New structures for goat corrals to control peridomestic populations of *Triatoma infestans* (Hemiptera: Reduviidae) in the Gran Chaco of Argentina

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Goat production is an important economic activity for rural communities in the Gran Chaco of Argentina. Goat corrals are important for the survival of peridomestic populations of Triatoma infestans. *This study evaluated the impact of modifying the traditional structure of goat corrals on* T. infestans *populations and goat productivity in the region of Los Llanos (La Rioja). Thirty-nine experimental corrals were constructed and 57 traditional corrals were used as controls. We evaluated the infestations of the control and experimental corrals for five years following construction of the structures. The results showed that the new structures did not prevent the colonization, although it enhanced the detection of infestation at low densities of* T. infestans. *No significant difference was found in T. infestans population abundance between control and experimental corrals, probably because of the different detectability in the two types of structures, especially among the small nymphs. Although goat productivity average was higher in experimental than in control corrals, no significant difference was found because of high variability. The new structures can be used as a complement to promote the development of rural communities. Acceptability and adoption of the new corrals by the owners was high, as the enclosures offered better protection for the goats, increased growth of kids and facilitated herd handling.*

Key words: Chagas disease - Triatominae - *Triatoma infestans* - goat corral - vector control - productivity

Goat breeding is one of the most important activities for the domestic economy of rural communities in the semi-arid Chaco. Domesticated goats are used as food and provide income from the sale of the kids. Traditionally, a goat corral is rectangular, with walls 1.6 m high that are made with layers of branches from local vegetation supported by vertical posts. One sector of the corral is used for the kids and this area usually has a roof made with layers of local vegetation and mud to provide better protection. In Los Llanos, La Rioja (central Argentina) and neighbouring regions, corral owners let goat droppings accumulate to sell once a year as a natural fertiliser for industrial crops.

In the Gran Chaco of Argentina, *Triatoma infestans* is the main vector of the parasite *Trypanosoma cruzi*. Among peridomestic structures, goat corrals are one of the main ecotopes for the survival of peridomestic populations of *T. infestans*. This has been reported for La Rioja (Soler et al. 1977) and Córdoba (Ronderos et al. 1980) and has later been confirmed by a number of studies (e.g., Cecere et al. 1997). Pyrethroid formulations applied to these structures as suspension concentrates have low efficacy for removing *T. infestans* and, as a consequence, commonly leave residual populations that recover their numbers after one or two years (Gorla 1992, Gürtler et al. 1994, 2004, Cecere et al. 1997, Porcasi et al. 2007).

The lower section of the corral walls that are in contact with goat droppings (especially in the kid area) is the place where the abundance of *T. infestans* populations is highest. Efforts to eliminate these populations using traditional vector control interventions, through professional or community-based pyrethroid insecticide applications, decreased the abundance of *T. infestans* populations, but did not eliminate the population. This is usually the case for intradomestic populations (Schofield et al. 2006). A number of factors contribute to this result, as has been shown by several studies (Gürtler et al. 2004, Porcasi et al. 2006). The inefficacy of pyrethroid insecticides on these types of structures encouraged evaluations of alternative approaches to eliminate the peridomestic populations of *T. infestans*. Among those approaches studied in the laboratory and/or the field are changing the insecticide application technique (Gürtler et al. 2004), varying the pyrethroid concentration (Cecere *et* al. 2006), using rubber dog collars impregnated with deltamethrin (Reithinger et al. 2006), using spot-on formulations to treat dogs, goats and chickens (Amelotti et al. 2009a, Gürtler et al. 2009) and using microencapsulated formulations (Dias & Jemmio 2008, Amelotti et al. 2009b, Alarico et al. 2010).

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In this study, the environmental manipulation approach of changing the structure of the goat corral for the elimination of peridomestic populations of *T. infestans* was explored in the region of Los Llanos. This region occupies four million hectares. It is located in the southern region of the Gran Chaco and represents one of the most arid and poorest regions of Argentina. Within the area, 72% of the rural population are small farm producers, occupying 38% of Los Llanos. These small producers carry out the integral exploitation of the available natural resources in a subsistence economic system to support their families.

The present study evaluated how the modification of goat corrals effected *T. infestans* populations and the productivity of the goat herd. The study tested the hypothesis that a procedure that decreases the likelihood of corral colonisation by *T. infestans* and simultaneously increases the number and unit value of the kids would be more attractive to the goat owners than a procedure that only decreases the likelihood of colonization.

MATERIALS AND METHODS

The study was conducted in two provincial departments of the Los Llanos, Peñaloza and Independencia, beginning in 2004 and 2006, respectively. Both departments are located south and southwest of La Rioja (Fig. 1). Rural houses in these departments had not received vector control interventions for 10 years prior to the present study.

The walls of a traditional corral are usually built using intertwined sticks of local vegetation. In one of the corners, inner walls are frequently added to support a roof that will better protect the kids. The roof is built the same as it is in rural houses, using multiple layers of mud and local vegetation. *T. infestans* usually occupies spaces within the walls that are in contact with the corral floor and roof (especially near the kid area because the kids are kept in the corral at all times).

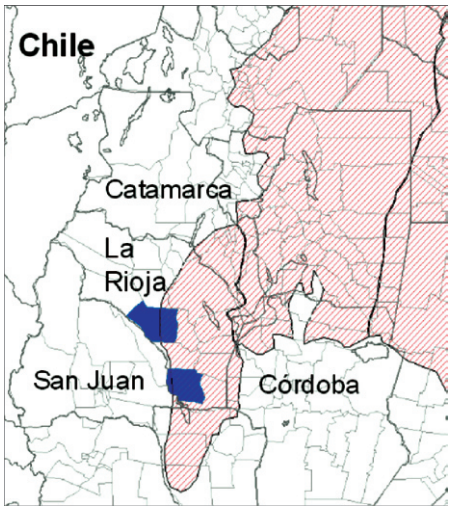

Fig. 1: study area. Insert: province of La Rioja in Argentina and southwest Gran Chaco (diagonal striped). La Rioja map shows in blue the departments of Peñaloza (bellow) and Independencia (above), where highly infested clusters of rural houses were found in 2004-2005 (Porcasi et al. 2007).

At both study sites, the new corrals were either installed in the same place as the traditional ones (Fig. 2A) or installed beside them. Complete replacement of the old corrals was not always possible because the size of the new corrals was not sufficiently large to accommodate all of the owner's goats. The traditional walls made of local vegetation are replaced by wire fences and a sector built with cement blocks. The roof above the kid area is replaced with a tin roof that can be used to collect rainfall. Inside the new corral, two inner wire fences delimit four areas for better management of different parts of the herd (Fig. 2B). The design of the new corrals was thought as an improvement of pyrethroid efficacy on *T. infestans* population control while also being respectful of local cultural traditions. Low cost and the ease of construction were also taken into account. Because climatic factors are critical for goat survival during the windy and cold winter months, the new corral included a walled and roofed area that provided extra protection. To estimate the abundance of the vector, we manually searched using a two-person fixed time of capture (man/hour method, 30 min active searching). *T. infestans* specimens were located using 0.2% tetramethrin as a dislodging agent.

Peñaloza study sites - The study emphasised the participation of the community in discussions of the new corral design and promoted and disseminated information regarding the upcoming interventions. In addition

Fig. 2A: typical structure of traditional goat corral, with walls of stacked branches; B: structure of the yard with new design, concrete wall, wire and tin roof.

to the research team members, technicians from Program Chagas La Rioja (PChLR), the Institute of Agricultural Technology of Argentina (INTA), the Program for Social Agriculture and members of the Cooperativa Chepes Sur, the Association of Santa Cruz Small Farmers and the Experimental Centre for Economic Housing-National Council of Scientific and Technical Research participated in the study at different times.

The technical team and community agreed to adopt the experimental design for goat corrals to be installed at the houses of 21 goat producers. Fourteen corrals were built at the beginning of the study and baseline data were collected from these corrals (Fig. 2B). Seven traditional goat corrals remained as controls. At the end of the project, the owners of the control corrals received the materials for constructing the new corrals. Materials for corral construction (including cement blocks) were provided by project funds. The owners built the corrals and technicians from the INTA supervised the general process. Each locality was considered a statistical stratum so that intervention and non-intervention groups could be compared under homogeneous environmental conditions.

To compare the performance of the new structures with the traditional structures, temperature, relative humidity and wind speed and direction were recorded every 2 h within the compounds of the control and experimental groups. The environmental conditions were recorded with Davis Weather Monitor II equipment during the winter months (June-August 2005). The stations were separated by only 12 ms; thus, while the macro-environmental conditions were similar, micro-environmental differences inside the experimental and control corrals could be compared.

Evaluations of the infestation in the experimental corrals were conducted in September 2005, April 2006, November 2008 and February 2010. The estimations of *T. infestans* abundance were grouped by age, with groups representing young nymphs (1st-3rd instar nymphs), older nymphs (4th and 5th instars) and adults (both sexes), based on 30 min of active searching by two experienced members of the research team.

Between February-December 2008, the PChLR conducted blanket vector control intervention, spraying the rural houses (intra and peridomestic structures) in Peñaloza, including the new corrals constructed during this study (60 mg/m^2 alpha-cypermethrin in the intradomestic area and 120 mg/m^2 in peridomestic buildings).

After corral construction was complete, a community survey was conducted in which goat owners were interviewed to assess any perceived difficulties in the construction of the new corrals and examine the interest in adopting this type of corral.

Independencia study sites - In Independencia, a total of 23 rural localities distributed over an area of 6.800 km^2 were identified during October 2006. There is an east-west elevation gradient rising from 400 m above sea level (masl) to 1.200 masl. A total of 189 rural houses were located, 43 of which were unoccupied. Data describing the structures of the houses and their entomological statuses are referred to as the 146 houses evaluated by the PChLR.

The homeowners had a variety of domestic animals, including dogs, cats, chickens, rabbits, cows and goats. Most rural households had at least one type of animal (72%), while 32.2% had all of the animal types. Cow and goat corrals were the most common peridomestic structures used for the animals' protection.

The intervention design included an experimental group comprising 25 newly designed goat corrals and a control group comprising 48 traditionally constructed corrals. In Independencia, the controls were not replaced by new corrals at the end of the study. A preliminary assessment of the infestation of houses conducted by the PChLR in April 2006 found that 57.3% of the peridomestic structures were infested by *T. infestans* (Porcasi et al. 2007). During the assessment, teams of two people searched the ecotopes in the peridomestic structures for at least 15 min using an aqueous solution of tetramethrin (0.2%) as a dislodging agent. When a live specimen of *T. infestans* was found, the search was stopped. No estimate was made regarding the abundance of *T. infestans* during the preliminary assessment.

Each house was identified by a number painted on the outer wall and was geographically located (latitude and longitude) using a portable GPS (Garmin Legend). All data were stored in the database of the PChLR geographical information system. Technicians from the INTA, department of Independencia officials, small farmers and the research team discussed aspects of the project. It was agreed that the goat owners, with the collaboration of the Independencia municipal government, would contribute the labour for the construction of new corrals using materials provided by project funds. Research team members and the INTA technicians supervised the on-going work. Project funds provided cement to the municipality of Independencia, which built and distributed the cement blocks to the goat owners (some up to 70 km away from the block production plant) between August-September 2006. During the same time period, meetings were held with small farmers to explain the project and discuss the conditions of participation.

Because entomological data showed no statistical aggregation of infested corrals using SatScan (Kulldorff 1997), the new corrals were randomly distributed as a proportion of the number of houses in a locality to the number of houses with traditional goat corrals that had tested positive for *T. infestans* in the preliminary evaluation.

The PChLR estimated the abundance of *T. infestans* before vector control intervention in August and September 2006. During October 2006, the PChLR sprayed all intradomiciles of the department of Independencia. Domestic animals were treated with veterinary pour-on formulations (6% cypermethrin on goats and 1% fipronil on dogs). Peridomestic structures were not sprayed with pyrethroids during this time. New evaluations of post-treatment infestations of selected houses were conducted in January and April 2007 and August 2009. In August 2009, nominal doses of 60 mg/m^2 of beta-cypermethrin were manually sprayed onto intradomestic and peridomestic structures. The estimation of *T. infestans* population abundance was conducted using the same methods from the preliminary estimation.

To test the hypothesis of increased productivity in the goat herds that were maintained in the new structures, measurements of mortality, development rate, head size, weight and body height of kids born during June and July 2007 were made. A comparable number of kids born in traditional corrals were also studied. The measurements were taken from the same kid on two dates (June 13 and July 13) to estimate its growth rate. Male kids are better nourished than female kids because they are prepared for sale when they are 30-45 days of age and the regular weight range of male kids is 7-10 kg; thus, the data were analysed by sex. Female kids are usually incorporated into the herd to continue the reproductive process.

RESULTS

Peñaloza study sites - Infestation by T. infestans of control and experimental units - The entomological evaluation conducted before the construction of the new corrals showed that all traditional corrals assigned either to the control or experimental group were positive for *T. infestans*. The construction of the new goat corrals by the owners, including the production of cement blocks, took longer than estimated. Experimental corrals were finished on March 2005 and none of them showed signs of colonisation by September 2005, while the infestation of the controls remained the same as it was during the initial evaluation (Fig. 3).

By April 2006, 15 new corrals were finished. Ten of these corrals were colonised by *T. infestans*; two new corrals had a high abundance of the insects (ranging from 45-61, counted in an active 2-person search lasting 30 min) and eight new corrals had a medium or low abundance of the insects (ranging from 1-14). After the insecticide application on all of the houses in the department (intra and peridomestic structures) in August 2009, goat corral infestation decreased to 10% (controls) and 33% (experimental). Among the seven infested experimental corrals, only one had a high abundance of *T. infestans* (44 insects found in a 30 min search) and six had low abundance (ranging from 1-2 insects). The latest entomological evaluation (February 2010), performed on 19 of the 21 experimental corrals, showed that all corrals were completed and in use. Fifty-two percent of the corrals (10/19) were negative for *T. infestans*. Among the nine infested ones (47.4%), three had a high abundance of the insects (ranging from 33-80) and the rest had a medium to low abundance of the insects (ranging from 2-20) (Fig. 3).

Climatic conditions in control and experimental goat corrals - The climatic conditions were measured during the winter months of July and August 2005. The temperature (minimum and maximum) was higher in experimental corrals than control corrals. The average and maximum wind speed was higher in the control corrals than in the experimental corrals (Table I).

The minimum temperatures of control and experimental corrals showed a significant linear relationship ($y = 1.51 + 0.91x$; $r = 0.98$, $n = 62$). The slope was not significantly different from 1 ($p > 0.05$), but had an intercept equal to 1.5ºC, indicating that the experimental corral had a minimum temperature that was higher than that recorded in the control corral. The experimental structure had a damping effect on the maximum temperature because it had a slope < 1 and intercept > 0 (i.e., warmer at low temperatures and cooler at high temperatures) ($y = 5.27 + 0.74x$; $r = 0.74$). The maximum wind speed in the experimental corral did not exceed 10 km/h on average, while in the control corral, gusts of up to 25 km/h were recorded.

Owners' reactions to new goat corrals - The survey conducted with the 21 goat owners to evaluate the acceptability and adoption of the new corral structure showed that all were highly satisfied with the new type of structure because it provides more effective protection for livestock (especially for kids) than the old structure. Forty percent of respondents mentioned that the survival and growth rate of young goats were higher. All producers reported facilitated manipulation of the herd and they observed positive economic progress.

Of the 19 corrals evaluated in 2010, eight doubled or tripled in size between 2008-2009. Additionally, four of the owners built houses that had a similar structure to the corral.

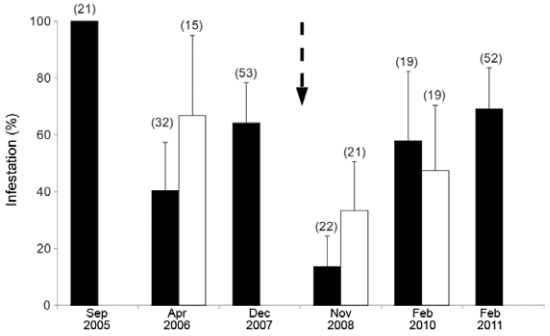

Fig. 3: proportion of *Triatoma infestans* infested goat corrals in the department of Peñaloza. Control corrals: filled bars; experimental corrals: white bars. Vertical lines represent standard deviations. Between brackets: number of corrals evaluated. Broken arrow indicates the date of betacypermethrin application on intra and peridomestic structures by the Program Chagas La Rioja.

TABLE I

Descriptive statistics (mean and standard deviation) of environmental variables measured within control and experimental corrals from June 17-August 17

Variable	Experimental mean (SD)	Control mean (SD)
Mean temperature (ºC)	11.4 (4.1)[a]	10.8 (4.03)[a]
Max. temperature (ºC)	17.2 (4.47)[a]	16.3 (4.48)[a]
Min. temperature (ºC)	6.8 (3.27)[a]	5.8 (3.52)[b]
Wind mean speed (km/h)	0.4 (0.48)[a]	1.6 (1.1)[b]

different letters indicate significant differences ($p < 0.05$, t test). Daily data, $n = 62$. SD: standard deviation.

Independencia study site - Preliminary entomological survey - The percentage of houses infested by *T. infestans* (intra and/or peridomestic structures) was 62.3% (91 of 146 homes) and infestation was significantly correlated with the number of peridomestic structures (Spearman rank correlation = 0.77, $p < 0.001$). A frequency analysis showed that of the 146 houses evaluated, those without domestic animals of any type (41) showed no infestation by *T. infestans.* Among the 105 that had animals of some type, 91 (86.7%) were infested by *T. infestans* in peridomestic structures [relative risk = 7.5, 95% confidence interval (CI) = 4.6-12.2, Fisher exact test, $p < 0.0001$].

Building the new goat corrals - The new corrals were built in the same place or very near to the traditional corrals. Thirty-six percent (9/25) of traditional corrals were dismantled after the goats were moved to the new corral. The time it took to complete the construction of the corrals and their building quality were heterogeneous between goat owners. In April 2007, eight months after the materials were delivered to the small farmers, 14 (56%) of the 25 corrals were completed and ready to be used. All corrals were completed between November 2006-October 2007.

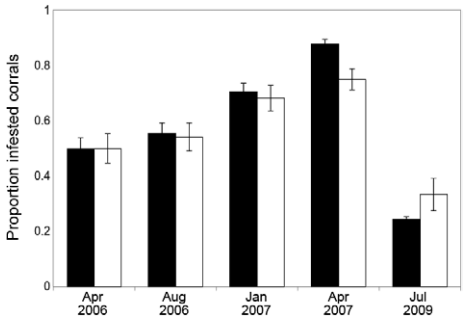

Fig. 4: proportion of *Triatoma infestans* infested goat corrals in the department of Independencia. Control corrals: filled bars; experimental corrals: white bars. Vertical lines represent standard deviations. Infestation on April 2006 represents the pre-intervention value.

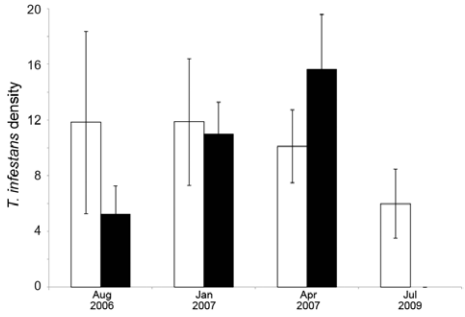

Fig. 5: mean density of *Triatoma infestans* (30 min active search) in experimental corrals (empty bars) and controls (filled bars) in the department of Independencia. Data for August 2006 correspond to the baseline prior to construction of new corrals. January and April 2007 and July 2009 correspond to data after the construction and use of experimental corrals.

Infestation by T. infestans of control and experimental units - After the insecticide application in October 2006, no intradomestic structures were found to be infested in April 2007. In August 2009, the PChLR conducted the second evaluation and insecticide application on 291 dwellings and showed a 5.5% intradomestic infestation (16/291) and 22% (64/291) peridomestic infestation.

Goat corrals in the control group showed a sustained infestation, even after the PChLR interventions. The infestation prevalence had low variability, with an average of 60% in August 2006 and 80% in April 2007. However, 64% of the new experimental corrals were found infested with young nymphs in April 2007 (8 of 14 corrals showed no old nymphs or adults) (Fig. 4).

The *T. infestans* density in the control group increased from 5.2 individuals/corral to 15.6 individuals/corral from August 2006-April 2007. No significant difference in density (Kruskal-Wallis test, $p > 0.05$) was found between the control and experimental corrals until April 2007. In July 2009, the mean density of *T. infestans* in experimental corrals decreased to six insects/corral (Fig. 5). The reduction in density occurred prior to the insecticide application in August 2009 and it was likely a consequence of the low winter temperature during the infestation evaluation. No differences were found between kids born in the control corrals and those that were born in the experimental corrals in morphometric and body growth rate measurements. Although no significant differences in goat fertility (1.8 vs. 1.5 kids/goat), the mortality rate of kids (4.9% vs. 6.1%) and percentage of kids sold to kids born (experimental group: 7.7% CI: 5.61-10.2 and control group: 4.42% CI: 2.96-6.33) (Table II) were detected between experimental and control groups, the averages always suggested an improvement in the experimental corrals.

DISCUSSION

The study conducted in the departments of Peñaloza and Independencia showed that the new structure of goat corrals did not guarantee the absence of reinfestation by *T. infestans*. Between two-four months after the use of the new corrals began, insects had colonised the new

TABLE II

Demographic variables of goats flocks in experimental and control corrals for the department of Independencia trial

	Group	
Demographic variable	Experimental (n)	Control (n)
No corrals analysed	12	27
Adult goats	326	449
Kids born	517	605
Kids dead	29	41
Kids sold	43	28
Kids/goat	1.8	1.5
Kids mortality (%)	5.61 (3.79-7.96)	6.78 (4.91-9.08)

structures. Two causes could explain the rapidity of this process. The new corrals were constructed in the same place as or very close to the highly infested traditional corrals (mean distance = 139 m, standard deviation = 75.6 m), providing a source of the insects that could colonise the new structures. The distance between traditional and new corrals was well within the range of *T. infestans* active dispersal (Schofield et al. 1992). Although the new goat corrals leave less space for colonisation, they could harbour populations of *T. infestans* if the structures were poorly constructed or had cracks in the walls or between the posts and cement.

There was no significant difference in the estimated population abundance of *T. infestans* between experimental and control corrals. Nevertheless, the observed values do not necessarily show that the absolute abundance in both types of structures was the same, even when the same collection method was used. Active manual collecting by fixed effort is a method that relies heavily on the visibility of the insects, a fact that is well-known from early studies on Triatominae sampling (Schofield 1978). In this study, the insect visibility in traditional and experimental corrals was very different. In traditional corrals, the insects are found within the walls (within the mixture of branches and goat droppings) and within the roofs that protect the kid area. In general, insect detection in these corrals is very low. In the experimental corrals, the insects can only hide in little cracks in the cement walls or spaces between the posts and tin roofs. In these corrals, the visibility of the insects (even those in the smaller age classes) is higher than in the traditional corrals. The difference in the visibility of the insects between the old and new corrals is greatest in the case of young nymphs. In this study, these were the most common sign of infestation. Although the data do not show a lower absolute abundance in the new corrals, their simpler structure allows the detection of a low infestation in a more efficient way than in the traditional corral. Because of the lower structural complexity and type of construction material used in the new corrals, it is expected that using pyrethroids for the control of *T. infestans* populations should be more effective in these than in the traditional corrals.

The goat herds have a higher average productivity in the new corrals than the traditional corrals, although high variability prevented the detection of significant differences.

Whether the local farmers agree to modify the corral structures depended on the existence of a subsidy for (at least) the provision of building materials because the community economy cannot cover such costs. If goat production is exclusively for self-consumption and if some type of social organisation of goat farmers does not exist (for example, through a production cooperative), then there is a smaller likelihood of new corral construction. Those producers for whom an increase in the production of kids represented an increase in income not only completed the construction of the new corrals, but they also expanded the corral areas and added chicken coops that were similar in structure.

Only 14 of the 25 experimental corrals (56%) in the department of Independencia were completed and in use by the owners. This fraction is smaller than in the department of Peñaloza, where 100% of the corrals were completed. The difference between the two places was that a goat producer cooperative supported by governmental agriculture agencies is present in Peñaloza, but absent in Independencia. The producers in Independencia had no such organisation, held no group meetings, did not receive technical support from agricultural agencies and few of the producers understood that goat farming activity could help support the family economy.

The success of eliminating or reducing the population abundance of *T. infestans* is associated with the construction quality of the corral, existence of nearby *T. infestans* sources and frequency of vector control interventions with pyrethroid insecticides. When corral construction was of good quality, with no cracks in the cement wall or bark of wooden poles used for the fenced perimeter and roof columns, the corral had a low chance of being colonised, even if it was located near other structures colonised by *T. infestans*. Walls constructed of hollow concrete blocks did not appear to be the best option because even with good construction quality, cracks and holes appear after three years as a consequence of the repeated blows to the walls by the goats. Another option to be considered for future corrals is cooked, solid bricks or similar materials.

The results of this study showed that improvement of the goat corral structure is necessary to lower the population abundance of *T. infestans*, but it is not sufficient to eliminate the populations after five years. The improvement of the corral structure also has the potential to increase goat production and it may be an idea around which local development actions can be organised through government agencies and non-governmental organisations. The modification of peridomestic structures is not the final solution for eliminating peridomestic populations of *T. infestans*, but may be an important complement to other control approaches, such as traditional spraying with pyrethroid insecticides (Cecere et al. 2006) or the non-traditional use of formulations for insecticide application (Reithinger et al. 2006, Amelotti et al. 2009a, b).

Information collected in the south of the department of Peñaloza indicated that a government project started in 2008 allowed the construction or expansion of approximately 300 new corrals and chicken coops with a similar structure to the one developed by our group in 2004.

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