Chapter 1

Biorational Insecticides and Diatomaceous Earth for Control Sustainability of Pest in Chickpea and Mexican Bean Weevil

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Additional information is available at the end of the chapter

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Abstract

Sustainability involving the conservation and/or enhancement of natural resources and environmental protection can be practiced with biorational insecticides or diatomaceous earth. Two researches were carried out; in one, the objective was to determine the efficacy of biorational insecticides in controlling chickpea leaf miner, *Liriomyza sativae* Blanchard, without completely inhibiting the presence of parasitoids of this pest. Biorational insecticides were chlorantraniliprole, cyromazine and spinosad, and conventional insecticide was chlorpyrifos, which were similarly effective to control adults and larvae of Liriomyza. Most chickpea production in 2012–2013 (1993.3 and 1806.8 kg ha^{-1}) was obtained where chlorantraniliprole and chlorpyrifos were applied, respectively, and where spinosad and cyromazine were applied also exceeded the performance of absolute control (1213.6 kg ha^{-1}). In 2013–2014, the increased production was 1621.9 kg ha^{-1} with chlorantraniliprole and 1556.3 kg ha^{-1} with chlorpyrifos, significantly different from the absolute control that produced 1136.5 kg ha^{-1}. Earnings were MX$ 21011.7 in 2012–2013 and MX$ 16036.7 in 2013–2014 with chlorantraniliprole, while in the absolute control, earnings were MX$ 12305.1 and MX$ 11083.5. Chlorantraniliprole was the biorational insecticide that caused greater effect in the management of this pest of chickpea and crop yields. While in another research, the objective was to determine the efficacy of different doses of diatomaceous earth against Mexican bean weevil *Zabrotes subfasciatus* Boheman. An experiment was carried out in two phases: in first, one tested diatomaceous earth at doses of 1.0, 2.0, 3.0, 4.0, and 5.0 g kg^{-1} of seed, with samples at 15, 30, 45, and 60 days after application (daa), while in the second, the doses were 0.2, 0.4, 0.6, 0.8, and 1.0 g kg^{-1} and samples at 10, 20, 30, and 40 daa. The parameters evaluated were weevil mortality and seed germination. The results indicated that the doses from 0.8 to 5.0 g kg^{-1} of diatomaceous earth efficiently controlled the Mexican bean weevil. The treatments did not inhibit seed germination.

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Keywords: *Liriomyza sativae* Blanchard, parasitoids, *Zabrotes subfasciatus* Boheman, chickpea, beans

1. Introduction

The chickpea crop is the second most important grain of the family Fabaceae grown in Asia, Mediterranean regions, Australia, Canada, USA, and Africa [1]. Globally, the chickpea is planted on an area of nearly 12 million hectares with an approximate production of 11,308,684 tons. This crop develops during the winter under different agroclimatic conditions; its production in Mexico is 271,894 tons annually, of which Sinaloa and Sonora generate 70 and 20%, respectively. Most of it is destined for the international market [2]. Chickpea is an important crop for Sinaloa due to the harvested area, volume, and quality of grain produced over an area of 60,000 hectares, with an average yield of 1.7 tons per hectare [3].

The study of the biological activity of some compounds present in plants offers an opportunity to discover new and efficient insecticides for pest control [4, 5] which could be tolerated by crops and harmless to consumer; different researches have been observed and reported the insecticidal action of different plant extracts [6–8]. The objective of this research was to determine the efficacy of biorational insecticides to sustainably control the leaf miner (*Liriomyza sativae* Blanchard) without totally inhibiting the presence of the parasitoids of this pest in chickpea cultivation.

On the other hand, beans is one of the most sown and consumed legumes in Mexico. During the 2014–2015 agricultural cycle, 220,263 ha was sown at the state of Sinaloa, 58,550 ha, to be placed in the first place in terms of sowing and harvesting of this grain [9]. Bean is one of the essential foods for the world population, which makes necessary the conservation and protection of this grain against various factors that affect it, within these stands the importance of the Mexican weevil (*Zabrotes subfasciatus* Boheman, Coleoptera: Bruchidae) of the bean. The larva feeds on grain and causes severe damage and decreases the germinative power of the seed, by considerably damaging the cotyledons, on which the damages by oviposition and the perforations that are the feeding chambers of these insects can be observed [10, 11].

Storage pests are one of the most important problems in storage of grains and seeds, if they are not controlled in a timely manner, and cause direct damages that affect the conservation of the grain. Likewise, they cause damages indirectly when they are invaded by various microorganisms such as fungi and bacteria that contaminate them, which can cause problems in humans when consumed. There are few products that can be used reliably for stored grains for pest control, mainly insecticides and fumigants that are not very persistent in Mexico and in the world, which makes it necessary to seek more alternatives to reduce the damages that cause the pests of stored grains, which do not affect the environment and human health. At the global level, different alternatives for the control of storage pests have been tested. These include treatments based on heat and cold; the use of plant extracts and mineral substances; pheromones; biological control; and the use of chemicals that are preferably under residual power and do not cause effects on grains, seeds, and consumers [12–15].

2. Biorational insecticides for control sustainability of leaf miner (*Liriomyza sativae* Blanchard) in chickpea (*Cicer arietinum* L.)

The research on *Liriomyza sativae* Blanchard was performed by two experiments that were established in the experimental field of the Faculty of Agronomy of the Autonomous University of Sinaloa, located at 17.5 km of Culiacan-Eldorado road, Culiacan, Sinaloa, Mexico, with coordinates 24° 48′ 30″ N, 107° 24′ 30″ W and 38.54 m. The climate of this region is very warm to semidry. Average annual rainfall varies from 500 to 700 mm. The average annual maximum temperature is 25°C. The soils of this region are predominantly clayey [16].

The experiment design was randomized complete blocks with four replicates, where the experimental plot consisted of six furrows of 10 m long with 0.8 m distance from each other. The useful plot was the two central grooves minus 1 m from each end. The first planting took place on December 21, 2012 and the second planting on December 30, 2013, both manually with a density of 15 plants per linear meter. Five treatments were evaluated: three biorational insecticides: chlorantraniliprole + ethoxylated alkyl aryl phosphate ester (100 mL + 1.0 L ha^{-1}), cyromazine + *Bacillus thuringiensis* (80 g + 1 kg ha^{-1}), spinosad + sugar (416.6 mL + 2.08 kg ha^{-1}), cyromazine + *Bacillus thuringiensis* (80 g + 1 kg ha^{-1}), spinosad + sugar (416.6 mL + 2.08 kg ha^{-1}); one conventional insecticide chlorpyrifos + ester ethoxylate alkyl aryl phosphate (1.5 L + 1.0 L ha^{-1}); and absolute control (without application of insecticides), applying them on the foliage twice. This was done in each evaluation year.

Two applications per cycle were performed on February 9 and March 16, 2013; 02 and 23 February, 2014 with a Maruyama motor pump with a capacity of 25 L, an output boom, and cone nozzle TX5, whose water expenditure was 208 L ha^{-1}. The insecticides were applied when the population and leaf miner damage exceeded the economic threshold of 20% to the foliage [17].

Samples of live larvae and empty mines were carried out weekly on a leaf of 10 randomly selected plants. Of each useful plot, 100 leaves were collected and confined in 0.5-L plastic containers at room temperature. After 12 days, the adult miners and emerged parasitoids were separated and confined in glass flasks with 70% alcohol. For identification of the miner, the male abdomen was introduced into a 10% potassium hydroxide solution to soak the tissue for 10 minutes at 80°C and then washed with distilled water to remove the potassium hydroxide. With the preparation immersed in 70% alcohol, the cuticle and tissues were separated from the abdomen until the complete genitalia were cleaned and exposed [18]. With the help of codes and schemes of the male genitalia published by Spencer and Stegmaier [19] and Spencer and Steyskal [20] the taxonomic determination was made. Identification of the parasitoids emerged from the leaf samples was carried out using the keys of Wharton [21] for the genus of the Braconidae family, whereas for the genus of the Eulophidae family, the keys of La Salle and Parrella [22].

To determine the percentage of damage, weekly damage and healthy leafs of three plants per repetition were counted, and the percentage of damage was calculated with a three rule simple modified. Harvest was performed when the culture reached its physiological maturity and the data were transformed to be analyzed with the statistical package SAS 9.1 [23] and then this showed significant differences that were submitted to Duncan's multiple range test with $\alpha = 0.05$ for mean separation.

While in the entomology laboratory of the same, faculty research was done to determine the efficacy of diatomaceous earth doses, where the colony of beans weevil (*Zabrotes subfasciatus* Boheman) was purified in glass bottles with a capacity of 5 kg, which were kept under a temperature that fluctuated between 30 and 35°C, with a purpose of having a homogeneous colony for the test.

To establish the tests; polystyrene beakers with capacity of 500 g, and 2 kg of bean per treatment were used; the application of the diatomaceous earth was homogenized on the grain, then 20 adults of bean weevil were deposited in each repetition and covered with organza cloth. The investigation was carried out in two phases: (a) the first one was done in a completely random design with seven treatments and four repetitions. The treatments were diatomaceous earth at doses of 1.0, 2.0, 3.0, 4.0, and 5.0 g kg^{-1} of seed, a chemical control (deltamethrin) at a dose of 1.0 mL kg^{-1} of seed, plus an absolute control (without application of substances); (b) the second phase consisted of another completely random experimental design with the same amount of treatments and repetitions, but with the doses of 0.2, 0.4, 0.6, 0.8, and 1.0 g kg^{-1} of diatomaceous earth, a chemical control (deltamethrin) at a dose of 0.1 mL kg^{-1} of seed plus the absolute control.

In the both phases of the experiment, the response variables were the percentage of dead adults and the germination of bean seeds. In the first phase, mortality was determined with the number of live and dead insects in each experimental unit, at 15, 30, 45, and 60 days after application (daa), while in the second phase, it was done at 10, 20 30, and 40 daa. With the averages of mortality in each experimental unit, the percentage of effectiveness was obtained by the following Eq. [24]:

$$\text{Corrected mortality} = \frac{(\text{mortality of the treatment–mortality of the absolute control}) \times 100}{100 - \text{mortality of the absolute control}}$$

Germination was evaluated with 100 bean seeds planted in polystyrene trays filled with peat moss and determined at 10, 20 and 30 daa of the diatomaceous earth and deltamethrin doses, counting the seedlings emerged in each of the experimental units and comparison of averages with respect at average of the absolute control, while percentages were also determined with the equation of Abbott [24]. All data were subjected to an analysis of variance and multiple comparison of means of Tukey test (α = 0.05) of the statistical package SAS 9.1 [23].

3. Efficacy of biorational insecticides on *Liriomyza sativae* Blanchard without totally inhibiting the presence of the parasitoids

The leaf miner species present in the chickpea is *Liriomyza sativae* Blanchard. The aedeagus presents a barely conspicuous constriction (**Figure 1A**), where the edges of the distifalo have only a slight undulation. The ejaculatory pump apodema has a thin base that is wider at the distal end than the diameter of the bulb (**Figure 1C**).

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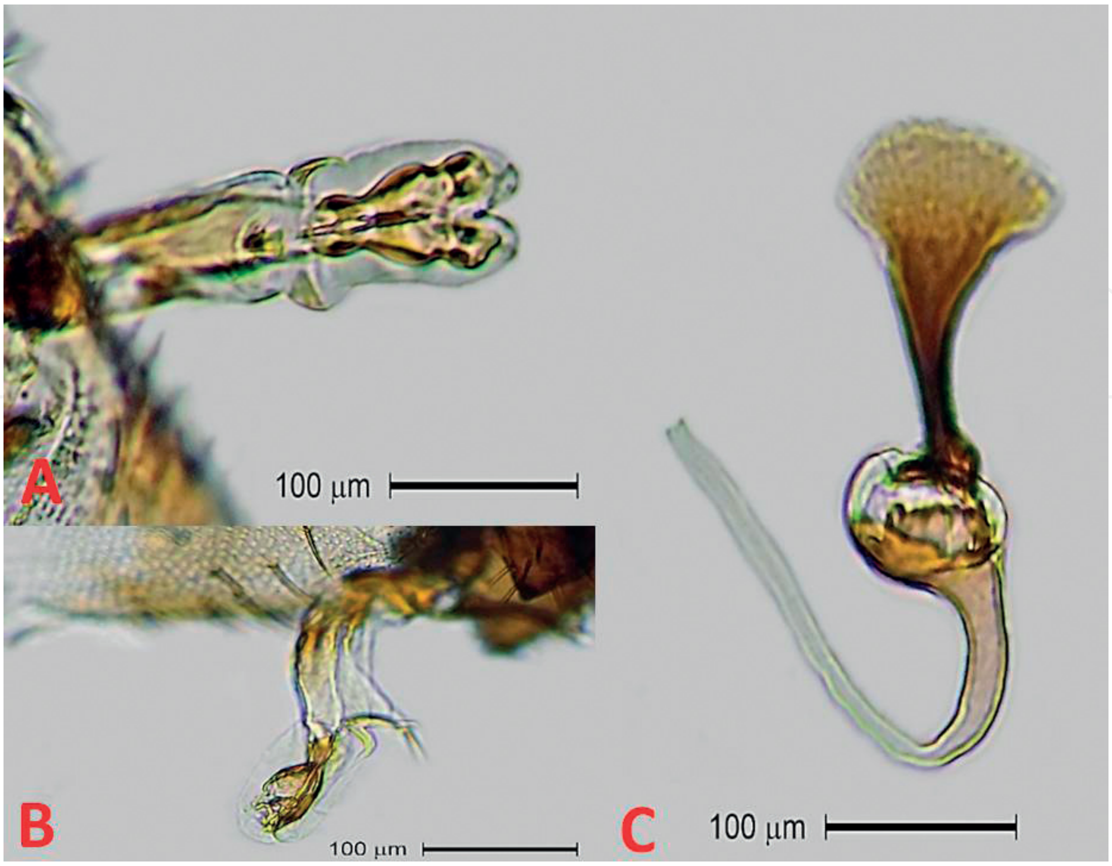

Figure 1. Liriomyza Sativae: (A) aedeagus ventral view, (B) aedeagus side view, and (C) sperm pump.

Based on the final averages of the two experiments (**Table 1**), it could be interpreted that after applying the biorational insecticides, chlorantraniliprole, cyromazine, and spinosad, twice as well as the conventional insecticide, chlorpyrifos, there was no statistical difference between the efficacy of the biorationals and that of the conventional one, and live larval populations of *L. sativae* were reduced to 43, 33, 22, and 39%, respectively, compared to the 100% presence of larvae in the foliage on average in the absolute control in the cycle 2013, while in 2014, the respective decreases were 55, 47, 45, and 46%. The tendency of the population of *L. sativae* to stay below the economic threshold in the two experiments, from the second application, was perhaps due to the physiological maturity of the chickpea approaching the senescence of the foliage and, consequently, to the harvest grain.

According to the final averages of **Table 2**, in 2013, the percentage of empty mines was reduced to 29, 37, 11, and 29% with chlorantraniliprole, cyromazine, spinosad, and chlorpyrifos, respectively, compared with 100% represented by the average of the control. In 2014, the respective decreases were 19, 3, 16, and 22% with the same treatments. In addition, the time of action of biorationals was very similar to that of chlorpyrifos. The results allowed to corroborate that the biorationals are products that can be used for the control of *L. sativae* with the same effectiveness of the conventional insecticide chlorpyrifos.

Treatments	February 2013				March 2013				Final Average
	7[1]	14	21	28	7	14[2]	22	28	
Chlorantraniliprole	2.30	1.65	0.20^{bc*}	0.35^{b}	1.65	3.95	0.40^{b}	0.05^{b}	1.17^{b}
Cyromazine	2.20	1.85	0.30^{b}	0.55^{b}	1.75	3.80	0.70^{ab}	0.75^{ab}	1.38^{b}
Spinosad	2.00	1.85	0.75^{a}	0.80^{ab}	1.90	4.15	0.40^{b}	1.30^{a}	1.59^{ab}
Chlorpyrifos	2.30	1.15	0.10^{c}	0.35^{b}	1.65	3.70	0.20^{b}	1.60^{a}	1.25^{b}
Absolute control	2.35	2.30	0.75^{a}	1.55^{a}	1.90	3.95	2.00^{a}	1.90^{a}	2.05^{a}
	February 2014				March 2014				
	7[3]	14	21[2]	28	7	14	22	28	
Chlorantraniliprole	0.70^{ab}	1.60	2.65^{b}	0.83^{b}	1.58	1.20	1.00	1.05^{b}	1.32^{b}
Cyromazine	0.78^{ab}	1.80	2.70^{b}	0.73^{b}	1.85	1.20	1.88	1.68^{b}	1.57^{b}
Spinosad	1.58^{ab}	1.83	2.75^{b}	0.85^{b}	1.35	1.98	1.40	1.25^{b}	1.62^{b}
Chlorpyrifos	0.75^{b}	1.85	3.85^{a}	1.00^{ab}	1.88	1.25	1.03	1.05^{b}	1.58^{b}
Absolute control	3.90^{a}	3.83	3.68^{a}	2.03^{a}	2.68	2.30	2.13	3.10^{a}	2.95^{a}

*Means with the same letter in each column are statistically the same (Duncan $\alpha \leq 0.05$).
[1]Two days before the first application.
[2]Two days before the second application.
[3]Five days after the first application.

Table 1. Average live larvae of leaf miner *Liriomyza sativae* Blanchard in 40 chickpea leaves in Culiacan, Sinaloa, Mexico.

Treatments	February 2013				March 2013				Final average
	7[1]	14	21	28	7	14[2]	22	28	
Chlorantraniliprole	1.58	1.73	1.03^{a*}	0.38^{ab}	0.83	0.65	1.33	0.98^{bc}	0.99^{bc}
Cyromazine	1.30	1.30	0.68^{ab}	0.60^{a}	0.78	1.00	1.15	0.70^{c}	0.88^{c}
Spinosad	1.38	1.58	0.80^{ab}	0.85^{a}	1.18	1.13	1.68	1.50^{a}	1.24^{ab}
Chlorpyrifos	1.28	1.70	0.38^{b}	0.08^{b}	1.30	1.33	1.23	0.95^{bc}	0.99^{bc}
Absolute control	1.38	1.78	1.38^{a}	0.85^{a}	1.33	1.38	1.95	1.15^{ab}	1.40^{a}
	February 2014				March 2014				
	7[3]	14	21[2]	28	7	14	22	28	
Chlorantraniliprole	2.58^{b}	0.28^{b}	1.08	1.68	1.10	3.20^{ab}	3.05	2.43^{ab}	1.92^{b}
Cyromazine	2.20^{b}	0.98^{ab}	1.45	1.38	0.83	3.93^{a}	3.88	3.68^{a}	2.29^{ab}
Spinosad	3.53^{a}	1.33^{a}	1.23	1.63	0.83	2.08^{b}	2.55	2.70^{ab}	1.98^{ab}
Chlorpyrifos	1.35^{c}	0.85^{ab}	1.50	1.13	1.10	3.75^{a}	2.85	2.25^{b}	1.84^{b}
Absolute control	2.78^{ab}	1.93^{a}	1.45	1.48	1.28	3.40^{ab}	3.28	3.43^{ab}	2.37^{a}

*Means with the same letter in each column are statistically the same (Duncan $\alpha \leq 0.05$).
[1]Two days before the first application.
[2]Two days before the second application.
[3]Five days after the first application.

Table 2. Average empty mines of leaf miner *Liriomyza sativae* Blanchard in 40 chickpea leaves in Culiacan, Sinaloa, Mexico.

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Treatments	February 2013				March 2013				Final
	7[1]	14	21	28	7	14[2]	22	28	Average
Chlorantraniliprole	1.40^{ab}	1.49^{ab}	1.00^{ab}	0.77^{bc}	1.59^{ab}	1.61	1.25^{b}	0.79^{b}	1.21^{b}
Cyromazine	1.30^{ab}	1.05^{ab}	0.84^{b}	0.60^{c}	0.89^{b}	2.08	1.59^{ab}	1.40^{ab}	1.20^{b}
Spinosad	1.29^{ab}	1.73^{a}	1.52^{a}	1.39^{ab}	1.95^{ab}	2.16	2.50^{ab}	1.01^{ab}	1.75^{ab}
Chlorpyrifos	1.79^{a}	0.61^{b}	1.56^{a}	0.51^{c}	2.34^{a}	1.09	1.07^{b}	3.04^{a}	1.46^{ab}
Absolute control	0.98^{b}	1.51^{ab}	1.59^{a}	1.70^{a}	1.74^{ab}	1.85	3.15^{a}	2.36^{ab}	1.98^{a}
	February 2014				March 2014				
	7[3]	14	21[2]	28	7	14	22	28	
Chlorantraniliprole	1.18^{b}	2.05^{b}	0.35^{b}	0.73^{ab}	4.30	3.93	1.20^{b}	9.78	2.94^{bc}
Cyromazine	0.00^{c}	1.38^{b}	0.08^{b}	0.28^{b}	7.20	2.08	1.05^{b}	2.63	1.83^{c}
Spinosad	4.15^{a}	6.88^{a}	0.25^{b}	1.15^{ab}	10.93	2.75	5.08^{a}	7.78	4.87^{a}
Chlorpyrifos	0.35^{bc}	9.95^{a}	0.03^{b}	0.75^{ab}	8.70	0.38	5.28^{a}	6.85	4.03^{b}
Absolute control	5.98^{a}	6.53^{a}	1.13^{a}	1.68^{a}	9.98	2.93	7.10^{a}	7.85	5.39^{a}

*Means with the same letter in each column are statistically the same (Duncan $\alpha \leq 0.05$).
[1]Two days before the first application.
[2]Two days before the second application.
[3]Five days after the first application.

Table 3. Average adult leaf miner *Liriomyza sativae* Blanchard in 40 chickpea leaves in Culiacan, Sinaloa, Mexico.

Treatments	February 2013				March 2013				Final
	7[1]	14	21	28	7	14[2]	22	28	Average
Chlorantraniliprole	20.1	9.7^{b}	9.9^{b}	5.1^{b}	2.8^{b}	20.4	8.4^{b}	4.5^{b}	8.7^{b}
Cyromazine	20.2	9.1^{b}	5.9^{bc}	6.6^{b}	5.0^{b}	20.1	7.5^{b}	8.1^{b}	8.9^{b}
Spinosad	20.1	12.2^{b}	4.9^{c}	8.6^{b}	4.6^{b}	22.1	8.0^{b}	8.6^{b}	9.9^{b}
Chlorpyrifos	21.2	9.3^{b}	4.2^{c}	6.2^{b}	3.2^{b}	22.0	8.9^{b}	9.5^{b}	9.0^{b}
Absolute control	20.9	22.7^{a}	22.1^{a}	22.6^{a}	31.2^{a}	25.8	21.8^{a}	23.9^{a}	24.3^{a}
	February 2014				March 2014				
	7[3]	14	21[2]	28	7	14	22	28	
Chlorantraniliprole	11.2^{ab}	9.8^{bc}	20.2	13.9	9.7	8.9	9.4^{b}	7.9^{d}	11.4^{d}
Cyromazine	16.4^{ab}	14.8^{ab}	21.0	19.7	7.6	11.1	9.3^{b}	10.9^{cd}	13.8^{bc}
Spinosad	18.5^{a}	13.8^{ab}	21.3	16.8	6.7	14.9	12.4^{ab}	15.4^{b}	15.0^{b}
Chlorpyrifos	11.1^{b}	8.0^{c}	20.4	16.0	8.6	12.3	10.5^{ab}	14.3^{bc}	12.7^{c}
Absolute control	20.3^{ab}	20.2^{a}	20.4	20.1	20.2	20.2	20.9^{a}	22.2^{a}	20.5^{a}

*Means with the same letter in each column are statistically the same (Duncan $\alpha \leq 0.05$).
[1]Two days before the first application.
[2]Two days before the second application.
[3]Five days after the first application.

Table 4. Percentage of damage by leaf miner *Liriomyza sativae* Blanchard in leaf chickpea plants. Culiacan, Sinaloa, Mexico.

Treatments		Parasitoid species				Total
2013		***Neochrysocharis* spp.**	***Opius* spp.**	***Closterocerus* spp.**	***Diglyphus* spp.**	
	LLs					74
Chlorantraniliprole	Ptoid	0	7	2	1	10
	Ptism	0	9.45	2.70	1.35	14
	LLs					37
Cyromazine	Ptoid	0	1	1	1	3
	Ptism	0	2.70	2.70	2.70	8
	LLs					75
Spinosad	Ptoid	0	1	0	0	1
	Ptism	0	1.33	0	0	1
	LLs					184
Chlorpyrifos	Ptoid	0	6	0	1	7
	Ptism	0	3.26	0	0.54	4
	LLs					116
Absolute control	Ptoid	15	0	7	0	22
	Ptism	12.9	0	6.03	0	19
2014						
	LLs					325
Chlorantraniliprole	Ptoid	10	1	0	25	36
	Ptism	3.08	0.31	0	7.69	11
	LLs					242
Cyromazine	Ptoid	5	1	0	0	6
	Ptism	2.07	0.41	0	0	2
	LLs					318
Spinosad	Ptoid	2	2	0	2	6
	Ptism	0.63	0.63	0	0.63	2
	LLs					392
Chlorpyrifos	Ptoid	10	0	0	2	12
	Ptism	2.55	0	0	0.51	3
	LLs					240
Absolute control	Ptoid	10	0	0	20	30
	Ptism	4.1	0	0	8.3	12

LLs = Larvae of *L. sativae*, Ptoid = Parasitoid, and Ptism = Parasitism.

Table 5. Parasitoid species and parasitism (%) of larvae of *Liriomyza sativae* Blanchard in 400 chickpea leaves. Culiacan, Sinaloa, Mexico.

It was observed in 2013 that the number of adults of the leaf miner emerged from leafs decreased to 39, 39, 12, and 26%, with chlorantraniliprole, cyromazine, spinosad, and chlorpyrifos, with respect to 100% of the absolute control (**Table 3**). In 2014, it was decreased to 45, 66, 10, and 25%. The above was to be expected, since the same effect had been observed in the number of live larvae and empty mines. In this way, the results of this research can help increase local awareness to reduce the use of broad-spectrum insecticides [25].

The percentage of folioles damaged after application of insecticides in 2013 indicates that, with chlorantraniliprole, cyromazine, and spinosad, the damage decreased to 64, 63, and 59, respectively (**Table 4**), while chlorpyrifos was 63%. In 2014, the damages decreased to 44, 33, 27, and 38%, respectively, in relation to 100% of the absolute control.

The parasitoids obtained from the leaf miner of the chickpea were *Opius* spp. (Braconidae), *Diglyphus* spp., *Neochrysocharis* spp., and *Closterocerus* spp. (Eulophidae) (**Table 5**). In 2013, the leaf miner parasitism was 1% where spinosad was applied, 4% in plots treated with chlorpyrifos, 8% with cyromazine, and 14% in plots managed with chlorantraniliprole, compared to the average of 19% of observed parasitism in the control plot. In 2014, the parasitism was 2, 3, 2, and 11%, respectively, and in the control 12%. Three types of parasitoids found and the percentage of parasitism in the chickpea, with respect to what was observed in the absolute control, coincide with the results [26]; since 2006 and 2007, they found parasitoids *Opius monilicornis*, *Diglyphus crassinervis* and *Neochrysocharis ambitiosa*.

The estimate of net utility was determined by considering the value of production minus the cost of the crop, minus the value of the insecticides. The value of the ton of chickpea taken into account for operations was MX$ 12,700. In 2013, the highest production of chickpea was obtained where chlorantraniliprole was applied, with a net utility of MX$ 21,011, surpassing it to control with 71%, since its net utility was MX$ 12,305. With chlorpyrifos, spinosad, and cyromazine, a production was obtained that surpassed to control in 53, 48, and 37%, respectively.

In 2014, the highest production of chickpea was also obtained from the plots applied with chlorantraniliprole, from where a net utility of MX$ 16,036 was obtained, surpassing the control with 45%, whose net utility was MX$ 11,083. With chlorpyrifos, spinosad, and cyromazine, the respective increases were 39, 34, and 21%. Utility differences from 1 year to other may be due to the higher incidence and damage of *Liriomyza sativae* Blanchard in 2014.

4. Efficiency of diatomaceous earth for control of Mexican bean weevil (*Zabrotes subfasciatus* Boheman)

The results show that all doses of diatomaceous earth (DE) exerted an excellent control, such that in the evaluations registered at 15 days after application; 100% mortality was recorded in doses 4.0 and 5.0 g kg^{-1}, similar to those observed with the chemical control (deltamethrin). The doses of 2.0 and 3.0 g kg^{-1} of DE caused 95 and 96% mortality, in adults of *Zabrotes subfasciatus*. The dose of 1.0 g of DE caused 93% mortality, without statistical differences between the averages obtained with doses of DE and deltamethrin (**Table 6**), although these averages were significantly different from the average observed in the absolute control. The same behavior was observed in the evaluations recorded at 30, 45, and 60 daa (**Table 6**), where it can be seen that all DE doses used for pest control caused mortalities higher than 90%; this indicates that although the period of exposure was 2 months, mortality rates were maintained at 100% with the doses of 3.0, 4.0, and 5.0 g kg^{-1} of DE and deltamethrin at dose 1.0 mL kg^{-1} of seed. The lowest doses (1.0 and 2.0 g kg^{-1}) also exerted excellent control of *Zabrotes subfasciatus* Boh., with statistical differences in mortality only in relation to that obtained in the absolute control.

The results of the first experiment served to make the decision to perform a second experiment with lower doses that were 0.2, 0.4, 0.6, 0.8, and 1.0 g kg^{-1} DE, 0.1 mL kg^{-1} Deltamethrin (chemical) and an absolute control (without application). The results indicated that at 10 daa DE, the doses of 0.6, 0.8, and 1.0 g kg^{-1} of seed resulted in 100% mortality (**Table 7**), similar to that caused by the chemical control (deltamethrin), without significant differences between the averages. However, these mortality rates were significantly different from those at 0.2 and 0.4 g kg^{-1} of seeds, and even more with respect to the percentage of mortality (0) in the absolute control. At 20 daa, it was observed that where doses of 0.6, 0.8, and 1.0 g kg^{-1} of DE and 0.1 mL kg^{-1} of deltamethrin (chemical) were applied, mortality rates were 100% for adult weevil of the bean, but were not significantly different to the 95% that was achieved with the dose of 0.4 g kg^{-1} of DE. However, if they were statistically different from the mortality (28% less) of that was achieved with the dose of 0.2 g kg^{-1} of DE, likewise, with respect to the 0% observed in the absolute control.

At 40 daa, the treatments in doses of 0.6, 0.8, and 1.0 g kg^{-1} of DE and 0.1 mL kg^{-1} of deltamethrin, the mortality was 100% (**Table 7**), without significant difference with that caused by the dose of 0.4 g kg^{-1} of DE. However, these percentages were significantly different from the mortality that occurred with the dose of 0.2 g kg^{-1} of DE and with the absolute control.

Treatment/doses	**Mortality (%)**			
	15 dda	**30 dda**	**45 dda**	**60 dda**
Absolute control	1.2 b*	1.2 b	1.2 b	2.5 b
Deltamethrin/1.0 mL kg^{-1}	100 a	100 a	100 a	100 a
DE/1.0 g kg^{-1}	93.0 a	93.0 a	93.0 a	98.7 a
DE/2.0 g kg^{-1}	95.0 a	97.5 a	97.0 a	98.7 a
DE/3.0 g kg^{-1}	96.0 a	97.5 a	97.0 a	100 a
DE/4.0 g kg^{-1}	100 a	100 a	100 a	100 a
DE/5.0 g kg^{-1}	100 a	100 a	100 a	100 a

*Means with different letters in each column are statistically different, according to Tukey test ($\alpha \leq 0.05$); dda = days after application.

Table 6. Percentage of adult mortality of bean weevil (*Zabrotes subfasciatus* Boh.) treated with diatomaceous earth (DE).

Treatment/doses	Mortality (%)			
	10 dda	20 dda	30 dda	40 dda
Absolute control	0.0 d*	0.0 c	0.0 c	0.0 c
Deltamethrin/0.1 mL kg^{-1}	100 a	100 a	100 a	100 a
DE/0.2 g kg^{-1}	62.0 c	72.0 b	79.0 b	83.0 b
DE/0.4 g kg^{-1}	90.0 b	95.0 a	97.0 a	98.0 a
DE/0.6 g kg^{-1}	100 a	100 a	100 a	100 a
DE/0.8 g kg^{-1}	100 a	100 a	100 a	100 a
DE/1.0 g kg^{-1}	100 a	100 a	100 a	100 a

*Means with different letters in each column are statistically different, according to Tukey test ($\alpha \leq 0.05$); dda = days after application.

Table 7. Percentage of adult mortality of bean beetle (*Zabrotes subfasciatus* Boh.) treated with lower doses of diatomaceous earth (DE).

Seed germination was similar with all treatments applied, including the absolute control, with a seedling emergence ranging from 94 to 96%, considered as normal, and it was assumed that the diatomaceous earth had no effect on the seed germination.

These results coincide with the results of Mikami et al. [27], where it is pointed out that diatomaceous earth is a mineral with insecticidal potential against the bean weevil, applied in doses of 1.0 g kg^{-1} to have a 100% mortality of the 3–8 days after application. They also coincide with those of [12, 14, 28, 29], since they report that these inert powders have been used with great success in controlling large numbers of stored grain pests, among which are *Oryzaephilus surinamensis*, *R. dominica*, *Tribolium castaneum*, *T. confusum*, *Cryptolestes ferrugineus*, *S. zeamais*, *S. granarius*, *S. oryzae*, *Prostephanus truncatus*, *Acanthoscelides obtectus*, and *Zabrotes subfasciatus*. It is reported that diatomaceous earth doses of 0.5, 1.0, and 2.0 kg per ton of maize seed alone and combined with deltamethrin synergized with piperonyl butoxide cause mortality higher than 97% of maize weevil, up to 120 days after application [30], and this same behavior was observed when it was combined with the insecticide deltamethrin.

In addition, they agree with those of [31], because they indicate that diatomaceous earth is an alternative for the control of *Zabrotes subfasciatus* Boheman, since after 5 days of exposure and temperatures of 27–30°C, they had mortality of 100% with all the applied doses (0.5, 0.75, and 1.0 g kg^{-1} of seed), concluding that the suitable doses for the control of this pest of the store are those of 0.75 and 1.0 g kg^{-1} of seed.

Mineral powders such as zeolite can control stored grain pests such as *Sitophilus oryzae*, *Tribolium confusum*, and *Oryzaephilus surinamensis*, and that therefore, this material can be successfully used as a grain and seed protector [32]. Likewise it is reported that inert dusts cause abrasive effects on the cuticle of insects, resulting in loss of water and, consequently, death [33, 34]. In addition, these powders may be used in combination with other products, such as vegetable powders to increase the efficacy of pest control.

5. Conclusions

The use of biorational insecticides is a good alternative for the control of *Liriomyza sativae* Blanchard in chickpea. While that in bean, the doses of 0.8–5.0 g kg^{-1} of diatomaceous earth efficiently controlled the Mexican bean weevil, but the recommended dose is 0.8 g kg^{-1} of seed, since with this dose, it can be controlled with sustainability and does not affect seed germination, as with the other doses evaluated.

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