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Oligonychus perseae (Tetranychidae) Invasion in the Canary Islands: History, Management and Current Situation

Eduardo Torres [1], Carlos Álvarez-Acosta [1], Francisco Ferragut [2] and Estrella Marina Hernández-Suárez [1,*]

[1] Department of Plant Protection, Canarian Institute of Agricultural Research (ICIA), Ctra. El Boquerón s/n, 38270 La Laguna, Spain; torredlu@hotmail.com (E.T.); calvarez@icia.es (C.Á.-A.)
[2] Instituto Agroforestal Mediterráneo, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain; fjferrag@eaf.upv.es
* Correspondence: ehernand@icia.es

Abstract: Avocado production has boomed worldwide in recent years, and Spain, including the Canary Islands, has been no exception. The number of avocado growers in the region has increased significantly as growers recognize the potential of this crop. However, several species of spider mites (Tetranychidae) pose a risk to this crop, with the genus *Oligonychus* being the most diverse and having the greatest economic impact. In particular, *Oligonychus perseae* (Tuttle, Baker and Abbatiello) has been reported as the one mainly responsible for the economic damage in major avocado-producing regions worldwide. In this paper, we aim to present an overview of the studies conducted and the measures implemented to mitigate the impact of *O. perseae* after its arrival in the Canary Islands. Our objective is to provide a detailed description of the current status of this pest (*O. perseae*), with special attention to its situation 17 years after its first appearance in avocado crops in the Canary Islands. In doing so, we aim to provide valuable insights and knowledge to understand and manage better the challenges posed by *O. perseae* in this region.

Keywords: *Persea mite*; avocado; biological control; management

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1. Introduction

Globally, avocado (*Perseae americana*; Lauraceae) production has been on the rise. According to data from the Food and Agriculture Organization (FAO), global avocado production reached 7.4 million metric tons in 2020, a notable increase from 4.8 million metric tons in 2015 [1]. Spain, including the Canary Islands, has also experienced a significant rise in avocado cultivation in recent years, with an increasing number of farmers venturing into avocado production. According to the Ministry of Agriculture, Fisheries and Food of Spain, avocado production in the country reached 82,714 metric tons in 2020, with the Canary Islands producing 19,872 metric tons [2,3].

Avocado cultivation, like any agricultural activity, is not exempt from pest challenges. Avocado trees host numerous species of spider mites (Acari: Tetranychidae) worldwide. Twenty-nine species, belonging to the genera *Allonychus* (Pritchard and Baker), *Eotetranychus* (Oudemans), *Eutetranychus* (Banks), *Oligonychus* (Berlese), *Panonychus* (Yokoyama), and *Tetranychus* (Dufour), have been reported from different parts of the world, mainly from the Neotropical region [4].

By far the most diverse genus affecting avocados is *Oligonychus*, with 18 species, some of which are considered economically important global pests, such as *Oligonychus punicae* (Hirst) and *Oligonychus perseae* (Tuttle, Baker and Abbatiello). These are the ones responsible for most of the economic damage in major avocado-producing areas of the world [5]. The avocado brown mite, *O. punicae*, lives on the upper surface of the leaf, where it causes discoloration, browning and eventually drying of the leaves. The persea mite, *O. perseae*, is located on the underside of the leaf where the mites form dense colonies protected by dense web, under which individuals feed and reproduce. Other *Oligonychus* species have been reported affecting avocado cultivation to a greater or lesser extent, such as *O. yothersi* (McGregor) in Colombia, Argentina, Brazil, Chile, Costa Rica, Ecuador, USA and Mexico [6]; *O. cubensis* (Livschitz) in Cuba [7]; and *O. biharensis* (Hirst) in Southeast Asia (Taiwan, Thailand, Philippines) [8].

The genus *Oligonychus* was first reported on avocado trees in the Canary Islands in 1986 [9]. At that time, mite infestations were observed in some plots on the island of Tenerife, producing a diffuse discoloration on the upper side of the leaves [9]. Despite the high population density observed in some places, the economic impact was low, and no control measures were applied against these spider mites [10]. This mite was externally similar to *O. punicae*, but after many unsuccessful attempts to collect adult males, in different geographical areas and at different times of the year, the taxonomic identity of this mite remains unclear (Bastin et al., not published). In the genus *Oligonychus*, morphologically based differentiation among species always depends on the characterization of the key trait of the male aedeagus [11]. *Oligonychus mangiferus* (Rahman and Sapra) has also been reported in the Canary Islands on grapevines, pomegranates and mangos [9], although its host list also includes avocado [12]. *Oligonychus perseae* is native to arid regions of Mexico and, since the 1980s, it has spread to other cultivation areas in America, Asia, Africa and Europe [13]. In autumn 2001, the mite was found in Israel [14]; in 2004, it was detected in Málaga province (southern Spain) [15] and later in Portugal (Madeira Island) [16]. The arrival of *O. perseae* in the Canary Islands was much later, in February 2006, when it was identified on the island of Tenerife [17], although it seems that it arrived in 2005, during the transport of avocado plants from the south of the Spanish mainland to the island of La Palma [18]. Once the pest was established on the main avocado-producing islands, it spread to other islands with the crop. Indeed, it was found in Gran Canaria at the end of 2006, in La Gomera in 2007 and in El Hierro in 2008 [19]. More recently it has been found in the Portuguese region of Óbidos [20], Italy [21], Morocco [22] and the French Riviera [23].

The damage produced by *O. perseae* is the result of feeding, mating, reproduction and development of colonies, in which all developmental stages can be found [24]. These colonies are protected by dense webbing and are associated with irregular necrotic purplish spots along the midrib and main veins on the underside of leaves [25,26]. High mite densities (100 mites per leaf) can cause partial or severe defoliation. In these cases, many fruits and branches can be exposed to the sun, which severely damages them (sunburn), rendering fruits inappropriate for commercialization [27].

The arrival of *O. perseae* in the Canary Islands meant a drastic change in the management of avocado pests, since the application of phytosanitary treatments was practically non-existent at that time, due to the low level of damage caused by pests such as *Heliothrips haemorrhoidalis* (Bouché), *Protopulvinaria pyriformis* (Cockerell) and *Oligonychus* sp. While severe defoliation and economic losses occurred in the Canary Islands [28], in other affected Spanish areas, such as Malaga, defoliation was negligible and the economic impact was not so great [29]; therefore, the arrival of this species led to changes in crop management [30].

Understanding the status of a pest in a specific area provides crucial insights for competent authorities to establish effective regulations and standards. This knowledge enables them to implement preventive and control measures that aim to minimize the potential economic damage caused by the pest and prevent its spread to new territories.

Our aim with this work is to conduct a detailed review of all the studies we have carried out since the detection of *O. perseae* in the archipelago, in order to mitigate the impact and improve its integrated management. Additionally, we intend to provide a detailed description of the evolution of this pest and its current status, which can serve as a reference for other territories where it may be introduced.

2. Persea Mite Establishment, Distribution and Main Host Plants in the Canary Islands

Just three years after *O. perseae* first arrived in the Canary Islands, the mite had already infested the primary avocado-producing areas of the archipelago (Figure 1). This rapid spread between islands is notable, considering that the sea typically acts as a natural barrier and the dispersal of the pest through fruit is practically non-existent [30]. The primary factor contributing to this inter-island dispersion is believed to be the transportation of avocado plants already infested with the mite. This situation was facilitated by the favorable climatic conditions for thermophilic mites like *O. perseae* in the Canary Islands, which fall within the Macaronesian zone. This scenario closely resembles the patterns observed in other regions where *O. perseae* had previously established itself [30].

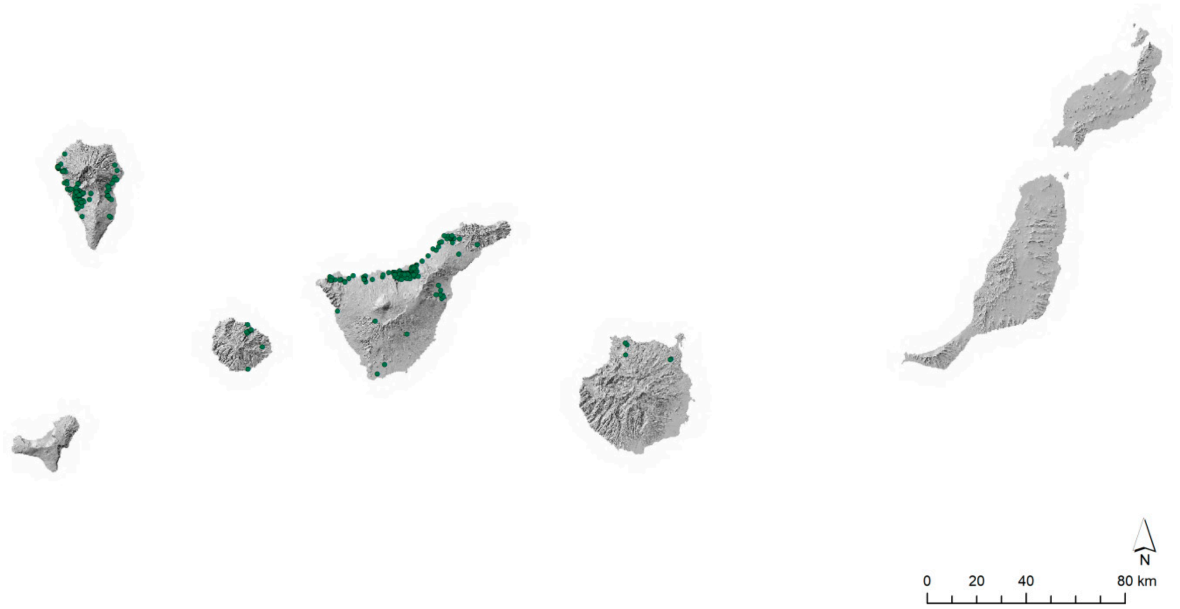

Figure 1. Distribution map of *Oligonychus perseae* in the Canary Islands (latitude: 27–29° N; longitude: 13–18° W) in 2018. Green spots indicate the presence of the pest in production areas.

During the establishment and dispersal of *O. perseae* in the Canary Islands, colonies of the mite were observed on various host plants, including *Prunus persica* (L.) Batsch, *Vitis vinifera* L., *Rosa* spp., *Passiflora edulis* Sims, and *Capsicum* spp. Additionally, it was found on weed flora such as *Ricinus communis* L., *Bidens pilosa* L., *Sonchus oleraceus* L. and *Oxalis corniculata* L. [31]. Notably, in the summer of 2022, the pest was also observed on *Castanea sativa* Mill. on the island of Tenerife. Globally, *O. perseae* has been recorded on approximately 20 different hosts across 17 botanical families [31]. Based on the criteria outlined in Regulation (EU) 2016/2031, the EFSA (European Food Safety Authority) has concluded that *O. perseae* fulfils all the requirements to be considered a potential Union quarantine pest [32].

3. Persea Mite Management Approaches and Their Limitations

Integrated pest management (IPM) promotes sustainable pest management by balancing the use of different methods and minimizing reliance on chemical control alone [33]. This approach improves crop sustainability, reduces environmental impact and optimizes the efficiency of pest management practices [34]. Key principles of IPM include regular pest monitoring, the establishment of action thresholds [35] and a holistic approach based on the implementation of preventive or suppressive measures for pest management that comprise both farm- and crop-level practices [36]. This includes, for example, the use of cultural practices, such as crop rotation, the use of physical and mechanical methods, such as trapping and exclusion, the use of biological control by means of natural enemies, and the targeted and judicious use of chemical control methods where necessary. Successful implementation of IPM requires knowledge, time and resources for planning and effective decision-making [37]. For decision-making within IPM, monitoring of pest populations plays an important role in determining the need for intervention and the appropriate timing of such measures [38,39]. Once monitoring is conducted and the damage threshold is determined, decisions regarding control strategies must be made. These strategies are classified based on priority, with the following order from highest to lowest: preventive or cultural methods, physical or mechanical methods, biological control, use of biorational products, and finally, the use of chemicals (pesticides). This approach ensures that the most environmentally friendly and sustainable control methods are applied first before resorting to chemical intervention, and this is the approach that has been followed throughout our experimentation to improve the management of this pest on the islands.

4. Monitoring of *O. perseae*

In the initial stages following the introduction of *O. perseae* in the Canary Islands, farmers resorted to applying acaricide products on their avocados without considering the actual mite population present. These applications were either done prematurely, with insufficient mite presence on the leaves, or delayed until the leaves exhibited significant damage [32]. This situation highlighted the importance of understanding the population dynamics of the pest, as well as determining the economic injury level (EIL) as represented by the percentage of maximum leaf damage (PLAD). This knowledge forms a crucial aspect of IPM, enabling informed decisions regarding pest control, as mentioned above.

Studies conducted by Torres et al. [40] revealed an increase in the *O. perseae* population at the beginning of summer, reaching peak densities of 284 $\pm$ 95.45 and 253 $\pm$ 84.08 mites per leaf in 2007 and 2008, respectively. Population numbers decreased during the summer and then rose again in autumn. Other researchers, such as Kerguelen and Hoddle [40], observed that high densities of *O. perseae* could lead to partial defoliation in avocado varieties like Hass and Gwen. They associated a density threshold of 100 mites per leaf with leaf drop. Our own investigations in Tenerife demonstrated that commercial avocado crops reached population values exceeding 100 mites per leaf, even with chemical mite control measures in place, resulting in extensive defoliation [40].

In Israel, action thresholds were established at a population density of 50–100 mites per leaf or an EIL of approximately 15% PLAD [41]. Under our conditions, Torres et al. [40] observed that infestation levels of 18,300 $\pm$ 300 (seasonal cumulative mite days per leaf) were associated with reduced tree yield. Therefore, they proposed an EIL of approximately 17% PLAD as the thresh.old not to be exceeded. This coincided with the presence of 178 mobile forms of *O. perseae* per leaf or 18 mobile *O. perseae* when counted on the beam of the second vein to the left of the midrib, also known as UML2 [26].

5. Preventive Cultural Management

Following the invasion of *O. perseae* in the Canary Islands, no evaluation trials focusing on preventive or cultural control methods were carried out, due to the difficulties encountered in using cultural control methods in other areas. For example, Takano-Lee and Hoddle [42] conducted a study in California using three different cultural control methods against *O. perseae*: (a) Tanglefoot® barriers on tree trunks, (b) canopy and leaf litter removal under the leaf zone of the tree, and (c) a combination of Tanglefoot® barriers and canopy removal; however, there were no significant differences between the treatments and the control in terms of *O. perseae* populations or leaf damage. On the other hand, to reduce the growth and development of *O. perseae*, Bragard et al. [31] suggested the use of less susceptible avocado varieties, such as Fuerte, Lamb Hass or Bacon. It is important to note that varieties such as Gwen and Hass are more susceptible to the mite attack [43]. In the Canary Islands, Hass is the predominant variety grown and the most appreciated by growers, which has hampered efforts to limit the development of the pest and its further spread between the islands by selecting varieties less susceptible to the mite [40]. For these reasons, from the beginning, it was decided to work on other pest management strategies in the archipelago.

6. Biological Control

Classical biological control trials were conducted in both California [27,44–46] and Israel [47] to address the mite infestation. In California, the trials demonstrated that the predatory phytoseiid mite *Neoseiulus californicus* (McGregor) could provide control similar to that achieved with acaricide applications. Nevertheless, it was observed that as the spider mite population declined, the population of *N. californicus* also decreased, indicating that the establishment of the spider mite in the crop was hindered. This challenge was further compounded by the presence of another phytoseiid species, *Euseius hibisci* (Chant) [27,44]. In Israel, trials were conducted in different regions where *N. californicus* was released (two consecutive releases of 2000 mites per tree). These trials demonstrated a reduction in the population of *O. perseae* compared to the control; however, the population level of the released *N. californicus* remained negligible when compared to the indigenous species *Euseius scutalis* (Athias-Henriot) [47]. Trials in both California and Israel highlight the potential of classical biological means of controlling *O. perseae* populations, although challenges such as competition with indigenous phytoseiid species need to be carefully considered when implementing this biological control strategy.

In the Canary Islands, initial sampling conducted in several commercial avocado orchards revealed a significant presence of native phytoseiid species [40]. The main species identified in this study were *Euseius stipulatus* (Athias-Henriot), *N. californicus* and *E. scutalis*. Despite the diverse range of phytoseiid species identified, the substantial reduction in phytoseiid populations observed during chemical control trials motivated us to conduct five field experiments between 2006 and 2010 using commercially available phytoseiid mites (Table 1). The predatory species employed in these experiments were *N. californicus*, *Amblyseius swirskii* (Athias-Henriot) and *Iphiseius degenerans* (Berlese). Among the three species used in the different trials, only *A. swirskii* had not been naturally found in avocado cultivation. We tested three different release rates: 500 phytoseiids per tree (exclusively with *I. degenerans*), and 1000 or 2000 phytoseiids per tree in the case of *N. californicus* and *A. swirskii* (Table 1). All trials were designed as randomized blocks comparing a control and the different phytoseiid species or doses. To monitor pests and natural enemies, ten leaves were randomly selected from each orchard tree and the density of *O. perseae* was estimated using Machlitt's method [48], while the number of phytoseiids per leaf was counted using a binocular microscope and further identified to species level.

Table 1 shows the reduction percentages observed in all these trials. Based on the results of the first two trials, which showed very low pest reductions, a third trial was designed in which the start date of the releases was delayed until late autumn, and water was applied beforehand to facilitate the entry of predatory mites into the nests. Although the percentage reduction of *O. perseae* was relatively higher than in previous trials, the phytoseiid population remained extremely low throughout the trial, with no phytoseiids observed at the end of the experiment. The reduced populations were attributed to the timing of the trial and the limited availability of undamaged leaves for *O. perseae* feeding, as described by Aponte and McMurtry [24].

A fourth experiment was designed in which two different release times were tested: "early" (early spring) and "late" (early summer). Interestingly, the early release resulted in the highest reduction of *O. perseae* (86.11%). In April 2010, a fifth trial was conducted on a crop located on the southeastern slopes of Tenerife. Two flooded releases were carried out, one month apart. Phytoseiid populations reached a maximum of 5.8 phytoseiids/leaf 56 days after the second release, coinciding with a density of 359.8 *O. perseae*/leaf.

Table 1. Biological control trials of *Oligonychus perseae* in avocado commercial orchards.

Field Trial	Coordinates Latitude (N) Longitude (W)	Phytoseiid Species Released	Maximum Percentage of Reduction of PM	Maximum Number of Phytoseiids/Leaf Observed	Phytoseiid Species Identified (%)
N° 1 (2007)	28°23′13.58″ (N) 16°32′41.53″ (W)	*N. californicus* (Koppert Biological Systems)	0.00 *	4.1	Phytoseiids were not identified
			36.61 **	7.27	
N° 2 (2007)	28°24′31.09″ (N) 16°30′43.22″ (W)	*N. californicus* (Koppert B.S.)	10.87 *	2.63	*E. stipulatus* (89.2)
			29.37 **	2.08	*E. stipulatus* (54.5)
		A. swirskii (Koppert B.S.)	0.00 *	0.83	*I. degenerans* (40)
			15.53 **	0.55	*A. swirskii* (46.4)
		A. swirskii (Syngenta Bioline)	49 **	1.25	*E. stipulatus* (55.6)
N° 3 (2008)	28°23′27.10″ (N) 16°36′1.19″ (W)	*N. californicus*	84 **	0.88	*E. stipulatus* (100)
			44.30 W **	0.93	*E. stipulatus* (90.5)
		A. swirskii	53.37 **	0.53	*E. stipulatus* (87.5)
			68.53 W **	0.65	*E. stipulatus* (93.5)
		I. degenerans	66.32 ***	0.65	*E. stipulatus* (50) *N. californicus* (50)
			39.10 W ***	0.93	*E. stipulatus* (80)
N° 4 (2009)	28°24′20.47″ (N) 16°31′20.47″ (W)	*N. californicus*	86.11 **	4.35	*E. stipulatus* (52.5) *N. californicus* (47.5)
			63.59 **	2.98	*E. stipulatus* (57.5) *N. californicus* (42.5)
N° 5 (2010)	28°18′36.50″ (N) 16°25′22.15″ (W)	*N. californicus*	51 **	5.08	*Euseius* spp. (53.3) *E. scutalis* (46.7) *N. californicus* (45) *E. stipulatus* (5.6)

PM: Persea mite. W: treatment with water at 20 bar 24 h before release. * Dose of 1000 mites/tree; ** Dose of 2000 mites/tree; *** Dose of 500 mites/tree.

When analysing the 1624 phytoseiids collected for identification in all the different field trials, we observed the prevalence of *E. stipulatus* in the trials carried out in the northern region and of *E. scutalis* in the trial carried out in the southern region of Tenerife. Conversely, *N. californicus* showed low abundances in most of the trials carried out on the northern slope, except in August and September when it reached almost 45% abundance. However, in the trial conducted on the southern slope of Tenerife, *N. californicus* maintained an abundance of 45%. Experiments in California showed that commercial predators were not established in the crop when released early [27,44]. However, late releases did lead to establishment of *N. californicus* and *Galendromus helveolus* (Chant), although they did not effectively control *O. perseae* [44]. Moreover, trials in Israel with releases of *N. californicus* showed minimal impact on *O. perseae*, and population levels of *N. californicus* were negligible compared to those of the native *E. scutalis* [47].

In order to specifically evaluate the efficacy of *N. californicus* in controlling *O. perseae*, excluding the influence of other phytoseiid species, a sixth trial was carried out under semi-field conditions at the facilities of the Canarian Institute of Agricultural Research (ICIA). The trial was designed as a randomized block design with four replications, using the avocado plant as the experimental unit, and different predator-prey ratios were tested, including 1:50, 1:20 and 1:5. To establish similar initial abundance of *O. perseae* females, artificial infestations were carried out. Weekly counts were taken to monitor the number of *O. perseae* females present on preselected leaves throughout the experiment.

Figure 2 provides a clear visualization of the population growth of *O. perseae* in the control and 1:50 treatments, indicating a noticeable pest increase 14 days after the release (T0). In the 1:20 treatment, the population increase occurs 7 days later and is comparatively less pronounced. On the other hand, *O. perseae* females in the 1:5 treatment remained remarkably stable throughout the trial, demonstrating effective control. After 21 days, the control treatment showed a higher population of *O. perseae* than in the 1:5 treatment ($F = 9.168$; $df = 3$; $p < 0.01$).

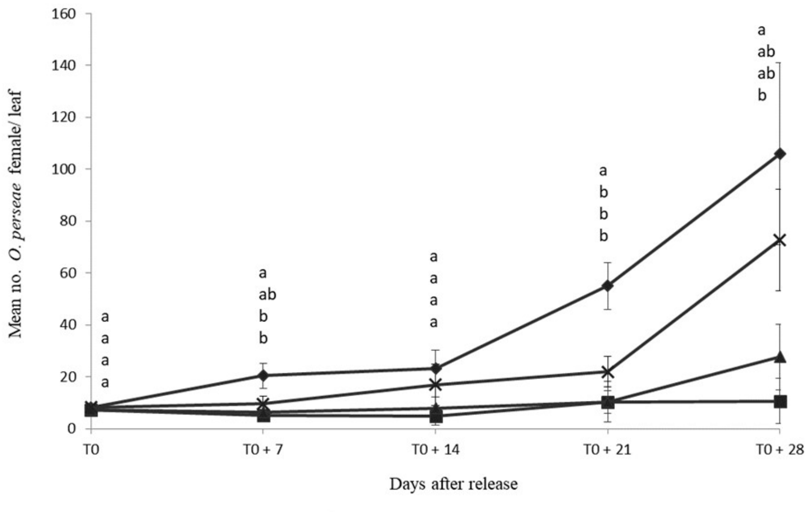

Figure 2. Evolution of the female population of *Oligonychus perseae* after different releases of *Neoseiulus californicus* under semi-field conditions. Different letters above each day after release indicate significant differences between treatments according to a Tukey HSD test ($p < 0.05$).

It is worth noting that all phytoseiids collected at the end of the trial were identified as *N. californicus*. The predator-prey ratios observed in the different trials described in Table 1 greatly exceed the 1:5 ratio, reaching ratios of 1:222 in trial 4 and 1:100 in trial 5, which shows the difficulty of achieving the 1:5 ratio under normal field conditions. Several authors [49,50] have indicated that a ratio of 1:10 is sufficient for effective control of red spider mite in various horticultural crops. Gómez Moya and Ferragut [51] observed that *N.*

californicus provided significant control of red spider mite in tomato or bean crops only at a predator-prey ratio of 1:4.

The great diversity of phytoseiid species observed in avocado orchards in the Canary Islands (Table 2), many of which were also present in the wild vegetation associated with the orchard, makes it necessary to focus on conservative biological control strategies. The aim is to increase the populations of phytoseiids of the genus *Euseius* present in the orchard, with *E. stipulatus* being the predominant species in orchards in the north of Tenerife, and *E. scutalis* in orchards in the south of the island [19,40]. Although the abundance of phytoseiids occurring in the resident wild ground cover is much lower than that observed on avocado leaves, they are very frequent, mainly from species belonging to the Urticaceae and Asteraceae families [40].

Table 2. Phytoseiid species present on avocado trees and in associated resident wild ground cover.

Phytoseiids	Avocado Trees	Resident Ground Cover
Euseius scutalis (Athias-Henriot)	Present	Present
Euseius stipulatus (Athias-Henriot)	Present	Present
Neoseiulus californicus (McGregor)	Present	Present
Typhlodromus phialatus Athias-Henriot	Present	Present
Iphiseius degenerans (Berlese)	Present	Present
Neoseiulus barkeri Hughes	Present	Present
Neoseiulella canariensis Ferragut and Peña-Estévez	Present	Present
Typhlodromus rhenanoides Athias-Henriot	Present	Present
Typhlodromina tropica (Chant)	Present	Absent
Typhlodromus pyri (Scheuten)	Present	Absent

This information is crucial for the development of a conservation strategy aimed at promoting native phytoseiid populations as an effective alternative to relying solely on releases for biological control. Pollen introduction trials have also been carried out in other countries to increase phytoseiid populations, notably *E. scutalis* in Israel, resulting in a reduction of the pest [47,52]. Similar trials have been carried out for *E. stipulatus* in avocado crops in southern Spain [53]. In both cases, the presence of pollen on avocado leaves contributed to the increase in phytoseiids and subsequent reduction of *O. perseae*. These trials involved manual application of pollen, typically by spraying maize pollen with electric atomisers. Maoz et al. [47] experimented with Rhodes grass (*Chloris gayana* Kunth), while González-Fernández et al. [54] included maize plants between rows of avocado plants. Growers in the Canary Islands are already implementing such strategies, and research is underway to select appropriate plant cover that enhances the presence and abundance of phytoseiid predators in the archipelago. This proactive approach to maintaining and improving biological control measures demonstrates a commitment to sustainable and integrated pest management practices. Continued research and collaboration between growers and researchers can help optimize these strategies and contribute to the long-term health and productivity of avocado crops in the Canary Islands.

7. Chemical Control of *Oligonychus perseae*

The primary objective of this study was to provide both conventional and organic growers with a tool to effectively reduce pest populations and mitigate indirect damage such as leaf drop and fruit sunburn. Four field trials were conducted between 2007 and 2015 to guide formulation selection (Table 3). These trials used registered acaricides, as well as other acaricides of interest for exceptional use under authorization within specific timeframes [55]. Low-toxicity products registered for use in organic crops were also included. A consistent methodology was used for all trials, with a randomly complete blocks design, with four to six replications of treatments and one plant as experimental unit. Ten leaves were collected weekly from each tree, and the density of *O. perseae* was estimated using the Machlitt method [48].

Table 3. Acaricides and lower-risk insecticides screened in field trials to keep *Oligonychus perseae* under control.

Field Trial	Coordinates Plot	Treatment		Dose	Maximum Efficacy (%)	Maximum Reduction of Phytoseiids (%)
	Latitude (N) Longitude (W)	Active Ingredient	Trade Name Manufacturer (Register N°)			
N°1 1 (2007)	28°24′25.55″ (N) 16°31′3.37″ (W)	Summer oil 83% EC	Oil Oro® [1] Químicas Oro (12,797)	1%	62	24
		Ricinus oil and Sulphur 30% SC	Melamyel and Gescen® [2] Myelosgreen	0.3% 0.20%	3	41
		Sulphur 80% SC	Sufrevit® [3] Sipcam (16,419)	0.50%	84	56
N°2 2 (2008)	28°23′27.10″ (N) 16°36′1.19″ (W)	Azadirachtin 2.6% EC	Align® [3] Sipcam (23,291)	0.15%	65	50
		Potassium soap 50% SC	Kabon® [3] Atlántica A. (4840)	0.5%	64	55
		Abamectin 1.8% EC	Vertimec® [1] Syngenta (16,784)	0.05%	4.2	10
		Sulphur 80% SC	Sufrevit® [3] Sipcam (16,419)	0.50%	53	70
N°3 3 (2010)	28°18′36.50″ (N) 16° 25′22.15″ (W)	Abamectin 1.8% EC	Vertimec® [1] Syngenta (16,784)	0.05%	99	96
		Abamectin 1.8% EC	Apache® [1] Afrasa (21,854)	0.05%	98	87
		Sulphur 80% SC	Sufrevit® [3] Sipcam (16,419)	0.50%	99	82
		Spirodiclofen 24% SC	Envidor® [1] Bayer (23,972)	0.02%	98	89

Table 3. *Cont.*

Field Trial	Coordinates Plot: Latitude (N) Longitude (W)	Treatment: Active Ingredient	Treatment: Trade Name Manufacturer (Register N°)	Dose	Maximum Efficacy (%)	Maximum Reduction of Phytoseiids (%)
N°4 4 (2015)	28°24′23.19″ (N) 16°30′58.35″ (W)	*Ascophyllum nodosum* algae extract 100% (PS)	Stimul® [3] Sipcam	0.06%	65.08	29.4
		Zinc soluble 25% (*w*/*w*) and plant adjuvants at 13%	Cinamite® [2] Biocolor	0.20%	93.10	67.8
		Cinnamomum zeylanicum and other plant extracts. 90% organic matter and Citrus oil 40% (*w*/*w*)	Cinatec® and Olitec® [3] Agrotecnologia Group	0.30% 0.20%	68.5	52.1
		Spirodiclofen 24% SC	Envidor® [1] Bayer (23,972)	0.02%	98.28	60

The percentage of efficacy was calculated using the Henderson–Tilton formula. The percentage of reduction of phytoseiids was calculated as (1-(LPT/LPC)) × 100 where PLT represents the live phytoseiids in each treatment for each sample and LPC represents the live phytoseiids in each treatment for each sample. [1] Acaricide; [2] Fertilizer; [3] Low-impact insecticide.

In 2007, it was observed that the availability of authorized acaricides for avocado cultivation was very low, with sulphur in different concentrations and formulations being the only one authorized. Among the registered sulphur products, Sufrevit® was selected because it was easy for growers to use, provided a homogeneous mixture that did not clump and allowed adequate application to the underside of the leaves. A compatible combination of oil (Melamyel) and sulphur (Gescen) and a summer oil (Oil Oro) were also tested in this first trial. In 2008, a second trial was set up which included the biorational acaricide products potassium soap (Kabon®), azadirachtin 3.2% (Align®) and abamectin 1.8% (Vertimec®). In 2010, a third trial was conducted to evaluate cost-effective alternatives for pest control, specifically spirodiclofen 24% and abamectin 1.8% (Apache®). In addition, sulphur 80% and abamectin 1.8% EC (Vertimec®) were retested to compare their efficacy. In 2015, several products were selected in a fourth trial, including *Ascophillum nodosum* (Stimul®), a Zn-based fertiliser (Cinamite®), *Cinnamomum zeylanicum* (Cinatec®) and citrus oil (Olitec®). At that time, these products were applied when the pest had reached 60% incidence in the orchard.

The results of the different trials are summarized in Table 3. The first trial showed that sulphur 80% was the most effective product tested, but also gave the highest reduction in phytoseiids. Azadirachtin and potassium soap tested in the second trial showed *O. perseae* control rates of 82% and 77% respectively, and abamectin showed an efficacy rate of 73.3%. Abamectin showed the lowest reduction in the incidence of the products on the phytoseiid population. Spirodiclofen showed the highest efficacy, with 95% efficacy at 7 days after application in the third trial. In addition, all products tested had a negative impact on the phytoseiid population, with reductions of more than 80%. Among the products, abamectin (Vertimec®) produced the most significant reduction in phytoseiid density (97%). Finally, Cinamite® achieved 93% efficacy, but products based on *A. nodosum* and the combination of *C. zeylanicum* and citrus oil showed lower efficacy. In terms of phytoseiid population, both Cinamite® and spirodiclofen produced the greatest reduction, followed by the combination of *C. zeylanicum* and citrus oil. *Ascophillum nodosum* showed the lowest percentage reduction of predatory mites. The results of these trials provide conventional and organic growers with different options for controlling *O. perseae*.

Similar results were obtained in California, where products such as Agri-Mek® (abamectin) and NR-435 oil® (mineral oil) showed effective control of *O. perseae*; however, a significant reduction in the population of natural enemies in the crop was also observed [26]. Research by Humeres and Morse [56] showed that repeated treatments with abamectin over the years slightly but significantly increased the LC50 and LC90 values for the most susceptible cultivar, suggesting early-stage resistance in the mites to this product. Hoddle and Morse [57] pointed out that, although growers have used abamectin for many years to control both avocado thrips and persea mite, there are other products (e.g., Envidor®) that display strong activity against *O. perseae* and help to prevent potential resistance in mite populations. Sulphur has also been reported as the most effective chemical control measure, resulting in a 95% reduction of persea mite [58].

Unlike the experiments carried out in California [58], applications in the Canary Islands are carried out manually by means of pressure pumps, with an application of approximately 4000 litres of liquid per hectare. The results obtained in the different trials have shown farmers that two applications per year, 15 days apart, can be very effective, always taking into account the pest density at treatment, while a greater number of applications may not give greater benefit to the farmer [28].

Recent studies have highlighted the potential of cinnamon leaf and bark extracts (*Cinnamomum* sp.) as acaricides against the two-spotted spider mite *Tetranychus urticae* (Koch), showing repellent and mortal effects on the pest. These extracts were also found to significantly reduce oviposition in female spider mites, with a minimal effect (10% reduction) on phytoseiids [59]. Similar results were obtained in their study, with a 20% reduction in *O. perseae* populations observed during the first 35 days of the experiment. On the other hand, the inclusion of Stimul was based on previous research by Holden and

Ross [60], who observed a reduction in *O. perseae* colonies in trees treated with a commercial extract of the brown seaweed *Ascophyllum nodosum*. However, under the specific conditions of their study, the *A. nodosum* extract did not produce a pest decrease.

8. Conclusions

Seventeen years after the arrival of *O. perseae* in the Canary Islands, some defoliation is still observed in plots where the mite is poorly managed. The population dynamics observed by Torres et al. [40] are variable depending on the climatic conditions, with some years seeing a single population peak occurring in mid (June) or late summer (July), and other years two peaks, the second one occurring in late autumn (October).

Achieving effective *O. perseae* control with inundative biological control was challenging, as phytoseiid populations remained low throughout all the trials. Adjustments to release timing and dose, particularly early releases, resulted in greater reductions in *O. perseae* populations. Further analysis under semi-field conditions highlighted the importance of predator-prey ratios, with a ratio of 1:5 demonstrating effective control of *O. perseae* by *N. californicus*, although this predator-prey ratio has never been observed in the field. Given the rich diversity of phytoseiid species observed in Canary Islands orchards, conservation strategies focused on promoting native populations offer a promising avenue for conservation biological control.

Field trials conducted over several years, evaluating the efficacy of various chemical and organic products and taking into account their impact on beneficial predatory mite populations, have provided growers with several products which, if used correctly, can reduce *O. perseae* populations. Sulphur is currently the most widely used product, although it has the disadvantage of spotting the fruit due to its roughness and size when used in the autumn. For pest control in autumn, just as avocado harvesting begins, transparent products such as Cinnamite® are used, and appear effective.

This study provides valuable insights into integrated pest management strategies for avocado production, offering growers a range of options to effectively manage pest populations while minimizing harm to beneficial organisms and promoting sustainable agricultural practices. These results are applicable to the Canary Islands, but also to areas where *O. persea* has newly invaded.

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