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Survey of insecticide resistance in Mexican populations of maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)

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Abstract

Topical application bioassays of DDT, lindane, malathion, pirimiphos-methyl, deltamethrin, and permethrin were undertaken with 11 field strains of maize weevil, *Sitophilus zeamais* Motschulsky, collected from nine states in Mexico. Concentration-mortality regression lines were estimated to compare the resistance ratios for each insecticide and strain. For each insecticide, resistance ratios were determined relative to the most susceptible strain. The field-collected strains showed low to moderate levels of resistance to DDT (1.3- to 14.1-fold), moderate to high levels of resistance to lindane (4.7- to 20.9-fold), low to high levels of resistance to malathion (1.6- to 31.4-fold), and low levels of resistance to pirimiphos-methyl (3.0- to 3.7-fold), deltamethrin (1.2- to 1.8-fold), and permethrin (2.3- to 3.5-fold). This is the first report of high levels of lindane and malathion resistance in strains of *S. zeamais* in Mexico. Given this information, I conclude that insecticide resistance in *S. zeamais* in Mexico is important, and may become a more serious problem in the future. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: *Sitophilus zeamais*; Maize weevil; Insecticide resistance; Mexico

1. Introduction

Prevention of quality loss due to insect damage in stored products is important to farmers, grain handlers, grain processors, and consumers. Under most circumstances the easiest, most rapid, and economical method of controlling insects is with insecticides (White and Leesch, 1995). In fact, insecticides are generally the most effective management tool and in many instances provide the only feasible method of reducing insect pest populations or reducing them to acceptable levels (Harein and Davis, 1992).

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The tactics for control of stored product pests in commercial facilities in Mexico are almost completely dependent on pesticides, but in recent years, managers of commercial bins have reported control failures (Perez-Mendoza, 1993). Field failures can occur if an insecticide is applied at less than the labeled rate, resulting in exposure of insects to sublethal doses. However, the most likely reason for possible field failures is insecticide resistance in the target pests (Subramanyam and Hagstrum, 1995).

Among the stored product pests present in Mexico, the maize weevil, *Sitophilus zeamais* Motschulsky is one of the most destructive and causes extensive damage to maize and other cereals in storage (Rodriguez-Rivera, 1976). This insect is widely distributed in Mexico and it is able to infest maize in the field before harvest (Perez-Mendoza, 1993).

Champ and Dyte (1976) included some Mexican populations of maize weevils in their global survey of pesticide susceptibility with discriminating dose tests for resistance, and they found that some populations were resistant to lindane. However, more extensive dose-mortality studies with maize weevil and other stored product pests do not exist in Mexico. Because malathion and lindane have been widely and intensively used in storage commodities for the control of stored product pests (Ramirez-Genel, 1960; Diaz-Castro, 1970) and because in recent years managers of commercial bins have reported control failures, a monitoring program was initiated with several strains of maize weevil from different states of the country. The objective of this study was to obtain baseline data for maize weevil populations from around Mexico.

2. Materials and methods

2.1. Insecticides

The six technical grade (>90% purity) insecticides used in this study were DDT, lindane, malathion, deltamethrin (Laboratorios Helios, Mexico, DF), pirimiphos-methyl (ICI Mexico, Mexico, DF), and permethrin (FMC Mexico, Mexico, DF). DDT is not currently used in Mexico, but this insecticide was extensively used before 1960 (Ramirez-Genel, 1960). Lindane is registered for use only as a treatment to the interior of storage facilities and as a perimeter treatment outside the facility.

2.2. Insect strains

Field collections of maize weevil populations from nine Mexican states (Fig. 1; Table 1) were made between 1988 and 1992. The individual populations were reared on whole maize under constant conditions of $27 \pm 2°C$ and $65 \pm 5\%$ r.h.

2.3. Insect bioassays

Bioassays of field strains were conducted as soon as enough weevils were available. This usually required rearing the field strains for two or three generations in the laboratory. The dose-mortality line for each insecticide was estimated from five to six doses with 10 unsexed,

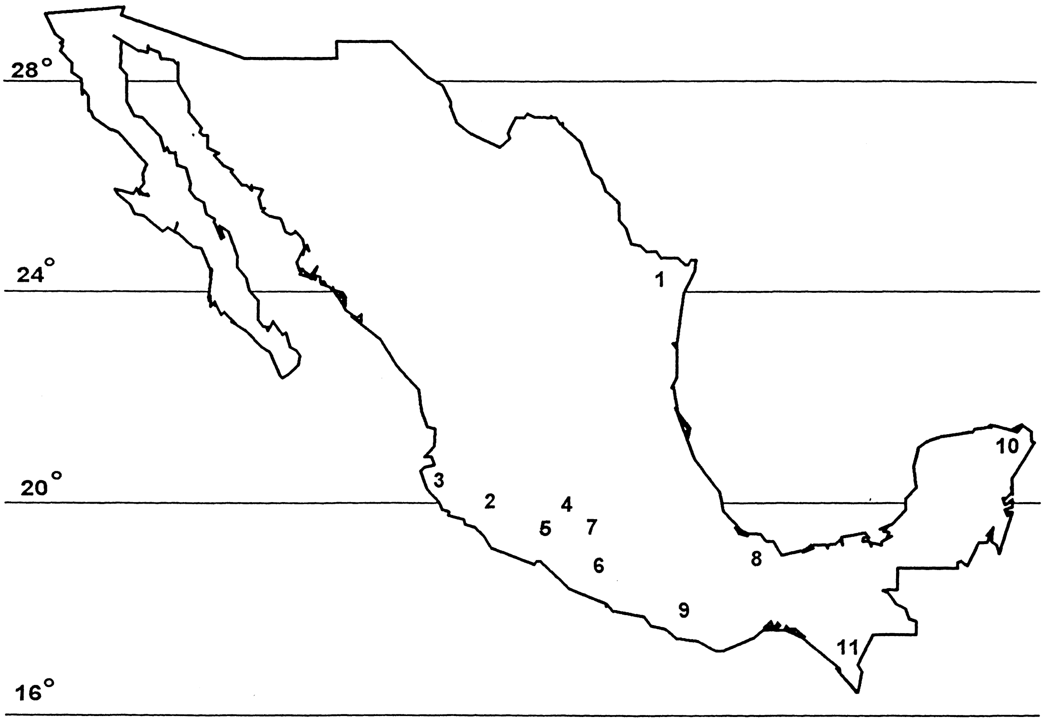

Fig. 1. Sampling sites for maize weevil populations in Mexico. Numbers correspond to locations indicated in Table 1.

1- to 3-week-old adults treated per dose (four replicates per dose were used). Control insects were treated with acetone.

Insecticides were topically applied with 0.42 μl of an acetone solution of technical grade insecticide applied to the dorsal surface of the thorax with a manual microapplicator (designed

Table 1
Origin and place of collection of maize weevil, *Sitophilus zeamais* populations in Mexico

Code No.	Locality	State	Facility
1	Rio Bravo	Tamaulipas	Elevator
2	Tamazula	Jalisco	Farm storage
3	Tomatlan	Jalisco	Elevator
4	Celaya	Guanajuato	Farm storage
5	Yuriria	Guanajuato	Elevator
6	Huehuetlan	Puebla	Farm storage
7	Chapingo	Edo. de Mexico	Farm storage
8	Jesus Carranza	Veracruz	Farm storage
9	Oaxaca	Oaxaca	Farm storage
10	Uxmal	Yucatan	Farm storage
11	Villa Morelos	Chiapas	Farm storage

in the Colegio of Postgraduados, Chapingo, Mexico) equipped with a 0.25-ml calibrated tuberculin syringe. Adults were placed in Petri dishes (100 × 15 mm, Fisher brand) and held at 27 ± 2°C, 65 ± 5% r.h. in a rearing chamber until mortality was recorded 24 h after treatment. Insects were counted as dead if they were unable to stand up and walk.

For these studies I did not have a standard susceptible laboratory strain for comparison. Therefore, the most sensitive field strain for each insecticide was used for calculating resistance ratios for the remaining strains.

2.4. Statistical analysis

Mortality data were analyzed by probit analysis (SAS Institute, 1985). At least 200 insects were used for each lethal dose (LD). Control mortality was ≤5%; data were corrected for control mortality by Abbott's (1925) formula. Resistance ratios for all assays were calculated for each insecticide by dividing LD_{50} values for resistant strains by the LD_{50} value of the most susceptible strain. Results were expressed as μg/insect. Slopes and LD_{50} values were compared; failure of 95% CL (confidence level) to overlap was used as a criterion to assess significant differences in LD_{50}'s.

3. Results

3.1. DDT resistance

Ten populations of maize weevils from eight states in Mexico were tested against DDT. Toxicity data indicated that maize weevils collected in Rio Bravo, Tamaulipas, and Villa Morelos, Chiapas were significantly more susceptible to DDT than the other populations, based on failure of 95% CL to overlap at LD_{50} for the populations tested (Table 2). Therefore, the response of the first population (as the most susceptible) was used to establish the

Table 2
Comparative susceptibility of maize weevil populations to DDT

Population	LD_{50} μg/insect	(95% CL)	Equation of regression	Slope ± SE	Resistance ratio*
Rio Bravo	0.15	0.14–0.18	$y = 7.5 + 3.0x$	3.0 ± 0.46	—
Villa Morelos	0.20	0.17–0.24	$y = 6.3 + 1.9x$	1.9 ± 0.12	1.3x
Huehuetlan	0.68	0.40–1.13	$y = 5.3 + 1.8x$	1.8 ± 0.14	4.5x
Celaya	0.83	0.73–0.95	$y = 5.3 + 3.3x$	3.3 ± 0.51	5.3x
Jesus Carranza	1.06	0.93–1.21	$y = 4.9 + 3.0x$	3.0 ± 0.42	7.1x
Uxmal	1.18	1.02–1.37	$y = 4.8 + 3.0x$	3.0 ± 0.56	7.9x
Tamazula	1.28	1.13–1.45	$y = 4.6 + 3.4x$	3.4 ± 0.67	8.5x
Chapingo	1.32	1.22–1.44	$y = 4.6 + 3.2x$	3.2 ± 0.48	8.8x
Tomatlan	1.32	1.13–1.55	$y = 4.7 + 2.3x$	2.3 ± 0.36	8.8x
Yuriria	2.11	1.80–2.51	$y = 4.3 + 2.2x$	2.2 ± 0.40	14.1x

*Resistant ratio = LD_{50} resistant population ÷ LD_{50} susceptible population (Rio Bravo).

Table 3
Comparative susceptibility of maize weevil populations to lindane

Population	LD_{50} µg/insect	(95% CL)	Equation of regression	Slope ± SE	Resistance ratio*
Villa Morelos	0.02	0.02–0.03	$y = 9.3 + 2.6x$	2.6 ± 0.47	—
Uxmal	0.10	0.09–0.11	$y = 8.5 + 3.5x$	3.5 ± 0.51	5.0x
Huehuetlan	0.15	0.12–0.17	$y = 7.2 + 2.7x$	2.7 ± 0.37	7.5x
Tamazula	0.16	0.14–0.18	$y = 7.4 + 3.0x$	3.0 ± 0.32	8.0x
Rio Bravo	0.18	0.15–0.21	$y = 6.8 + 2.4x$	2.4 ± 0.26	9.0x
Jesus Carranza	0.21	0.17–0.25	$y = 6.4 + 2.0x$	2.0 ± 0.29	10.5x
Yuriria	0.24	0.20–0.28	$y = 6.3 + 2.1x$	2.1 ± 0.23	12.0x
Celaya	0.27	0.22–0.34	$y = 6.2 + 2.1x$	2.1 ± 0.25	13.5x
Chapingo	0.33	0.28–0.38	$y = 5.9 + 1.9x$	1.9 ±0.19	16.5x
Tomatlan	0.44	0.37–0.54	$y = 5.8 + 2.3x$	2.3 ± 0.31	22.0x

*Resistance ratio = LD_{50} resistant population ÷ LD_{50} susceptible population (Villa Morelos).

resistance ratio used in resistance monitoring. DDT resistance ratios ranged from 1.3- to 14.1-fold among the resistant populations (Table 2). The populations with high resistance ratios against DDT were collected in Jesus Carranza, Veracruz (7.1-fold), Uxmal, Yucatan (7.9-fold), Tamazula, Jalisco (8.5-fold), Chapingo, Edo de Mexico (8.8-fold), Tomatlan, Jalisco (8.8-fold), and Yuriria, Guanajuato (14.1-fold) (Table 2).

3.2. Lindane resistance

The same 10 insect populations were also tested against lindane. The population collected in Villa Morelos, Chiapas was the most susceptible to this insecticide (Table 3). Consequently, I used the response of these insects to establish the resistance ratio for the rest of the populations. Lindane resistance ratios ranged from 4.7- to 20.9-fold among the resistant populations (Table 3). The populations with highest resistance ratios to lindane were collected in Jesus Carranza, Veracruz (9.9-fold), Yuriria (11.2-fold), and Celaya (13-fold), Guanajuato, Chapingo, Edo de Mexico (15.6-fold), and Tomatlan, Jalisco (20.9-fold) (Table 3).

3.3. Malathion resistance

Eleven populations of maize weevil from nine states of Mexico were tested against malathion. From these populations, the strain collected in Celaya, Guanajuato was the most susceptible to malathion (Table 4). LD_{50}s for malathion were greater for the remaining populations of maize weevil relative to the susceptible population, based on the 95% CLs (Table 4). However, malathion resistance ratios of populations collected in Oaxaca, Oaxaca; Uxmal, Yucatan; Huehuetlan, Puebla; and Jesus Carranza, Veracruz were not significantly different from that of the susceptible population (Table 4). Malathion resistance ratios ranged from 1.6- to 31.4-fold among the resistant populations. The most resistant populations were collected in Villa Morelos, Chiapas; Tomatlan, Jalisco; and Yuriria, Guanajuato (Table 4).

Table 4
Comparative susceptibility of maize weevil populations to malathion

Population	LD_{50} μg/insect	(95% CL)	Equation of regression	Slope ± SE	Resistance ratio*
Celaya	0.008	0.0043–0.015	$y = 8.8 + 1.8x$	1.8 ± 0.18	—
Oaxaca	0.013	0.011–0.014	$y = 11.2 + 3.3x$	3.3 ± 0.61	1.6x
Uxmal	0.013	0.010–0.016	$y = 11.0 + 3.2x$	3.2 ± 0.52	1.6x
Huehuetlan	0.014	0.0097–0.022	$y = 10.2 + 2.8x$	2.8 ± 0.48	1.8x
Jesus Carranza	0.015	0.012–0.016	$y = 11.3 + 3.4x$	3.4 ± 0.59	1.9x
Tamazula	0.021	0.010–0.035	$y = 10.7 + 3.9x$	3.9 ± 0.70	2.7x
Chapingo	0.029	0.017–0.046	$y = 8.3 + 2.1x$	2.1 ± 0.43	3.6x
Rio Bravo	0.040	0.036–0.043	$y = 12.1 + 5.1x$	5.1 ± 0.87	5.1x
Villa Morelos	0.082	0.070–0.095	$y = 7.8 + 2.6x$	2.6 ± 0.53	10.2x
Tomatlan	0.175	0.164–0.185	$y = 10.3 + 7.0x$	7.0 ± 0.91	21.9x
Yuriria	0.251	0.238–0.267	$y = 9.5 + 7.5x$	7.5 ± 0.87	31.4x

*Resistance ratio = LD_{50} resistance population ÷ LD_{50} susceptible population (Celaya).

3.4. Pirimiphos-methyl resistance

Only three populations of maize weevil were tested for resistance to pirimiphos-methyl in this study. The population most susceptible to this insecticide was collected in Villa Morelos, Chiapas (Table 5). Consequently, the response of these insects was used to establish the resistance ratios of the other two populations. Pirimiphos-methyl resistance ratios ranged from 3.0-fold, in the population collected in Tomatlan, Jalisco, to 3.7-fold, which was present in the population collected in Yuriria, Guanajuato (Table 5).

3.5. Deltamethrin resistance

The same three maize weevil populations tested for pirimiphos-methyl resistance were also tested with deltamethrin. The population collected in Yuriria, Guanajuato was the most susceptible to deltamethrin (Table 5). Therefore, the response of those insects was used to

Table 5
Comparative susceptibility of maize weevil populations to pirimiphos-methyl and deltamethrin

Insecticide	Population	LD_{50} μg/insect	(95% CL)	Equation of regression	Slope ± SE	Resistant ratio*
Pirimiphos-methyl	Villa Morelos	0.012	0.011–0.014	$y = 12.0 + 3.7x$	3.7 ± 0.08	—
	Tomatlan	0.038	0.033–0.043	$y = 9.2 + 3.0x$	3.0 ± 0.10	3.0x
	Yuriria	0.048	0.041–0.055	$y = 8.2 + 2.5x$	2.5 ± 0.12	3.7x
Deltamethrin	Yuriria	0.009	0.007–0.010	$y = 10.0 + 2.5x$	2.5 ± 0.13	—
	Villa Morelos	0.011	0.009–0.012	$y = 11.8 + 3.5x$	3.5 ± 0.18	1.2x
	Tomatlan	0.017	0.014–0.019	$y = 9.5 + 2.5x$	2.5 ± 0.15	1.8x

*Resistance ratio = LD_{50} resistant population ÷ LD_{50} susceptible population (Villa Morelos and Yuriria).

Table 6
Comparative susceptibility of maize weevil populations to permethrin

Population	LD_{50} μg/insect	(95% CL)	Equation of regression	Slope $\pm$ SE	Resistance ratio*
Celaya	0.03	0.025–0.039	$y = 8.0 + 2.0x$	2.0 ± 0.20	—
Tamazula	0.07	0.061–0.087	$y = 7.7 + 2.4x$	2.4 ± 0.18	2.3x
Uxmal	0.09	0.074–0.097	$y = 8.2 + 3.0x$	3.0 ± 0.37	2.7x
Rio Bravo	0.09	0.080–0.099	$y = 8.7 + 3.6x$	3.6 ± 0.33	3.0x
Huehuetlan	0.09	0.065–0.127	$y = 7.6 + 2.5x$	2.5 ± 0.09	3.0x
Jesus Carranza	0.10	0.085–0.111	$y = 8.3 + 3.3x$	3.3 ± 0.42	3.3
Chapingo	0.11	0.090–0.126	$y = 8.6 + 3.7x$	3.7 ± 0.51	3.7

*Resistance ratio = LD_{50} resistant population ÷ LD_{50} susceptible population (Celaya).

calculate the resistance ratio for the other two populations. The population collected in Villa Morelos, Chiapas had a resistance ratio of 1.2-fold, whereas the resistance ratio of the population collected in Tomatlan, Jalisco was 1.8-fold (Table 5).

3.6. Permethrin resistance

Seven maize weevil populations collected in seven states of Mexico were tested for resistance to permethrin. The population collected in Celaya, Guanajuato was the most susceptible to permethrin. Therefore, this population was used to establish the resistance ratios for the rest of the populations tested. LD_{50}s for permethrin were greater for the other six populations of maize weevil (Table 6). Permethrin resistance ratios ranged from 2.3- to 3.5-fold among the resistant populations (Table 6).

Slopes of the concentration-mortality curves were greater for the susceptible population than the resistant strains for DDT, lindane, and pirimiphos-methyl suggesting homogeneity of response to the insecticides in these populations. The slopes of the susceptible strains to malathion, deltamethrin, and permethrin were smaller than the slopes of some resistant strains suggesting heterogeneity of response to the insecticides among these populations.

4. Discussion

High DDT resistance levels were detected in almost all the populations tested, despite the fact that DDT has not been widely used in Mexico since 1960. These results suggest that DDT-resistant genes are still present in the populations tested; this may have a significant effect on the use of pyrethroids because of similar mechanisms of action between DDT and pyrethroids (Miller and Adams, 1982). Thus, high resistance levels to pyrethroids may occur soon.

Lindane resistance in Mexican populations of maize weevil was reported initially by Champ and Dyte (1976) with discriminating-dose tests for resistance. However, this is the first report of high levels of lindane resistance in maize weevil in the country. It is also the first report to establish resistance ratios for maize weevil populations although lindane is registered for use only as a treatment to the interior of storage facilities (walls, sacks, sanitary cordons, etc.) and as a perimeter treatment outside the facility. However, many farmers in rural areas in Mexico use it as a protectant treatment. This explains in part the existence of high levels of resistance among the populations tested in this study.

Resistance to malathion in one Mexican population of maize weevil was also first reported by Champ and Dyte (1976). However, this is the first report in which several populations of this species from different states of the country were tested for malathion resistance. The presence of high levels of malathion resistance in maize weevil populations is not surprising because this insecticide has been intensively used since it was introduced in 1960. The development of malathion resistance in maize weevil populations in Mexico may be explained partly by the fact that the application rate had to be increased several times to protect stored maize and stored wheat from insect damage. In 1960, malathion was applied at 8 ppm to protect stored maize and stored wheat (Ramirez-Genel, 1960). Ten years later, Diaz-Castro (1970) stated that the malathion dose had to be increased to 15 ppm to protect the same grain in storage. Sixteen years later, Ceballos (1976) determined that malathion had to be applied at 20 ppm to achieve efficient protection of stored maize against maize weevil populations. In 1993, the application rate of malathion was increased again to 40 ppm to efficiently protect stored maize and wheat (Perez-Mendoza, 1993).

The levels of resistance to pirimiphos-methyl detected in the populations of maize weevil tested in this study were low, and these results suggest that the establishment of resistance to this insecticide in Mexican maize weevil populations is in its initial stages. This may be the result of cross-resistance from malathion. This suggestion is supported by the fact that this insecticide has been used only by a small proportion of commercial facilities and rural storages because it is more expensive than lindane and malathion, and also because it was registered in Mexico after 1980 (Ortiz-Cornejo, 1980).

Maize weevil resistance to deltamethrin and permethrin is in its initial stages perhaps because these insecticides were registered as grain protectants in Mexico after 1992 (Sanidad Vegetal, 1992). However, the presence of resistance genes to DDT in maize weevil populations may accelerate the development of resistance to both pyrethroids.

In summary, these results indicate that populations of maize weevil from different states of the country are resistant to DDT, lindane, and malathion. Resistance to pirimiphos-methyl, deltamethrin, and permethrin is in its initial stages. Given this information, it is apparent that insecticide resistance among strains of maize weevil in Mexico is important, and may become a much more serious problem in the future. Therefore, more research should be conducted to monitor this problem in the major stored product insect pest populations throughout Mexico.

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References

Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18, 265–267.

Ceballos, R.E., 1976. Control quimico de plagas de granos almacenados con dos insecticidas en Iguala, Guerrero. In Resumenes del XI Congreso Nacional de Entomologia (S.M.E.), p. 59. Mexico, DF.

Champ, B.R., Dyte, C.E., 1976. Report of the FAO Global Survey of Pesticide Susceptibility of Stored Grain Pests. FAO Plant Production and Protection Series No. 5.

Diaz-Castro, G., 1970. Evaluacion de malation para controlar el gorgojo del maiz, Sitophilus zeamais Motsch. (Coleoptera: Curculionidae) en tres tipos de grano. Agricultura Tecnica en Mexico 3, 36–38.

Harein, P.K., Davis, R. 1992. Control of stored-grain insects. In: Sauer, D.B. (Ed.), Storage of Cereal Grains and their Products, pp. 492–534. American Association of Cereal Chemists, Inc. St. Paul, MN, USA.

Miller, T.A., Adams, M.E., 1982. Mode of action of pyrethroids. In: Coats, J.R. (Ed.), Insecticide Mode of Action, pp. 3–27. Academic Press, New York, USA.

Ortiz-Cornejo, A., 1980. Utilizacion de metil-pirimifos en la conservacion de granos almacenados. In: Moreno-Martinez, E., Ramirez-Martinez, M. (Eds), Memorias del Coloquio Internacional sobre Conservacion de Semillas y Granos Alimenticios, pp. 52–86. Instituto de Biologia, UNAM. Oaxtepec, Morelos, Mexico.

Perez-Mendoza, J., 1993. El Uso de Insecticidas en el Combate de Insectos de Almacen. In: Perez-Mendoza, P. (Ed.), Insectos de Granos Almacenados: Biologia, Daños, Deteccion y Combate, pp. 171–217. Secretaria de Agricultura y Recursos Hidraulicos (SARH). INIFAP, Celaya, Guanajuato, Mexico.

Ramirez-Genel, M., 1960. Protectores de grano: Toxicidad comparativa de cuatro materiales. Agricultura Tecnica en Mexico 1, 36–38.

Rodriguez-Rivera, R., 1976. Determinacion del Daño causado por plagas de almacen a variedades de maiz en Yucatan. Agricultura Tecnica en Mexico 3, 442–445.

Sanidad, V., 1992. Catalogo Oficial de Plaguicidas. In: Secretaria de Agricultura y Recursos Hidraulicos, Mexico, pp. 79–187.

SAS Institute, 1985. User's guide: Statistics, version 5. ed. SAS Institute, Cary, NC.

Subramanyam, B., Hagstrum, D.W., 1995. Resistance measurement and management. In: Subramanyam, B., Hagstrum, D.W. (Eds) Integrated Management of Insects in Stored Products, pp. 331–397. Marcel Dekker, Inc. New York, NY.

White, N.D.G., Leesch, J.G., 1995. Chemical control. In: Subramanyam B., Hagstrum, D.W. (Eds), Integrated Management of Insects in Stored Products, pp. 287–330. Marcel Dekker, Inc. New York, NY.