Factors limiting the domestic density of *Triatoma infestans* in north-west Argentina: a longitudinal study

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Reported are the environmental and demographic risk factors associated with the domestic infestation and density of Triatoma infestans *in three heavily infested rural villages in Santiago del Estero Province, Argentina. In a one-factor unadjusted analysis, the number of* T. infestans *captured per person-hour was associated significantly and negatively with the use of domestic insecticides by householders, type of thatch used in the roofs and the age of the house; and positively with the following: degree of cracking of the indoor walls and presence of hens nesting indoors. In one model, using multiple linear regression and a backward stepwise elimination procedure, most of the variation in the overall abundance of* T. infestans *was explained by insecticide use and the presence of hens nesting indoors; in another model using the same procedure it was explained by insecticide use, bug density in 1988 and previous spraying with deltamethrin in 1985. Variations in bug density per capture stratum (household goods, beds, walls and roof) were explained by the bug density in other strata and by one or two of the following risk factors: hens nesting indoors, type of roof, presence of cracks in the walls and number of people living in the house. Bug density might be locally controlled by the availability of refuges in the roofs and walls, by the presence of hens nesting indoors and by the use of domestic insecticides. Certain local materials, such as a grass known as* simbol, *could be successfully used in rural housing improvement programmes aimed at reducing the availability of refuges for insects in the roof.*

Introduction

Triatoma infestans Klug is probably the most important vector of *Trypanosoma cruzi*, the causal agent of Chagas disease (*1*). The prevalence and incidence of human infection with *T. cruzi* have been reported to increase with bug density, both of *T. infestans* (*2*) and of *Panstrongylus megistus* (*3, 4*). Factors limiting the domestic density of triatomine bugs are therefore of the utmost importance for predicting vector density and transmission of *T. cruzi*.

The main factors associated with the prevalence or density of domestic bug infestations are the types of material used to build the roof and walls (*3, 5*), the numbers and types of resident host (*6, 7*), and the use of domestic insecticides reported by householders (*8*). Most previous studies have used one-factor (unadjusted) analysis (*3, 6, 9–11*). Only two studies (*12, 13*) used multivariate analysis; these considered house infestation but not vector density as the dependent variable.

In infested rural communities from the Chaco Region of Argentina that had not been sprayed with residual insecticides, houses with roofs made of a grass known as *simbol* (*Pennisetum* sp.) harboured lower domestic densities of *T. infestans* than other houses (*14*). The presence of cracks in the walls and the numbers of people and dogs living together were also positively and significantly associated with domestic bug density. Another study (*15*) showed that the presence of hens nesting indoors or the percentage of domestic bugs that fed on poultry were the only demographic predictors of the density of bugs in houses. These studies were cross-sectional, however, and did not include the history of infestation and the age of the houses. A relationship between the presence and number of peridomestic outhouses and domestic infestation has been suspected but not studied in detail.

In this study we used longitudinal data to test

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the association between bug density and the type of roof. The effects of other factors were adjusted for using multiple linear regression. We also searched for other environmental and demographic risk factors that might be related to house infestation, and analysed the distribution and density of *T. infestans* in four capture strata inside houses. The relationship between the presence of hens nesting indoors and domestic bug density, based on some of these data, has been reported previously (*15*). A better understanding of which factors affect the distribution and density of domestic *T. infestans* populations could assist in the design of innovative control measures in a housing improvement programme aimed at their reduction or elimination.

Materials and methods

Study area

The survey was carried out in the adjacent rural villages of Amamá, Trinidad, and Mercedes in Moreno Department, Santiago del Estero Province, Argentina (27°S, 63°W). The area is semi-arid with hardwood thorn forest and has been described previously (*14*). All houses in Amamá were sprayed with residual insecticides by official control services for the first time in 1985. By 1988, 54% of the houses had become reinfested with *T. infestans* (*16*). In 1988, 95% of houses in Trinidad and Mercedes, which had never been sprayed with insecticides, were infested (*14*).

Study design

The cross-sectional survey carried out in March 1992 has been described previously (*15*). A total of 71 houses were visited. Three of these were excluded from further analysis because they had metal or brick roofs, well plastered walls, and cement floors. The houses usually had two contiguous bedrooms and a front porch 5–10 m wide where people and dogs slept during 10 months of the year. These areas shared a common roof and are referred to here as domestic structures. Peridomestic structures (kitchen, store rooms and corrals) lay between 4 m and 110 m from the bedrooms.

At each house, the perimeter of the domestic structure and its distance from each peridomestic structure were paced out and drawn on a sketch map. All family members, dogs and cats were counted. The head of each household was asked to supply the numbers of poultry and corral animals (goats, sheep, cows, horses and mules) owned by the family. The materials used for the roofs and walls and the existence and state of wall plaster were recorded. The degree of wall cracking (none, few or many cracks) and the type of plaster used (cement or mud) were noted. Cracks were taken to be any crevices that could serve as a refuge for a triatomine nymph or adult (i.e. at least approximately 2 mm wide and 2 mm long). Thatched roofs were classified as composed entirely of *simbol*, partly of *simbol*, or made of *jarilla* (*Larrea* sp.) or other brushwood materials (*14*). Photographs were taken to document the different types of structure. Householders were asked when their houses had been built and about recent improvements to them, the length of time that the family had lived in the house, and the domestic use of insecticides (type, frequency, mode, and date of last application). The place where hens usually nested was evaluated in each house by direct observation in March 1992, October 1992, October 1993, and November 1994, and by interviewing the head of the household in May 1993 and November 1994. Householders were considered to be in the habit of allowing hens to nest indoors when this was directly observed at least once, or when they reported the habit in both interviews. The habit was classified as domiciliary when hens nested in bedrooms, in porch areas, against the outside of bedroom walls or in rooms adjacent to bedrooms (regardless of whether hens also nested in peridomestic areas) or peridomiciliary when hens nested exclusively outdoors.

Entomological methods

The procedures for bug collection have been described previously (*17*). A two-person expert team from the National Chagas Disease Control Service searched all bedroom areas, household goods and beds for triatomine bugs for 30 minutes both before and after repeated spraying of the walls and roof with a 0.2% (w/v) tetramethrin solution. Bugs were collected separately from four strata: household goods, beds, walls, and roof. Similar searches were made in all peridomestic structures for a total of 10 minutes per house. All domestic and peridomestic structures in the three villages were sprayed with deltamethrin in October 1992 (*18*).

Bugs collected from different sites and by different methods were stored separately in labelled plastic bags, identified by species, counted by instar and sex, and stored for identification of blood meal sources (*19*). A house was considered to be infested if at least one live *T. infestans* (except eggs) was caught in a domestic area. The overall density of *T. infestans* was the sum of the numbers of bugs found in each stratum.

Data analysis

Environmental risk factors were represented by the following: domestic use of insecticides, type of roof, degree of wall cracking, age of house (in years), house surface area (in m^2), number of peridomestic structures, peridomestic bug density (number of live *T. infestans* per 1/3 person-hour), any infested peridomestic structure, distance from the domestic to the closest peridomestic structure (in m), distance to the closest infested peridomestic structure (in m), previous spraying with deltamethrin in 1985, and the community and domestic densities of *T. infestans* in 1988. The overall domestic density of *T. infestans* in 1988 was estimated by spending 4 person-hours capturing bugs in each house in September (Trinidad) or December (Amamá and Mercedes).

Demographic risk factors were represented by the following: numbers of people, children, children per bedroom, people per bedroom, dogs, cats, people plus dogs, corral animals, poultry, the presence of hens nesting indoors, and the percentage of bugs that fed on poultry. Before analysis began, discrete and continuous variables (x) were transformed to $\log_{10}(x + 1)$ to normalize the data. The presence of hens in bedroom areas was described by a dummy variable based on householders' reports and visual inspections during vector collection; this took a value of 0 when hens did not nest indoors and of 1 when they did. The domestic use of insecticides by householders, the presence of cracks in bedroom walls and a roof partly or totally made of *simbol* were all treated as dummy variables; the condition that favoured triatomine bug infestation (no insecticide use, cracks in walls and no use of *simbol* in the roof) took a value of 1.

We used multiple linear regression and backward stepwise elimination, implemented using Statistica (release 4.3) software, to find the best set of predictors describing variations among overall or stratum-specific abundances of domestic *T. infestans*. All factors significantly associated with bug density in univariate analyses were considered independent variables (x). Other factors (numbers of people and dogs, previous spraying with deltamethrin, domestic bug abundance in 1988, and community) were included because of established associations. In one model, the relationship between overall bug density and the nine factors listed in Table 4 was studied by standard linear regression for 68 houses. Significant variables were then selected by backward stepwise regression. Another backward regression was carried out using these significant variables after including the effects of their interactions. The overall bug density was also analysed by backward regression, taking into account domestic bug density in 1988 plus the 10 factors listed in Table 1 for 52 of the 68 houses for which data were available. In a second model, backward regression was used to analyse the abundance of bugs per stratum according to the seven preselected factors listed in Table 5; we then added bug density in the other strata and followed the same steps as before. In the second model, the age of the house, community and previous spraying with deltamethrin were excluded because they were considered to be distantly associated with the density of bugs per stratum. The results of all statistical tests for regression analysis were taken to be significant at the $P = 0.05$ level.

Results

T. infestans was captured in 66 (93%) of 71 houses in March 1992, with a total of 1429 being captured in domestic areas of 55 houses (77%) and 472 in peridomestic sites of 35 houses (49%). In domestic areas, most bugs were captured from walls (47%), followed by roofs (26%), and beds or household goods (27%).

Table 1 shows the distribution of infested houses and the density of *T. infestans*, by environmental risk factors. The number of categories for each factor was determined in such a way that not more than 20% of the cells in each contingency table had expected frequencies <5. Houses of surface area $\geq 80\,m^2$ that had been constructed at least 20 years previously and whose inhabitants claimed to use insecticides were significantly less infested than other houses of each corresponding category. The only factors significantly associated with the domestic density of *T. infestans* were insecticide use, the degree of cracking of the walls, and the age of the house. The type of roof was only marginally associated with bug density.

Houses whose walls were made only of fired bricks had a lower infestation rate (12/18; 67%) than those with walls made of mud bricks (14/17; 82%), mud and sticks (6/7; 86%), both mud bricks and mud and sticks (11/12; 92%) or a combination of fired bricks, mud bricks and mud and sticks (12/14; 86%). Houses with walls plastered with cement had a lower infestation rate (4/6; 67%) than those plastered with mud (46/56; 82%) or left unplastered (5/6; 83%). The insecticides used by householders were lindane, applied as a powder or wet suspension or burnt as a candle, and dichlorvos sprays. Householders did not apply insecticides using the appropriate equipment, and burned wood, tyres, etc. in the belief that smoke repelled or killed the bugs.

Among the demographic factors, only the presence of hens nesting indoors was significantly associ-

Table 1: **Prevalence of infestation with and domestic density of *Triatoma infestans*, by environmental risk factors, Amamá, Trinidad, and Mercedes, Argentina, March 1992**

Environmental factors	No. houses surveyed	% houses infested	*P*-value[a]	Median bug density	Q_1–Q_3	*P*-value[b]
Insecticide use						
Yes	41	73		3	0–18	
No	27	93	0.05	14	8–33	<0.01
Type of roof						
All *simbol*	11	64		1	0–7	
Partly *simbol*	7	86 } 84[c]		10	6–28	
No *simbol*	50	84	1.00	11	2–34	0.06
Presence of cracks in walls						
None	14	71 } 76[c]		5	0–10	
Some	37	78		8	1–31	
Many	17	94	1.00	18	8–42	0.04
Age of house (years)						
0.3–19	32	97		14	7–70	
20–123	36	67	<0.01	3	0–23	<0.01
House area (m^2)[d]						
20–39	12	92 } 89[c]		33	6–77	
40–79	33	88		8	3–18	
80–100	20	65	0.04	3	0–31	0.11
No. of peridomestic structures[e]						
0–1	20	85		16	1–9	
2–4	34	79 } 79[c]		7	7–38	
5–8	14	79	1.00	5	1–34	0.14
Peridomestic bug density						
0–1	28	89		8	3–31	
2–14	20	75 } 77[c]		6	1–18	
16–59	10	80	0.30	11	2–32	0.54
Any infested peridomestic structure[f]						
No	26	92		9	3–31	
Yes	32	75	0.16	5	1–24	0.13
Community						
Amamá	44	77		11	2–40	
Trinidad and Mercedes	24	88	0.31	20	1–34	0.18
Previous spraying in 1985						
No	33	88		8	2–30	
Yes	35	74	0.15	11	1–32	0.69

[a] Fisher's exact test, except for insecticide use and age of house where the χ^2 test with one degree of freedom was used.
[b] Kruskal–Wallis test.
[c] Average value.
[d] The number of bedrooms was not significantly associated with infestation or bug density.
[e] The number of corrals was not significantly associated with infestation or bug density.
[f] The distance to the closest peridomestic structure and to the closest infested peridomestic structure (according to the categories 2–4, 5–11 and 12–50 m) was not significantly associated with infestation or bug density.

ated with the domestic density of *T. infestans* and was marginally associated with infestation (Table 2). Both the prevalence and density of infestation tended to rise with the number of children. Environmental and demographic factors related to peridomestic structures did not show any significant relationship with the domestic prevalence or density of *T. infestans* (Tables 1 and 2).

Several of the above-mentioned factors were significantly associated:

— the reported use of insecticides with *simbol* roofs and house surface area;
— the number of bedrooms with house surface area, the number of peridomestic structures (including corrals), and the total number of poultry or ducks;
— the number of people living in the house with the number of dogs and cats; and
— the number of peridomestic structures with the number of corral animals or corrals and the

Table 2: **Prevalence of infestation and domestic density of *Triatoma infestans*, by demographic risk factors, Amamá, Trinidad and Mercedes, Argentina, March 1992**

Demographic factors	No. houses surveyed	% houses infested	*P*-value[a]	Median bug density	Q_1–Q_3	*P*-value[b]
No. of children[c]						
0	18	72 }77[d]		3	0–28	
1–3	26	81		7	1–18	
≥4	24	88	0.23	14	8–36	0.16
No. of people[e]						
1–4	32	81		8	1–29	
5–8	26	81 }81[d]		9	1–38	
9–13	10	80	0.94	10	2–21	0.93
No. of dogs[f]						
0–1	21	86		7	1–31	
2–3	36	75 }79[d]		8	1–27	
4–7	11	91	1.00	11	9–54	0.24
Hens nesting indoors						
No	38	74		4	0–15	
Yes	30	90	0.09	18	5–62	<0.01
No. of poultry						
0–10	14	79 }86[d]		9	2–30	
11–30	22	91		10	3–35	
31–100	20	75	0.47	8	1–24	0.58
No. of corral animals						
0–10	31	77		14	3–30	
11–30	20	90 }83[d]		9	2–32	
34–100	10	70	0.56	4	0–8	0.15

[a] Fisher's exact test, except for number of people, hens nesting indoors and number of corral animals, where the χ^2 test with one degree of freedom was used.
[b] Kruskal–Wallis test.
[c] Children ≤15 years of age; the number of children per bedroom was not significantly associated with infestation or bug density.
[d] Average value.
[e] The number of people per bedroom, number of people plus dogs, and number of people plus cats were not significantly associated with infestation or bug density.
[f] The relationship between infestation or bug density and the total number of people, dogs, cats, or dogs and cats combined was not statistically significant.

distance from the domestic area to the closest peridomestic structure.

The type of roof and the age of the house were marginally associated (χ^2 test = 3.65; P = 0.06; df = 1). A total of 72% (13/18) of houses with roofs made totally or partly of *simbol* and 46% (23/50) of houses with other types of roof had been constructed at least 20 years previously.

The proportion of all domestic *T. infestans* captured per stratum was modified by the type of roof and the degree of cracking of the walls, but not by the use of insecticides (Table 3). In houses with roofs made totally of *simbol*, most *T. infestans* were captured in walls and beds, whereas in houses with no *simbol* in the roofs most bugs were captured in walls and roofs. In houses with well plastered and uncracked walls, most *T. infestans* were captured mostly in roofs, whereas in houses with cracked walls most were captured in walls. The median capture of *T. infestans* in walls increased from zero in houses with uncracked walls to 12 when the walls were cracked. Among households using insecticides, fewer *T. infestans* were captured in roofs, goods and walls when *simbol* was present in the roofs.

Table 4 shows the results of the linear multiple regression analysis and backward stepwise elimination of the total density of *T. infestans* on selected factors. The presence of hens nesting indoors was the only significant variable, explaining 30% of the total variance. After backward elimination, only two of the nine independent variables remained significant. Variations in total bug density were accounted for by the presence of hens nesting indoors (with positive effects) and insecticide use (with negative effects), which explained 23% of the total variance. In a similar analysis involving 52 houses for which we had data on the density of *T. infestans* in 1988, the variables selected were insecticide use (with negative effects) and bug density in 1988 and previous spray-

Table 3: **Distribution of *Triatoma infestans* by capture stratum, according to house characteristics, Amamá, Trinidad, and Mercedes, Argentina, March 1992**

House characteristics	No. houses surveyed	No. bugs captured	% of bugs captured in: Beds	Goods	Roof	Walls
Type of roof						
All *simbol*	11	68	40 (0)[a]	7 (0)	10 (0)	43 (0)
Partly *simbol*	7	149	26 (2)	12 (3)	22 (2)	40 (2)
No *simbol*	50	1212	7 (0)	17 (1)	27 (2)	49 (4)
Presence of cracks in walls						
None	14	107	21 (0)	24 (0)	35 (2)	20 (0)
Some	37	750	10 (0)	14 (0)	25 (0)	51 (3)
Many	17	572	8 (0)	18 (3)	26 (3)	48 (12)
Insecticide use						
Yes	41	599	11 (0)	14 (0)	24 (0)	51 (0)
No	27	830	10 (0)	18 (2)	27 (2)	44 (7)

[a] Figures in parentheses are the median numbers of bugs.

ing with deltamethrin in 1985 (with positive effects); all explained 30% of the total variance (Table 4). Addition of interaction terms did not improve the fit of the model.

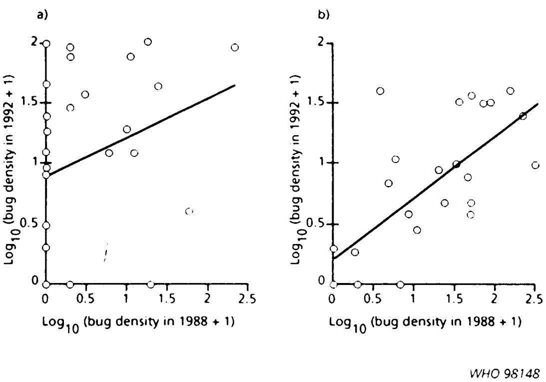
In the light of the results in Table 4, we analysed the relation between spraying with deltamethrin in 1985 and the density of *T. infestans* in 1988 and 1992 in 52 houses. In 1988, the median density of *T.*

Table 4: **Standard and backward stepwise regression and analysis of variance for the models that fitted the overall density of domestic *Triatoma infestans* to ten independent variables, interaction terms and bug abundance in 1988, Amamá, Trinidad, and Mercedes, Argentina, March 1992**

Dependent variable	Independent variables	Regression coefficient	Standard error	*t*	*F*	R^2
Overall bug density	*Standard model*					
	Intercept	1.20	0.39	3.05[a]		
	Hens nesting indoors	0.46	0.16	2.89[a]		
	Insecticide use	−0.30	0.17	−1.79		
	{ *Simbol* roof	−0.22	0.24	−0.90		
	Partly *simbol* roof	0.09	0.27	0.34		
	Cracks in walls	0.14	0.19	0.71		
	No. of people	−0.31	0.31	−0.98		
	No. of dogs	0.19	0.40	0.47		
	Previous spraying in 1985	−0.09	0.30	−0.30		
	Age of house	−0.10	0.25	−0.42		
	Community	−0.22	0.33	−0.67	2.42[b]	0.30
	Backward model					
	Intercept	1.00	0.13	7.44[a]		
	Hens nesting indoors	0.42	0.14	2.94[a]		
	Insecticide use	−0.42	0.15	−2.86[a]	9.61[a]	0.23
	Addition of bug abundance in 1988[c] *and backward model*					
	Intercept	0.66	0.23	2.93[a]		
	Insecticide use	−0.38	0.17	2.29[b]		
	Bug density in 1988	0.34	0.12	2.85[a]		
	Previous spraying in 1985	0.48	0.17	2.73[a]	6.85[a]	0.30
	Interaction: none to add					

[a] $P < 0.01$.
[b] $P < 0.05$.
[c] The number of study houses was reduced from 68 to 52 when bug abundance in 1988 was included.

Fig. 1. **Relationship between the domestic density of *Triatoma infestans* ($\log_{10}$ transformed data) in 1988 and 1992 for houses that a) had and b) had not previously been sprayed with deltamethrin in 1985. a): R^2 = 0.09; F = 2.5; P = 0.12; y = 0.89 + 0.33x; n = 28. b): R^2 = 0.47; F = 19.6; P < 0.01; y = 0.24 + 0.5x; n = 24.**



infestans was significantly greater (P < 0.01) in unsprayed (22; Q_1–Q_3, 4–50) than in sprayed houses (1; Q_1–Q_3, 0–9). In 1992, median *T. infestans* densities did not differ significantly (P = 0.23) between sprayed (11; Q_1–Q_3, 2–42) and unsprayed houses (7; Q_1–Q_3, 2–26). In the sprayed houses, *T. infestans* densities in 1992 and 1988 were not linearly related (Fig. 1). In unsprayed houses, the density of infestation rose significantly between 1988 and 1992 (Fig. 1). The use of insecticides by householders increased between 1988 and 1992 from 46% (13/28) to 68% (19/28) among sprayed houses and decreased slightly from 71% (17/24) to 58% (14/24) among unsprayed houses.

Table 5 shows the results obtained with the elimination model that fitted the density of *T. infestans* per stratum to seven variables: hens nesting indoors, insecticide use, type of roof (*simbol* or partly *simbol* counting as two variables), cracks in walls, number of people and number of dogs. These independent variables were selected from the ten variables analysed in Table 4. After backward elimination, the more frequently significant factors selected were roofs wholly or partly made from *simbol* and hens nesting indoors, which accounted for 8% (beds) to 20–23% (roof and walls) of the total variance in the density of *T. infestans* per stratum. Addition of *T. infestans* densities in other strata strongly increased the fit of the models (Table 5). In this analysis, the dependent variable was explained to a greater extent by the density of *T. infestans* in other strata and to a lesser extent by type of roof, cracks in walls, hens nesting indoors and number of resident people. Bug density in roofs increased with the presence of hens nesting indoors and bug density in walls, and decreased with the presence of cracks in walls. Bug density in walls increased with bug density in roofs and goods and the presence of cracks in walls. Bug density in beds increased with roofs partly containing *simbol* and roof bug density, and decreased with the number of resident people. In household goods, bug density varied significantly only with bug density in walls. The interaction terms contributed marginally to increase R^2 (Table 5).

Table 6 and Table 7 show the domestic density of *T. infestans* in 1992 according to type of roof and the degree of cracking of walls assessed in 1988 and 1992. Houses that retained a wholly *simbol* roof had significantly lower densities of *T. infestans* in 1992 than those that retained roofs containing some or no *simbol*. Houses that maintained walls without cracks had significantly lower densities of *T. infestans* in 1992 than those with cracked walls in 1988 and 1992. These 52 houses were significantly different (P < 0.05) from the other 16 houses in terms of the numbers of peridomestic structures, corral animals and corrals and the age of the house, but did not differ significantly in terms of the numbers of people, dogs and poultry or in house surface area.

Discussion

This study suggests that the domestic density of *T. infestans* is strongly limited by the domestic use of insecticides by householders, by the presence of hens nesting indoors, and by the availability of refuges for bugs in roofs and walls. The association between insecticide use and the domestic density of *T. infestans* has varied among studies. This study and two earlier ones in Santiago del Estero (*8*, *20*) showed significant and negative effects of insecticide use on bug density, whereas in Trinidad and Mercedes such effects varied with the type of roof (*14*). In contrast, the domestic use of insecticides against *T. infestans* reported by householders was ineffective in a longitudinal study carried out in Brazil (*6*). These differences in results may be due to one or more of three factors. First, all studies relied on the reports of householders to assess insecticide use, reports that might be affected by questionnaire procedures and the attitudes of local populations. Second, estimates of insecticide use did not take account of the frequency and amount of insecticide used or if it was well applied and effective. Third, householders used domestic insecticides in response to high densities of bugs, as a preventive measure in the absence of bugs, or indiscriminately against mosqui-

Table 5: **Backward stepwise regression and analysis of variance for the models that fitted the density of domestic *Triatoma infestans* at each capture stratum to seven independent variables,[a] interaction terms and bug density in other strata, Amamá, Trinidad, and Mercedes, Argentina, March 1992**

Dependent variables	Independent variables	Regression coefficient	Standard error	t	F	R^2
Roof bug density	Intercept	0.35	0.08	4.29[b]		
	Hens nesting indoors	0.37	0.12	3.20[b]		
	Simbol roof	−0.38	0.16	−2.44[c]	8.00[b]	0.20
	Addition of bug density in other strata					
	Intercept	0.20	0.10	1.94		
	Hens nesting indoors	0.20	0.10	2.04[c]		
	Cracks in walls	−0.24	0.12	−1.99[c]		
	Wall density	0.56	0.08	6.84[b]	20.82[b]	0.49
	Interaction:[d] one to add				26.49[b]	0.55
Wall bug density	Intercept	0.27	0.16	1.71		
	Hens nesting indoors	0.31	0.14	2.25[c]		
	Cracks in walls	0.37	0.17	2.15[c]		
	Simbol roof	−0.45	0.18	−2.46[c]	6.47	0.23
	Addition of bug density in other strata					
	Intercept	−0.08	0.12	−0.70		
	Cracks in walls	0.35	0.12	2.85[b]		
	Goods density	0.46	0.14	3.40[b]		
	Roof density	0.55	0.11	4.87[b]	30.51[b]	0.59
	Interaction:[e] one to add				49.06[b]	0.60
Bed bug density	Intercept	0.24	0.05	4.90[b]		
	Partly *simbol* roof	0.36	0.15	2.37[c]	5.61[c]	0.08
	Addition of bug density in other strata					
	Intercept	0.40	0.12	3.36[b]		
	Partly *simbol* roof	0.40	0.15	2.72[b]		
	No. of people	−0.40	0.17	−2.33[c]		
	Roof density	0.21	0.08	2.49[c]	4.51[b]	0.21
	Interaction:[f] two to add				5.96[b]	0.22
Goods bug density	Intercept	0.32	0.07	4.59[b]		
	Hens nesting indoors	0.26	0.10	2.60[c]		
	Simbol roof	−0.33	0.14	−2.41[c]	6.22[b]	0.16
	Addition of bug density in other strata					
	Intercept	0.11	0.06	1.76		
	Wall density	0.44	0.07	6.48[b]	42.03[b]	0.39
	Interaction: none to add					

[a] Hens nesting indoors, insecticide use, *simbol* or partly *simbol* roof, cracks in walls, number of people, and number of dogs.
[b] $P < 0.01$.
[c] $P < 0.05$.
[d] Interaction between hens nesting indoors and wall density was significant.
[e] Interaction between roof density and cracks in walls was significant.
[f] Interactions between roof density and number of people and between a partly *simbol* roof and number of people were significant.

tos, flies or bugs. In view of the mode and frequency of application and the types of insecticide reported by householders, it is somewhat surprising that they exerted such significant effects on bug density. A further explanation may be that the reported use of insecticides also constituted a surrogate variable for certain attitudes of householders towards bugs and domestic hygiene that were not measured by us. The reported use of insecticides was significantly associated with house surface area, which is possibly an indicator of wealth and well-being.

Triatomine bug populations may be regulated by host availability or accessibility, which would affect fecundity, survival and time of development (*1*). Several studies have reported a significant relationship between bug density and the number of people (*6, 7*) or dogs (*14*) living in the house. In the present study, the only factor related to host availability that was significantly associated with bug density was the presence of hens nesting indoors. In houses where hens nested indoors the density of *T. infestans* increased linearly and significantly with the proportion of bugs that fed on chickens (*15*).

Space has been considered an elastic resource that acts as a limiting factor when it is severely restricted (*1*). In regression analyses, variables related

Table 6: **Density of *Triatoma infestans* in 1992, by type of roof, in 52 houses in 1992 and 1988**

	Type of roof in 1992								
	Simbol			Partly *simbol*			No *simbol*		
Type of roof in 1988	Q_1	median	Q_3	Q_1	median	Q_3	Q_1	median	Q_3
Simbol	0	1	6	NA[a]	0	NA		—	
		(8)[b]			(1)			—	
Partly *simbol*	NA	19	NA	10	17	36	5	8	20
		(2)			(4)			(3)	
No *simbol*		—		NA	17	NA	3	13	36
		—			(2)			(32)	

[a] NA = not available.
[b] Figures in parentheses are the numbers of houses.

to house construction exerted significant effects on bug density per capture stratum but not on total density. Houses with well plastered walls offered fewer refuges and had fewer bugs than those with cracked walls. In Brazil, a *T. infestans* population was completely eliminated by plastering the walls of a house (*21*). The effects of type of roof on *T. infestans* density might also be associated with the availability of refuges and adequate oviposition sites, physiological preferences (thigmotaxis, temperature, humidity) (*22*) or some repellent effect, though these remain to be investigated. Fewer bugs were captured in roofs made totally of *simbol*, suggesting that some property of this material or its compact structure would not offer adequate refuges for bugs. *Simbol* might also retain insecticide residue (*14*). In the present study, among households using insecticide, the capture of *T. infestans* from roofs, walls and goods decreased when *simbol* was present in the roofs.

The age of the house was inversely associated with infestation, which contradicts other observations (*6*). The proportion of older houses with *simbol* roofs, however, was larger than that of newer houses with such roofs. In recent decades, *simbol* has not been readily available to local people and its use may thus indicate a careful selection of materials associated with traditional styles of construction based on its advantages. In addition, the effects of such materials on bug infestation would persist over time. Houses that provided less refuge for bugs in walls and roofs from 1988 to 1992 had lower bug densities in 1992 than those with cracks in the walls and no *simbol* in the roofs. In a logistic multiple regression analysis (*2*), people living in houses with *simbol* in the roofs were more likely to have a lower seropositivity for *T. cruzi* than those living in houses with other types of roof.

According to a census taken during house demolition (*23*), *T. infestans* density was greater in roofs and walls than in beds or household goods. The distribution of bug density in the house was modified by the presence of cracks in the walls and the type of roof. Other small-scale studies associated with house demolition also showed that the distribution of *T. infestans* (*24*) and *Rhodnius prolixus* (*25*) varied with the construction materials used in the roofs and walls. The variation in the distribution of *T. infestans*

Table 7: **Density of *Triatoma infestans* in 1992, by degree of wall cracking, in 52 houses in 1992 and 1988**

	Presence of cracks in walls in 1992								
	None			Some			Many		
Presence of cracks in walls in 1988	Q_1	median	Q_3	Q_1	median	Q_3	Q_1	median	Q_3
None	1	7	11	1	3	10	4	8	35
		(11)[a]			(19)			(5)	
Many		—		14	31	37	16	27	32
					(10)			(7)	

[a] Figures in parentheses are the numbers of houses.

according to the type of house construction justifies stratified sampling.

For the subset of 52 houses for which we had data for both 1988 and 1992, the density of *T. infestans* in 1992 was significantly and positively related to density in 1988 and to spraying with deltametrin in 1985. In a logistic multiple regression analysis (*16*), bug density before a single deltamethrin application helped predict the rate of house reinfestation in Amamá. Among other studies that included the history of house infestation (*4, 6, 10*), none compared bug densities at the same houses on different occasions. Fig. 1 shows that infestation was mostly irreversible after colonization became established. Previous bug density may therefore help predict future bug density in the absence of effective interventions.

The positive effect of deltamethrin spraying in 1985 on bug density in 1992 was an unexpected result and may have several causes. The mass use of insecticides affected the target pest and its putative predators, as reported for agrosystems under chemical control (*26*). Although there are many species of arthropod predators in houses, their effect on the population dynamics of domestic triatomine bug populations remains largely unknown (*27*). If all study villages had comparable densities of infestation before Amamá was sprayed in 1985, the suppressant effect of spraying with deltamethrin on domestic *T. infestans* populations was still evident in 1988, when the use of insecticides by householders was lower than in 1992. Thus in the absence of natural predators and with infrequent use of domestic insecticides, *T. infestans* populations increased rapidly once the residual effects of the insecticide had faded away.

Several factors related to the peridomestic environment and the peridomestic density of *T. infestans* assessed in this study were not related to domestic bug density. Although goat corrals sustained large triatomine bug populations (*23*), the host-feeding patterns of *T. infestans* did not reveal large movement of bugs between domestic and peridomestic areas (*19*). After application of residual insecticides and during the initial stages of reinfestation, however, houses were recolonized from peridomestic structures (*18*). Once domestic infestations have become established, the peridomestic environment would contribute only marginally to the usually highly abundant domestic bug populations.

Limitations of the study

The data collected suffer from some problems that limit the interpretation of the results. First, timed manual collection assisted with a flushing-out spray is an insensitive method, producing biased density estimates (*17*). Bug density would be underestimated because the smaller instars are more difficult to capture (*25*) and are less affected by the flushing-out agent (*28*) and because the structure of some roofs, such as those made from *jarilla*, may impair the ability of collectors to see and catch the bugs. Within the same survey, density estimates among houses were comparable because the same team searched all houses. In contrast, bug density estimates from year to year were less comparable. Despite several limitations, the number of bugs collected per person-hour can be taken as a proportional index of bug density (*25*). In the present study, this index was in close agreement with subsequent estimates obtained by knock-down collections using insecticide fumigant canisters and plastic sheets on the floor (Gürtler, R. et al., unpublished data, 1992).

Second, the degree of cracking of the walls was assessed qualitatively by the same person in all surveys; hence the data were collected using the same criteria but were dependent on the inspector's subjective assessment. Other variables, such as insecticide use or age of the house, depended on householders' recollections, making them less reliable than measured variables.

Third, as observed by Starr et al. (*12*), several factors were associated. Multiple linear regression models allowed joint evaluation of the effects of the main factors affecting *T. infestans* density, with the aim of controlling confounding factors. These models were chosen because they were the simplest but the fit to the data was weak.

Fourth, the present study did not consider the spatial layout of the houses or villages. For example, houses close to others that are densely infested are expected to be at greater risk of invasion by triatomine bugs and subsequent colonization. Amamá is located on a paved road, exports forest products, and people come from the surrounding areas to catch the bus there. Trinidad and Mercedes are more isolated and connected by dirt roads. Amamá is therefore more likely to be exposed to the passive transport of bugs than Trinidad and Mercedes. Despite this spatial heterogeneity, however, the community concerned was not a significant predictor of domestic bug density.

Conclusions

House construction features determine the availability of refuges for domestic *T. infestans*, and thus affect bug mortality and population growth rates. Studies that control refuges and host availability might shed light on the relative role of these factors in the population dynamics of *T. infestans*.

According to our results, households with *simbol* roofs, smoothly plastered walls, no chickens nesting indoors and occasional applications of insecticide had an expected density of *T. infestans* (median = 1; Q_1–Q_3 = 0–6; n = 6) 27 times lower than households with none of these characteristics (median = 95; Q_1–Q_3 = 70–101; n = 4). The human prevalence of seropositivity for *T. cruzi* was 22% (4/18) and 50% (11/22), respectively, in the two sets of houses (*2*).

The present study suggests that the density of *T. infestans* might be controlled locally by using environmental management measures that restrict the availability of refuges in roofs and walls and the presence of hens indoors. *Simbol* could be used as an appropriate material for roofs. Plastering of walls with crack-resistant soil–cement mixtures might prevent the early formation of crevices. Further studies on environmental aspects related to house construction and health care might help define the criteria that should be applied by local residents in selecting building materials. Education programmes that promote knowledge, attitudes and practices concerning health protection, currently lacking in the affected rural areas, may play a crucial role in the control of triatomine bug infestations.

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Résumé

Facteurs limitants de la densité domiciliaire de *Triatoma infestans* dans le nord-ouest de l'Argentine: étude longitudinale

Les facteurs de risque environnementaux et démographiques associés à l'infestation domiciliaire par *Triatoma infestans* et à sa densité dans les habitations ont été étudiés dans trois villages ruraux massivement infestés de la province de Santiago del Estero en Argentine. Une analyse monofactorielle sans ajustement a montré que le nombre de *T. infestans* capturés par heure-homme est associé significativement et négativement à l'usage d'insecticides domestiques par les occupants, au type de chaume de la toiture et à l'âge de l'habitation; l'association est positive avec la présence de fissures dans les murs intérieurs et quand les poules nichent dans l'habitation. Un modèle analysé par régression linéaire multiple et obtenu par élimination progressive des variables (procédure descendante) montre que l'essentiel de la variation de la densité globale de *T. infestans* s'explique par l'utilisation d'insecticide et la présence des poules nichant dans la maison; un autre modèle analysé par la même technique explique la variation par l'utilisation d'insecticide, la densité des triatomes en 1988 et une pulvérisation de deltaméthrine en 1985. Les variations de densité des triatomes en fonction du lieu de capture (meubles, lits, murs et toit) s'expliquent par la densité dans les autres localisations et par un ou deux facteurs de risque, notamment les poules nichant à l'intérieur, le type de toit, la présence de fissures dans les murs et le nombre de personnes vivant au foyer. La densité des triatomes pourrait être maîtrisée localement en réduisant la présence des refuges dans les toits et les murs, en interdisant aux poules de nicher à l'intérieur et en utilisant des insecticides domestiques. Certains matériaux locaux, par exemple une graminée connue sous le nom de *simbol* (*Pennisetum* sp.), pourraient être utilisés avec succès dans les programmes d'amélioration de l'habitat rural visant à diminuer la présence des refuges dans les toitures. Cette étude est la première étude multivariée des facteurs qui modifient la densité domiciliaire de *T. infestans* dans un secteur bien défini.

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