

Evaluation of Phytoseiidae mites and *Chrysoperla carnea* (Stephens) on the control of *Tetranychus urticae* in *Carica papaya* L.

Evaluación de ácaros Phytoseiidae y *Chrysoperla carnea* (Stephens) sobre el control de *Tetranychus urticae* en *Carica papaya* L.

Yuri Mercedes Mena¹, Nora Cristina Mesa^{1*}, Alexander Escobar², and Santiago Pérez³

ABSTRACT

In order to evaluate the establishment and biological effectiveness of the predators *Phytoseiulus persimilis*, *Neoseiulus californicus* and *Chrysoperla carnea* on populations of *Tetranychus urticae*, a trial was established at the farm "La Pola" (with a cumulative precipitation of 445.9 mm), located in the municipality of Roldanillo, Valle del Cauca, Colombia. An experiment was performed under field conditions between September 2017 and May 2018 and using the papaya hybrid Tainung-1 between the stages of vegetative growth and fruit filling. Four treatments were established: T1: 12 releases of *P. persimilis* and *N. californicus*; T2: 10 releases of *C. carnea*; T3: treatment with no predator releases (control); and T4: grower's practice (15 applications of pesticides) in a randomized complete block design with three replicates per treatment. Samples were collected every eight days by measuring the following variables: infestation percentage, number of fruits/plant, population of *T. urticae*, *P. persimilis*, *N. californicus*, and *C. carnea*/leaf and the diameter of the stem (every 30 d). The largest *T. urticae* populations were found in T3 and the lowest ones in T4. The populations of immature and adult *T. urticae* did not show significant differences between T1 and T2 but there were significant differences between T3 and T4. The variables diameter of the stem, number of leaves per plant, percentage of infestation, and number of fruits per plant showed significant differences between treatments. The T1 and T2 were equal to T3. T4 had the highest number of leaves and fruits per plant. The released predators did not control the populations of the mite *T. urticae* under the conditions of the present experiment.

Key words: settlement, *Neoseiulus californicus*, *Phytoseiulus persimilis*, effectiveness, Tainung-1.

RESUMEN

Con el fin de evaluar el establecimiento y la efectividad biológica de los depredadores *Phytoseiulus persimilis*, *Neoseiulus californicus* y *Chrysoperla carnea* sobre las poblaciones de *Tetranychus urticae*, se estableció un ensayo en la finca La Pola, ubicada en el municipio de Roldanillo, Valle del Cauca, Colombia. El experimento se realizó entre septiembre de 2017 a mayo de 2018 bajo condiciones de campo y con una precipitación acumulada de 445.9 mm utilizando el híbrido de papaya Tainung-1 entre la etapa de crecimiento vegetativo y llenado de frutos. Se establecieron cuatro tratamientos: T1: 12 liberaciones de *P. persimilis* y *N. californicus*; T2: 10 liberaciones de *C. carnea*; T3: testigo absoluto (control), y T4: testigo agricultor (15 aplicaciones de plaguicidas) en un diseño de bloques completos al azar con tres repeticiones por tratamiento. Se hicieron muestreos cada ocho días midiendo las variables porcentaje de infestación, número de frutos/planta, poblaciones de *T. urticae*, *P. persimilis*, *N. californicus* y *C. carnea*/hoja y diámetro del tallo (cada 30 d). Se encontraron las mayores poblaciones de *T. urticae* en el T3 y las menores para el T4. Las poblaciones de inmaduros y adultos de *T. urticae* no presentaron diferencia significativa entre los T1 y T2, pero sí con los T3 y T4. Las variables diámetro del tallo, número de hojas por planta, porcentaje de infestación y número de frutos por planta, presentaron diferencias significativas entre los tratamientos. Los T1 y T2 fueron iguales al T3. El T4 presentó el mayor número de hojas y frutos/planta. Los depredadores liberados no ejercieron un control de las poblaciones del ácaro *T. urticae* bajo las condiciones del presente trabajo experimental.

Palabras clave: establecimiento, *Neoseiulus californicus*, *Phytoseiulus persimilis*, efectividad, Tainung-1.

Introduction

The mite *Tetranychus urticae* Koch is one of the most limiting arthropods for papaya cultivation in various producing regions of the world, including the province of

Valle del Cauca in Colombia (Santa-Cecilia and Reis, 1986; Vieira *et al.*, 2004; Moraes and Flechtmann, 2008; Gómez *et al.*, 2014; Migeon and Dorkeld, 2006-2017). *Tetranychus urticae* feeds on a wide range of host plants (1140 plant species) that comprise diverse families (Migeon and Dorkeld,

Received for publication: 2 July, 2018. Accepted for publication: 2 March, 2020

Doi: 10.15446/agron.colomb.v38n1.73271

¹ Universidad Nacional de Colombia sede Palmira, Valle del Cauca (Colombia).

² Bichopolis-BioBee, Tabio, Cundinamarca (Colombia).

³ Frutas Tropicales S en C, La Union, Valle del Cauca (Colombia).

* Corresponding author: ncmesac@unal.edu.co



2006-2017). It frequently begins colonization of host plants on the mature leaves, and as its populations increase, it invades the younger leaves (Marín *et al.*, 1995; Seeman and Beard, 2011; Vásquez *et al.*, 2012). The mite develops its colonies on the underside of leaves and has a CW type of life (complex and complicated spider web production) according to the classification of Saito (2010). Their web provides shelter and protection for the immature stages against predator attacks, toxic substances, and adverse climatic conditions (Moraes and Flechtmann, 2008; Badii *et al.*, 2010). Two-spotted spider mites feed more commonly on older papaya leaves, which initially turn yellow on the upper sides and silver on the lower sides, followed by the appearance of necrotic areas and eventually leaf drop (Collier *et al.*, 2007). This damage, predominating in the dry season, directly influences photosynthesis and increases exposure to the sun, with negative consequences for fruit production and marketability. For this reason, pesticide applications in papaya orchards occur year-round, with the well-known risks to the environment and human health (Marín *et al.*, 1995).

Biological control of *T. urticae* has proven to be successful in different crops, and the predator mite *Neoseiulus californicus* (McGregor) is one of the major biological control agents of *T. urticae* in rose (*Rosa* spp.) crops in greenhouses of several countries (Marafeli *et al.*, 2011). In Colombia, the use of predators of the genera *Phytoseilus* spp. and *Amblyseius* spp. has been reported as an effective control of the mite *T. urticae* in roses (Valcárcel-Calderón, 2013) as well as the effective use of the entomopathogenic fungus *Isaria fumosorosea* Wize (Castro, 2010). For this same species of Tetranychidae, the releases of phytoseids *Phytoseiulus persimilis* Athias-Henriot and *N. californicus* were very effective in nursery conditions for clementine (*Citrus clementina* Hort. ex Tan.) orchards in Spain (Sá, 2012). Alternative products based on the neem *Azadirachta indica* (Juss) have also successfully exercised control of *T. urticae* populations in strawberry plants (Soto *et al.*, 2011). However, insecticides and acaricides have always played the central role in controlling this species of mite in different crops such as the papaya in Valle del Cauca (Gómez *et al.*, 2014).

Currently, a large number of compounds with different chemical structures and application modes is used (Knowles, 1997; Dekeyser, 2005; Van Leeuwen *et al.*, 2009). However, *T. urticae* has a high capacity for rapidly developing resistance to chemical products (Knowles, 1997; Van Leeuwen *et al.*, 2008). Its high reproductive potential, inbreeding, the condition of producing haploid males and

its short life cycle resulting in many generations per year, facilitate the rapid development of resistance to many acaricides after a limited number of applications (Nauen *et al.*, 2000; Van Leeuwen *et al.*, 2010). Among all the arthropods, *T. urticae* has the highest prevalence of resistance to pesticides (Van Leeuwen *et al.*, 2010; Grbić *et al.*, 2011). This very rapid resistance to new and commercially available chemical products affects integrated management programs (Cho *et al.*, 1995). Additionally, the excessive use of these chemicals has increased the health risks of farmers and consumers, in addition to the negative impact on the environment (Morera, 2015).

Some of the most effective biological controllers for the control of *T. urticae* are Phytoseiidae mites such as *P. persimilis* and *N. californicus* (Cloyd *et al.*, 2006; Rhodes *et al.*, 2006). Both species possess important attributes such as a shorter development cycle than that of *T. urticae*, a rapid development of populations, and high search capacity and voracity, among other details (Acosta, 2000; Gómez *et al.*, 2014). McMurtry *et al.* (2013) classify *P. persimilis* as a specialized predator of mite species of the genus *Tetranychus* (Type: Ia), and they classify *N. californicus* as a selective predator of mites of the family Tetranychidae (Type: II), which might be used in programs of integrated pest management.

Some studies have been conducted with Phytoseiidae mites in papaya but under controlled conditions. Collier *et al.* (2004) report *Neoseiulus idaeus* Denmark & Muma, 1973 in Brazil as a good candidate for biological control of *T. urticae*, based on laboratory results due to its high occurrence in papaya production systems with intensive use of acaricides, together with its favorable biological characteristics reported in the literature. López (2014) found that the predatory mites *N. californicus* and *Amblyseius swirskii* Athias-Henriot, 1962 are viable for the control of *T. merganser* in papaya cultivation under greenhouse conditions in Brazil.

Chrysoperla carnea (Neuroptera: Chrysopidae) is indicated as an important natural enemy of soft-bodied phytophagous arthropods, such as red spiders, in part because of its high voracity as well as its polyphagous nature (Pappas *et al.*, 2011). It is a species with wide geographical distribution, tolerance to insecticides such as abamectins, and ease of breeding in the laboratory, which allows its mass production in different laboratories of Valle del Cauca (Nasreen *et al.*, 2005; Cerna *et al.*, 2012). Hassanpour *et al.* (2009) recommend including *C. carnea* in red spider management programs due to its good predatory potential.

Predatory mites of the family Phytoseiidae and predatory insects such as *C. carnea* are widely included in biological control programs in various crops, due to their ability to survive, reproduce and tolerate some chemical compounds (Cloyd *et al.*, 2006). But a control exercised by these predators has not been evaluated on *T. urticae* in crops of *C. papaya* in Colombia. The hybrid Tainung-1 is the most cultivated material in the province with yield losses caused by *T. urticae*, considered to be the most limiting pest for the cultivation of papaya in this region of the country (Gómez *et al.*, 2014). That is the basis for this research, aimed at evaluating the control exercised by *P. persimilis*, *N. californicus* and *C. carnea* on populations of *T. urticae* in papaya Tainung-1 in Valle del Cauca, under field conditions.

Materials and methods

Obtaining *P. persimilis* and *N. californicus*

Individuals of *P. persimilis* and *N. californicus* used for field trials were obtained from the commercial company Bichopolis-BioBee® SAS., located in the municipality of Tabio, Cundinamarca. The mites were packed and sent in 60 ml plastic bottles whose lid had a dispenser. Each bottle contained 1,000 predatory mites mixed with vermiculite. Shipments from Tabio were made by land following the route Tabio-Cali-Roldanillo (to the farm “La Pola”) with an average time of 48 to 72 h from packing to release. The bottles contained the two species of Phytoseiidae, *P. persimilis* and *N. californicus*, in a 600:400 ratio, respectively, for each bottle.

Obtaining *C. carnea*

The individuals of *C. carnea* were obtained from the commercial company Perkins Ltda., located in the city of Palmira. Each package contained 100 eggs of *C. carnea* mixed with rice husk and *Sitotroga cerealella* eggs (Olivier) (Lepidoptera: Gelechiidae). These sealed packages were transported in a cooler with ice at the bottom, one day before the hatching of the eggs, from Palmira to the farm “La Pola” (municipality of Roldanillo).

The experiment under field conditions

The study was carried out between September 2017 and May 2018 under field conditions, at the farm “La Pola” (04°40' N and 76°10' W, at an altitude of 910 m a.s.l.). Climatic conditions during the releases were as follows: temperature 23.1°C (maximum: 25°C, minimum 20.3°C), relative humidity 81.3% (maximum: 95%, minimum 73%), and a cumulative rainfall of 445.9 mm with a maximum peak of 72.2 mm at 9 weeks after transplanting (WAT).

A randomized complete block design was used, with four treatments and three replicates per treatment. The experimental unit consisted of 16 plants of hybrid papaya Tainung-1, aged between the sixth and 36th week after transplanting, between the phenological stages of vegetative growth and fruit filling. A total of 192 plants were used for the experiment with a distance between plants of 1.5 m and a distance between rows of 3.5 m. Four treatments were established as described in Table 1.

The predatory mites were released on the leaves of the middle part of the 16 plants in each plot during the morning hours with a mean temperature of 23.1°C and relative humidity of 81.3%. Before opening the bottle, the cap was strongly tapped, since most of the mites were concentrated here, and the bottle was rotated in a horizontal position to allow an adequate mixture of the predatory mites in the vermiculite. The amount and time of release of the Phytoseiidae mites is listed in Table 1, following the recommendations of the producing company and its experience in the release of these Phytoseiidae under controlled conditions. Each bag of *C. carnea* was hung from each of the 16 plants of the three experimental plots. The release dates of the lacewings are listed in Table 1. The appearance of the first focus of *T. urticae* on the crop was used as the criterion for the release of predators.

TABLE 1. Description of the treatments for evaluating the control of predators on the populations of *Tetranychus urticae* in papaya Tainung-1.

Treatment 1	Release of <i>P. persimilis</i> and <i>N. californicus</i> . Twelve periodic releases were accomplished from 6 WAT*. Initial releases (20 mites/plant) at 6, 7, 9, 10, 11, 12 and 13 WAT. Flooding releases (1,000 mites/plant) at 15, 16 and 17 WAT. Semi-flooding releases (500 mites/plant) at 19 and 20 WAT.
Treatment 2	Release of <i>C. carnea</i> . Ten periodic releases of 100 larvae/plant were accomplished 6, 10, 11, 13, 14, 16, 17, 19, 20 and 22 WAT.
Treatment 3	Untreated treatment (control). Control of <i>T. urticae</i> was not carried out throughout the development of the crop.
Treatment 4	Grower's practice, mite management as is conventionally performed in a commercial crop where approximately 15 applications of chemical synthesis acaricides in rotation (abamectin, spiromesifen, cyflumetofen, fenazaquin, hexithiazox, acequinocyl, milbectin, bifentazate) are applied. This treatment was isolated from the other treatments by a green cloth used as an enclosure at 5 m of height.

*WAT: Weeks after transplanting.

The infestation of *T. urticae* in the experimental lot was natural for all treatments. However, this was increased early on by the presence of a nearby melon (*Cucumis melo* L.) crop, which was found infested with the mite, resulting in the experimental lot (mainly block I) being infested. An initial population mean of 7 adults, 39 immatures and

61 eggs per leaf was found for all treatments evaluated by direct counting on papaya leaves. In order to guarantee the highest percentage of hermaphrodite plants in the experimental lot, two plants were planted per site. Once the flowering took place, thinning was performed leaving a single plant, preferably the hermaphrodite plant. The phenological states presented by the culture of papaya are vegetative development (0-11 WAT), beginning of flowering (12 WAT), first fruiting (16 WAT) and reproductive period (more than 30 WAT). Treatments were begun on the sixth week after the transplanting.

Throughout the development of the crop all necessary agronomic work was carried out: irrigation, weed control, disease and insect vectors of diseases, as well as the necessary fertilizations. Plants that had obvious symptoms of virus were removed, but this practice did not affect the experimental design.

For an evaluation of populations of *T. urticae* before and after the release of predators as well as the populations of *P. persimilis*, *N. californicus* and *C. carnea*, four plants were randomly tagged in each lot with a weekly monitoring of the incidence of mite damage on the plant (number of leaves with damage/number of total leaves per plant). Leaves considered to be damaged were those that showed obvious chlorosis and food marks. Damage was determined in the inspected leaves using a scale of damage proposed by Tomkiewicz *et al.* (1993) (Tab. 2), registering the percentage of the foliar area affected.

TABLE 2. Chart of evaluation of *Tetranychus urticae*'s damage (Tomkiewicz *et al.*, 1993). Reproduced with permission of Experimental and Applied Acarology.

Rate of foliage damage	Definition	% affected foliage area
0	No damage on the leaf	0
1	Feeding marks in the base of the leaf or in the area near the ribbing.	5
2	Base of the leaf and area close to the ribbing affected.	15
3	Base of the leaf and area along the main ribbings with feeding marks.	30
4	Feeding marks that cover all the leaf, although the leaf still looks green.	60
5	Leaves are yellow and are beginning to wither.	80-100

From each lot, a leaf from the middle part of the plant was collected randomly, and then taken to the Acarology Laboratory of Universidad Nacional de Colombia, Palmira. The populations of each species (eggs, immature and adult stages) were counted with the help of a stereoscope Leica

EZ4 8X-35X zoom (Leica Microsystems, Switzerland). Eggs were recognized by their yellowish color and spherical shape, finding them along the leaf veins or above or between the cobwebs. The number of fruits and stem diameters were recorded monthly in order to detect the impact of phytophagous mite populations on crop production. All plants were brought to the first month of harvest and the crop yield was evaluated. Meteorological data were obtained from the RMA ZAR station: Zarzal of Cenicafía.

Data analysis was performed using the SAS 9.3 statistical package (SAS Institute, 2014). Data were subjected to an analysis of variance (ANOVA) and mean separation by least significant difference (LSD) at 5% significance.

Results and discussion

Evaluation of populations of *T. urticae* and predators

The populations of *T. urticae* appeared from the fourth week after transplanting (WAT). The presence of a crop of melon (*C. melo*) at harvest stage located next to the experiment was possibly a focus of the mite pest, increasing the population quickly mainly in block one, for all treatments. The largest populations of *T. urticae* occurred from the sixth week and increased at the beginning of flowering, reaching the highest peaks between 9 and 20 WAT in all treatments. Populations in T1 and T2 had maximum peaks of 2,699 and 1,862 eggs/leaf respectively. In T3, the populations were very high and reached peaks of 5,482 eggs/leaf. In the T4, the highest peak population was 407 eggs/leaf. When the 19th WAT was reached, the pest mite populations decreased considerably to the point of registering zero mites/leaf in all treatments. The development of *T. urticae* populations (eggs, immatures, and adults) in each of the treatments is shown in Figure 1.

In contrast, very few individuals of *P. persimilis* were found in T1 and T2, with population peaks of 50 and 40 individuals/leaf at 14 and 18 WAT respectively. Once the releases of the Phytoseiidae were finished (19 WAT), the populations practically disappeared. The presence of *P. persimilis* in T2 can be explained by air currents and the proximity of these treatments in the experiment, especially T1. No individuals of the species *N. californicus* were recovered in any treatment during all evaluations. Something similar occurred with *C. carnea* whose populations were very low, only a few individuals were found in T2 (4 eggs/leaf).

Regarding eggs, immatures and adult stages, the untreated T3 showed the largest populations of *T. urticae* in contrast to the grower's practice T4 that showed the lowest

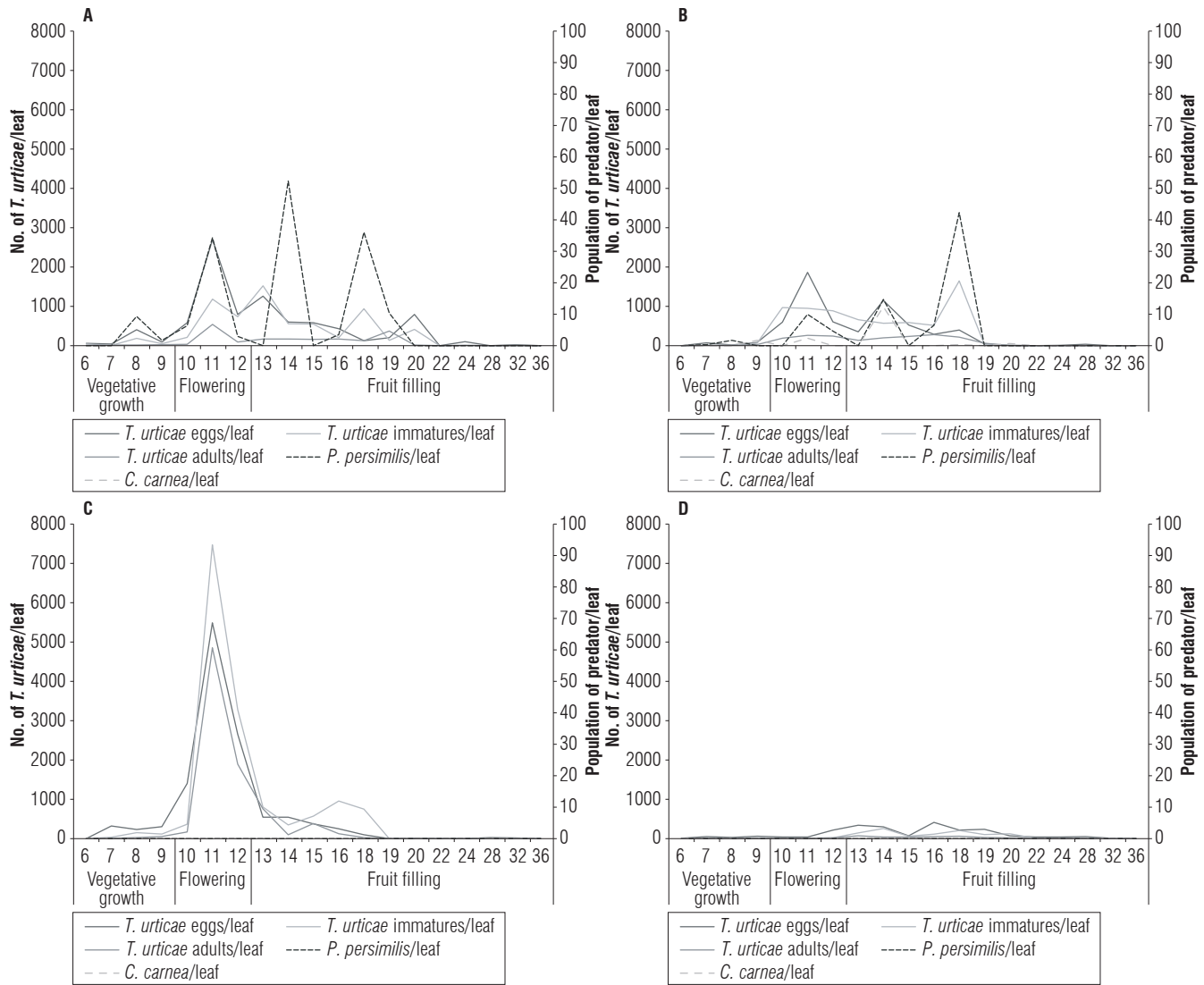


FIGURE 1. Development of the populations of *Tetranychus urticae* and predators in the different treatments A) T1: *Phytoseiulus persimilis* and *Neoseiulus californicus*, B) T2: *Chrysoperla carnea*, C) T3: Untreated (control) and D) T4: Grower's practice.

population levels. Eggs of *T. urticae* per leaf in treatments T1, T2 and T3 showed a significant difference in T4. The immature and adult populations of *T. urticae* showed no significant difference between T1 and T2 but between T3 and T4 (Fig. 2).

For the establishment of Phytoseiidae mites and *C. carnea*, phytoseiids disperse by walking or flying within a crop (Johnson and Croft, 1976; Hoy *et al.*, 1985; Jung and Croft, 2000). *Phytoseiulus persimilis* has the longest legs and moves faster than other species, so they move from leaf to leaf, from plant to plant, and can walk a few meters on the ground. These characteristics allow them to ensure a uniform distribution over the plant and adjacent plants, despite the difficulties of flooding releases of phytoseiids on all leaves where the prey is present (Hoy, 2011).

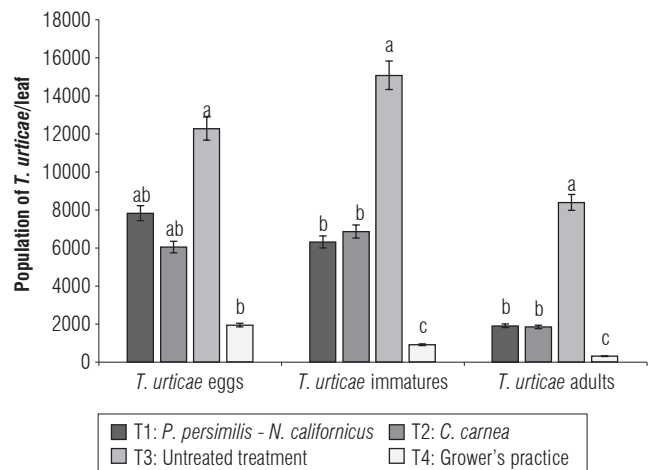


FIGURE 2. Comparison of the population of *Tetranychus urticae* (eggs, immatures, and adults) in different treatments. Vertical bars indicate the standard error.

This was not the situation observed in our experiment. In spite of the flooding releases of *P. persimilis*, *N. californicus* and *C. carnea*, no establishment of these natural regulators in *C. papaya* was accomplished and, therefore, no control effect on *T. urticae* was observed. Some factors, such as the low initial releases of the predators and the high infestation of *T. urticae* could have influenced these results. The releases were initiated from plants with an average of nine leaves in which the populations of *T. urticae* were on average 48 individuals per leaf (between eggs, immatures, and adults). Releases were initiated at a dose of 20 mites/plant/week approximately at 12 WAT. During this period the maximum number of *T. urticae* populations was 4,418 individuals per leaf, whereas the maximum number of individuals that *P. persimilis* showed at that time was 34 individuals between eggs and mobile stages per leaf.

Hoy (2011) indicates that augmented releases of phytoseiids should be performed early when the pest population is low, since these releases usually involve only adult females, which take time to move to adjacent leaves or plants in search of their prey after the releases. Reyes (2012) recommends the use of this predator with flooding releases in papaya for the control of *Tetranychus merganser* under laboratory conditions, since *P. persimilis* is not settled when showing a low hatching (5.14 eggs per female) when feeding on this Tetranychidae.

Another aspect that can affect the behavior of Phytoseiidae is the long storage period of predatory mites and *C. carnea* between the packaging and the releases. The Phytoseiidae were raised in the municipality of Tabio, Cundinamarca and sent by land courier service to the place of the experiment. The storage period was between 48 to 72 h before being released.

When opening the bottle containing the Phytoseiidae, most were located in the lid of the dispenser. This agrees with Daza *et al.* (2010), who finds that the effectiveness of

P. persimilis is diminished by the effect of the trip since it affects the quality and survival of the individuals. Mesa and Duque (1994) indicate the convenience of acclimatizing Phytoseiidae before releases by confining them in cages for a time, as pre-adaptation in the field. In our research, releases were performed directly from the jar with vermiculite to the papaya plants after the long transport.

It is important to consider the architecture of the papaya plant, whose leaves have long petioles, the leaves are distant from each other, and often have drops of latex. It is possible that some of these factors may have disturbed the behavior of the predators. According to Konno *et al.* (2004), the latex produced by the leaves of *C. papaya* presents a protease, papain that confers defense against the attack of herbivores, such as polyphagous insects, reducing their rate of growth on that host. *Tetranychus urticae*, has in its genome some detoxifying genes from bacteria, fungi and plants that it uses to combat the defense mechanisms of the plants it feeds on (Grbić *et al.*, 2011). These could prevent that this papain had a negative effect on this Tetranychidae, but they could have some effect on *P. persimilis*.

Also, the crop has a leaf blade with a smooth bundle and the underside has protuberant ridges (Arango and Roman 2000), which might prevent the shelter of predators. However, Collier *et al.* (2007) indicates that *T. urticae* reared on papaya or green bean is a suitable prey for the development and reproduction of the predatory mite *Neoseiulus idaeus* under laboratory conditions. This proves that under these conditions the host plant of *T. urticae* does not affect the predator, guaranteeing the success of *N. idaeus* as a biological control agent of *T. urticae* in papaya orchards.

Although there have been very few studies on *N. idaeus* in papaya crops, it may have the potential to regulate populations of two-spot spider mites in this crop, compared to other Phytoseiidae species. *Neoseiulus idaeus* is a type II specialized predator that shows substantial adaptations and

TABLE 3. Variables evaluated to measure the control exerted by predators for the different treatments.

Treatments	Infestation (%±SEM)	Number of leaves±SEM	Stem diameter (cm±SEM)	Number of fruits*±SEM	Average fruit weight (kg±SEM)*
T1: <i>P. persimilis</i>	78.3±1.3 b ¹	32.9±0.3 ab	21.2±0.7 b	2.7±0.8 b	1.1±0.2 b
T2: <i>C. carnea</i>	80.1±1.2 b	31.7±0.3 b	21.1±0.7 b	2.6±0.4 b	1.1±0.1 b
T3: Untreated treatment (control)	84.3±1.1 a	30.9±0.3 b	22.3±0.8 b	3.2±0.7 b	0.9±0.2 b
T4: Grower's practice	61.5±1.1 c	39.9±0.3 a	24.5±0.1a	6.4±0.8 a	1.5±0.1 a

¹Means followed by equal letters do not differ from each other according to the Tukey's test ($P < 0.05$).

SEM: Standard error of the mean.

*Data collected in the first month of harvest.

preference for spider mites. The presence and abundance of *N. idaeus* throughout the year in commercial orchards with constant acaricide applications indicates that it can develop resistance to pesticides, and this gives more support to its use as a control agent in papaya (Collier *et al.*, 2004).

The period in which the experiment took place coincided with the period of strong winds during the year in the municipality of Roldanillo between October and February with average wind speeds of more than 4.6 km/h (Cedar, 2018). Strong wind could carry predators to other plants different from the ones in which the releases were performed. These winds probably contributed to the rapid dispersion of *T. urticae* in the experimental plot since this arthropod has aerial-dispersal behaviors that facilitate its escape from the leaf-surface boundary layer and enable it to become airborne. In addition, as wind speed increases, the dispersion response increases (Smitley and Kennedy, 1985).

In relation to the variables stem diameter, number of leaves per plant, percentage of infestation and number, and the weight of fruits per plant, the analysis of variance showed significant differences between treatments (Tab. 3). Mean values were the same for T1, T2 and T3, showing a reduction in the number of leaves/plant and in the number of fruits/plant and a higher percentage of infestation. In the first month of harvest, the T1 and T2 treatments yielded 58.4% less fruits than the grower's practice, and even though in the T3 a smaller reduction was recorded (50%), the weight of fruits was lower, which is directly related to a lower yield. The grower's practice showed the highest values in the number of leaves per plant and the number and weight per fruit, and the lowest percentage of infestation.

The number of leaves is a clear indicator of productivity of papaya, considering that at least one fruit is formed in the bud of each leaf (Storey 1969; Mahouachi *et al.*, 2005). Similarly, the leaves synthesize the carbohydrates that are to be distributed among the different organs of the plant, which allows greater fruit production (Cuéllar and Arieta, 2010). Thus, a direct relation between the number of leaves and the number of fruits exists, and a decrease in the yield of the crop is observed due to the mites that cause defoliation.

Establishing experiments under real field conditions is important, since the crops grown by the producer entail facing multiple natural factors and problems that cannot be controlled and that do not affect the populations of the pest mite. Therefore, under the conditions of our research

the flood releases of predators *P. persimilis* and *N. californicus*, and *C. carnea* were not found to exert control of the *T. urticae* mite populations. It is possible that some abiotic or biotic factors described above did not allow them to settle down in the papaya crop since the populations of *T. urticae* in this crop were so high between weeks 6 and 19 after the transplantation that the number of predators released was not enough or these controllers were not released in a timely enough manner. In addition, perhaps some experimental errors could have been made.

Acknowledgments

The authors would like to thank the Acarology Research Group of Universidad Nacional de Colombia, Palmira campus. They would also like to thank the Information System of Research, the Extension and HERMES Laboratories, the Doctorate Scholarship Program of Colciencias and Norbey Marín.

Literature cited

- Acosta, A. 2000. Escrito sobre lo que seguramente usted ya ha oído de los famosos ácaros *Tetranychus spp.* Conocimientos generales y manejo integrado de *Tetranychus spp.* (Acariformes: Tetranychidae) en cultivos de flores. Facultad de Agronomía, Universidad Nacional de Colombia, Bogotá.
- Arango, L. and C. Roman. 2000. Aspectos agroeconómicos. pp. 8-12. In: Arango L.V. (ed.). El cultivo de la papaya en los Llanos Orientales de Colombia. Manual de asistencia técnica no. 4. CORPOICA, ASOHOFRUCOL and SENA, Villavicencio, Colombia.
- Badii, M.H., J. Landeros, and E. Cerna. 2010. Regulación poblacional de ácaros plaga de impacto agrícola (population regulation of pest mites of agricultural significance). *Daena J.* 5(1), 270-302.
- Castro, J. 2010. Evaluación del control biológico que ejerce la simbiosis del hongo *Paecilomyces fumosus* junto con el organismo quitinolítico aislado de cascarilla de camarón, sobre el ácaro *T. urticae* en cultivo de rosa bajo invernadero. Undergraduate thesis, Escuela Politécnica del Ejército, Sangolquí, Ecuador.
- Cedar. 2018. El clima promedio en Roldanillo. Viento. URL: <https://es.weatherspark.com/y/21524/Clima-promedio-en-Roldanillo-Colombia-durante-todo-el-a%C3%B1o> (accessed 20 May 2017).
- Cerna, A., S. Landeros, S. Sánchez, M. Badii, L. Aguirre, and Y. Ochoa. 2012. Comparación de la toxicidad y selectividad de insecticidas para la plaga *Bactericera cockerelli* y su depredador *Chrysoperla carnea*. *Agrociencia* 46, 783-793.
- Cho, K., C. Eckel, J. Walgenbach, and G. Kennedy. 1995. Spatial distribution and sampling procedures for *Frankliniella spp.* (Thysanoptera: Thripidae) in staked tomato. *J. Econ. Entomol.* 88(6), 1658-1665. Doi: 10.1093/jee/88.6.1658
- Cloyd, R., C. Galle, and S. Keith. 2006. Compatibility of three miticides with the predatory mites *Neoseiulus californicus* McGregor and *Phytoseiulus persimilis* Athias- Henriot

- (Acari: Phytoseiidae). HortSci. 41, 707-710. Doi: 10.21273/HORTSCI.41.3.707
- Collier, K., J. de Lima, and G. Albuquerque. 2004. Predaceous mites in papaya (*Carica papaya* L.) orchards: in search of a biological control agent of phytophagous mite pests. Neotrop. Entomol. 33(6), 799-803. Doi: 10.1590/S1519-566X2004000600020
- Collier, K., G. Albuquerque, J. de Lima, A. Pallini, and A. Molina-Rugama. 2007. *Neoseiulus idaeus* (Acari: Phytoseiidae) as a potential biocontrol agent of the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae) in papaya: performance on different prey stage-host plant combinations. Exp. Appl. Acarol. 41(1-2), 27-36. Doi: 10.1007/s10493-006-9041-2
- Cuéllar, N. and H. Arrieta. 2010. Evaluación de respuestas fisiológicas de la planta arbórea *Hibiscus rosasinensis* L. (Cayeno) en condiciones de campo y vivero. Corpoica Cienc. Tecnol. Agropec. 11, 61-72. Doi: 10.21930/rcta.vol11_num1_art:196
- Daza, M., H. Bustos, F. Cantor, D. Rodríguez, and J. Cure. 2010. Criterios para la producción de *Phytoseiulus persimilis* (Parasitiformes: Phytoseiidae) bajo condiciones de invernadero. Acta Biol. Colomb. 15(1), 37-46.
- Dekeyser, M. 2005. Acaricide mode of action. Pest Manage. Sci. 61,103-110. Doi: 10.1002/ps.994
- Gómez, E.D., N.C. Mesa, Y.M. Mena, C.A. Huertas, K. Imbachi, and J.A. Salazar. 2014. Programa de manejo fitosanitario en papaya en el Valle del Cauca. Universidad Nacional de Colombia, Palmira, Colombia.
- Grbić, M., T. Van Leeuwen, R.M. Clark, S. Rombauts, P. Rouze, and V. Grbić. 2011. The genome of *Tetranychus urticae* reveals herbivorous pest adaptations. Nature 479, 487-492. Doi: 10.1038/nature10640
- Hassanpour, M., G. Nouri-Ganbalani, J. Mohaghegh, and A. Enkegaard. 2009. Functional response of different larval instars of the green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae), to the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). J. Food. Agric. Environ. 7, 424-428.
- Hoy, M., R. Groot, and H. Van De Baan. 1985. Influence of aerial dispersal on persistence and spread of pesticide and spread of pesticide resistant *Metaseiulus occidentalis* in California almond orchards. Exp. Appl. Acarol. 37, 17-31. Doi: 10.1111/j.1570-7458.1985.tb03448.x
- Hoy, M. 2011. Agricultural acarology: introduction to integrated mite management. CRC Press, Boca Raton, USA.
- Johnson, D. and B. Croft. 1976. Laboratory study of the dispersal behavior of *Amblyseius fallacis* (Acarina: Phytoseiidae). Ann. Entomol. Soc. Am. 69, 1019-1023. Doi: 10.1093/aesa/69.6.1019
- Jung, C. and B. Croft. 2000. Survival and plant-prey finding by *Neoseiulus fallacis* (Acari: Phytoseiidae) on soil substrates after aerial dispersal. Exp. Appl. Acarol. 24, 579-596. Doi: 10.1023/A:1026593907917
- Knowles, C. 1997. Mechanisms of resistance to acaricides. pp. 57-77. In: Sjut, V. (ed.). Chemistry of plant protection. Molecular mechanisms of resistance to agrochemicals. Doi: 10.1007/978-3-662-03458-3_3
- Konno, K., C. Hirayama, M. Nakamura, K. Tateishi, Y. Tamura, M. Hattori, and K. Kohno. 2004. Papain protects papaya trees from herbivorous insects: role of cysteine proteases in latex. Plant J. 37(3), 370-378. Doi: 10.1046/j.1365-313X.2003.01968.x
- López, E. 2014. Incidencia de daño y estrategias de control de *Tetranychus merganser* en el cultivo de papaya (*Carica papaya* L.). MSc thesis, Colegio de Postgraduados, Veracruz, Mexico.
- Mahouachi, J., A. Pio, R. Socorro, C. Regalado, and P. Rodríguez. 2005. Respuestas de la papaya (*Carica papaya* L.) frente al estrés hídrico: crecimiento vegetativo y contenido de elementos minerales. Actas Portuguesas de Horticultura 6, 193-199.
- Marafeli, P., P. Reis, E. da Silveira, M. de Toledo, and G. Souza-Pimentel. 2011. *Neoseiulus californicus* (McGregor, 1954) preying in different life stages of *Tetranychus urticae* Koch, 1836 (Acari: Phytoseiidae, Tetranychidae). Acarologia 51(4), 499-506. Doi: 10.1051/acarologia/20112031
- Marín, S., J. Gomes, J. Salgado, D. Martins, and E. Fulin. 1995. Recomendações para a cultura do mamoeiro dos grupos Solo e Formosa no estado do Espírito Santo. Circ. Téc. 4(3), 1-57.
- McMurtry, J., G. De Moraes, and N. Sourassou. 2013. Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Syst. Appl. Acarol. 18(4), 297-320. Doi: 10.11158/saa.18.4.1
- Mesa, N. and M. Duque. 1994. Liberación y establecimiento de tres especies de ácaros Phytoseiidae para el control de ácaros Tetranychidae en un cultivo de yuca. Rev. Col. Entomol. 20(3), 169-177.
- Migeon, A. and F. Dorkeld. 2006-2017. Spider Mites Web: a comprehensive database for the Tetranychidae. URL: <http://www.montpellier.inra.fr/CBGP/spmweb> (accessed 10 May 2017).
- Moraes, G. and C. Flechtmann. 2008. Manual de ácarologia. Ácarologia. Básica e ácaros de plantas cultivadas no Brasil. Holos Editora, Riberão Preto, Brazil.
- Morera, I. 2015. Identificación de principios activos de plaguicidas en frutas, hortalizas y granos básicos en Costa Rica: Una propuesta para la implementación de nuevas metodologías de análisis. Revista Pensamiento Actual 15(25), 155-171.
- Nasreen, A., G. Mustafa, and M. Ashfaq. 2005. Mortality of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) after exposure to some insecticides; laboratory studies. S. Pac. Stud. 26(1), 1-6.
- Nauen, R., N. Stumpf, and A. Elbert. 2000. Efficacy of BAJ 2740, a new acaricidal tetronic acid derivative, against tetranychid spider mite species resistant to conventional acaricides. pp. 453-458. Proceedings of the BCPC Conference: Pests and diseases. 2000, November 13-16, Brighton, UK. Farnham, British Crop Protection Council.
- Pappas, M., G. Broufas, and D. Koveos. 2011. Chrysopid predator and their role in biological control. J. Entomol. 8(3), 301-326. Doi: 10.3923/je.2011.301.326
- Reyes, N. 2012. Implementación del control biológico de *Tetranychus merganser* Boudreaux, ácaro plaga del papayo en Veracruz, México. PhD thesis, Colegio de Postgraduados, Veracruz, Mexico.
- Rhodes, E., O. Liburd, C. Kelts, S. Rondon, and R. Francis. 2006. Comparison of single and combination treatments of *Phytoseiulus persimilis*, *Neoseiulus californicus* and Acramite (bifenazate) for control of twospotted spider mites in

- strawberries. *Exp. Appl. Acarol.* 39(3-4), 213-225. Doi: 10.1007/s10493-006-9005-6
- Sá, P. 2012. Gestión integrada de la araña roja *Tetranychus urticae* Koch (Acari: Tetranychidae): optimización de su control biológico en clementinos. PhD thesis, Universitat Politècnica de València, Valencia, Spain. Doi: 10.4995/Thesis/10251/17804
- Saito, Y. 2010. Plant mites and sociality: Diversity and evolution. Springer-Verlag, Tokyo. Doi: 10.1007/978-4-431-99456-5
- Santa-Cecília, L. and P. Reis. 1986. Pragas do mamoeiro. *Inf. Agropec.* 12, 49-52.
- SAS Institute. 2014. SAS/STAT version 9.3. SAS Institute, Cary, USA.
- Seeman, O. and J. Beard. 2011. Identification of exotic pest and Australian native and naturalised species of *Tetranychus* (Acari: Tetranychidae). *Zootaxa* (2961), 1-72. Doi: 10.11646/zootaxa.2961.1.1
- Smitley, D. and G. Kennedy. 1985. Photo-oriented aerial-dispersal behavior of *Tetranychus urticae* (Acari: Tetranychidae) enhances escape from the leaf surface. *Ann. Entomol. Soc. Am.* 78(5), 609-614. Doi: 10.1093/aesa/78.5.609
- Soto, A., H. Oliveira, and A. Pallini. 2011. Integración de control biológico y de productos alternativos contra *Tetranychus urticae* (Acari: Tetranychidae). *Revista U.D.C.A.* 15(1), 23-29.
- Storey, W. 1969. Pistillate papaya flower: a morphological anomaly. *Science* 163, 401-405. Doi: 10.1126/science.163.3865.401
- Tomkiewicz, J., H. Skovgård, G. Nachman, and M. Münster-Swendsen. 1993. A rapid and non-destructive method to assess leaf injury caused by the cassava green mite, *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae). *Exp. Appl. Acarol.* 17(1-2), 29-40.
- Valcárcel-Calderón, F. 2013. El control biológico de plagas en la floricultura colombiana. pp. 233-240. In: Rueda-Ramírez, D. and E. Torrado-León (eds.). *Memorias Congreso Colombiano de Entomología*. 2013, July 10-12, Bogota. Bogota, Sociedad Colombiana de Entomología.
- Van Leeuwen, T., B. Vanholme, S. Van Pottelberge, P. Van Nieuwenhuysse, R. Nauen, L. Tirry, and I. Denholm. 2008. Mitochondrial heteroplasmy and the evolution of insecticide resistance: non-Mendelian inheritance in action. *Proc. Natl. Acad. Sci.* 105, 5980-5985. Doi: 10.1073/pnas.0802224105
- Van Leeuwen, T., J. Vohtas, A. Tsagkarakou, and L. Tirry. 2009. Mechanisms of acaricide resistance in two spotted spider mite *Tetranychus urticae*. pp. 343-393. In: Ishaaya, I. and A. Horowitz (eds.). *Biorational Control of Arthropod Pests* Springer, Dordrecht, The Netherlands. Doi: 10.1007/978-90-481-2316-2_14
- Van Leeuwen, T., J. Vohtas, A. Tsagkarakou, W. Dermauw, and L. Tirry. 2010. Acaricide resistance mechanisms in the two-spotted spider mite *Tetranychus urticae* and other important acari: a review. *Insect Biochem. Molec. Biol.* 40(8), 563-572. Doi: 10.1016/j.ibmb.2010.05.008
- Vásquez, C., F. Da Silva, J. Morales, and M. Sandoval. 2012. Biological studies and pest management of Phytophagous mites in South America. pp. 354-376. In: Larramendy, M.L. and S. Soloneski (eds.). *Integrated pest management and pest control - current and future tactics*. InTech, Rijeka, Croatia. Doi: 10.5772/30250
- Vieira, M., L. Correa, T. Castro, L. Silva, and M. Monteverde. 2004. Efeito do cultivo do mamoeiro (*Carica papaya* L.) em ambiente protegido sobre a ocorrência de ácaros fitófagos e moscas-brancas. *Rev. Bras. Fruticultura* 26(3), 441-445. Doi: 10.1590/S0100-29452004000300017