the walls, and therefore refractory to infestation. El Naranjo had 55% community participation in house improvement and San Antonio 41.8%; however, both these villages were the most difficult to access to provide and transfer materials, given the state of the roads and weather conditions. Improving the houses depends on characteristics of each village such as Cosmo-vision, leadership performance, availability of families' time and amount of effort to bring the materials to the house; this explains the differences in the improvement of each village. All houses improved the walls and the floor of the main dormitory. The main reason for the lack of participation was time availability, while enhancing the living conditions was the main motivation for improving houses.

Community participation in house improvement in the study area was higher than the obtained previously in other villages, such as La Brea and El Tule, where 46% and 30% participation was reported (Monroy et al., 2009). Other ethnic groups in Guatemala, such as the Chortí, had low community participation in house improvement activities, with 45% of B and C houses improved (Soto et al., 2019). Other studies in Guatemala, El Salvador and Honduras reported that between 20 and 30% of the inhabitants of different villages carry out home improvements by their own means (Bustamante et al., 2015). Another study performed in three villages in Guatemala reported that 62% of the homes evaluated had made partial improvements and only 17% had made complete improvements (Monroy et al., 1998). The high participation percentages obtained for the current study show that inter-institutional and multidisciplinary cooperation allows reaching the population more effectively and therefore obtaining better results. As expressed by some community leaders, communities' confidence increases when several institutions work together because they perceive that the chances of receiving the materials for the house improvement will increase. For future research, to improve the level of participation, families' economy, environmental effects, and specific cultural factors of the most poor and vulnerable families should be addressed.

Removing risk factors from homes or making home improvements requires at least two weeks of work, which is time-consuming for families. The most frequent economic activity in the area is agriculture, so the sowing and harvesting seasons are particularly important for the inhabitants. Because of this, it is necessary for the home improvement to take place in a timely window of time, in which residents could have additional time to work on the improvements. In the localities where there were delays in the delivery of materials for house improvement (El Naranjo), there was an overlap between the planting season and the house improvement actions, which meant that the neighbors could not apply these actions in an efficient time, therefore, leading to low community participation. Another important factor for house improvement is the union of family efforts between men and women (Rodriguez-Triana et al., 2016), so it is essential to detect indicators for families which present more difficulties to participate, with the objective of providing support and performing follow-up activities to engage them more effectively and transforming them into more proactive participants in their health. Social innovation (Castro-Arroyave et al., 2020) and comprehensive educational actions (Soto et al., 2019) are recognized as important tools for enhancing participation in house improvements that makes them refractory to *T. dimidiata* infestation.

Regarding the serology study performed in Anonito and Matochal villages, participation was greater than 70% in both, which is higher than what has been previously reported in nearby communities (Barillas-Mendoza and López-Escobar, 2015), showing that the community awareness processes were appropriate. The seroprevalence found in each village, 7.3% for Anonito and 3.6% for Matochal, were consistent with the prevalence of 8.0% previously found for women of childbearing age in El Carrizo Village, also located in Comapa (Barillas-Mendoza and López-Escobar, 2015). Moreover, results show higher seroprevalence in females compared to men. This is a pattern previously described for *T. dimidiata*'s endemic areas in Mexico (Newton-Sánchez et al., 2017) and Ecuador (Guevara et al., 2005). This highlights the importance of education and empowerment in women in the community to ensure effective control of mother-to-child transmission of *T. cruzi*.

A marked difference in the prevalence of the disease was observed between different age ranges, with more than 80% of the positive cases concentrated in individuals older than 21 years of age in Anonito and Matochal. This pattern has been previously observed in nearby communities (Barillas-Mendoza and López-Escobar, 2015) and is probably due the current dominance of *T. dimidiata* in the area, a less efficient vector of *T. cruzi* than *R. prolixus* (Paz-Bailey et al., 2002; Hashimoto and Schofield, 2012). Finally, it is important to emphasize the absence of infection in children under 5 years of age for both villages, which was previously reported in nearby communities from Guatemala (Carías-Jimenez and Morales-Zepeda, 2013) and in a big scale analysis including more than 3,000 study subjects in Mexico, using different serological tests (Salazar-Schettino et al., 2016). This generates evidence that shows the interruption of vector transmission by *R. prolixus* and points to the possibility that *T. dimidiata* is an inefficient vector for the transmission of *T. cruzi*. Nevertheless, given the sensitivity of the HAI test (86.9%) used for initial screening, and that 20% of the negative samples were tested by different laboratories, we may have lost some few cases in all the age ranges; not invalidating however, that none of the children under the age of 5 years were found to be infected. The use of HIA, as well as all diagnostic tests, requires well-trained personnel, which this study included. Moreover, the technique is authorized by PAHO (PAHO, 2018) and is currently being used in Cordoba, Argentina (Mamani et al., 2021).

During the barrier seminar for diagnosis and treatment of Chagas Disease, the high participation of all the actors involved represented an advantage, since all the participants were directly involved in diagnosis and treatment, facilitating the identification of barriers and decision-making. The identified barriers are similar to those found in other Latin American countries; where the centralization of services, mismanagement of information, and poor education in the population make it difficult to access diagnosis and treatment of the disease (Klein et al., 2017; Olivera et al., 2018). Inter-institutional cooperation work requires adequate coordination and effective communication between all parties, facilitating the fulfillment of the objectives set for the project. Interinstitutional, cross-sectoral and multidisciplinary work is necessary to enrich, strengthen and provide feedback for the project (Monroy et al., 2012). An example of this was the barrier identification seminar, where multiple institutions (academic, governmental, community, patients and foreign entities) collaborated with a common goal, facilitating the articulation of information and future development of a roadmap for Chagas Disease health procedures.

Given that barriers were mostly related to low institutional articulation, thus creating difficulties at the planning stage for continuous and permanent actions due mainly to the lack of awareness of authorities and the centralization of healthcare and others procedures, the design and development of a comprehensive care roadmap for Chagas disease becomes necessary. This strategy was previously successful in Colombia, promoting the decentralization of processes, raising awareness of authorities and helping to ensure access to health (Ministerio de Salud y Protección Social, 2016a, 2016b). This approach is also enforced by the World Heart Federation (WHF), who promotes the development of a care roadmap for Chagas disease to provide comprehensive care for the patients. This framework, while at national, regional and global levels, balances the feasibility, acceptance and accessibility of the solutions presented for local implementation (Echeverría et al., 2020).

5. Conclusion

The participation of several institutions and partners in the project described herein helped gain people's confidence, thus facilitating the involvement of communities in the diverse activities implemented. During the activities mentioned herein, the high participation and involvement of communities was highlighted, with 83.4% overall participation in the entomological surveillance, more than 80% in the seroprevalence study, an average participation of 57% for house improvement activities (B and C categories), and a 90% participation in the barrier seminar. From the eleven villages surveyed, five showed a very high infestation and colonization rates, three showed high infestation and three had low infestation rates, indicating the need for an integrative control approach including house improvements and domestic animal management. None of the children under five years of age were found to be positive for *T. cruzi*, indicating the positive effects of *R. prolixus* elimination and/or the low transmission capacity of the actual vector *T. dimidiata*.

The implementation of the project in Comapa is providing the tools, experiences and design concept that will allow the expansion of the experience in other hot spots in Guatemala and Central America with similar context. The practice will serve as a model of implementation, making progress towards the elimination of Chagas as a public health problem.

Ethics approval and consent to participate

Study received clearance from San Carlos University bioethics committee, Guatemala City, Guatemala (AC-010-2018).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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