Relationship Between *Frankliniella occidentalis* (Thysanoptera: Thripidae) Population Density and Three of Its Natural Enemies in Commercial Lemon Orchards in Mexico[1]

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Abstract Thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), are among the main insect pests of lemon production in Mexico. They damage flowers and fruits, thus, requiring several pest management approaches, including biological control. To determine the relationship between the populations of these pests and their main natural enemies, we estimated the population densities of thrips and their natural enemies in the citrus growing area of Apatzingán Valley, Michoacán, Mexico, in five conventional Mexican lemon orchards from May 2018 to December 2022. The detected natural enemies were *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae) at a density of 0 to 0.57 individuals per branch, *Hippodamia convergens* (Guérin-Méneville) (Coleoptera: Coccinellidae) at 0 to 0.26 individuals per branch, and *Amblyseius swirskii* (Athias-Henriot) (Acarina: Phytoseiidae) at 0 to 3.18 individuals per branch. Nonlinear exponential regression analyses were conducted with the population density of *F. occidentalis*, population densities of its natural enemies, and the sum of the population densities of the natural enemies in each orchard. A strong correlation was observed with the mean population density of *F. occidentalis* and the accumulated population densities of *C. rufilabris*, *H. convergens*, and *A. swirskii*.

Key Words biological control, beneficial insects, insecticides, agricultural systems

Commercial production of the Mexican lemon, *Citrus aurantifolia* (Chistmann) Swingle, is highly important to Michoacán, Mexico, with 204,683 ha of cultivated area and 398,552 tons of fresh fruit produced per year valued at US$136 million (Servicio de Información Agroalimentaria y Pesquera 2025), which includes

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approximately 70,000 jobs annually (Pineda et al. 2023). The main pests affecting Mexican lemon trees are the Asian citrus psyllid *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) (Miranda-Salcedo et al. 2021) and the thrips *Frankliniella insularis* (Franklin), *Scirtothrips perseae* Nakahara, *Leptotrips* sp., and *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae). Thrips are more important because of the damage they cause to the fruit (Miranda-Salcedo et al. 2019), with *F. occidentalis* being the most difficult to manage because it is polyphagous habit (50 host species; Johansen 2001). In addition, *F. occidentalis* exhibits a complex reproductive behavior, a short life cycle, and produces up to 13 generations annually (Mound 1997, Mound and Teulon 1995). This species causes direct damage to the fruit, with the most notable being the formation of scabs on the epidermis, which are typically no more than 1 mm in size (Miranda-Salcedo et al. 2019).

The control strategy for *F. occidentalis* relies on synthetic insecticides; however, this type of pest management has been ineffective because of the biology and habits of this pest (Miranda-Salcedo et al. 2021). Thrip populations are present year-round in citrus orchards, and growers currently perceive population densities to be relatively high (Miranda-Ramirez et al. 2023), due to global warming (Pushpalatha et al. 2024), the development of insecticide resistance (Miranda-Salcedo et al. 2019, Mouden et al. 2017), and the decline of natural enemies due to the misuse of pesticides. The beneficial species negatively affected by these pesticides include predatory mites such as *Neoseiulus* spp. (Acarina: Phytoseiidae), the phytoseiid mite *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae), and the minute pirate bug *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) (Miranda-Ramírez et al. 2023, Miranda-Salcedo et al. 2019, Vázquez et al. 2008). The presence of these natural enemies influences the population density of thrips (Reitz et al. 2020, Toledo-Perdomo and Sagastume-Mena 2019) and, thus, should be explored as natural biological control agents for these pest species. If determined to be a viable pest management tactic for lemon production, it would be a feasible and ecologically beneficial alternative to the use of synthetic products that can harm human health, flora, and fauna (Hernández-Trejo et al. 2019). However, the relationship between the population density of *F. occidentalis* and the population density of its natural enemies has not been studied in commercial Mexican lemon orchards in the citrus-producing regions of Mexico. Therefore, the aim of this study was to determine the correlation of the density of *F. occidentalis* populations with those of their natural enemies in five commercial orchards in the citrus-growing region of the Apatzingán Valley, Michoacán, Mexico.

Materials and Methods

The study was conducted from May 2018 to December 2022 in five conventionally managed Mexican lemon orchards in the citrus-growing area of Apatzingán Valley, Michoacán, Mexico (Table 1). Orchard management was typical of the Apatzingán Valley region that consisted of the following: a 15-d furrow flood irrigation and a monthly application of pesticides with a rotation of different insecticides, including Imiland® (imidacloprid, 200 g a.i. [active ingredient]/L + lambda-cyhalothrin, 140 g a.i./L at 250 ml/ha; Dragón, Agricultura Nacional, Estado de Mexico, México); Sidelt® (deltamethrin, 25 g a.i./L at 0.5 L/ha; Dragón, Agricultura Nacional); and Actram 75 WDG® (thiamethoxam, 750 g a.i./kg at 180 g/100 L of water; Dragón, Agricultura Nacional),

Table 1. General characteristics of the five lemon (*Citrus aurantifolia*) orchards in which populations of *Frankliniella occidentalis* and three species of natural enemies were monitored.

Orchards	Geographic Coordinates	Elevation (AMSL)	Age (yr)	Surface Area (ha)
La Nopalera	19°02′40.6″N 102°18′58.6″W	325	10	8
Chandio	19°05′26″N 102°24′52.2″W	258	5	5
Antúnez	19°00′40.8″N 102°13′39.9″W	360	4	7
Ciudad Morelos	19°01′22.2″N 102°16′24.4″W	310	6	8
Parácuaro	19°06′15.0″N 102°12′50.5″W	469	6	9

alternated with the use of bioinsecticides derived from extracts of Mix protective-N® (neem extract, 205.96 g a.i./L at 1 L/ha, Agrosanidad, Sinaloa, México,) and Progranic® alfa (garlic extract, 956.92 g a.i./L at liters per ha; Promotora Técnica Industrial, Morelos, México). Foliar and soil fertilizer applications with minor and major elements were made twice a year at the end of spring and the beginning of the rainy season.

The sampling protocol for the five orchards was conducted once a week from May 2018 to December 2022. For each sampling, 20 trees were selected from each orchard. Thrips and their natural enemies were enumerated by beating branches on a 40 × 20 cm blue board three times to dislodge the pests and natural enemies that were identified using the taxonomic keys of Cédola and Polack (2011), González (2006), Soto-Rodríguez et al. (2017), and Valencia-Luna et al. (2006).

For the statistical analysis, dispersion diagrams were generated to visualize the possible relationships between the population density of *F. occidentalis* and the population density of each of the natural enemies found, in addition to the sum of the population densities of all natural enemies in each of the sampled orchards, hereafter referred to as *natural enemies*.

Subsequently, nonlinear exponential regression was conducted with the population density of *F. occidentalis*, the individual species of natural enemies, and the sum of the population densities of the natural enemies in each orchard. The observed correlations were categorized according to Evans (1996) as very low for coefficients of determination (r^2) < 0.2, low for those between 0.20 and 0.39, moderate for those between 0.4 and 0.59, strong for those between 0.6 and 0.79, and robust for those >0.8. The SAS statistical package version 9.3 ($P \leq 0.05$) was used for all statistical analyses (SAS Institute 2011).

Results and Discussion

Only the thrips of the species *F. occidentalis* were found in the five Mexican lemon orchards in the Apatzingán Valley. The natural enemies identified from the samples were *Chrysoperla rufilabris* (Burmeister), *Hippodamia convergens* (Guérin-Méneville), and *A. swirskii* (Table 2). Negative exponential correlations were observed between the

Table 2. Mean population density (individuals per branch ± SE) of *Frankliniella occidentalis* and its natural enemies (*Chrysoperla rufilabris, Hippodamia convergens, and Amblyseius swirskii*) in Apatzingán Valley orchards.

Orchard	Year	Dates*	*F. occidentalis*	Natural Enemies**	*C. rufilabris*	*H. convergens*	*A. swirskii*
Antúnez	2018	Apr–Jun	4.08 ± 3.64	0.2 ± 0.07	0.14 ± 0.05	0.06 ± 0.03	0
		Jul–Sep	6.41 ± 2.28	0.23 ± 0.11	0.11 ± 0.06	0.13 ± 0.07	0
		Oct–Dec	7.14 ± 1.95	0.22 ± 0.07	0.13 ± 0.03	0.08 ± 0.06	0
	2019	Jan–Mar	3.05 ± 0.14	0.4 ± 0.12	0.31 ± 0.06	0.09 ± 0.06	0
		Apr–Jun	5.28 ± 2.52	0.22 ± 0.07	0.22 ± 0.07	0	0
		Jul–Sep	5.32 ± 2.09	0.37 ± 0.23	0.29 ± 0.21	0.08 ± 0.04	0
		Oct–Dec	4.83 ± 2.19	0.77 ± 0.34	0.67 ± 0.32	0.1 ± 0.03	0
	2020	Jan–Mar	1.98 ± 0.41	0.5 ± 0.07	0.5 ± 0.07	0	0
		Apr–Jun	1.2 ± 0.48	0.31 ± 0.1	0.24 ± 0.13	0.06 ± 0.05	0.01 ± 0.01
		Jul–Sep	3.62 ± 2.18	0.14 ± 0.05	0.06 ± 0.03	0.04 ± 0.02	0.04 ± 0.02
		Oct–Dec	3.41 ± 2.09	0.19 ± 0.04	0.11 ± 0.02	0.05 ± 0.03	0.03 ± 0.01
	2021	Jan–Mar	4.3 ± 2.38	0.3 ± 0.1	0.2 ± 0.07	0.06 ± 0.04	0.04 ± 0.03
		Apr–Jun	3.55 ± 2.83	0.18 ± 0.06	0.13 ± 0.06	0.04 ± 0.02	0.01 ± 0.01
		Jul–Sep	6.27 ± 3.77	0.19 ± 0.1	0	0.03 ± 0.02	0.16 ± 0.1
		Oct–Dec	2.59 ± 2.59	0.18 ± 0.08	0	0.11 ± 0.05	0.06 ± 0.03
	2022	Jan–Mar	3.05 ± 2.99	0.17 ± 0.05	0.01 ± 0.01	0.08 ± 0.04	0.08 ± 0.03
		Apr–Jun	7.83 ± 3.33	0.33 ± 0.16	0.07 ± 0.04	0.03 ± 0.02	0.23 ± 0.12
		Jul–Sep	2.1 ± 1.98	0.2 ± 0.06	0.02 ± 0.01	0.1 ± 0.04	0.08 ± 0.03

Table 2. Continued.

Orchard	Year	Dates*	*F. occidentalis*	Natural Enemies**	*C. rufilabris*	*H. convergens*	*A. swirskii*
Parácuaro	2018	Apr–Jun	3.68 ± 0.8	0.09 ± 0.04	0.03 ± 0.01	0.06 ± 0.04	0
		Jul–Sep	3.53 ± 0.43	0.1 ± 0.02	0.04 ± 0.02	0.06 ± 0.02	0
		Oct–Dec	2.36 ± 0.67	0.2 ± 0.05	0.13 ± 0.05	0.08 ± 0.02	0
	2019	Jan–Mar	2.28 ± 1.16	0.38 ± 0.14	0.13 ± 0.06	0.25 ± 0.09	0
		Apr–Jun	4.15 ± 0.62	0.07 ± 0.03	0.07 ± 0.03	0	0
		Jul–Sep	3.81 ± 0.52	0.09 ± 0.03	0.03 ± 0.02	0.06 ± 0.04	0
		Oct–Dec	1.55 ± 0.35	0.28 ± 0.04	0.19 ± 0.04	0.09 ± 0.04	0
	2020	Jan–Mar	3.79 ± 1.64	0.3 ± 0.19	0.26 ± 0.18	0.04 ± 0.02	0
		Apr–Jun	2.71 ± 1.03	0.15 ± 0.06	0.09 ± 0.04	0	0.06 ± 0.05
		Jul–Sep	3.07 ± 0.71	0.15 ± 0.08	0.05 ± 0.02	0.02 ± 0.02	0.08 ± 0.07
		Oct–Dec	0.49 ± 0.34	1.38 ± 0.41	0.13 ± 0.03	0.01 ± 0.01	1.24 ± 0.4
	2021	Jan–Mar	0.94 ± 0.46	1.15 ± 0.55	0.03 ± 0.01	0.01 ± 0.01	1.11 ± 0.56
		Apr–Jun	3.14 ± 1.13	0.08 ± 0.03	0	0.03 ± 0.03	0.05 ± 0.02
		Jul–Sep	3.41 ± 0.87	0.06 ± 0.02	0.04 ± 0.02	0.01 ± 0.01	0.01 ± 0.01
		Oct–Dec	1.76 ± 1.02	0.2 ± 0.08	0.03 ± 0.03	0.05 ± 0.04	0.13 ± 0.04
	2022	Jan–Mar	2.6 ± 0.87	0.14 ± 0.05	0.01 ± 0.01	0.06 ± 0.02	0.07 ± 0.03
		Apr–Jun	3.68 ± 0.56	0.08 ± 0.04	0	0.05 ± 0.03	0.03 ± 0.03
		Jul–Sep	2.42 ± 0.66	0.21 ± 0.11	0	0.08 ± 0.02	0.13 ± 0.12

Table 2. Continued.

Orchard	Year	Dates*	*F. occidentalis*	Natural Enemies**	*C. rufilabris*	*H. convergens*	*A. swirskii*
Ciudad Morelos	2018	Apr–Jun	10.5 ± 0.48	0.25 ± 0.05	0.2 ± 0.05	0.05 ± 0.03	0
		Jul–Sep	8.94 ± 1.05	0.44 ± 0.11	0.34 ± 0.11	0.1 ± 0.02	0
		Oct–Dec	9.12 ± 0.98	0.44 ± 0.08	0.35 ± 0.09	0.09 ± 0.03	0
	2019	Jan–Mar	5.94 ± 0.72	0.78 ± 0.15	0.51 ± 0.13	0.26 ± 0.08	0
		Apr–Jun	12.1 ± 0.53	0.08 ± 0.03	0.08 ± 0.03	0	0
		Jul–Sep	10.6 ± 0.64	0.27 ± 0.06	0.17 ± 0.06	0.1 ± 0.03	0
		Oct–Dec	10.27 ± 1.16	0.25 ± 0.09	0.17 ± 0.07	0.08 ± 0.07	0
	2020	Jan–Mar	5.36 ± 1.22	0.83 ± 0.19	0.79 ± 0.19	0.04 ± 0.02	0
		Apr–Jun	11.66 ± 1.19	0.16 ± 0.09	0.14 ± 0.09	0	0.03 ± 0.03
		Jul–Sep	9.13 ± 2.08	0.38 ± 0.22	0.1 ± 0.06	0	0.28 ± 0.23
		Oct–Dec	1.52 ± 0.58	1.85 ± 0.32	0.09 ± 0.03	0.03 ± 0.02	1.73 ± 0.32
	2021	Jan–Mar	1.06 ± 0.78	3.35 ± 1.09	0.12 ± 0.05	0.05 ± 0.04	3.18 ± 1.07
		Apr–Jun	6.48 ± 0.8	0.46 ± 0.15	0.18 ± 0.1	0.05 ± 0.03	0.24 ± 0.06
		Jul–Sep	10.59 ± 1.3	0.18 ± 0.08	0.04 ± 0.03	0.05 ± 0.02	0.09 ± 0.05
		Oct–Dec	5.96 ± 1.85	0.64 ± 0.22	0.1 ± 0	0.09 ± 0.03	0.45 ± 0.22
	2022	Jan–Mar	6.42 ± 0.61	0.36 ± 0.06	0.12 ± 0.08	0.07 ± 0.04	0.17 ± 0.09
		Apr–Jun	9.58 ± 0.87	0.21 ± 0.08	0.08 ± 0.02	0.06 ± 0.04	0.07 ± 0.05
		Jul–Sep	9.88 ± 2.28	0.46 ± 0.32	0.01 ± 0.01	0.06 ± 0.03	0.39 ± 0.29

Table 2. Continued.

Orchard	Year	Dates*	*F. occidentalis*	Natural Enemies**	*C. rufilabris*	*H. convergens*	*A. swirskii*
La Nopalera	2018	Apr–Jun	6.83 ± 1.99	0.41 ± 0.13	0.36 ± 0.1	0.05 ± 0.05	0
		Jul–Sep	8.68 ± 0.98	0.14 ± 0.04	0.13 ± 0.04	0.02 ± 0.01	0
		Oct–Dec	7.27 ± 0.91	0.2 ± 0.06	0.18 ± 0.06	0.03 ± 0.02	0
	2019	Jan–Mar	5.9 ± 1.92	0.25 ± 0.09	0.24 ± 0.09	0.01 ± 0.01	0
		Apr–Jun	7.48 ± 1.92	0.35 ± 0.05	0.32 ± 0.04	0.03 ± 0.03	0
		Jul–Sep	6.83 ± 1.43	0.18 ± 0.06	0.13 ± 0.06	0.05 ± 0.02	0
		Oct–Dec	8.3 ± 0.82	0.2 ± 0.06	0.17 ± 0.07	0.03 ± 0.02	0
	2020	Jan–Mar	4.39 ± 0.87	0.54 ± 0.17	0.51 ± 0.16	0.03 ± 0.03	0
		Apr–Jun	4.64 ± 2.19	0.83 ± 0.43	0.75 ± 0.4	0.06 ± 0.04	0.01 ± 0.01
		Jul–Sep	6.13 ± 1.7	0.58 ± 0.3	0.08 ± 0.04	0.03 ± 0.02	0.48 ± 0.31
		Oct–Dec	2.77 ± 1.34	0.95 ± 0.23	0.12 ± 0.06	0.02 ± 0.01	0.82 ± 0.22
	2021	Jan–Mar	3.87 ± 2.33	1.79 ± 0.78	0.07 ± 0.05	0.01 ± 0.01	1.71 ± 0.76
		Apr–Jun	1.96 ± 1.25	1.11 ± 0.27	0.48 ± 0.12	0.03 ± 0.03	0.61 ± 0.27
		Jul–Sep	6.91 ± 1.56	0.33 ± 0.22	0.11 ± 0.06	0.02 ± 0.01	0.2 ± 0.18
		Oct–Dec	0.69 ± 0.44	1.8 ± 0.31	0.1 ± 0.06	0.01 ± 0.01	1.69 ± 0.29
	2022	Jan–Mar	3.3 ± 1.51	0.76 ± 0.23	0.1 ± 0.05	0.02 ± 0.01	0.64 ± 0.2
		Apr–Jun	5.45 ± 1.57	0.43 ± 0.15	0.04 ± 0.03	0.02 ± 0.01	0.38 ± 0.16
		Jul–Sep	6.5 ± 2.01	0.52 ± 0.33	0.02 ± 0.01	0.01 ± 0.01	0.49 ± 0.34

Table 2. Continued.

Orchard	Year	Dates*	*F. occidentalis*	Natural Enemies**	*C. rufilabris*	*H. convergens*	*A. swirskii*
Chandio	2018	Apr–Jun	3.39 ± 0.53	0.05 ± 0.02	0.01 ± 0.01	0.04 ± 0.02	0
		Jul–Sep	1.61 ± 0.33	0.27 ± 0.05	0.08 ± 0.03	0.18 ± 0.06	0
		Oct–Dec	2.05 ± 0.45	0.18 ± 0.06	0.06 ± 0.04	0.13 ± 0.03	0
	2019	Jan–Mar	1.51 ± 0.34	0.28 ± 0.08	0.21 ± 0.09	0.06 ± 0.03	0
		Apr–Jun	1.42 ± 0.64	0.18 ± 0.04	0.12 ± 0.02	0.07 ± 0.03	0
		Jul–Sep	1.79 ± 0.42	0.17 ± 0.03	0.09 ± 0.03	0.08 ± 0.02	0
		Oct–Dec	2 ± 0.31	0.17 ± 0.02	0.08 ± 0.03	0.08 ± 0.02	0
	2020	Jan–Mar	1.34 ± 0.28	0.21 ± 0.02	0.18 ± 0.01	0.04 ± 0.02	0
		Apr–Jun	3.3 ± 0.66	0.08 ± 0.04	0.06 ± 0.03	0	0.01 ± 0.01
		Jul–Sep	1.86 ± 0.63	0.55 ± 0.41	0.06 ± 0.03	0.03 ± 0.02	0.46 ± 0.42
		Oct–Dec	1.48 ± 0.83	0.43 ± 0.15	0.03 ± 0.01	0 ± 0	0.4 ± 0.14
	2021	Jan–Mar	0.56 ± 0.29	0.76 ± 0.21	0.08 ± 0.05	0.04 ± 0.03	0.64 ± 0.21
		Apr–Jun	1.95 ± 0.45	0.24 ± 0.09	0.03 ± 0.01	0.03 ± 0.01	0.19 ± 0.08
		Jul–Sep	2.18 ± 0.68	0.18 ± 0.07	0.02 ± 0.01	0.15 ± 0.06	0.01 ± 0.01
		Oct–Dec	2.48 ± 0.92	0.16 ± 0.07	0	0.11 ± 0.08	0.05 ± 0.03
	2022	Jan–Mar	1.98 ± 0.43	0.13 ± 0.04	0.01 ± 0.01	0.07 ± 0.03	0.05 ± 0.05
		Apr–Jun	3.18 ± 0.5	0.06 ± 0.02	0	0.03 ± 0.02	0.03 ± 0.02
		Jul–Sep	2.94 ± 0.65	0.07 ± 0.03	0	0.06 ± 0.03	0.01 ± 0.01

* The original field data were obtained on a biweekly basis but were averaged on a 3-mo basis for representation in this table.
** Natural enemies = a sum of the population densities of each of the natural enemies sampled.

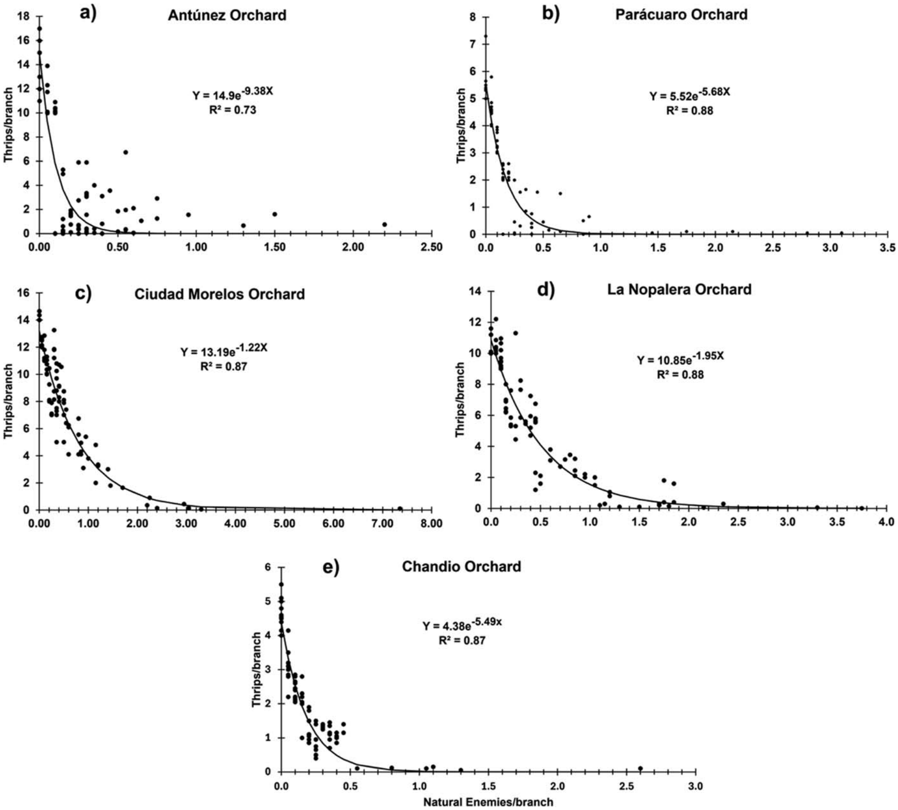

Fig. 1. Dispersion diagrams between the population densities of thrips (*Frankliniella occidentalis*) and the sum of the population densities of their natural enemies (*Chrysoperla rufilabris*, *Hippodamia convergens*, and *Amblyseius swirskii*) in five Mexican lemon orchards in Michoacán, Mexico.

mean density of *F. occidentalis* and the mean density of its natural enemies in each of the sampled orchards, as shown in dispersion diagrams (Fig. 1), with strong and robust exponential correlations ($r^2 > 0.6$) observed in some cases.

In the Antunez orchard, the relationships between the mean population density of *F. occidentalis* and the mean population densities of *C. rufilabris*, *H. convergens*, and *A. swirskii* presented statistically significant negative exponential correlations with low and very low coefficients of determination (Table 3). However, the correlation between *F. occidentalis* population density and the accumulated population densities of these natural enemies was strong, with a coefficient of determination of $r^2 = 0.73$ (Table 3).

In the Parácuaro orchard, the correlation was statistically significant ($P < 0.001$) and low ($r^2 = 0.25$) between the mean population density of *F. occidentalis* and the mean population densities of *C. rufilabris* and *A. swirskii* and very low with *H. convergens*, but a robust correlation was observed ($r^2 = 0.88$) with the sum of the

Table 3. Nonlinear exponential regression of the population density of thrips (*Frankliniella occidentalis*) and their natural enemies (*Chrysoperla rufilabris, Hippodamia convergens,* and *Amblyseius swirskii*) in commercial Mexican lemon orchards.

	Variable				Exponential Equation† $Y = a * e^{(b * X)}$					
Orchard	Dependent	Independent	df	r^2	a	±SE	Pr(>|t|)#	*b*	±SE	Pr(>|*t*|)
Antúnez	Thrips	Natural enemies*	87	0.73**	14.9	0.78	<0.001	−9.38	0.90	<0.001
		C. rufilabris	87	0.17	7.07	0.82	<0.001	−5.55	1.88	0.004
		H. convergens	87	0.23	7.26	0.75	<0.001	−14.87	4.70	0.002
		A. swirskii	87	0.15	5.75	0.63	<0.001	−16.20	8.69	0.065
Parácuaro	Thrips	Natural enemies*	87	0.88**	5.52	0.15	<0.001	−5.68	0.34	<0.001
		C. rufilabris	87	0.25	3.60	0.23	<0.001	−5.85	1.46	<0.001
		H. convergens	87	0.16	3.31	0.24	<0.001	−5.38	1.68	0.001
		A. swirskii	87	0.35	3.33	0.18	<0.001	−5.21	1.83	0.005
Ciudad Morelos	Thrips	Natural enemies*	87	0.87**	13.19	0.31	<0.001	−1.22	0.07	<0.001
		C. rufilabris	87	0.08	9.06	0.57	<0.001	−0.68	0.28	0.018
		H. convergens	87	0.03	8.60	0.53	<0.001	−1.11	0.68	0.108
		A. swirskii	87	0.58	9.81	0.31	<0.001	−1.23	0.24	<0.001
La Nopalera	Thrips	Natural enemies*	87	0.88**	10.85	0.29	<0.001	−1.95	0.13	<0.001
		C. rufilabris	87	0.12	6.83	0.55	<0.001	−1.27	0.47	0.008
		H. convergens	87	0.01	5.84	0.47	<0.001	−1.99	2.02	0.32
		A. swirskii	87	0.57	7.50	0.31	<0.001	−1.88	0.42	<0.001

Table 3. Continued.

	Variable				Exponential Equation† $Y = a * e^{(b * X)}$					
Orchard	Dependent	Independent	df	r^2	a	±SE	Pr(>|t|)#	*b*	±SE	Pr(>|*t*|)
Chandio	Thrips	Natural enemies*	87	0.87**	4.38	0.11	<0.001	−5.49	0.28	<0.001
		C. rufilabris	87	0.19	2.54	0.16	<0.001	−4.82	1.31	<0.001
		H. convergens	87	0.13	2.51	0.18	<0.001	−3.59	1.15	0.002
		A. swirskii	87	0.23	2.35	0.14	<0.001	−2.88	1.20	0.019

* Natural enemies = a sum of the population densities of each of the natural enemies sampled.
** Variables with strong or robust correlation ($r^2 > 0.6$) according to Evans (1996).
† Asterisks in Exponential Equation represent multiplication (x).
# Pr(.|t|) = probability of absolute value of t is equal to or greater than the given value, under the null hypothesis.

mean population densities of the natural enemies. In the Ciudad Morelos and La Nopalera orchards, a statistically significant ($P < 0.001$) but very low correlation ($r^2 = 0.08$, $r^2 = 0.03$, $r^2 = 0.12$, and $r^2 = 0.01$) was observed between the mean population density of *F. occidentalis* and the mean population densities of *C. rufilabris* and *H. convergens*; a moderate correlation ($r^2 = 0.58$ and $r^2 = 0.57$, respectively) was observed with the mean population density of *A. swirskii*, and a robust correlation ($r^2 = 0.87$ and $r^2 = 0.88$, respectively) was observed with the mean cumulative population density of the natural enemies. In the Chandio orchard, a statistically significant ($P < 0.001$) but very low correlation was observed between the mean population density of *F. occidentalis* and the mean population density of *C. rufilabris* and *H. convergens* ($r^2 = 0.19$ and $r^2 = 0.13$, respectively), a low correlation ($r^2 = 0.23$) was observed with the mean population density of *A. swirskii*, and a robust correlation ($r^2 = 0.87$) was observed with the mean accumulated population density of the natural enemies.

The correlations of the mean population densities of *C. rufilabris* and *H. convergens* with the mean population densities of *F. occidentalis* in the sampled orchards were low or very low in all cases, indicating a weak influence of these two natural enemies alone in the regulation of the population density of *F. occidentalis* in the lemon orchards. For the mean population densities of *A. swirskii*, the correlation with the mean population densities of *F. occidentalis* in the sampled orchards was moderate in most cases, indicating that this natural enemy has a greater effect alone on the regulation of the population density of *F. occidentalis* than *C. rufilabris* and *H. convergens.*

The strongest correlation observed was between the mean population density of *F. occidentalis* and the cumulative mean population densities of the three natural enemies in all cases studied ($r^2 = 0.73$, $r^2 = 0.88$, $r^2 = 0.87$, $r^2 = 0.88$, and $r^2 = 0.87$). This finding indicates an important cumulative effect of the natural enemies as a whole on the regulation of the mean population density of *F. occidentalis* in the Mexican lemon crop, in addition to other intervening factors such as the phenological stage of the crop, the presence or absence of rain, wind speed, and relative humidity gradients (Toledo-Perdomo and Sagastume-Mena 2019).

The three identified beneficial insect species are recognized as effective thrip control agents globally (Aristizábal and Arthurs 2014, Miranda-Salcedo et al. 2021, Xu and Enkegaard 2010) and have been reproduced and sold in Mexico for years. For example, *A. swirskii* has been in commercial use since 2015 and was used on over 3,265 ha in 2020, while *H. convergens* has been used since 1973, and more than 34.6 million adults were applied in 2 yr on 2,961 ha, and *C. rufilabris* has been available since 2008 in rearing centers at a relatively affordable cost (Bahena 2008). Therefore, on the basis of our results, if a choice is required among *A. swirskii, C. rufilabris*, and *H. convergens* for use as a biological agent against *F. occidentalis*, *C. rufilabris* is the best option.

We identified a sparse community of beneficial organisms. This finding could be because the experimental orchards were located in the middle of an agricultural region with intensive phytosanitary management, and such a hostile environment has been identified as a factor contributing to biodiversity loss (Ballal et al. 2021, Fanfarillo et al. 2022). If faunistic listings are made, almost no beneficial insects are recorded (Kremen and Miles 2012, Welch and Harwood 2014), as demonstrated by Norton and Welter (1996) on *Anaphesiole girault* Girault (Hymenoptera: Mymaridae), when after 96 h of field release, the parasitoid population decreased by 93%. Therefore, to favor natural populations of beneficial insects, the appropriate use of chemical insecticides tolerated by these insects, the release of beneficial insects, and the encouragement of an increase in populations through conservation and biological control (Blanco and Leyva 2007), such as the proper management of weed plants that act as refuges for thrips predators (Atakan and Pehlivan 2019).

In conclusion, the results of this investigation indicate that there is an exponential correlation between the population density of *F. occidentalis* and the cumulative density of its natural enemies, specifically *C. rufilabris*, *H. convergens*, and *A. swirskii*. Predation plays a crucial role in the natural regulation of *F. occidentalis*. Future research controlling for different factors that influence natural enemies, such as agronomic management and the application of chemicals, is needed to further corroborate the results of the present study.

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