Colegio de Postgraduados

Agroecological Alternatives for Pest and Disease Management in Mexican Lime [*Citrus aurantifolia* (Christm.) Swingle] Cultivation

Zepeda-Batista, José Luis[1], Tirado-González, Deli N.[2]; Gayosso-Barragán, Odilón[3]; Carrillo-Díaz María I.[1*]; Chávez-Aguilar, Griselda[3*]

[1] Universidad de Colima, Facultad de Medicina Veterinaria y Zootecnia. Autopista Colima-Manzanillo, Km. 40, Crucero de Tecomán, Tecomán, Colima, México. C.P. 28934.

[2] Instituto Tecnológico el Llano Aguascalientes, Tecnológico Nacional de México. Carretera Aguascalientes-San Luis Potosí, Km. 18, El Llano, Aguascalientes. México. C.P. 20330.

[3] Centro Nacional de Investigación Disciplinaria en Agricultura Familiar, Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP). Carretera Ojuelos-Lagos de Moreno Km 8.5, Ojuelos, Jalisco, México. C.P. 47540.

* Correspondence: mcarrillo13@ucol.mx, chavez.griselda@inifap.gob.mx

ABSTRACT

Objective: To evaluate the effect of commercial bioinsecticides and mineral broths as agroecological alternatives for the integrated management of recurrent pests in Mexican lime (*Citrus aurantifolia*); as well as to establish possible synergies with the commercial bioinsecticide.

Design/methodology/approach: This experiment was conducted in two phases: 1) visual monitoring and pre-identification of pests and fungal diseases in the Mexican lime crop, and 2) application and evaluation of the effect of application of commercial bioinsecticide (Biocanela) and mineral broths (bordeaux broth and sulfocalcium broth) alone and mixtures.

Results: The pests with highest incidence were thrips (*Pezothrips kellynus*), Asian citrus psyllid (*Diaphorina citri*), whitefly (*Bemisia tabaci*), fruit fly (*Drosophila melanogaster*), and red spider mite (*Tetranychus urticae*), while the main fungal diseases were sooty mold (*Capnodium citri*), red algae (*Cephaleuros virescens*), citrus greasy spot (*Mycosphaerella citri*), and anthracnose (*Colletotrichum acutatum*). The mixture of mineral broths with the bioinsecticide Biocanela showed the highest fungicide and insecticide activity, and repellency on various pests and diseases of the Mexican lemon crop.

Limitations on study/implications: Generate scientific knowledge regarding to the best agroecological alternatives for the integrated management of citrus pests and diseases that are economically and environmentally profitable.

Findings/conclusions: Application of the mixture of sulfocalcium broth and Biocanela showed repellency effectiveness against pests such as thrips (*Pezothrips kellyanus*), Asian citrus psyllid (*Diaphorina citri*), whitefly (*Bemisia tabaci*), and fruit fly (*Drosophila melanogaster*). Likewise, it was effective against sooty mold (*Capnodium citri*), red algae (*Cephaleuros virescens*), and citrus greasy spot (*Mycosphaerella citri*), while the effect was lighter against anthracnose (*Colletotrichum acutatum*). Additionally, it induces new, healthy shoots in Mexican lemon trees.

Keywords: mineral broths, commercial bio-insecticides, citrus, phytopathology

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INTRODUCTION

Lime cultivation in Mexico is carried out in 27 states, where three varieties are grown: Mexican lime [*Citrus aurantifolia* (Christm.) Swingle], Persian lime (*C. latifolia* L.), and Italian lemon (*C. lemon* L.). Among these, Mexican lime has the largest area of commercial orchards (Martínez *et al.*, 2023), with an annual production of approximately 3.1 million tons valued at 28,141 million pesos (SIAP, 2022). The production of lime in all its varieties developed during the 20th century, with the first plantations starting in the state of Michoacán. This was done to meet the demand for fresh lime and lime oil in the U.S. and French markets, as well as the growing local consumption (Galván-Vela and Santos-González, 2019). Currently, Mexican lime cultivation covers 80% of the cultivated area in the state of Colima, with Tecomán and Armería being the municipalities with the largest cultivated areas (Orozco-Santos *et al.*, 2014). However, the tropical climate in which this crop is predominantly grown fosters the presence of pests and diseases, making agroecological alternatives necessary for the management of these pathologies.

The use of synthetic pesticides for pest control in citrus has been the primary option for managing phytopathogens, despite their residuality and high costs, as well as the potential for pests to develop tolerance (González-Castro *et al.*, 2019). Synthetic pesticides are made from chemical products such as specific polymers for different pests; these include those used for weed control (herbicides), fungi (fungicides), mites (acaricides), bacteria (bactericides), insects (insecticides), nematodes (nematicides), etc., which form the basis of their classification (Anakwue, 2019; Rakhimol *et al.*, 2020). Although synthetic pesticides have positive effects on crop yield and productivity, they also have some negative impacts on soil biodiversity, wildlife, and aquatic life (Faroq *et al.*, 2019). Similarly, they affect soil microorganisms by limiting their biological services in the production of certain plant growth-promoting traits, such as siderophores, nitrogen, and indole-3-acetic acid, among others (Kumar and Kumar, 2019).

In the past 20 years, the development of production systems, technologies, and integrated pest management plans that reduce or eliminate these problems has shown rapid growth worldwide (Seufert *et al.*, 2017). In this regard, technological alternatives for integrated pest management include the use of bioinsecticides and mineral broths (Tijjani *et al.*, 2016). Bioinsecticides are natural substances composed of living organisms that control pests through mechanisms with minimal negative impact on the environment (Mazid *et al.*, 2011); meanwhile, mineral broths are liquid organic fertilizers that act as fungicides, insecticides, and acaricides while also providing nutritional benefits to crops (Leal and Reyes, 2015).

In Mexico, statistics on the use of agroecological alternatives such as bioinsecticides and mineral broths show widespread use in crops like avocado, corn, and chickpeas (Bouriga-Valdivia *et al.*, 2016). Specifically, in the state of Colima, the use of these bioinsecticides is still limited, with their primary application being in banana cultivation (Arévalos, 2017). The objective of this study was to evaluate commercial bioinsecticides and mineral broths as agroecological alternatives for the integrated management of recurrent pests in Mexican lime cultivation, as well as to establish possible synergies with the commercial bioinsecticide.

MATERIALS AND METHODS

Experimental Area and Biological Material

The experiment was conducted in the community of Cofradía de Juárez in the municipality of Armería, Colima, located at coordinates 18° 59' 44" North latitude, 103° 55' 45" West longitude, at an altitude of 46 meters (INEGI, 2019; Google Earth, 2019). The property borders a low deciduous forest area to the south (INEGI, 2019), and to the north, it is adjacent to the main unpaved road without a dust protective fence. The land area is one hectare with a planting density of 400 Mexican lime trees, averaging 5 to 6 years old, and a previously established planting frame of 6×7 meters. The study included two stages: the first involved monitoring and preliminary identification of pests and fungal diseases present in the crop, and the second involved the application of the specified treatments to each row of the crop.

Monitoring and Identification of Pests and Fungal Diseases in Mexican Lime Cultivation

Monitoring was carried out during the first 15 days of the experiment in November and December. The experimental area was divided into five quadrants (four at each corner and one in the center forming a "five of coins" pattern), and a yellow trap measuring 12.5×21.5 cm, with thick gauge and glue on both sides from the *Ferommis Group* (Culiacán, Sinaloa), was placed at the center of each quadrant. Every 15 days during the monitoring period, different sides of the traps were examined to accurately determine the pests and their densities.

Pest identification was done visually, while density was determined using the guidelines provided by the trap supplier during the counting of insects in the grid sections of each trap. Fungal disease identification was also conducted visually, through monitoring 15 randomly selected trees in one of the rows corresponding to each treatment.

Treatment of the Crop and Pest Sampling

The experimental stage included cycles of spraying and pest monitoring. Eight treatments with three replications were used for the control of fungal infections and pests. The treatments were: absolute control, control 1 (commercial chemical insecticide: Bannen 1.8%), the bioinsecticide (Biocanela), sulfocalcium broth+bioinsecticide (Biocanela), sulfocalcium broth, Bordeaux broth+bioinsecticide (Biocanela), Bordeaux broth, control 2 (commercial chemical fungicide: Funlate 50%) (Table 1). Before application, all products were mixed with an adjuvant (Bionex®). The active ingredients and the doses corresponding to each treatment are shown in Table 1. The trees selected for pest monitoring (15 per treatment) were evaluated directly (visually) to determine the incidence of fungal pathologies in four zones corresponding to the cardinal points, monitoring the trunk, primary branches, secondary branches, and fruiting branches in each zone. Applications were made using a 20 L motor pump (Mitsubishi F-767) (Duran-Trujillo *et al.*, 2017). Spraying was conducted from February to April, with one application every 15 days throughout the experimental period (6 months). Each tree was sprayed according to the cardinal points with the eight treatments; subsequently, the trees were labeled with

Table 1. Treatments and doses evaluated for pest control in Mexican Lime during the experiment.

Treatments	Name	Active ingredient	Dose (L ha^{-1})
T1 (absolute control)	Water	H_2O	200
T2 (control sample 1)	Funlate 50%	Benomyl	300
T3	Biocanela	Cinnamon oil	1.5
T4	Sulphocalcium broth + Biocanela	Sulfur + calcium oxide + cinnamon oil	40 + 1.5
T5	Sulphocalcium broth	Sulfur + calcium oxide	40
T6	Bordeaux broth + Biocanela	Copper sulfate + hydrated lime + cinnamon oil	40 + 1.5
T7	Bordeaux broth	Copper sulfate + hydrated lime	40
T8 (control sample 2)	Bannen 1.8%	Abamectin	1.5

the treatment name, time, and date to track the applications. Additionally, one yellow trap from *Ferommis Group* (Culiacán, Sinaloa) was placed per treatment and replication. The 24 traps were placed randomly within each replication. To track population fluctuations of the species and measure the effect of the treatments, monitoring was conducted 5, 7, 9, 11, and 13 days after each application. The adjuvant Bionex® was added to all treatments at a concentration of 1 L ha^{-1}.

Experimental Design

A completely randomized mixed effects generalized linear model with three replications was used. The effects included in the model were: number of insects per trap before application, number of insects per trap after application, and number of insects killed on the branches. The direct observation method was used to determine the fungicidal effectiveness of the mineral broths.

Data Analysis

The reductions in pest populations due to the treatments were calculated by comparing them with the number of insects in the control plot (Duran-Trujillo *et al.*, 2017). The percentage of reduction (R%) in infestation was estimated using the Henderson and Tilton (1955) equation with the SAS 9.3 statistical package, through the following formula:

$$\textit{Infestation percentage} = \sum\left(\frac{n.v}{N.V.}\right)\times 100$$

Where n=number of monitoring units in each category, N=total number of monitoring units, v=value of each category, and V=value of the highest category.

The results were transformed using the arcsine function and subsequently analyzed with SAS 9.3 software. For the comparison of treatments, analysis of variance (ANOVA) was used, and mean comparisons were conducted with the Tukey test. For correlation, the Pearson test was employed. In all cases, $\alpha=0.05\%$ (Duran-Trujillo *et al.*, 2017).

The behavior of the accumulated incidence (AI) of each fungal pathology due to the treatments was determined using the formula employed by Fajardo-Gutiérrez (2017):

$$Accumulate\ Incidence\ of\ Fungal\ Pathology\ (\%) = \frac{\#\ infected\ plants}{total\ number\ of\ monitored\ plants} \times 100$$

To determine the AI in each application cycle, the average number of diseased trees identified during the monitoring was used, while the AI for the entire study was based on the infected plants reported in the final monitoring conducted during the study.

RESULTS AND DISCUSSION

The pests with the highest initial presence recorded on the sampled trees were thrips (*P. kellyanus*): 260, Asian citrus psyllid (*D. citri*): 130, whitefly (*B. tabaci*): 277, fruit fly (*D. melanogaster*): 185, and red spider mite (*T. urticae*): 76; additionally, fungal diseases observed in trees included anthracnose (*C. acutatum*): 79, red algae (*C. virescens*): 118, sooty mold (*C. citri*): 114, and citrus greasy spot (*M. citri*): 81; all of which have a significant economic impact on the development of citrus crops. The effectiveness of the tested treatments for implementing integrated pest and disease management were different (Table 2).

The significant difference in the number of applications indicates that the insecticidal effect of the treatments used in this study begins with the second application (Table 3), while the fungicidal effect is evident only by the third application (Table 6), with its effectiveness

Table 2. Significance level for the effects included in the models to analyze the insect-trap ratio (ITR) and dead insects on trees (DIT).

Variable	$Application_z$	Day_y	$Treatment_x$	$Rep\ (Trat)_w$
ITR	<0.0001	<0.0001	<0.0001	<0.0001
DIT	<0.0001	<0.0001	<0.0001	0.9999

Rep (Trat): repetition nested within treatment.

Table 3. Tukey's mean comparison test for the overall effect by application of mineral broths and commercial products on insect-trap relationship (ITR) and insect mortality (DIT) in Mexican lime trees after five application cycles.

Application*	N	ITR¥	DIT¥
1	120	95.98 ± 38.40^{a}	10.82 ± 14.84^{a}
2	120	76.30 ± 37.78^{b}	9.79 ± 13.51^{ab}
3	120	71.90 ± 39.09^{b}	10.14 ± 12.62^{ab}
4	120	54.10 ± 32.01^{c}	8.50 ± 10.63^{bc}
5	120	49.08 ± 27.65^{c}	6.38 ± 8.61^{c}

ITR: insect-trap ratio; DIT: Insects Mortality in trees, *Interval between applications: 15 days, ¥Values with the same letter within each column are not significantly different ($p<0.05$).

increasing as the number of applications progresses (Tables 3 and 6). Additionally, it was demonstrated that the repellent, insecticidal, and fungicidal behavior exhibited by all treatments does not change with subsequent applications, although the magnitude of the effect does.

It was determined that the number of days elapsed since the application of each treatment influenced the effectiveness of mineral broths and commercial products in terms of insect-trap relationship and insect mortality in trees, with partial pest control maintained up to nine days post-application (Table 4). A significant difference in repellent effectiveness was observed during the 13 days following the first application. However, the difference in its insecticidal behavior from day five to day 13 post-application was significantly low.

The combinations of Bordeaux mixture (BM) with Biocanela (CBR+BC) and sulfur-calcium broth with Biocanela (SCB+BC) generally exhibited the highest effectiveness as repellents, with insect-trap ratios of 46.85 and 53.80, respectively, and a reduction in overall pest incidence ranging between 71% and 79% (Table 5). Both broths exhibited significant repellent action against whitefly (WF), showing reductions ranging from 54% to 74%, along with treatment 5 of sulfur-calcium broth (Table 5 and 6). Similarly, in terms of pest type, the SC+BC treatment was found to be the most effective repellent for thrips

Table 4. Tukey's Mean Comparison Test of the General Effect of Days Post-Application (DAA) of Mineral Broths and Commercial Products on the Insect-Trap Ratio (ITR) and Insects Mortality (DIT) in Mexican lime Trees for Each Application Cycle.

DAA	N	ITR[¥]	DIT[¥]
5	120	54.45 ± 29.93^{a}	25.63 ± 17.57^{a}
7	120	63.09 ± 33.83^{b}	9.93 ± 6.69^{b}
9	120	69.52 ± 37.65^{c}	5.52 ± 3.83^{c}
11	120	76.65 ± 41.91^{d}	3.03 ± 2.58^{c}
13	120	83.67 ± 43.59^{e}	1.53 ± 1.67^{c}

DAA: days Post-Application; ITR: insect-trap ratio; DIT: Insects Mortality in trees, [¥]Values with the same letter within each column are not significantly different ($p<0.05$).

Table 5. Tukey's mean comparison test of treatments based on mineral broths and commercial products on insect-trap ratios and insect mortality in Mexican lime trees after five application cycles.

Treatments		N	IMI	ITR[¥]	DIT[¥]
T1	Water (absolute control)	75	211.80	135.88 ± 31.45^{a}	0.00 ± 0.00^{e}
T2	Funlate 50% (benomyl) control sample 1	75	189.30	80.29 ± 22.14^{b}	0.02 ± 0.16^{e}
T3	Bio-canela	75	197.73	55.96 ± 22.80^{d}	9.01 ± 8.83^{cd}
T4	Sulphocalcium broth + Bio-canela	75	192.40	53.80 ± 30.02^{de}	13.05 ± 13.29^{b}
T5	Sulphocalcium broth	75	190.67	66.21 ± 36.99^{c}	12.98 ± 12.87^{b}
T6	Bordeaux broth + Bio-canela	75	197.07	46.85 ± 18.43^{e}	11.77 ± 12.18^{cb}
T7	Bordeaux broth	75	205.00	60.02 ± 24.30^{cd}	8.52 ± 9.14^{d}
T8	Bannen 1.8% (abamectin) control sample 2	75	188.93	56.77 ± 35.75^{d}	17.65 ± 17.09^{a}

IMI: average number of insects in trap after initial monitoring; ITR: insect-trap ratio; DIT: Insects Mortality in trees, [¶]Mixed with 1 L ha^{-1} of Bionex® adjuvant, [¥]Values with the same letter within each column are not significantly different ($p<0.05$).

(TRP) (incidence reduction: 50%) and red spider mite (RSM) (incidence reduction: 85%), while for the Asian citrus psyllid (ACP), the BM and fruit fly (FF) were ranked as the second-best options, with incidence reductions of 64%, 62%, and 65%, respectively (Table 6 and Figure 1). In this regard, Soto *et al.* (2013) highlighted the effectiveness of sulfur-calcium broth in controlling red spider mite (RSM) populations at concentrations above 20%. Meanwhile, Monteon-Ojeda *et al.* (2020) reported a reduction in TRP populations in mango cultivation of up to 85%.

The results of the repellency effect of Treatment 8 (Control 2, Bannen 1.8%: abamectin) in the present study indicate a possible development of resistance by pests to this chemical, maintaining its effectiveness only for the Asian citrus psyllid (PAC) (incidence reduction greater than 80%) and a partial effect in controlling spider mites (AR) (72% reduction). In this sense, the limited pest control of thrips (TRP), whitefly (WF), and fruit fly (FF), with incidence reductions of approximately 40%, highlights the loss of repellency effectiveness of this chemical against two of the most common pests based on the results obtained during the initial monitoring and the development of this study (Table 6). In this regard, Aguilar *et al.* (2017) determined that the application of abamectin in onion crops showed insecticidal effects with few or no repellency effects.

On the other hand, the repellent effect specifically achieved by the bioinsecticide Biocanela (BC) is also considered suitable for controlling trips (TRP) and red spider mites (AR), with reductions of 48% and 66%, respectively. For whitefly (WF) and fruit fly (FF), treatment 5 (sulfur-calcium broth, SC) demonstrated the best effectiveness as a repellent, with incidence reductions ranging from 74% to 77%. In this regard, Barrón-Contreras *et al.* (2022) determined that, following the application of SC in chili crops, the population of MB is reduced by up to 45%.

The presence of Insects Mortality on the tree (DIT) indicated that treatments based on simple sulfur or in combination with BC (T5: SC and T4: SC+BC), as well as those based on copper combined with Biocanela (T6: CBR+BC), showed the highest insecticidal effect among the agroecological treatments, with a DIT ranging between 11 and 13 insects after treatment (Table 5). Maintaining its residual insecticidal effect for up to 13 days on

Table 6. Average number of insects trapped per pest after the first and fifth applications of each treatment.

Treatments	THRIPS		DIAPHO		BEMISIA		DROSOPH		TETRANYC	
	AP1¥	AP5¥)	AP1¥	AP5¥	AP1¥	AP5¥	AP1¥	AP5¥	AP1¥	AP5¥
T1 Water (absolute control)	9.60	10.47	19.47	18.93	64.13	53.53	52.33	37.93	1.20	1.00
T2 Funlate 50% (benomyl) control sample 1	7.13	9.53	7.00	10.47	40.07	35.00	27.27	24.73	1.00	1.13
T3 Bio-canela	3.27	1.67	7.60	2.73	38.60	18.53	33.07	13.33	1.20	0.40
T4 Sulphocalcium broth + Bio-canela	2.00	1.47	11.67	4.13	39.80	15.07	33.00	11.33	1.07	0.33
T5 Sulphocalcium broth	1.33	1.73	11.67	6.60	56.07	14.27	47.33	10.53	1.20	0.73
T6 Bordeaux broth + Bio-canela	1.73	0.87	7.53	4.07	32.93	14.93	29.60	12.13	3.80	0.53
T7 Bordeaux broth	2.27	1.13	8.13	4.67	42.67	23.00	37.13	17.00	0.80	0.80
T8 Bannen 1.8% (abamectin) control sample 2	2.33	1.40	4.67	0.80	43.60	25.13	34.07	20.27	0.60	0.13

THRIPS: Citrus thrips (*P. kellyanus*); DIAPHO: Asian citrus psyllid (*D. citri*); BEMISIA: Whitefly (*B. tabaci*); DROSOPH: Fruit fly (*D. melanogaster*); TETRANYC: Citrus red spider (*T. urticae*). AP1¥: application 1; AP5¥: application 5.

Figure 1. Insect presence in trees treated with: Bordeaux mixture + Biocanela, a) first count after the first application and b) fifth count after the fifth application; sulfur-calcium broth + Biocanela, c) first count after the first application and d) fifth count after the fifth application.

TRP, PAC, and MB, in the case of treatments including SC (T4 and T5). Martínez (2023) identified the insecticidal effect of cinnamon extract in controlling MB in zucchini crops under open sky conditions, achieving population reductions exceeding 85%.

For the case of Testigo 2 (T8, Bannen 1.8%: abamectin), unlike the repellent results obtained, the insecticidal effect of this treatment was the highest among all the compounds used in the study, exceeding the results obtained by the other treatments by up to 26%, indicating its effectiveness as an insecticide for the pests monitored in the study. In this regard, Restrepo-García and Soto-Giraldo (2017) determined an insecticidal effectiveness of up to 53% against PAC.

Table 7. Accumulated incidence (AI) of fungal diseases identified in the monitoring of Mexican lime trees for each treatment application cycle.

Disease	N	Initial ¶	AP1¥	AP2¥	AP3¥	AP4¥	AP5¥
Anthracnose	120	65.83	65.83	55.83	47.50	37.50	25.00
Sooty mold	120	95.00	95.00	95.00	56.67	30.83	26.67
Algal spot	120	98.33	98.33	95.83	63.33	34.17	24.17
Greasy spot	120	67.50	67.50	67.50	64.17	40.00	29.17

¶Initial incidence value of the fungal diseases in initial monitoring. ¥Accumulated incidence value of the fungal diseases identified in each application. AP1: application 1; AP2: application 2; AP3: application 3; AP4: application 4; AP5: application 5.

Regarding the control of fungal diseases present during the initial monitoring, treatments containing copper (T6: BM with Biocanela; T7: BM, CBR) proved to be the best options for controlling anthracnose, reducing the presence of diseased tissues by 87% to 100% (Table 8). In this context, Park *et al.* (2014) demonstrated a reduction in the presence of anthracnose by up to 61% in bell pepper crops sprayed with BM at 14-day intervals. Similarly, Treatment 6 (BM+BC) shows similar effectiveness in controlling sooty mold, red alga, and greasy spot, being even more effective than the chemical in Test 1 (Funlate 50%: benomyl), which achieved approximately 80% reduction in incidents of anthracnose, sooty mold, and red alga, similar to what was indicated by Guillén *et al.* (2018) for anthracnose and greasy spot in Valencia orange (*Citrus sinensis*) crops. The lower fungicidal effect of benomyl compared to treatments based on mineral broths may indicate the development of probable resistance of field strains to commercial chemical fungicides, as determined by Gutiérrez *et al.* (2003) in mango trees from five regions of the country, where the strains exhibited a median lethal concentration higher than 50 ppm of benomyl.

Although the cumulative incidences of fungal phytopathologies were reduced with the use of copper treatments, a marked defoliation of the trees subjected to these treatments was recorded during the study, which could suggest an episode of copper phytotoxicity, as indicated by Sáenz *et al.* (2019) in citrus subjected to antifungal treatment with copper salts. In this regard, treatment 4 (SCB+BC) also showed significant effectiveness in the control of sooty mold, red algae, and greasy spot (Figure 2).

Similarly to copper compounds, this treatment (SCB+BC) was even more effective in managing some of the reported fungal diseases (sooty mold and red algae). For the control of greasy spot, the efficacy was similar to that determined for Treatment 2 (Funlate 50%: benomyl), where an approximate reduction of 80% and a final accumulated incidence of 2.67% were achieved (Table 8 and Figure 2). This is similar to what was reported by Guillén *et al.* (2018), where they determined that only 1.3% of the trees showed signs of the pathology after treating the crop with benomyl.

On the other hand, although the combined treatment based on sulfur and BC showed antifungal efficacy, the treatments of each compound separately (T3: BC; T5: CS) exhibited limited effectiveness in treating fungal diseases. This is different from what was

Table 8. Effect of the treatments on the Accumulated incidence (AI) of fungal diseases identified in the monitoring of Mexican lime trees at the beginning and end of the study.

Treatments	N	Anthracnose		Sooty mold		Algal spot		Greasy spot	
		Initial	Last	Initial	Last	Initial	Last	Initial	Last
T1 Water (absolute control)	75	17.33	14.67	17.33	17.33	14.67	14.67	13.33	12.00
T2 Funlate 50% (benomyl) control sample 1	75	16.00	2.67	24.200	5.33	14.67	2.67	14.67	2.67
T3 Bio-canela	75	10.67	2.67	17.33	1.33	24.00	2.67	10.67	4.00
T4 Sulphocalcium broth + Bio-canela	75	13.33	5.33	22.67	0.00	24.00	1.33	13.33	2.67
T5 Sulphocalcium broth	75	12.00	2.67	18.67	1.33	21.33	1.33	16.00	4.00
T6 Bordeaux broth + Bio-canela	75	13.33	0.00	21.33	0.00	22.67	0.00	14.67	4.00
T7 Bordeaux broth	75	10.67	1.33	14.67	1.33	20.00	1.33	13.33	4.00
T8 Bannen 1.8% (abamectin) control sample 2	75	12.00	10.67	16.00	16.00	16.00	14.67	12.00	12.00

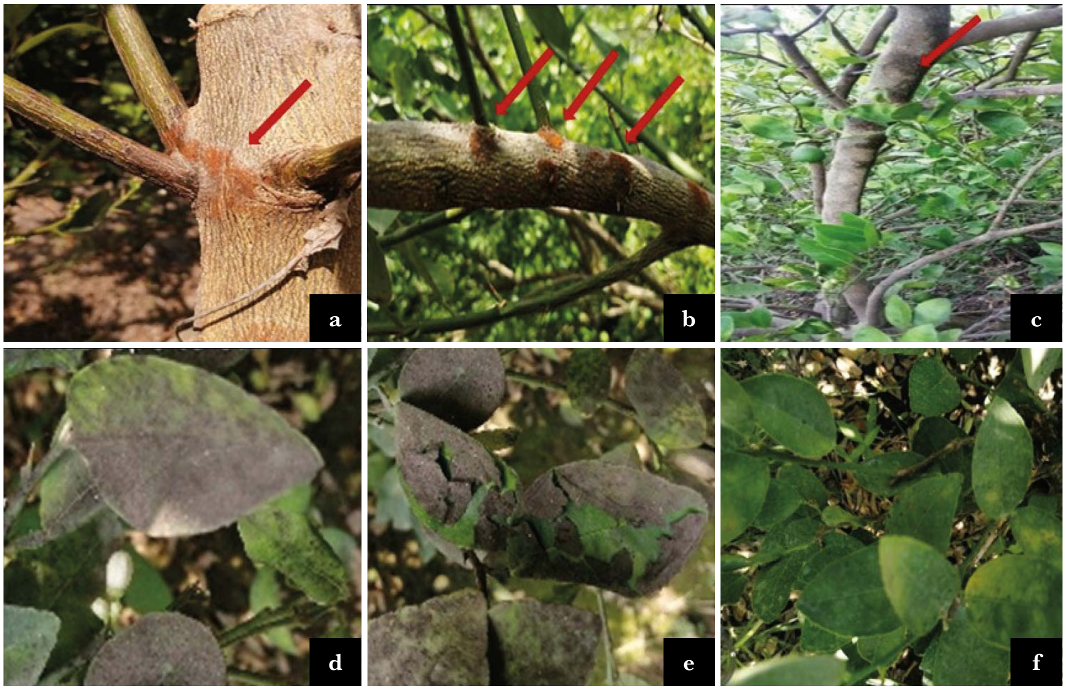

Figure 2. Monitoring of diseases in Mexican lime trees under treatment with Sulfur-Calcium Broth + Biocanela. a) Presence of red algae, initial monitoring. b) 1st count, second application, red algae. c) 3rd count, third application, dry red algae. d) Initial monitoring of diseases, presence of sooty mold. e) 1st count, second application, sooty mold beginning to dry. f) 2nd count, third application, dry and absent sooty mold on the leaf.

determined by Darmadi *et al.* (2022), who found inhibition of anthracnose using crude cinnamon leaf extract.

CONCLUSIONS

Given the overall effectiveness as a repellent, insecticide, and fungicide demonstrated by Treatment 4, the use and application of the combination of sulfur-calcium broth + Biocanela emerges as a viable agroecological alternative for the treatment and control of pests and fungal diseases in Mexican lime crops. On the other hand, the defoliation caused by the use of Bordeaux mixture, both individually and in combination, necessitates a review of dosages and application timing in citrus crops to avoid potential phytotoxicity. Similarly, the results of both chemical controls (T2: benomyl and T8: abamectin), which showed evident limitations against certain pests and fungal diseases, highlight the need for future studies related to possible resistance to these agrochemicals.

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