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Harvesting grasshoppers *Sphenarium purpurascens* in Mexico for human consumption: A comparison with insecticidal control for managing pest outbreaks

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Abstract

Predominant crops (corn, bean and alfalfa) in the Puebla–Tlaxcala Valley are routinely attacked by the grasshopper *Sphenarium purpurascens* (Orthoptera: Pyrgomophidae). The traditional method for managing this pest in México has been the application of organophosphorus insecticides such as malathion. Inhabitants from Central Mexico also capture the grasshoppers for sale as food. In this study, we compared the capture of grasshoppers for human consumption to the conventional application of insecticides as a pest management strategy. The number of oothecae (egg pod), eggs, eggs per ootheca and the reproductive rate (Ro) were estimated over 2 years of the study. Counts were made on the edge and inner part of nine alfalfa plots. Egg density was found to be significantly affected by control tactic, with control > manual harvest > insecticide application. Egg density at the edge of farming plots was 14.9 times higher than within a plot. Ros ranged from 1.74 to 4.88 in the control, from 0.21 to 0.98 in the plots under manual harvest and from 0.38 to 0.77 in the plots under insecticide application. Similar results were found comparing oothecae densities. A mean of 39.5 eggs/ootheca was found, which constitutes the highest recorded value for this species. This research shows that manual harvest reduces the density of *S. purpurascens* and suggests that implementation of this mechanical method of control may be substituted for chemical control. Mechanical control provides general advantages: (1) a second profitable product for the human community; (2) savings realized from reduced cost of insecticides; and (3) reduced risk of soil and water contamination by insecticides. We propose that the manual harvest of insects is a practical method of pest control, which could be extensively applied in other crop systems in the world.

Keywords: *Sphenarium purpurascens*; Pest management; Pest control; Grasshopper control; Edible insect; Ootheca density

1. Introduction

The grasshopper *Sphenarium purpurascens* Charpentier (Orthoptera: Pyrgomorphidae) is a wingless insect. It completes one generation per year, which starts in May when eggs emerge during the rainy season (Cano-Santana, 1994). The five nymphal instars require approximately 5–6 weeks to complete development and the adult are active from 13 to 14 weeks (Alfaro, 1995). Females produce one to two oothecae with the egg number per ootheca varying depending on habitat resources, and ranging from 15 (Serrano-Limón and Ramos-Elorduy, 1990) to 38 (Castellanos-Vargas, 2001). Oviposition occurs within the soil, where the eggs remain in the oothecae for 17 weeks approximately (Serrano-Limón and Ramos-Elorduy, 1990). This species ranges from Central Mexico to Guatemala and some Caribbean islands (Kevan, 1977); however, in recent years it has been recorded in crops in northern Mexico (R. Cerritos, unpublished data).

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This grasshopper is one of the most important pest species in Mexico (SARH-DGSV, 1991). The Puebla–Tlaxcala Valley has experienced the highest infestation of the grasshopper. By 1995, 30,339 ha had been reported to be infested with the grasshopper in the state of Tlaxcala (CESAVETLAX, 1995). The most affected crops in the region are corn, bean, alfalfa, squash, and broad bean, though it has been reported that the grasshoppers can also feed on wild plants and thicket found on the borders of cultivated land (SARH-Tlaxcala, 1993; CESAVETLAX, 1995).

The primary method used to control grasshoppers in the Puebla–Tlaxcala Valley is the application of insecticides, mainly parathion and malathion (Méndez, 1992). These insecticides have been used intensively since the 1980s (SARH-DGSV, 1988); however, major control efforts have not been necessary in recent years (M. Omaña, unpublished data). People normally apply the insecticide three to five times per year as concentrate or diluted in water, 50% vol/vol (5 l/ha), using a manual aspersion pump. No precautionary measures are typically taken during insecticide applications. Other alternative methods used to manage *S. purpurascens* include biological control with *Beauveria bassiana* (Alfaro, 1995), use of insecticidal substances from natural extracts (Méndez, 1992), and experimental use of certain sound frequencies (Rojas, 1994). However, none of these control alternatives has proven economically feasible.

S. purpurascens is one of the most important edible insects in North America (Barrientos, 1995). The consumption of edible insects has been recorded since prehispanic cultures ($>$500 years ago), mainly among the Aztecs (Sahagún, 1829). These grasshoppers have a high nutritional value (Ramos-Elorduy, 1987; Ramos-Elorduy and Pino, 1990) and are a key species in today's Mesoamerican diet. Between May and December the people of Santa María Zacatepec, Puebla, capture this grasshopper and sell it in the state of Oaxaca. Every day, local residents begin the harvest at 0400–0500 h, which facilitates capture due to the insects' low metabolism at colder temperatures. Harvesters use conical nets (ca. 80 cm diam. and 90 cm depth) without handles to lightly beat the alfalfa plants, allowing each local family to obtain about 50–70 kg of grasshoppers weekly. It is estimated that at least 75–100 ton (fresh weight) per year are extracted in this valley alone (R. Cerritos, unpublished data).

As this harvest level is so high, capturing *S. purpurascens* for human consumption could result in an alternative control method for this pest and provide a nourishing resource for humans. At the same time, such activity could have sociological and economical benefits for the local community.

How does the impact of harvesting *S. purpurascens* affect the population density of the pest and how does this compare with the standard use of chemical insecticides? To address this question, we compared the impact of each control strategy on oothecae production, total egg density and reproductive rate *of S. purpurascens* in the inner and outer edges of alfalfa plots over 2 years.

2. Materials and methods

2.1. Site of study

The Puebla–Tlaxcala Valley (19°00′–19°30′N; 98°00′–98°30′W; elevation 2100–2500 m) including ca. 185,786 ha is located in central Mexico, straddling the states of Puebla and Tlaxca (Fig. 1). The valley is bordered to the north by the city of Tlaxcala, to the southwest by the Izúcar de Matamoros and Chiautla Valleys, to the east by the Malinche Volcano and to the west by the Sierra Nevada. The climate is mild and subhumid with a summer rainy season and mean temperatures ranging from 12 to 18 °C. The total annual rainfall varies between 700 and 1500 mm; the average winter rainfall is less than 5 mm (INEGI, 1999). The valley has a variety of soil types, primarily regosole, fluviosole, cambizole and chernozen (INEGI, 1999). The principal agricultural products, in descending order, include corn (*Zea mays* L.), kidney beans (*Phaseolus vulgaris* L.), alfalfa (*Medicago sativa* L.), spinach (*Spinacea oleracea* L.), cauliflower (*Brassica oleracea* L.), radish (*Raphanus sativa* L.), carrot (*Daucus carota* L.), and broad bean (*Vicia faba* L.) (CESAVETLAX, 1995).

2.2. Site selection

Corn is grown on most of the land in the valley, but insecticide is very rarely applied to the crop. The capture of grasshoppers for human consumption is extremely low in corn fields because the structure of the plants inhibit the use of circular nets, necessary for collecting. We therefore focused on alfalfa, the crop where grasshoppers are commonly harvested for food use. Alfalfa is harvested by cutting the entire stem, there can be from six to 12 harvests per year and the plants can remain in the parcel from 2 to 10 years. Alfalfa plots were chosen where *S. purpurascens* populations had experienced chemical and mechanical control.

Exploratory analyses of grasshoppers populations and plots conditions in the valley were made prior to the study (2000) in order to estimate population size, anthropogenical pressures (type and intensity of grasshopper population control), natural pressures (predation and competition), conditions surrounding the plots (irrigation type and soil treatment), and the degree to which the farmers would permit research of their fields. Nine alfalfa plots, 1.0–1.5 ha in size, were selected in the valley. Three plots (Huejotzingo 2, Moyotzingo, Tepetitla) were sprayed with insecticides to control grasshoppers. Three plots (Huejotzingo1, Panotla, Nativitas), were harvested manually using conical nets. Three plots (San Antonio Atotonilco, San Jorge, San Diego Xocoyucan) were used as checks. For the insecticide, malathion (Malathion 1000 E®, Dragon, Izúcar de Matamoros, Puebla, México) was

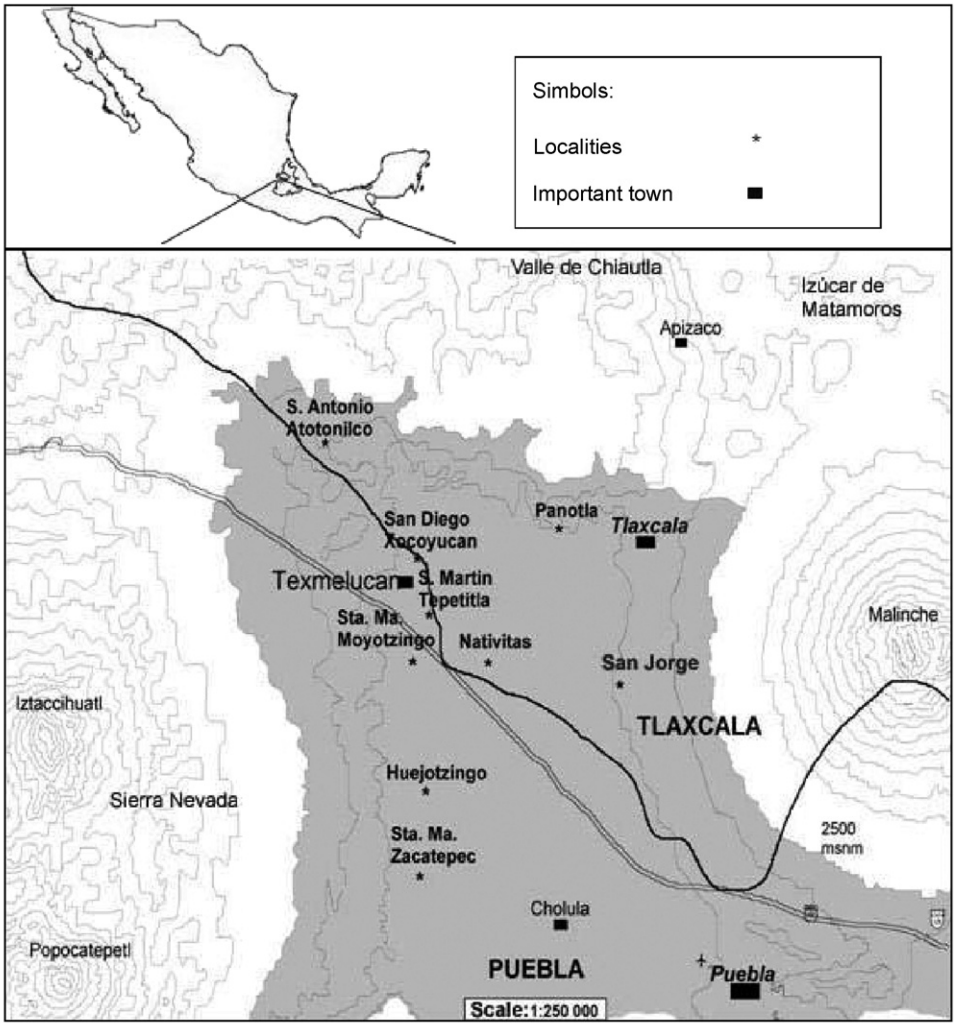

Fig. 1. Puebla–Tlaxcala Valley and locations studied.

applied three to five times per year diluted in water 50% vol/vol (5 l/ha), using a manual aspersion pump. Sites did not vary by more than 100 m in elevation.

2.3. Density of oothecae and eggs per ootheca

Randomly selected areas ($n = 120$) of soil (30×30 cm and 20 cm deep) were sampled at each plot in March of 2001 and 2002. Sixty samples were obtained along the edge of the plot (every 2 m) and 60 samples were taken from the interior. Soil was extracted with a shovel and the dirt sifted in a rectangular sieve 80×50 cm with a 5 mm mesh opening. All oothecae were collected and counted on the sieve and then taken to the laboratory in paper bags and stored in a dry place until the number of eggs in each could be counted. Counting was done by manually opening all the oothecae. Density was defined as the mean number of oothecae and eggs per square meter.

The number of oothecae as well as the number of eggs per ootheca were transformed using $\sqrt{(x+0.5)}$ (Zar, 1999). To determine the effect of treatment, locality and habitat (edge vs. interior) on ootheca density, and number of eggs per ootheca, we performed a nested ANOVA using the JMP 3.1.6.2, program (SAS-Institute, 1998). The variable "habitat" was nested in the location, while the variable "treatment" was independently analyzed according to the nesting.

2.4. Ro values

To determine the pattern of *S. purpurascens* population growth between 2001 and 2002 the reproductive rate (Ro) was calculated for each site. This value was obtained by dividing the number of eggs in the year 2002 ($Nt+1$) by the number of eggs in the previous generation (Nt) (2001) (Begon et al., 1996). To determine the effect of treatment on Ro, we performed an ANOVA using the JMP 3.1.6.2, program (SAS Institute, 1998).

3. Results

3.1. Egg and ootheca density

In 2002, treatment had a significant effect on egg density, but not for 2001 (2001: $F = 3.2$, df 2, 6, $P = 0.07$; 2002:

$F = 7.7$, df 2, 6, $P<0.05$). The highest border egg densities were found in check plots: Atotonilco, Xocoyucan, and San Jorge. In contrast, the lowest egg densities were recorded from plots treated with insecticide. The border of check plots showed a much higher egg density in 2002 ($11{,}100 \pm 1232$ eggs/m^2) than in the previous year (3994 ± 670 eggs/m^2) (Table 1). However, data from the plots that were treated with insecticide, or from those where grasshoppers were manually harvested, showed an inverted pattern; there was a higher egg density in the first year than in the second.

Location of sampling also had a significant effect on the density of eggs in both years of the study (2001: $F = 6.9$, df 2, 1062, $P<0.001$; 2002: $F = 15.8$, df 2, 1062, $P<0.001$). Generally, higher densities of eggs were found at Atotonilco and lower densities at Tepetitla.

A significant effect of habitat on egg density was also found for 2001 and 2002 (2001: $F = 31.9$, df 1, 1062, $P = 0.004$; 2002: $F = 98.9$, df 1, 1062, $P<0.001$). In both years, samples from the border of the plots supported higher egg densities than those from the interior.

In 2002, there was a significant effect on ootheca density, but the effect was not significant in 2001 (2001: $F = 3.5$, df 2, 6, $P>0.05$; 2002: $F = 9.6$, df 2, 6, $P<0.01$). Higher densities of oothecae were found in control sites and lower densities were found in sites treated with insecticides (Fig. 2). Ootheca density in the borders of check plots was almost three times greater in 2002 than in 2001 at 295.1 ($\pm$SE 35.3) and 100.5 ($\pm$16.2) oothecae/m^2, respectively. However, densities in the borders of sprayed and manually harvested plots were lower in 2002 than in 2001.

Location of sampling showed a significant effect on ootheca density in both years (2001: $F = 4.85$, df 2, 1062, $P<0.001$; 2002: $F = 15.13$, df 2, 1062, $P<0.001$). Higher densities of oothecae were found at Atotonilco and lower densities were recorded at Tepetitla (Fig. 3).

Table 1
Mean egg densities ($\pm$SE) and reproductive rates of *S. purpurascens* by treatment in two consecutive years

Plots	2001 eggs/m^2	2002 eggs/m^2	Ro
Control			
Atotonilco	6561 ($\pm$1603)	18,961 (2100)	2.89
Xocoyucan	3365 ($\pm$734)	5855 (1113)	1.74
San Jorge	2210 ($\pm$396)	10,784 (1992)	4.88
Mean	4045 ($\pm$911)	11866 (1735)	2.93
Capture			
Nativitas	2309 ($\pm$388)	2147 (351)	0.93
Panotla	1939 ($\pm$461)	1826 (412)	0.98
Huejotzingo 1	2190 ($\pm$371)	459 (111)	0.21
Mean	2144 ($\pm$406)	1477 (291)	0.68
Insecticide			
Moyotzingo	2202 ($\pm$452)	1695 (252)	0.77
Huejotzingo 2	863 ($\pm$157)	327 (87)	0.38
Tepetitla	352 ($\pm$123)	151 (83)	0.43
Mean	1139 ($\pm$244)	624 (140)	0.54

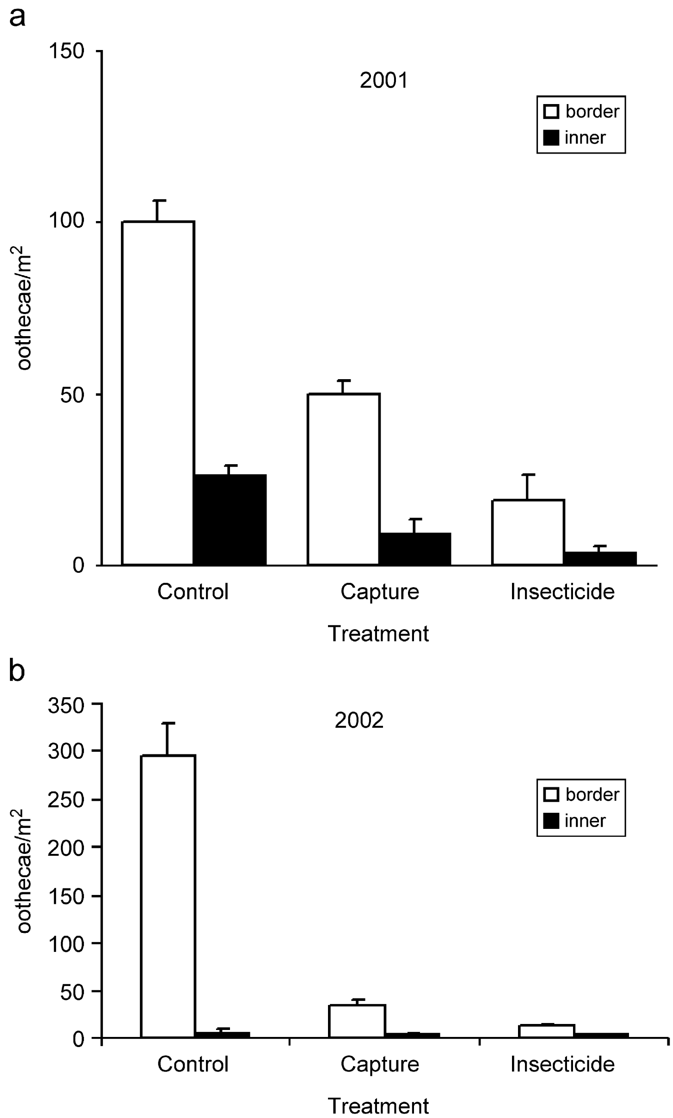

Fig. 2. Density of *S. purpurascens* oothecae (mean$\pm$SE) by treatment in the Puebla–Tlaxcala Valley in 2001 (a) and 2002 (b). The data of both habitats of agrosystem are presented.

Ootheca density on the edges of the plots was 12–27 times higher than in the interior (mean of 19 times higher) (2001: $F = 234.97$, df 1, 1062, $P = 0.003$; 2002: $F = 13.05$, df 1, 1062, $P = 0.025$). The lowest ootheca densities were recorded in the border of the insecticide-treated plots at Tepetitla at 5.2 ($\pm$2.0 SE) and 2.4 ($\pm$0.9) oothecae/m^2 in 2001 and 2002, respectively, while the highest densities were recorded in the check plots at Atotonilco at 155.5 ($\pm$39.0) and 450.4 ($\pm$74.7) oothecae/m^2 in 2001 and 2002, respectively (Fig. 3).

3.2. Number of eggs per ootheca

In 2001 and in 2002, significant effects of treatment (2001: $F = 16.8$, df 2, 6, $P<0.01$; 2002: $F = 17.3$, df 2, 6, $P<0.01$) and plot location (2001: $F = 37.9$, df 2, 2874, $P<0.01$; 2002: $F = 13.9$, df 2, 1313, $P<0.01$) were found

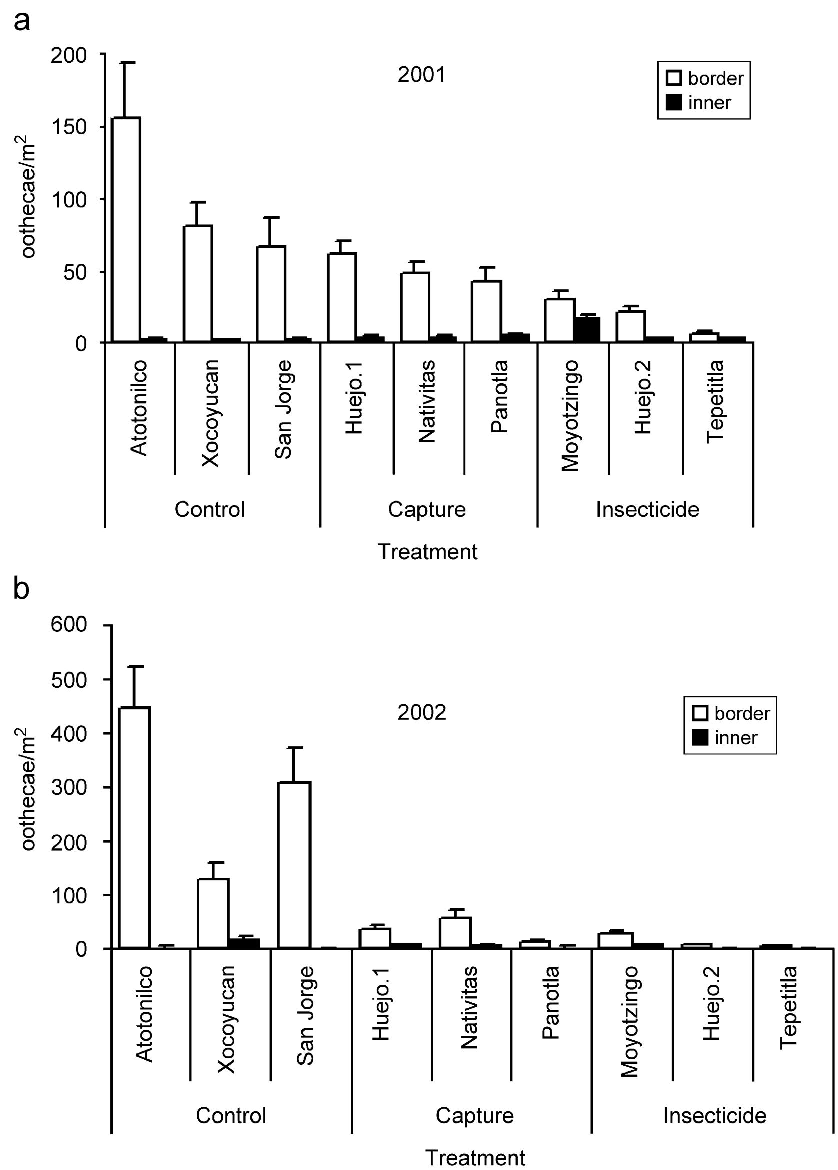

Fig. 3. Density of *S. purpurascens* oothecae (mean ± SE) on alfalfa plots at nine locations in the Puebla–Tlaxcala Valley in 2001 (a) and 2002 (b) by treatment. The data of both habitats of agrosystem are shown.

on the number of eggs per ootheca, while habitat did not have any effect (2001: $F = 0.1$, df 1, 2874, $P = 0.686$; 2002: $F = 0.01$, df 1, 1313, $P = 0.910$). Oothecae collected from insecticide-treated plots contained a higher number of eggs than those in the control and in the manually harvested treatment (insecticide-treated = 40.0 ± 0.6; check = 33.6 ± 0.9; manually harvested = 36.1 ± 0.4) (Fig. 4). The number of eggs per ootheca varied from 30.5 ± 0.8 (San Jorge, 2002) to 48.6 ± 1.0 (Moyotzingo, 2001) (Fig. 5). Compared with the other plots, San Jorge, Huejotzingo 1, and Huejotzingo 2 had lower numbers of eggs per ootheca.

3.3. Reproductive rate

Significant treatment effects ($F = 27$, df 2, 6, $P < 0.01$) were found for Ros. Mean Ro for the control treatment indicated that these populations increased their size ca. 300% per year (Table 1). Ros in check plots ranged from 1.74 to 4.88. Treatment by grasshopper capture exhibited an Ro mean of 0.68, indicating that *S. purpurascens* population size decreased during the 2 years of the study. Mean Ro of 0.54 for the insecticide treatment was the lowest when compared with the other two treatments, also indicating that grasshopper populations decreased (Table 1).

4. Discussion

The lowest densities of oothecae and eggs were found in locations where insecticide had been applied. However, the results also showed that grasshopper population size in plots in which grasshoppers had been manually collected was lower than in the untreated check plots. The Ro values

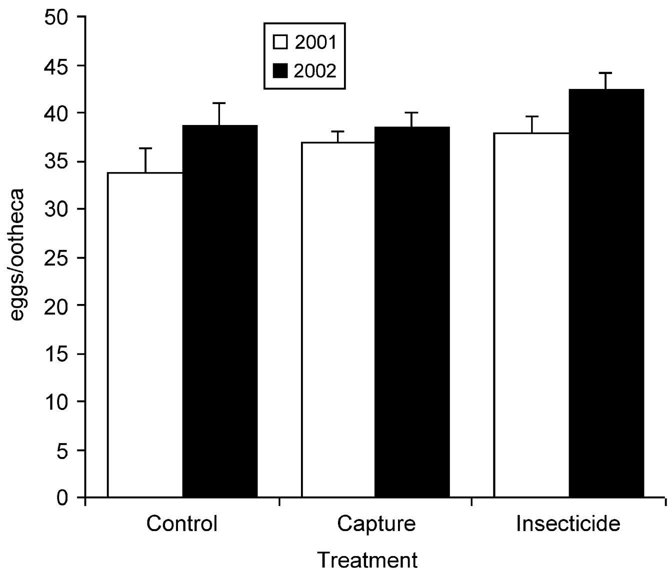

Fig. 4. Number of *S. purpurascens* eggs/oothecae (mean ± SE) by treatment in 2001 and 2002.

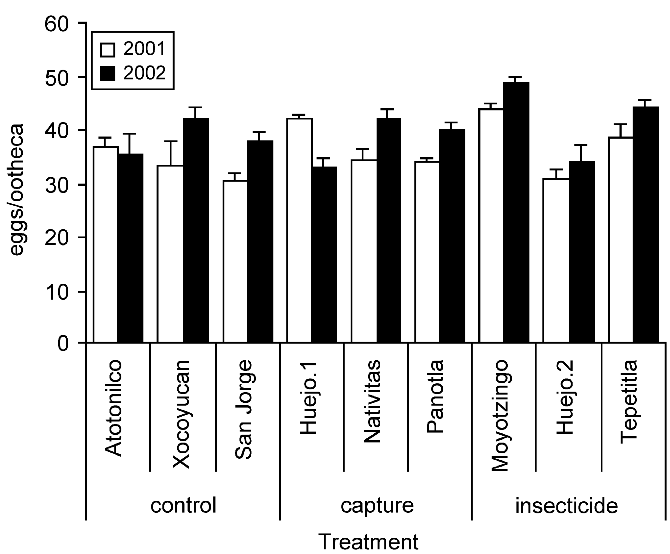

Fig. 5. Number of *S. purpurascens* eggs/oothecae (mean ± SE) by plot in 2001 and 2002.

obtained from the 2-year study indicate that although the application of insecticides reduced the *S. purpurascens* population, manual control also reduced *S. purpurascens* populations or, at least, kept them stable (Table 1). This suggests that *S. purpurascens* pest control by mechanical capture has a significant effect, although less than the insecticide application method. Manual harvesting of grasshoppers also avoids the negative repercussions that insecticides can have on the environment. Although insecticides used for pest management represent an enormous benefit in terms of food production, they may also increase environmental risk (Scott, 1995; Jensen, 2000).

In recent years, concern about the conservation of insects has grown, along with the implementation of conservation programs (Lockwood, 1998; Stewart, 1998; Lockwood and Sergeev, 2000). A diverse complex of insect species with low population densities, which would rarely be economic threats, has been observed in Mexican agricultural plots including alfalfa and corn (R. Cerritos, unpublished data). Some orthopterans have also been threatened or exterminated in agricultural crops (IUCN, 1996; Hoekstra, 1998; Lockwood, 1998; Lockwood and Sergeev, 2000). One of the first orthopterans exterminated in the 19th century was *Melanoplus spretus* (Lockwood and DeBrey, 1990). Stewart (1998) discusses how the extinction of this endemic South African grasshopper was caused by applying insecticide with the intent to control the locust *Lacustana pardalina*. Various species of acridids associated with agricultural plots such as in the Puebla–Tlaxcala Valley are likely to have a restricted range, making their conservation status particularly susceptible to the application of chemical insecticides (R. Cerritos, unpublished data). Pfadt (1994) points out that *Melanoplus sanguinipes* at high densities can be a devastating pest. However, at low densities this species can be beneficial because it prefers to feed on weeds.

Lockwood (1998) pointed out that the advantage of mechanical control is the direct, fine-tuned effect on the target pest, as opposed to chemical control which also impacts non-target species. In the Puebla–Tlaxcala Valley, the use of mechanical control for *S. purpurascens* would help preserve beneficial species or rare acridids in agricultural crops.

There are also a number of studies that have recorded the indirect effects of insecticides, such as malathion, on non-target aquatic organisms and humans (Thi et al., 1997; Boleas et al., 1998; Lahr, 1998; Peveling et al., 1999a, b; Abou-Arab and Donia, 2001; Cortet et al., 2002). For example, application of insecticides for control of the locust *Schistocerca gregaria* may result in organophosphorate residues in water bodies and directly affects a large number of species (Lahr, 1998). In addition, in the Puebla–Tlaxcala Valley organophosphorus insecticides such a malathion are applied directly by farmers, often without proper personal safety equipment. The harmful effects of malathion on farmers and applicators are well known (Giri et al., 2002; Liu and Pleil, 2002): respiratory disorders (Bos and Kilibarda, 1998), and genotoxic and citotoxic effects resulting in chromosome deviation and abnormal sperm (Giri et al., 2002). Several studies have also demonstrated the presence of organophosphate compounds in food (Jury et al., 1983; Soliman, 2001; Amer et al., 2002). Most of the alfalfa produced in the Puebla–Tlaxcala Valley is used for feeding cattle for meat and milk production. Usually, grasshoppers are harvested in crops where insecticide has not been applied for several days. However, it is possible that grasshoppers contaminated with malathion could also be consumed by humans due to a lack of communication between farmers and "grasshoppers hunters."

Results of this study indicate that the use of mechanical harvesting of *S. purpurascens* may have two additional advantages. First, for the residents of Santa María Zacatepec (Puebla), grasshopper harvesting has become the principal source of income during 6 months of the year. The primary market for their products includes the states of Oaxaca, Puebla, Morelos and Mexico City. Sale of grasshoppers yields annual profits of about US$3000 per family (R. Cerritos unpublished data). In contrast, insecticide application represents an additional cost of ca. US$150 per farmer. At present, grasshoppers are often harvested surreptitiously where grasshopper hunters frequently capture *S. purpurascens* without permission from landowners. The local authorities have tried to avoid clandestine harvesting by convincing farmers to invite grasshoppers hunters to collect these insects in their plots. Farmers can take advantage in two ways: one, by avoiding the expense of insecticides and increasing crop production. On the other hand, grasshopper hunters can obtain economical benefits when selling these insects.

Secondly, *S. purpurascens* is a high-quality food for human consumption. The protein content of *S. purpurascens* ranges from 51.1% to 73.3% dry weight (Ramos-Elorduy et al., 1982) and the digestibility of this insect protein in vitro is 85% (Ramos-Elorduy et al., 1981). This exceeds the protein content of most commonly consumed foods (Ramos-Elorduy and Pino, 1990). In Mexico, as in other developing countries, a large part of the population suffers protein and caloric deficiencies, which could be resolved with insect protein consumption (Ramos-Elorduy, 1997).

With respect to the oviposition sites, the borders of all plots had higher egg and ootheca densities than the interior. The physical characteristics of the soil between the border and the interior of the plots are very different, particularly in compactness. The soil in the border of the plots is less compact than in the interior, possibly due to lack of farming. Soil humidity inside the plot can be more homogeneous all year long, which could increase exposure of the eggs to fungi and bacteria. In contrast, the border soil has a lower compactness and a period of decreased humidity during and after oviposition. One option to control *S. purpurascens* densities could be to reduce the area of plot border.

A review of the literature suggests that there has been a general increase in the number of eggs contained in ootheca of *S. purpurascens* since 1962. Márquez (1962) reported 15–20 eggs/ootheca, Serrano-Limón and Ramos-Elorduy (1990) reported 20 eggs/ootheca and Alfaro (1995) reported 31 eggs/ootheca. We found 39.8 and 36.6 eggs/ootheca in 2001 and 2002, respectively. We hypothesize that it is possible that the number of progeny per female has increased in the valley due to pressures of anthropogenic selection, mainly from the use of insecticides. It is expected that in environments subject to continuous disturbance due to insecticide application, insects that increase the number of eggs have better possibilities of survival. In this study, the highest number of eggs per ootheca was recorded in sites subject to insecticide use (Fig. 5).

In summary, we recommend the mechanical method as an effective approach for the management of this pest, and also suggest that this method should be considered for other crop systems. A great amount of insects that are considered as pests can be used not only for human consumption but also to feed farm animals, particularly in non-developed countries, where protein sources for human consumption are scarce. Native people inhabiting regions of America, Africa, and Asia include a great variety of insect species in their diet (Bodenheimer, 1951). Our research suggests that insects that are considered pests, and that are potentially edible, could be mechanically controlled, thus decreasing the deleterious effect of insecticide use in crops and natural environments.

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References

Abou-Arab, A., Donia, A., 2001. Pesticide residues in some Egyptian species and medicinal plants as affected by processing. Food Chem. 72, 439–445.

Alfaro, A.L., 1995. Biología de *Sphenarium purpurascens* Charpentier (Orthoptera: Acrididae) y patogenicidad de *Beauveria bassiana* en laboratorio. Tesis Profesional, Universidad Autónoma de Chapingo, Chapingo, México.

Amer, S., Fahmy, M., Aly, M., Farghaly, A., 2002. Cytogenetic studies on the effect of feeding mice with stored wheat grains treated with malathion. Mutat. Res. 513, 1–10.

Barrientos, L.L., 1995. El problema de langostas y saltamontes (Insecta-Orthoptera) en Latinoamérica. Biotam 7, 43–48.

Begon, M., Mortimer, M., Thompson, D., 1996. Population Ecology, A Unified Study of Animals and Plants. Blackwell Science, Oxford.

Bodenheimer, F.S., 1951. Insect as Human Food. W. Juuk, The Hague.

Boleas, S., Carbonell, G., Fernández, C., Carballo, M., Ortiz, J., Tarazona, J., 1998. Comparison between stress response and toxicant exposure biomarkers in Gilthead Sea Bream, *Sparus aurata* L., Exposed to cadmiun, malathion and/or arochlor 1254. Mar. Environ. Res. 46, 122–123.

Bos, I., Kilibarda, T., 1998. Characteristics of respiratory disorders in acute poisoning with organophosphorous insecticides. Toxicol. Lett. 95, 142.

Cano-Santana, Z., 1994. Flujo de energía a través de *Sphenarium purpurascens* (Orthoptera: Acrididae) y productividad primaria neta aérea en una comunidad xerófita. Tesis Doctoral, Centro de Ecología, UNAM, México.

Castellanos-Vargas, I., 2001. Ecología de la oviposición de *Sphenarium purpurascens* (Orthoptera: Pyrgomorphidae) en la reserva del Pedregal de San Ángel, México, D.F. Tesis Profesional, Facultad de Ciencias, UNAM, México.

CESAVETLAX, Comité Estatal de Sanidad Vegetal de Tlaxcala, 1995. Informe técnico del Comité Estatal de Sanidad Vegetal en Tlaxcala. Campaña contra el Chapulín. Tlaxcala, México.

Cortet, J., Gillen, D., Joffre, R., Ourcival, J.-M., Poinsot-Balanguer, T., 2002. Effects of pesticides on organic matter recycling and microarthropods in a maize field: use and discussion of the litterbag methodology. Eur. J. Soil Biol. 38, 261–271.

Giri, S., Prasad, S., Giri, A., Sharma, G., 2002. Genotoxic effects of malathion: an organophosphorus insecticide, using three mammalian bioassays in vivo. Mutat. Res. 514, 223–231.

Hoekstra, J., 1998. Conserving Orthoptera in the wild: lessons from *Trimerotropis infantilis* (Oedipodinae). J. Ins. Conserv. 2, 179–185.

INEGI Instituto Nacional de Estadística Geografía e Informática, 1999. Información Geográfica del Estado de Puebla y Tlaxcala. México, D.F.

IUCN, 1996. IUCN Red List of Threatened Animals. Gland, Switzerland.

Jensen, S.T., 2000. Insecticide resistance in the western flower thrips, *Franklinella occidentalis*. Integr. Pest Manage. Rev. 5, 131–146.

Jury, W., Spencer, W., Farmer, W., 1983. Use of models for assessing relative volatility, mobility and persistence of pesticides and the other trace organics in soils systems. In: Hazard Assessment of Chemical. Academic Press, San Diego.

Kevan, D.K., 1977. The American Pirgomorphidae. Rev. Soc. Entomol. Argentina 36, 3–28.

Lahr, J., 1998. An ecological assessment of the hazard of eight insecticides used in desert locusts control, to invertebrates in temporary ponds in the Sahel. Aquat. Ecol. 32, 153–162.

Liu, S., Pleil, J., 2002. Human blood and environmental media screening methods for pesticides and polychlorinated biphenyl compounds using liquid extraction and gas chromatography–mass spectrometry analysis. J. Chromatogr. 769, 155–167.

Lockwood, J.A., 1998. Management of orthopteran pest: a conservation perspective. J. Ins. Conserv. 2, 253–261.

Lockwood, J.A., DeBrey, L.D., 1990. A solution for the sudden and unexplained extinction of the Rocky Mountain locust, *Melanoplus spretus* (Walsh). Environ. Entomol. 19, 1194–1205.

Lockwood, J.A., Sergeev, G.M., 2000. Comparative biogeography of grasshoppers (Orthoptera: Acrididae) in North America and Siberia: applications to the conservation of biodiversity. J. Ins. Conserv. 4, 161–172.

Márquez, M.C., 1962. Estudio de las especies del género *Sphenarium* basado en su genitalia (Acrididae, Orthoptera), con la descripción de una nueva especie. An. Inst. Biol. Univ. Nal. Aut. Mex. 33, 247–258.

Méndez, D.R., 1992. Uso de sustancias y extractos vegetales como una alternativa de control del chapulín *Sphenarium purpurascens* Charpentier (Orthoptera: Acrididae) en maíz (*Zea mays*) en Huejotzingo, Puebla. Tesis Profesional, Universidad Autónoma de Chapingo, Chapingo, México.

Peveling, R., Attignon, S., Langewald, J., Ouambama, Z., 1999a. An assessment of the impact of biological and chemical grasshopper control agents on ground-dwelling arthropods in Niger, based on presence/absence sampling. Crop Prot. 18, 323–339.

Peveling, R., Rafanomezantsoa, J., Razafinirina, R., Tovonkery, R., Zafimaniry, R., 1999b. Enviromental impact of the locust control agents fenitrothion, fenitrothion-esfebvalerate and triflumuron on terrestrial arthropods in Madagascar. Crop Prot. 18, 659–676.

Pfadt, R.E., 1994. Field guide to the common western grasshoppers. J. Econ. Entomol. 73, 548–551.

Ramos-Elorduy, J., 1987. Los Insectos como Fuente de Proteínas en el Futuro. Limusa, México.

Ramos-Elorduy, J., 1997. Insect: a sustainable source of food. Ecol. Food Nutr. 36, 247–276.

Ramos-Elorduy, J., Pino, M.J., 1990. Contenido calórico de algunos insectos comestibles de México. Soc. Quím. Mexi. 2, 56–68.

Ramos-Elorduy, J., Pino, M.J., González, M.O., 1981. Digestibilidad in vitro de algunos insectos comestibles en México. Folia Entomol. Mex. 49, 141–154.

Ramos-Elorduy, J., Bourges, R., Pino, M., 1982. Valor nutritivo y calidad de la proteína de algunos insectos comestibles en México. Folia Entomol. Mex. 58, 111–118.

Rojas, R.S., 1994. Control del chapulín (Orthoptera: Acrididae) en maíz (*Zea mays*) por sonidos de alta y baja frecuencia. Tesis Profesional, Universidad Autónoma de Chapingo, Chapingo, Mexico.

Sahagún, F.B., 1829. Historia General de las Cosas de Nueva España. Porrúa (1992), Mexico.

SARH-DGSV, Secretaría de Agricultura y Recursos Hidráulicos, 1988. Manual técnico operativo de la campaña emergente contra chapulines: *Melanoplus* sp., *Sphenarium* sp. y *Brachistola* sp. Dirección General de Sanidad Vegetal, Mexico.

SARH-DGSV, Secretaría de Agricultura y Recursos Hidráulicos, 1991. Manual técnico operativo de la campaña emergente contra chapulines: *Melanoplus* sp., *Sphenarium* sp. y *Brachistola* sp. Dirección General de Sanidad Vegetal, Mexico.

SARH-Tlaxcala, Secretaría de Agricultura y Recursos Hidráulicos, 1993. Evaluación de la campaña contra los Chapulines en Tlaxcala en el ciclo Primavera-Verano 1993–94. Subdelegación de Agricultura. Programa de Sanidad Vegetal, Mexico.

SAS Institute, 1998. Campus Drive.

Scott, G.J., 1995. Insecticide Resistance in Insects. Handbook of Pest Management.

Serrano-Limón, G., Ramos-Elorduy, J., 1990. Biología de *Sphenarium purpurascens* Charpentier y algunos aspectos de su comportamiento (Orthoptera: Acrididae). An. Inst. Biol. UNAM Ser. Zool. 59, 139–152.

Soliman, K.M., 2001. Changes in concentration of pesticide residues in potatoes during washing and home preparation. Food Chem. Toxicol. 39, 887–891.

Stewart, D., 1998. Non-targed grasshoppers as indicators of the side-effect of chemical locust control in the Karoo, South Africa. J. Ins. Conserv. 2, 263–276.

Thi, H., Adriaens, D., Janssen, C., 1997. Morphological abnormalities in African catfish (*Clarias gariepinus*) larvae exposed to malathion. Chemosphere 35, 1475–1486.

Zar, J., 1999. Biostatistical Analysis. Prentice-Hall, Upper Saddle River, NJ.