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Biorational products on thrips *Frankinella occidentalis* Pergande 1895 (Thysanoptera: Trhipidae) and its natural enemies for Mexican lemon.

Productos biorracionales sobre trips *Frankinella occidentalis* Pergande 1895 (Thysanoptera: Trhipidae) y sus enemigos naturales para limón mexicano.

Miranda-Ramírez, J.M.[1], *Perales-Segovia, C.*[2*], *Miranda-Salcedo, M.A.*[3], *Miranda-Medina, D.*[1], *Perales-Aguilar, L.*.[2]

[1] *Tecnológico Nacional de México / ITS de Apatzingán. Km. 3.5 carretera Apatzingán-Aguililla, C.P.60710, Apatzingán Michoacán, México.*
[2] *Tecnológico Nacional de México / IT El Llano Aguascalientes. Km. 18 carretera Aguascalientes-San Luís Potosí, CP 20330, Aguascalientes, México.*
[3] *INIFAP-CIRPAC-Campo Experimental Valle de Apatzingán. Km. 17 Carretera Apatzingán-Cuatro Caminos, C.P. 60781, Antúnez, municipio de Parácuaro, Michoacán, México.*

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ABSTRACT

Frankliniella occidentalis is a pest persistent that attacks the Mexican lemon fruit. Given this, the effect of biorational insecticides on thrips pest management and the impact on natural enemies for the cultivation of Mexican lemon in Michoacán, Mexico, was evaluated, in a completely randomized design, with twelve treatments and ten repetitions; the experimental unit was a tree. The variance data homogeneity test, ANOVA, and Tukey's comparison of means ($p \leq 0.05$) were applied. In the data collection, a previous sampling was done as the starting point of the study and comparison. After treatments, samples were taken at 3, 6, 12, 20, 26, 35, and 41 days later. The study variables were: 1) the number of *Frankliniella occidentalis* thrips; 2) The number of Olla *v-nigrum* lady beetles (Coleoptera: Coccinellidae); 3) The number of lacewings *Chrysoperla rufilabris* (Neuroptera: Chrysopidae); 4) The number of phytoseiids [predatory mites] *Phytoseiulus persimilis* (Acari: Phytoseiidae). Garlic extract + chamomile and rue extract reduced the thrips population by 58.47; 9.30; 71.43; 40.20; 50.17; 90.37 and 99.67 % at 3, 6, 12, 20, 26, 35, and 41 days after application, respectively. Tolfenpyrad reached its greatest effect by reducing the coccinellid population by 100 % at 3, 6, 12, 26, and 41 days after application. Garlic oil proved to be a good option for thrips control by reducing its population by an average of 60 % and increasing phytoseiid mites by 800 %.

KEY WORDS: Sustainability, *Citrus aurantifolia*, Pest management, Reduction of arthropod pests, Predatory insects, Biorational.

***Corresponding Author:**

Catarino Perales Segovia. Tecnológico Nacional de México / IT El Llano Aguascalientes. Km. 18 carretera Aguascalientes-San Luís Potosí, CP 20330, Aguascalientes, México. Phone: +52 449 962 1100. E-mail: catarino.ps@llano.tecnm.mx

RESUMEN

Frankinella occidentalis es una plaga muy persistente que ataca al limón mexicano. Ante ello, se evaluó el efecto de insecticidas biorracionales para el manejo de trips plaga y el impacto sobre los enemigos naturales para el cultivo de limón mexicano en Michoacán, México, en un diseño completamente al azar, con doce tratamientos y diez repeticiones; la unidad experimental fue un árbol. Se aplicó la prueba de homogeneidad de datos de las varianzas, ANOVA y comparación de medias de Tukey ($p \leq 0,05$). En la recolección de datos, se hizo un muestreo previo como punto de inicio del estudio y comparación. Posterior a los tratamientos, se realizaron muestreos a los 3, 6, 12, 20, 26, 35 y 41 días después. Las variables de estudio fueron: 1) Número de trips *Frankinella occidentalis*; 2) Número de catarinas *Olla v-nigrum* (Coleoptera: Coccinellidae); 3) Número de crisopas *Chrysoperla rufilabris* (Neuroptera: Chrysopidae); 4) Número de fitoseidos [ácaros depredadores] *Phytoseiulus persimilis* (Acari: Phytoseiidae). El Extracto de ajo + extracto de manzanilla y ruda redujo la población de trips en un 58,47; 9,30; 71,43; 40,20; 50,17; 90,37 y 99,67 % a los 3, 6, 12, 20, 26, 35 y 41 días después de la aplicación respectivamente. El Tolfenpyrad alcanzó su mayor efecto de al disminuir en un 100 % la población de coccinélidos a los 3, 6, 12, 26 y 41 días después de la aplicación. El Aceite de ajo mostró ser una buena opción para el control de trips al disminuir la su población en un promedio de 60 %, e incrementó en un 800 % los ácaros fitoseidos.

PALABRAS CLAVE: Sustentabilidad, *Citrus aurantifolia*, Manejo de plagas, Disminución de artrópodos plaga, Insectos depredadores, Biorracional.

Introduction

About 2.7 million tons of limes and lemons are produced annually in Mexico (FAO, 2021a). Most of the Mexican lemon [*Citrus aurantifolia* (Christm.) Swingle] production is concentrated in Michoacán, in the Apatzingán Valley, with an established area of 60 thousand hectares, distributed in the municipalities of Múgica, Parácuaro, Apatzingán, Aguililla, and Tepalcatepec mainly, with a production of 1.22 million tons annually, representing an economic spillover of USD $ 328.21 million annually (SIAP, 2021). However, during the Mexican lemon production process in the Apatzingán Valley, citrus growers observe the presence of pests such as the Asian psyllid *Diaphorina citri* (Kuwayama), red spider mite *Tetranychus urticae* (Koch) and Thrips (Thysanoptera: Thripidae). This last pest became the most important pest in terms of fruit damage, causing lacerations in the epidermis in the early stages of development. Consequently, at the time of harvesting, the damage that occurs in production causes a marketing problem that is reflected in lower prices and, in very severe cases, the rejection of the crop. In addition, the excess of insecticide applications (organophosphates, carbamates, neonicotinoids, pyrethroids/pyrethrins) has caused the development of multiple resistance of the pest and the mortality of most beneficial insects that can control pest populations, leaving residues in food, intoxications to users, contamination to natural resources (Bejarano-González, 2017) and technological dependence.

Among several pest management options, the adoption of integrated management through biorational control and biological control by conservation has stood out. In the case of severe thrips infestations on Mexican lime, the most indicated is to reduce chemical insecticide applications and make good management of herbaceous plants, which act as a refuge for thrips predators such as *Chrysoperla rufilabris, Ceraeochrysa cincta, Stetorus sp, Cycloneda sanguinea, Hippodamia convergens, Olla v-nigrum, Zelus renardii, Leptotrips sp*. and several spider species (Atakan & Pehlivan, 2019; Miranda-Salcedo & Loera-Alvarado, 2019).

In relation to the above, there are antecedents on the management of thrips in Mexican lime, such as the case of Miranda-Salcedo *et al*. (2021) who reported for the insecticide Spirotetramat at a dose of 0.5 ml L^{-1}, 2 days after application a decrease in the population of thrips *F. occidentalis* Pergande 1895 by 100 % (from 1.6 thrips to 0 thrips), in Michoacán, Mexico.

Monteon-Ojeda *et al*. (2020) found a 73 % presence of *Frankliniella invasor* in the mango manila crop in Actopan, Veracruz. They reported that Spinetoram at a dose of 500 mL ha^{-1}, maintained an average of 0.71 thrips per inflorescence and an efficacy of 87 % at 7 daa, while garlic, chili, and cinnamon extract at a dose of 2 L ha^{-1} controlled 85.46 % of the population at 14 daa.

Miranda-Salcedo *et al*. (2020) in Michoacán Mexico, showed that Spirotetramat at a dose of 0.75 mL L^{-1} decreased the population of *F. occidentalis* thrips on Mexican lime by 70 % (from 1.0 to 0.3 thrips) at 18 daa. In addition, they observed a wide group of natural enemies that can control the pest such as *Cereaochrysa cincta* Schneider, 1851, *Chrysoperla rufilabris* Burmeister, 1839, *Cycloneda sanguinea* L., 1763, *Hippodamia convergens* Guerin-Meneville, 1842, *Leptotrips sp*. and different spider species. Olla *v-nigrum* Mulsant, 1866, *Sthetorus* sp., *Tamarixia radiata* Waterston, 1922, *Zelus renardii* Kolenati, 1857. However, Avendaño-Gutiérrez *et al*. (2020), collected 4968 Thysanoptera on Mexican lime and identified four thrips predatory species: *Scolotrhips sexmaculatus, Leptotrhips micconelli, Stomatotrhips brunneus*, and *Scolotrhips palidus*, also in Michoacán Mexico.

In Germany, in an apple crop, Viñuela *et al*. (1996) showed that neem (EC, 1 % azaradactin) at a dose of 0.3 % had low toxicity (20 % mortality) on *Chrysoperla carnea* larvae in the field, because the substance has a repellent effect.

Bennison *et al*. (2002) reported that rosemary plants (*Rosmarinus officinalis*) associated with chrysanthemum crops showed great potential as repellent plants for the California thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae); however, there was observed evidence of a repellent effect on its biological predator *Orius laevigatus* (Hemiptera: Anthocoridae). This corroborates a “push-pull” strategy based on the combination of stimuli, which modifies the distribution and abundance of arthropod pests and their enemies (Salas *et al.,* 2021).

Therefore, through the application of biorational insecticides along with conservation and management of natural enemies, good thrips management is obtained for the Mexican lemon crop. This study aimed to evaluate the effect of biorational products on thrips management and to record the impact on their natural enemies, for the Mexican lemon crop in Michoacán, Mexico.

Material and Methods

Study site

This research was conducted at 19°00'44.10'' N, 102°13'38.57'' W, 346 masl (Google Earth, 2021) at the Campo Agrícola Experimental del Valle de Apatzingán del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (CEVA-INIFAP) at km 17, Apatzingán-Cuatro Camino's highway, municipality of Parácuaro Michoacán, Mexico. The site corresponds to a tropical depression between the mountainous axes, which limit it to the north and south with the Neovolcanic axis and the Sierra Madre del Sur del Pacífico, Mexico (García, 1987). The soil type is clayey pelic vertisolic, with dry climate type BS1 warm semi-dry (Instituto Nacional de Estadística y Geografía [INEGI], 2022), mean annual temperature of 30 °C and 650 mm of annual rainfall (Comisión Nacional del Agua [CONAGUA], 2022).

Phenological characterization of the orchard

The site where the study was conducted is characterized by an area of 3 ha with trees in development of 3 years old, with an average height of 2 m, a crown diameter of 2.5 m, in normal vigor conditions according to their age and good bearing, with Macrophylla rootstock and Mexican lime variety.

The spring season was selected for the establishment of the experiment, during the month of May 2021, which is characterized by the highest temperatures of the year, up to 42.5 °C on average during the day, with a relative humidity of 26 %, without rain (CONAGUA, 2022).

Treatments

For biorationals selection, the effect of the damage caused on human and animal health, biodiversity, and the environment was taken into account (FAO, 2021b). Twelve treatments were evaluated including the absolute control and the regional commercial control (Table 1). Spirotetramat is not considered highly toxic (PAN, 2016), however, Tolfenpyrad is highly toxic to bees, aquatic species, and humans (PAN, 2016). In relation to Pyrifluquinazon is a highly toxic insecticide to humans as well as carcinogenic (PAN, 2016; Lewis *et al.,* 2016). The other treatments are considered as plant extracts and are valid within agroecological pest management (Bejarano- González, 2017).

In all treatments, a 20.2 % ethoxylated fatty alcohol-based commercial adherent [1 mL L^{-1} - Inex A®, Cosmocel, Mexico] was used. The application was carried out at the same time with a spray solution directed to the foliage of trees. Three new Swissmex manual backpack pumps, model Lola 20, with a capacity of 20 liters of water, and Swissmex high volume nozzles, model Solo 501, previously calibrated and washed were used.

Table 1. Treatments used for the control management of thrips and the impact on their natural enemies.

Number	Treatment	Dose mL/L^{-1}	Commercial product / Company / Country
T1	Tolfenpyrad 15 %	1.25	Hachi Hachi / Nichino / Mexico
T2	Pyrifluquinazon 20.2 %	0.58	Pyriflu / Nichino / Mexico
T3	Garlic oil (*A. sativum L.*) 95 %	2	Garlic / Biotech / Mexico
T4	Garlic extract (*A. sativum*) at 87 %, chamomile (*Matricaria chamomilla* L.) and rue (*Ruta graveolens* L.) extract at 10 %	2	Bio Crack / Berni Labs / Mexico
T5	Neem (Azadirachta indica A. Juss) at 95 %	2	Neemtech / Biotech / Mexico
T6	Fenpyroximate 5 %	1.25	Portal / Nichino / Mexico
T7	Citrus extract + 10 % keratin	2	Fractal / Berni Labs / Mexico
T8	Spirotetramat 15.3 %	0.3	Movento 150 OD / Bayer Crop Science / Mexico (trade witness of the region)
T9	Castor oil (*Ricinus communis* L.) 95 %	2,0	Higuerilla / Biotech / Mexico
T10	Neem oil (*A. indica*) at 18%, castor oil (*R. communis*) at 18 %, governor oil (*Larrea tridentata* (Sessé & Moc ex DC.) Coville) at 18 %, cinnamon oil (*Cinnamomum zeylanicum*) at 18 %, garlic oil (*A. sativum*) at 1 %, mustard oil (*Sinapis alba* L.) at 18 %	2	KillerPlus / Biotech / Mexico
T11	Vegetable Spinosin- Spinosad 62.5 gr/L	2	Lifetech S60 / Biotech / Mexico
T12	Water	-	Absolute control

Study variables

The measurement of the study variables was structured in two categories, the first one contemplates the variable of insect pest: 1) Number of thrips *F. occidentalis.* The second, contemplates three variables of the arthropods considered as natural enemies: 2) Number of Olla *v-nigrum* (Mulsant, 1866) catarinae (Coleoptera: Coccinellidae); 3) Number of lacewings *Chrysoperla rufilabris* (Burmeister, 1839) (Neuroptera: Chrysopidae); 4) Number of phytoseiids [predatory mites] *Phytoseiulus persimilis* (Athias-Henriot, 1957) (Acari: Tetranychidae: Phytoseiidae). To convert the number of insects of the variables into percentages, Equation 1 was used.

$$Arthropod\ population\ in\ \% = \left[\frac{Number\ of\ arthropods\ from\ the\ previous\ sampling}{Number\ of\ arthropods\ in\ later\ ours\ (dda)}\right] * 100\%$$

Technique and instruments for field data collection

The technique used to record pest insect infestation in the field was "tapping sampling". The materials used were a 38 x 21 cm wooden board lined with blue adhesive paper and a wooden handle 30 cm long and 3 cm in diameter. One lateral branch per tree was selected at approximately 1.50 m of height and three light blows were given with the wooden handle so that arthropods fell on the board and at the same moment they were identified, counted *in situ* and capture data recorded (Miranda-Ramírez *et al.,* 2021).

For data collection, a previous sampling was done as a starting point for the study and comparison. After the application of the treatments, sampling was carried out at 3, 6, 12, 20, 26, 35 and 41 days after application (daa).

Experimental design and statistical analysis

The design used was completely randomized, with twelve treatments, and ten replications; the experimental unit was a tree. For the statistical analysis, the Post Hoc test of homogeneity of variances data, ANDEVA, and Tukey's test of comparison of means ($p \leq 0.05$) were performed, using the statistical package Statistica version 13 (StatSoft Inc., 2017).

Results and Discussion

Number of thrips

The results of the test for homogeneity of variances of data showed a linear coincidence, likewise, the samplings presented a normal distribution that guaranteed its reliability.

The analysis of variance indicated that there is no statistical difference ($p \leq 0.05$) between treatments for the population means, thus they are statistically equal, except for the samplings at 35 and 41 daa, which did show significant differences (Table 2).

The results of the Tukey mean comparison test ($p \leq 0.05$) showed a differential effect between treatments at 3, 6 and, 26 daa (Table 3). From the twelve treatments evaluated, nine showed a decrease in the thrips population, which fell in a range from 6 to 100 % compared to T12 from 16.05 to 100 %, and for T8, considered as the chemical control for the region, the range was 34.37 to 100 %.

At 3 daa the treatments that showed the best results in relation to the decrease in the number of thrips are presented in descending order and were: T5 (0.54 thrips) equivalent to 83.02 %, T11 with (0.63) 76.92 %; T10 with (0.56) 76.74 %; compared to T8 (0.55) 67.26 % and T12 with (1.28) 57.19 % (Table 3). From the above, it can be deduced that the thrips population was sensitive to these treatments where the population decreased in a short time span of 72 hours.

Table 2. Levene´s analysis ($p \leq 0.05$) for the variable number of thrips prior to application and after 3, 6, 12, 20, 26, 35, and 41 daa.

Sampling dda	MS Effect	Error MS	F Levene	df	*p*-value
Previous	0.35514	0.39829	0.891660	11.108	0.550939
3	0.12185	0.08374	1.455060	11.108	0.159336
6	0.18360	0.11834	1.551500	11.108	0.123860
12	0.06249	0.05695	1.097260	11.108	0.370470
20	0.34979	0.24602	1.421770	11.108	0.173453
26	0.07736	0.21823	0.354470	11.108	0.970265
35	0.06672	0.00607	10.985440	11.108	0.000000*
41	0.00838	0.00093	8.970850	11.108	0.000000*

MS= mean square, df= degrees of freedom, *significant ($p \leq 0.05$).

At 6 daa T9 (1.24) 61.61 % showed a greater reduction effect on the thrips population compared to T8 (0.81) 51.79 % and T12 (1.50) 35.45 %. T11 (1.50) 45.05 % showed a value below T8, but not T12 and T1 (2.42) 41.50 % showed a greater reduction effect compared to T1 (Table 3).

At 12, 20, 35 and 41 daa, results of the treatments were non-significant, Tukey ($p \leq 0.05$). However, treatments that denoted the lowest numerical values in relation to the decrease in thrips population at 12 daa were: T11 (0.26) 90.48 %; T3 (0.40) 71.43 %. At 20 daa, T5 (1.59) 50 % and T11 (1.64) 30.93 %. At 35 days were T6 (0.00) 100 %; T1 (0.23) 98.79 % and T5 (0.23) 92.77 % and at 41 days were T5; T6; T7; T8; T9; T10 and T12 with values of 0.00 which equals 100 % (Table 3).

At 26 daa T3 (0.81) and T9 (1.29) showed a reduction effect on thrips population of 49.69 and 60.06 % respectively among other treatments and compared to T8 (1.13) with 32.47 % and T12 (2.08) with 30.43 % (Table 3).

Number of coccinellid predators

Homogeneity of variances of data showed a slight dispersion on the straight line, and in the observations made in all samplings presented sparse values with a normal distribution that evidences the low reliability of sampling.

The analysis of variance showed statistical difference ($p \leq 0.05$) among treatments for all samplings including the previous sampling (Table 4).

Tukey's test of means ($p \leq 0.05$) did not identify significant statistical differences between treatments. However, the treatment that obtained the best numerical results was T12, which maintained an average of 0.01 coccinellids at 3 daa, subsequently, there was an increase in the population at

6 daa of 0.03, an increase of 42 %. In relation to T12, the previous sampling presented a number of coccinellids of 0.019 and at 6 daa an increase in the population of 0.190 was observed, which corresponds to an increase of 100 %.

Table 3. Effect of treatments on Tukey thrips ($p \leq 0,05$)*.

Treatment	Previous sampling	Days after application (daa)						
		3	6	12	20	26	35	41
T1	4.136^{b}	1.099^{ab}	2.422^{abc}	0.702^{a}	1.852^{a}	2.273^{a}	0.232^{a}	0.059^{a}
T2	3.018^{ab}	1.030^{ab}	2.197^{abc}	0.713^{a}	2.177^{a}	2.027^{a}	0.298^{a}	0.019^{a}
T3	1.611^{a}	0.616^{ab}	2.192^{abcd}	0.409^{a}	1.941^{a}	0.819^{b}	0.370^{a}	0.038^{a}
T4	3.011^{ab}	1.251^{ab}	2.723^{bc}	0.836^{a}	1.808^{a}	1.507^{ab}	0.292^{a}	0.019^{a}
T5	3.186^{ab}	0.543^{ab}	2.030^{abcd}	0.573^{a}	1.594^{a}	1.681^{ab}	0.232^{a}	0.000^{a}
T6	2.189^{a}	1.100^{ab}	2.959^{c}	0.906^{a}	1.873^{a}	1.709^{ab}	0.000^{a}	0.000^{a}
T7	1.522^{a}	0.400^{a}	1.064^{ef}	0.514^{a}	1.781^{a}	1.407^{ab}	0.305^{a}	0.000^{a}
T8	1.682^{a}	$0.55^{7a}b$	0.817^{e}	0.782^{a}	1.918^{a}	1.130^{ab}	0.371^{a}	0.000^{a}
T9	3.237^{ab}	0.797^{ab}	1.240^{def}	0.436^{a}	2.123^{a}	1.295^{ab}	1.162^{a}	0.000^{a}
T10	2.388^{a}	0.561^{ab}	2.230^{abcd}	0.333^{a}	1.859^{a}	1.518^{ab}	1.664^{a}	0.000^{a}
T11	2.732^{ab}	0.639^{ab}	1.501^{adef}	0.264^{a}	1.642^{a}	1.806^{ab}	0.232^{a}	0.019^{a}
T12	2.991^{ab}	1.282^{b}	1.931^{abdf}	0.878^{a}	2.519^{a}	2.086^{a}	0.205^{a}	0.000^{a}

T1) Tolfenpyrad – 1,25 mL/L^{-1}; T2) Pyrifluquinazon – 0.58 mL/L^{-1}; T3) Garlic oil – 2 mL/L^{-1}; T4) Garlic extract + chamomile and rue extract – 2 ml/L^{-1}; T5) Neem oil – 2 mL/L^{-1}; T6) Fenpyroximate 1.25 mL/L^{-1}; T7) Citrus extract + keratin 2 mL/L^{-1}; T8) Spirotetramat – 0,31 mL/L^{-1}; T9) Castor oil – 2 mL/L^{-1}; T10) Neem + castor oil + governor oil + cinnamon oil + garlic oil + mustard oil – 2 mL/L^{-1}; T11) Vegetable spinosin – 2 mL/L^{-1} and T12) Water.

* Means with different letters in the column are statistically different (Tukey, $p \leq 0.05$).

Number of lacewings

In this case, the homogeneity of the variances of data indicated a slight dispersion on the straight line. It was observed that all samplings exhibit sparse values with a normal distribution, thus corroborating the reliability of sampling.

An analysis of variance showed statistical differences ($p \leq 0.05$) among treatments for all samplings (Table 5).

Table 4. Levene´s analysis ($p \leq 0.05$) for the variable number of ladybugs prior to application and after 3, 6, 12, 26, 35, and 41 daa.

Sampling dda	MS Effect	Error MS	F Levene	df	*p*-value
Previous	0.011858	0.001387	8.54876	11.108	0.000000*
3	0.006808	0.000720	9.45776	11.108	0.000000*
6	0.007937	0.000606	13.08815	11.108	0.000000*
12	0.006346	0.001001	6.33977	11.108	0.000000*
26	0.006346	0.001001	6.33977	11.108	0.000000*
35	0.001843	0.000400	4.60227	11.108	0.000010*
41	0.001014	0.000200	5.06250	11.108	0.000002*

MS= mean square, df= degrees of freedom, *significant ($p \leq 0.05$).

Table 5. Levene´s analysis ($p \leq 0.05$) for the variable number of lacewings prior to application and after 3, 6, 12, 20, 26, 35, and 41 daa.

Sampling daa	MS Effect	Error MS	F Levene	df	*p*-value
Previous	0.006104	0.001777	3.43611	11.108	0.000403*
3	0.008023	0.001436	5.58878	11.108	0.000000*
6	0.007060	0.001641	4.30215	11.108	0.000026*
12	0.017697	0.001252	14.14041	11.108	0.000000*
20	0.005773	0.001401	4.11932	11.108	0.000046*
26	0.004135	0.001602	2.58168	11.108	0.005992*
35	0.006152	0.001201	5.12121	11.108	0.000002*
41	0.002949	0.000801	3.68182	11.108	0.000184*

MS= mean square, df= degrees of freedom, *significant ($p \leq 0.05$).

Treatments that showed an increase in the population of lacewings at 12 daa were: T1 (0.08 lacewings) 30 %; T3 (0.08) 50 % in relation to T8 (0.06) 3 % and T12 (0.08) 33 % (Table 6). Consequently, T1 and T3 evidenced to be less aggressive in the decrease against these insect predators of thrips. Among all the treatments evaluated, T3 proved to be the only insecticide that presented an increase in the population of 75, 125, and 50 % at 3, 6, and 12 daa, respectively (Table 6).

Number of phytoseiids

In predatory mites, the homogeneity of data variances showed minimal deviations of the points from linearity. All observations in the samples followed a normal distribution, which guaranteed the reliability of this variable.

The analysis of variance showed a statistical difference ($p \leq 0.05$) between treatments for all samples (Table 7).

Table 6. Effect of treatments on Tukey lacewings ($p < 0,05$)*.

Treatment	Previous sampling	Days after application						
		3	6	12	20	26	35	41
T1	0.060[a]	0.190[a]	0.000[a]	0.080[ab]	0.000[a]	0.019[a]	0.000[a]	0.019[a]
T2	0.020[a]	0.000[a]	0.030[a]	0.020[ab]	0.038[a]	0.019[a]	0.000[a]	0.000[a]
T3	0.040[a]	0.070[a]	0.090[a]	0.080[ab]	0.000[a]	0.019[a]	0.019[a]	0.000[a]
T4	0.060[a]	0.010[a]	0.030[a]	0.040[ab]	0.019[a]	0.000[a]	0.038[a]	0.000[a]
T5	0.080[a]	0.000[a]	0.030[a]	0.120[b]	0.019[a]	0.038[a]	0.019[a]	0.000[a]
T6	0.060[a]	0.010[a]	0.090[a]	0.000[a]	0.019[a]	0.019[a]	0.019[a]	0.019[a]
T7	0.020[a]	0.010[a]	0.030[a]	0.000[a]	0.019[a]	0.019[a]	0.019[a]	0.000[a]
T8	0.060[a]	0.010[a]	0.030[a]	0.063[ab]	0.019[a]	0.000[a]	0.000[a]	0.000[a]
T9	0.020[a]	0.000[a]	0.030[a]	0.000[a]	0.000[a]	0.019[a]	0.000[a]	0.019[a]
T10	0.060[a]	0.010[a]	0.010[a]	0.04[2ab]	0.000[a]	0.000[a]	0.000[a]	0.019[a]
T11	0.100[a]	0.000[a]	0.050[a]	0.042[ab]	0.038[a]	0.000[a]	0.038[a]	0.000[a]
T12	0.060[a]	0.030[a]	0.050[a]	0.084[ab]	0.038[a]	0.019[a]	0.000[a]	0000[a]

T1) Tolfenpyrad – 1.25 mL/L^{-1}; T2) Pyrifluquinazon – 0.58 mL/L^{-1}; T3) Garlic oil – 2 mL/L^{-1}; T4) Garlic extract + chamomile and rue extract – 2 ml/L^{-1}; T5) Neem oil – 2 mL/L^{-1}; T6) Fenpyroximate 1.25 mL/L^{-1}; T7) Citrus extract + keratin 2 mL/L^{-1}; T8) Spirotetramat – 0.31 mL/L^{-1}; T9) Castor oil – 2 mL/L^{-1}; T10) Neem + castor oil + governor oil + cinnamon oil + garlic oil + mustard oil – 2 mL/L^{-1}; T11) Vegetable spinosin – 2 mL/L^{-1} and T12) Water.

* Means with different letters in the column are statistically different (Tukey, $p \leq 0.05$).

Statistical differences between Tukey treatments ($p < 0.05$) were only present in the sampling carried out at 35 daa (Table 8). Treatments with null effects on the decrease of phytoseiids were T3 (0.45) and T2 (0.45); on the contrary, they allowed growth in the phytoseiids population of 866.96 and 69.55 %, respectively. These results seem to indicate that phytoseiids are arthropods that show some tolerance to these insecticides during thrips control despite being scarce during initial sampling. However, treatments T8 (0.09) and T12 (0.06) showed a decrease in population of 45.45 and 81.29 % respectively (Table 8).

Table 7. Levene´s analysis (*p* ≤ 0.05) for the variable number of phytoseiids prior to application and after 3, 6, 12, 20, 26, 35, and 41 daa.

Sampling daa	MS Effect	Error MS	F Levene	df	*p*-value
Previous	0.048065	0.012115	3.96752	11.108	0.000075*
3	0.001014	0.000200	5.06250	11.108	0.000002*
6	0.051611	0.013177	3.91672	11.108	0.000088*
12	0.008037	0.001137	7.06672	11.108	0.000000*
26	0.013262	0.001298	10.21954	11.108	0.000000*
35	0.089133	0.015240	5.84875	11.108	0.000000*
41	0.002949	0.000801	3.68182	11.108	0.000184*

MS= mean square, df= degrees of freedom, *significant (*p* ≤ 0.05).

Table 8. Effect of treatments on Tukey phytoseiids (*p* < *0,05*).

Treatment	Previous sampling	Days after application					
		3	6	12	26	35	41
T1	0.274[a]	0.000[a]	0.096[a]	0.000[a]	0.000[a]	0.204[abc]	0.019[a]
T2	0.266[a]	0.000[a]	0.357[a]	0.000[a]	0.019[a]	0.451[bcd]	0.000[a]
T3	0.046[a]	0,000[a]	0.254[a]	0.000[a]	0.000[a]	0.454[cd]	0.000[a]
T4	0.214[a]	0.000[a]	0.395[a]	0.019[a]	0.038[a]	0.295[abcd]	0.019[a]
T5	0.416[a]	0.000[a]	0.184[a]	0.000[a]	0.039[a]	0.381[abcd]	0000[a]
T6	0.262[a]	0.000[a]	0.144[a]	0.000[a]	0.000[a]	0.163[abc]	0.000[a]
T7	0.425[a]	0.000[a]	0.192a	0.019[a]	0.000[a]	0.095[abc]	0.019[a]
T8	0.168[a]	0.019[a]	0.048[a]	0.019[a]	0.078[a]	0.09[5ab]c	0.000[a]
T9	0.215[a]	0.000[a]	0.158[a]	0.019[a]	0.039[a]	0.000[a]	0.000[a]
T10	0.181[a]	0.000[a]	0.441[a]	0.000[a]	0.039[a]	0.261[abcd]	0.019[a]
T11	0.185[a]	0.000[a]	0.479[a]	0.058[a]	0.058[a]	0.646[c]	0.000[a]
T12	0.326[a]	0.000[a]	0.445[a]	0.039[a]	0.058[a]	0.061[ab]	0.000[a]

T1) Tolfenpyrad – 1.25 mL/L^{-1}; T2) Pyrifluquinazon – 0.58 mL/L^{-1}; T3) Garlic oil – 2 mL/L^{-1}; T4) Garlic extract + chamomile and rue extract – 2 ml/L^{-1}; T5) Neem oil – 2 mL/L^{-1}; T6) Fenpyroximate 1.25 mL/L^{-1}; T7) Citrus extract + keratin 2 mL/L^{-1}; T8) Spirotetramat – 0.31 mL/L^{-1}; T9) Castor oil – 2 mL/L^{-1}; T10) Neem + castor oil + governor oil + cinnamon oil + garlic oil + mustard oil – 2 mL/L^{-1}; T11) Vegetable spinosin – 2 mL/L^{-1} and T12) Water.

* Means with different letters in the column are statistically different (Tukey, *p* ≤ 0.05).

Discussion

The present work corroborates an analysis of the agronomic management of thrips and its natural enemies in the Mexican lemon crop. The results showed that there is a sustainable alternative for the management of thrips populations, supported by some commercial botanical insecticides and the biorational effect on natural enemies.

There is a large number of chemical products that control thrips, but they may also affect its natural enemies, which increases damage to Mexican lemon foliage and fruit (Miranda-Salcedo *et al.,* 2020; Miranda-Salcedo *et al.,* 2021). Argolo *et al*. (2014), reported persistence of secondary effects of Spirotetramat for Phytoseiulus persimilis of zero days, with mortality ranging from 30 to 79 %. This insecticide has a rapid and temporary impact on insect populations and citrus growers prefer to use it, because it seems easy to obtain visible results with a rapid decrease in insect populations, including beneficial insects (Xiao *et al.,* 2010; Raza *et al.,* 2017). On the other hand, Ferragut *et al*. (1990) pointed out, that phytoseiid mites found on wild plants, exhibit good tolerance to some insecticides, and are very common in field crops and feed on small-sized arthropods such as pest thrips.

Argolo *et al.* (2013), reported in Spain, mortality of less than 30 % of phytoseiids with the application of neem oil (azadirachtin) and a persistence effect of zero days for citrus. The control efficiency of these phytoseiid mites on thrips pests depends largely on the percentage decrease caused by the effect of insecticides, which are used during the management of this pest. Argolo *et al.* (2014), found that the phytoseiid species most sensitive to mineral oils is *Phytoseiulus persimilis*.

Phytoseiid mites can show persistence to plant Spinosina for up to seven days, with a decrease of 30 to 79 % (San-Andres *et al.,* 2006; Argolo *et al.,* 2013). However, to identify biorational insecticides that could be used in combination with a biological control strategy, it is important to know any side effects on natural enemies (Sterk *et al.,* 1999). One way to control *F. occidentalis* thrips is by releasing native phytoseiid mites (Urbaneja *et al.,* 2005) which at one point in time and in the near future may eventually reduce the excess application of insecticides in the Apatzingán valley.

Esparza-Díaz *et al.* (2010) pointed out that the effect of azadirachtin depends on its dose and the pest species to be controlled since it can reduce feeding, survival, nymph viability, progeny, and can even produce acute toxicity. This oil acts as an alarm pheromone and makes insects stop eating, and its active substances are biodegradable and non-toxic to humans and domestic animals (Guerra-Maldonado, 2021).

In relation to chrysopids, Luna-Cruz *et al*. (2018) applied an insecticide composed of argemonin (Chicalote, *Argemone mexicana* L.), berberine (*Berberis sp.*) ricinine (higuerilla, *Ricinus communis* L.) and α-Terthienyl by direct contact and reported a mortality of 9 % at 24 h, the highest mortality of 11 % at 98 h, under laboratory conditions.

Planes *et al. (*2013) pointed out, that the conservation of natural enemies is key to being able to carry out an effective "Integrated Management" of pests in citrus since a major part of the pests are naturally controlled by some of these natural enemies.

Conclusions

Tolfenpyrad product proved to be a very efficient chemical insecticide in reducing the number of thrips during all sampling dates and remained constant with a range of 41.40 to 98.78 % mortality. However, for the number of coccinellids, the effect was devastating, showing a reduction in the population of 100 % in all the samplings except for 35 daa; for lacewings, it also reached levels of decrease in the population up to 100 %, so it is considered of high impact for the natural enemies of thrips.

The insecticides that showed a decrease in the population of thrips based on plant extracts were garlic extract + chamomile and rue extract, castor oil, Neem + castor oil + governess oil + cinnamon oil + garlic oil + mustard oil, neem oil, and vegetable Spinosin on all sampling dates and with the effect observed up to 41 daa. Garlic oil proved to be a good option for the control of thrips by reducing their population by an average of 60 %, and in phytoseiid mites, there was an increase of an average of 800 %. These extracts may represent an alternative for the control of thrips on Mexican lime in the Apatzingán Valley.

Conflicts of interest

The authors declare that there are no conflicts of interest with respect to the publication of this article.

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