Article

Spatial distribution and fluctuating populations of predatory mites (Mesostigmata: Phytoseiidae), phytophagous mites (Acari: Eriophyidae, Tetranychidae) and their relationships with wild chili pepper phenological stages in two Natural Protected Areas of Mexico

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Abstract

Ecological interactions between mites (predatory and phytophagous) and wild plants growing in undisturbed environments play a crucial role to understand their natural settlement, development and dispersion patterns. Pequin chili pepper, *Capsicum annuum* L. var. *glabriusculum*, is a low-cost natural resource for local communities living inside Natural Protected Areas (ANP) of Tamaulipas State in Mexico. The aims of this research work were: 1) determine the spatial distribution pattern of predatory and phytophagous mites, 2) determine the spatiotemporal association between predatory and phytophagous mites, and 3) determine the association among different mite species and some phenological stages of Pequin chili pepper. The most abundant phytophagous mites were *Tetranychus merganser* and *Aculops lycpoersici*, and the predatory species were *Amblyseius similoides*, *Euseius mesembrinus* and *Metaseiulus* (*Metaseiulus*) *negundinis*. Most mite species showed an aggregated distribution pattern according to the plant phenological stages. However, the distribution of mite species throughout time showed different types of aggregation. On the other hand, we found positive associations among *A. lycopersici* and *T. merganser* phytophagous mites with *A. similoides*, *E. mesembrinus* and *M.* (*M.*) *negundinis* predators mites. The association between plants and mite species were influenced by the phenological stages of Pequin chili pepper. This is an indication of the complexity among trophic-chain interactions that depend largely on the available resources and competition. These two factors serve as foundations for settlement, development and dispersion patterns of certain species.

Key words: *Euseius mesembrinus*, *Metaseiulus* (*Metaseiulus*) *negundinis*, *Amblyseius similoides*, *Aculpos lycopersici*, *Tetranychus merganser*, *Capsicum annuum* var, *glabriusculum*

Introduction

Pequin chili pepper *Capsicum annuum* var. *glabriusculum* (Dunal) Heiser & Pickersgill, is a wild species, currently growing from Colombia to USA's Southeast region. In Mexico, this species grows from Yucatan Peninsula to Tamaulipas in deep soils covered by dense vegetation of perennial leaves, as well as in xeric regions of Sonora Desert and the Central Plateau, which in turn is associated to nurse trees (Tewksbury *et al.* 1999). Local people collect and sell the ripe and unripe fruits as

cooking condiments (Hernández-Verdugo *et al*. 2008; González-Jara *et al*. 2011; Kraft *et al*. 2013; Hayano-Kanashiro *et al*. 2016; Monjarás-Barrera 2020).

In Tamaulipas, Mexico, Pequin chili pepper species are established naturally under different types of vegetation, including scrubland (high, submontane and riparian scrublands), oak forests and low deciduous forests located inside Natural Protected Areas (NPA), like "El Cielo" Biosphere Reserve and "Altas Cumbres" (Lara-Villalón 2009; Monjarás-Barrera 2020). Natural Protected Areas within the Mexican Transition Zone (MTZ) in Tamaulipas state have abundant fauna and rich flora diversity, with a high number of endemic species (Morrone 2005; Herrera-Izaguirre *et al*. 2014). Few research works have studied the mites living in these Natural Protected Areas (Monjarás-Barrera *et al*. 2020). These authors only reported about the richness and diversity of mite species living on Pequin chili pepper.

The majority of Mesostigmata and Prostigmata mites and in particular mites living on the leaves' surface, feed and reproduce on them (Moraes & Flechtmann 2008; Saito 2010). Plants shelter a large diversity of mites with different feeding habits, such as predators and phytophagous (Krantz & Walter 2009; Fathipour & Maleknia 2016; Araújo *et al*. 2018). These different feeding habits are determinant to several ecological interactions affecting the way in which mites interact with their host plants. For instance, phytophagous mites are closely associated to plants because they feed on their fluids; while predatory mites feed on preys, pollen, fungal spores and plant exudates, using the plant structures in search for shelter and mating, without causing any harm (McMurtry *et al*. 2013; Fathipour & Maleknia 2016; Araújo *et al*. 2018).

Phytoseiidae is the most important family among Mesostigamata and their preservation is crucial to a successful integrated pest management approach in agriculture (Gerson *et al*. 2003; Hoy 2011). The importance of knowing the distribution patterns of these species in a given habitat is essential for us to understand the structures and dynamics of their populations and communities (Liu *et al*. 2018). Spatial distribution or aggregation among predatory mites and their prey usually occur in a given habitat during a certain time. Aggregation can be easily affected by factors like the interaction between prey and predator, life-style and abundance in the number of predators, territoriality, mobility, dispersion, mate's search, fertility, oviposition, development, quality and quantity of plants or prey; as well as changes in plant height (Strong *et al*. 1997; Slone & Croft 1998; Walzer *et al*. 2009; McMurtry *et al*. 2013). We did not find any reference in literature to research works studying the relationship between plant phenological stages and the abundance and spatial distribution of predatory and phytophagous mites in Natural Protected Areas, or in other type of habitats. Monjarás-Barrera *et al*. (2019) reported about the diversity of mites living on Pequin chili pepper plants, but they did not informed about the relationship between the abundance of several mite species (predator-prey ratio) and the different plant phenological stages.

Knowledge on the spatial patterns under natural conditions provides essential information leading to understand the basic behavior of certain species (Davis 1994; Taylor 2019). This research work arises from the hypothesis that abundance and distribution patterns of predatory and phytophagous mites relate to different phenological stages of Pequin chili pepper, such as leaf production, flowering, fructification and maturation. The aims of this research work were: 1) determine the spatial distribution of phytophagous and predatory mites from Phytoseiidae family 2) determine the spatiotemporal association among predatory and phytophagous mites and 3) determine the association among different mite species and some phenological stages of Pequin chili pepper.

Materials and Methods

Study areas

Two experimental sites inside "Altas Cumbres" Natural Protected Area (ANP-AC) and another experimental site at "El Cielo" Biosphere Reserve (RBC) were established. "Altas Cumbres" NPA experimental sites were established at "Altas Cumbres" (AC) (23°41'52" N, 99°11'04" W) and at "Cañón de la Peregrina" (CP) (23°46'41" N, 99 ° 12'12" W). "El Cielo" (RBC) experimental site was established at "Ojo de Agua" (OA) (23 ° 01'7" N, 99 ° 08'54 "W). The experimental sites at AC and CP are surrounded by mountains with many different terrains, slopes (415 msnm) and canyons (365 msnm), respectively. These two sites have submontane scrubland vegetation with arboreal strata of 5-m tall trees. The experimental site at OA has low-forest sub-deciduous vegetation (175 m.s.n.m.), combining a mixture of deciduous and perennial species with average height of 25 m (Monjarás-Barrera *et al*. 2019).

Experimental design

The research work at AC and CP was conducted at maximum and minimum temperatures of 33.54 ± 3.24 ° C and 18.83 ± 3.87 ° C, respectively; while at OA the maximum and minimum temperatures were 31.04 ± 2.65 ° C, 20.54 ± 2.58 ° C (CONAGUA 2019). We used two sampling systems to collect the leaves of *C. annuum* var. *glabriusculum*. A 100-m long linear transect was used at AC and OA sites; while at CP the transect had a "W" shape, because San Marcos stream crosses the site and it was impossible to mark a linear transect (Bautista *et al*. 2011). The transect width was 10 m in both systems, which provided a larger range for collecting Pequin chili pepper leaves.

The population density at *C. annuum* var. *glabriusculum* plant leaves growing under natural conditions was low, since local people cut the vegetative parts or the whole plant when picking the Pequin chili pepper fruits, leading to a reduction in the number of leaves (Villalón-Mendoza *et al*. 2016; Ramírez-Novoa *et al*. 2018). We conducted 21 randomized samplings at 14-day intervals from February to November 2017, collecting 50 leaves from 22±1 (average ± SD) plants per site in each sampling. We collected 1050 leaves per site, recording the phenological stages of Pequin chili pepper during that time.

The collected samples were sealed in "Ziploc" bags inside a cooler, 2 ± 2 °C before taking them to the Laboratory of Population's Ecology at *Universidad Autónoma de Tamaulipas*□Institute of Applied Ecology. All mites were counted directly on the leaves using a digital counter and a stereoscopic microscope. The specimens were identified using the taxonomic keys Denmark & Evans (2011), Lee *et al*. (2011) and Baker & Tuttle (1994).

Spatial distribution pattern

We determined the spatial distribution of predatory and phytophagous mites at leaf scale in three stages: 1) by collection date 2) by Pequin chili pepper plant phenological stage, and 3) by 21 collection dates. We used Morisita index in the first stage, along with Z's adjusted goodness of fit test. In the second stage, we used the variance-to-mean ratio, the index of dispersion (I_D), and Morisita Index (I_M). In the third stage, we used the same indexes of stage two, plus Taylor's power law and Iwao□s regression to measure the aggregation patterns.

Morisita's aggregation Index I_M (Morisita 1962):

$$I_M = q \frac{\sum_{i=1}^{q} x(x-1)}{T(T-1)}$$

Where x, is the number of individuals in the *ith* sample unit, q is the number of sample units and $T = \sum_{i=1}^{q} x_i$. The distribution is aggregated if $I_M > 1$; uniform (regular) if $I_M < 1$ and random if $I_M = 1$. In order to determine if the population's sample is significantly different to the random pattern, we conducted the following test (Davis 1994; Hutcheson & Lyons 1989):

$$Z = (I_M - 1)/(2/nm^2)^{1/2}$$

Where m is the average of the population's sample and n is the number of sample units. The distribution is random, uniform (regular) or aggregated if $1.96 \geq Z \geq -1.96$; or $Z < -1.96$; or if $Z > 1.96$, respectively.

Index of dispersion (I_D)

The distribution spatial in the 21 samplings was determined by the index of dispersion (I_D). Dispersion in a population can be classified by the calculation of the variance-to-mean ratio, $s^2/m = 1$ random, < 1 uniform and >1 aggregated. The result of a random distribution can be tested by calculating the index of dispersion (I_D), when "n" is the number of samples:

$$I_D = [(n-1)s^2]/m$$

I_D is distributed approximately in χ^2 with n-1 degrees of freedom. Coefficient Z was used to test the values of I_D:

$$Z = (2I_D)^{1/2} - (2v-1)^{1/2}$$

Where $v = n-1$. If $1.96 \geq Z \geq -1.96$, showing that the mites spatial distribution is randomized; however if $Z < -1.96$, or $Z > 1.96$ the distribution is uniform or aggregated respectively (Southwood 1978; Davis 1994).

Iwao's patchiness regression

We used Iwao's method to quantify the relation between the mean overcrowding index (m*) and the mean (m) (Iwao 1968).

$$m^* = m + (s^2/m) - 1$$
$$m^* = \alpha + \beta m$$

Where α indicates the attraction (positive) and the repellence "competition" (negative) among organisms respectively, and β reflects the population's distribution in space. If $\beta = 1$, <1 and >1, the distribution is random, uniform and aggregated, respectively (Iwao 1968). We used "t Student" test to determine if the colony was formed by one individual ($\alpha = 0$) and if the colonies were dispersed at random $\beta = 1$.

$$t = (\alpha - 0)/s_\alpha$$

and

$$t = (\beta - 1)/s_\beta$$

Where s_α is the standard error of the intersection for the mean crowding regression and s_β is the standard error of the mean crowding regression slope. The calculated values are compared to *t* values tabulated with n-2 degrees of freedom and a probability level of 0.05 (Davis 1994). If t calculated value (t_c) > t-table (t=1.729; df=19; α=0.05) the nule hypothesis will be rejected $\beta = 1$ and there would be an aggregated distribution; however, if $t_c \leq t_t$ the distribution will be uniform or random, if $\beta < 1$ or $\beta = 1$.

Taylor's power law

Taylor's power law describes that the variance (s^2) relates to the mean (m) by a simple power law. The variance is proportional to a mean's fraction

$$s^2 = am^b$$

or,

$$\log(s^2) = \log(a) + b\log(m)$$

Where a is a scale factor related to the sample size, and b measures the species' aggregation (Taylor 1961), and it is measured like β from Iwao's patchiness regression. Just like we did with the mean crowding coefficient β, we used "t test" to detect random deviations, when b differs significantly from 1 (b=1).

Interspecific association

In this analysis, we used the most frequent mite species per leaf. The association among mite species was determined in two steps (Dice 1945). First, we used Chi-square test (χ^2) to determine if the species were associated. To this end, we arranged the data in a 2×2 contingency table. We used the table to record the number of leaves with both species (a); the number of leaves with only one species and vice versa (b, c) an the leaves with none of the two species present (d).

In second place, we used Dice (I_D) (Dice 1945), Ochiai (I_O) (1957) and Jaccard (I_J) (1908) Indexes to measure the degree of association between two species. Janson & Vegelius (1981) assessed 20 indexes using six criteria (symmetry, homogeneity, independence of *d*, minimum=0⇔ $a = 0$, maximum=1⇔ $b = c = 0$ and E-coefficient) and they recommended these three indexes (see Janson & Vegelius 1981):

$$I_D = 2a/(2a+b+c)$$
$$I_O = 2a/[(a+b)^{1/2}(a+c)^{1/2}]$$
$$I_J = a/(a+b+c)$$

Where a, b and c are described as before. The indexes range between 0 and 1; where 0 means that the two species were never found together and 1 means that both species were always found together.

In order to prevent any bias at Chi-square test (χ^2) the number of leaves without any mite species (d) was replaced by the total number of leaves where at least one or two species were present; since it is necessary that the two compared species were in fact closely associated within the same sample unit (Dice 1945). Furthermore, the number of samples where no species was found (d) is not essential to calculate the degree of association with indexes I_D, I_O, and I_J, and therefore this parameter is independent to hereinabove mentioned indexes (Janson & Vegelius 1981).

Association between mite species and Pequin chili pepper phenological stages

We used Chi-square test (χ^2) to learn about the association between two nominal variables: mite species and pequin chili pepper phenological stages. Mite species with less than five individuals in at least two phenological stages of Pequin chili pepper were not considered in this analysis, in order to avoid species that were not frequently present or with rare occurrence. Therefore, we arranged the data in 4×4 contingency tables for AC site; 4×4 tables for CP site and 4×3 tables for OA site.

We used the standardized residuals (r_i) to determine the positive or negative association among mite species and plant phenological stages.

$$r_i = (O_{ij} - E_{ij}) / [E_{ij}(1 - p_{i+})(1 - p_{+j})]^{1/2}$$

Where O_{ij} is the observed frequency, E_{ij} is the expected frequency, p_{i+} is the marginal proportion between the total of row *i* and the grand total; and p_{i+} is the marginal proportion between total of column *j* and the grand total (Agresti 2007). Values lower than -2 indicated that there were more expected than observed frequencies, apart from a negative association between species. Values greater than 2 indicated that the observed frequency was greater than the expected frequency and that means a positive association (Agresti 2007; Fowler *et al*. 2009). The standardized residuals were represented by a correlation chart, using *corrplot* package from R-project (R Core Team 2018). This chart has two colors. The blue color means positive association and the red color means negative association. Colors ranging from pale to dark indicate a mild or a strong association.

Results

According to data obtained from sampling sites "Altas Cumbres" (AC), "Cañón de la Peregrina" (CP) and "Ojo de Agua" (OA), we found four phenological stages of Pequin chili pepper plants growing in their natural environment. These phenological stages were identified as vegetative development (leaf production), flowering, fructification and maturation. The stages lasted from February to November (Fig. 1). Leaf production started on February 03 and lasted until September 01, approximately 180 days. Flowering began on July 07 and ended on September 29 (85 days). Fructification lasted from August 04 until November 10 (99 days) and lastly fruit ripening began on August 18 and ended on November 10 (85 days). Like any other deciduous plants, Pequin chili pepper plant loses its leaves in December and January.

This research work is focusing on Phytoseiidae species (predators), Tetranychidae and Eriophydae (phytophagous) found on Pequin chili pepper leaves. Predators (Mesostigmata: Phytoseiidae) in AC site were *Proprioseiopsis reventus*, *Phytoseius mexicanus*, *Metaseiulus* (*Metaseiulus*) *negundinis*, *Amblyseius coffeae*, *Euseius* sp. and *Euseius mesembrinus*. For CP site, the predators were *Amblyseius similoides*, *Typhlodromalus aripo*, *Galendromus* (*Galendromus*) *annectens*, *M.* (*M.*) *negundinis*, *E. mesembrinus*, *Phytoseius paludis*, and in OA site there was only one predator, *A. similoides*. However, the phytophagous *Tetranychus merganser* (Prostigmata: Tetranychidae) and *Aculops lycopersici* (Trombidiformes: Eriophyidae) were present in all the sites.

Population's abundance

In the 21 samplings conducted at every site, some Phytoseiidae species were not found in every sample and their abundance was almost null; therefore, their occurrence was rare at "Altas Cumbres" (AC) and "Cañón de la Peregrina" (CP). At AC, we found one individual of *P. reventus* (April 28), five individuals of *P. mexicanus* between May 12 and June 07 (five dates), one individual of *A. coffeae* on February 17, June 07 and August 18, one individual of *Euseius* sp. on April 28 and May 12 and lastly, nine individuals of *E. mesembrinus* were found (two on April 28, one on May 12, two on June 09, one on June 23, one on August 4 and two on August 18). At CP, we observed one individual of *T. aripo* (June 09); two individuals from *G. (G.) annectens* (one on March 31 and the other May 26), one individual of *M. (M.) negundinis* on February 03, April 28, May 12 and lastly, we found one individual of *P. paludis* on May 12 and on November 10.

Figure 1 shows the fluctuation curves of the phytoseiid and phytophagous populations that were found at least in four collection dates during the ten months that this research work lasted. At AC, *A. lycopersici* was more abundant (4,843 individuals), followed by *T. merganser* (564 individuals) and *M. (M.) negundinis*, (160 individuals). The eriophyde *A. lycopersici* reached its highest population density during the overlapping between leaf production and flowering of Pequin chili pepper, on July 07. *T. merganser* reached peak density at leaf production, on March 03, with 110 individuals. *M. (M.) negundinis* reached peak density when the plants were at the fructification and maturation stages, on November 10, with 25 individuals. Furthermore, *M. (M.) negundinis* and *A. lycopersici* species showed cyclical dynamics that are typical in a predator-prey system, since *A. lycopersici* populations varied in terms of abundance, with some temporary delays similar to the population variations of *M. (M.) negundinis* (Figure 1A).

At CP site, *A. lycopersici* was the most abundant species (4650 individuals), followed by *T. merganser* (234 individuals), and lastly by the predators *A. similoides* (45 individuals) and *E. mesembrinus* (11 individuals). *Aculops lycopersici* reached its highest population density (1679 individuals) when the plants were developing new leaves and at flowering, on July 07; while *T. merganser* reached peak density at leave production stage on February 17, with 31 individuals, and at stage of fructification and maturation on October 13, with 32 individuals. *Amblyseius similoides*

was most abundant at flowering stage, on August 04, with 9 individuals; at fructification and maturation on November 10 with 8 individuals, and *E. mesembrinus* was most abundant at leaf production stage (May 26 with 5 individuals). On the other hand, *A. similoides* and *A. lycopersici* showed typical predator-prey behavior, since the abundance of *A. lycopersici* populations varied with some temporary delay, followed by variations in the populations of *A. similoides* (Figure 1B).
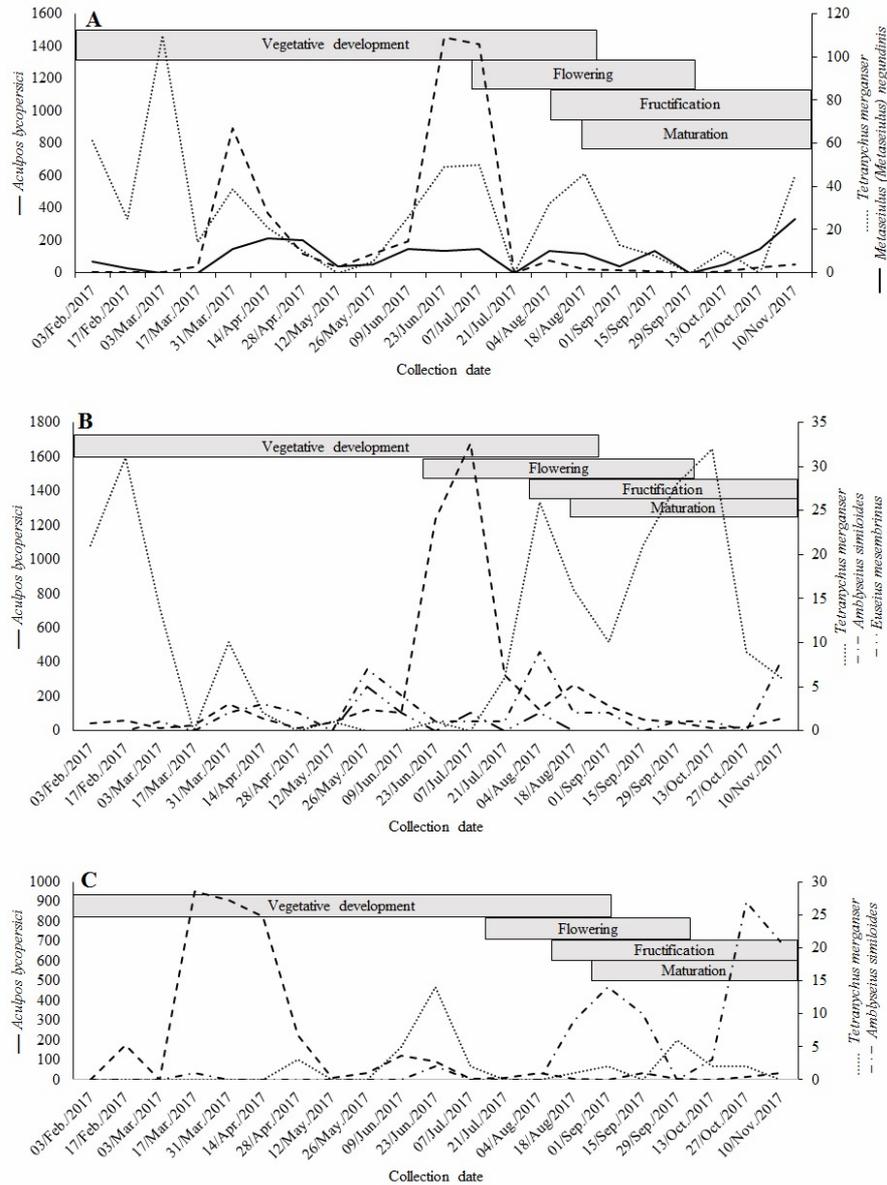
FIGURE 1. Fluctuation of predatory and phytophagous mites' populations and phenological stages of *Capsicum annuum* var. *glabriusculum* in A) Altas Cumbres B) Cañón de la Peregrina and C) Ojo de Agua, Tamaulipas, Mexico.

In OA site, *A. lycopercisi* was the most abundant species (3486 individuals), followed by *A. similoides*, (87 individuals) and *T. merganser* (37 individuals). *Aculops lycopersici,* reached the highest level of abundance at leaf production stage on March 17, with 951 individuals, while *T. merganser* reached peak abundance at leaf production stage on June 23 with 14 individuals. *A.*

similoides was most abundant at the fructification and maturation stages of Pequin chili pepper. Furthermore, the interaction of *A. similoides-A. lycopersici* and *A. similoides-T. merganser* did not show similar behaviors to the predator-prey system (Figure 1C).

Spatial distribution by sampling date

With Morisita Index (I_M) we were not able to obtain the pattern of distribution of some predatory mites, probably due to their low presence and low abundance in most samplings (Table 1). At AC site, not all mite species had the same spatial distribution. By using I_M the predatory mite, *M. (M.) negundinis* presented a regular distribution ($I_M < 1$) in almost all the sampling dates, with the exception of 5 dates, in which it showed aggregated distribution ($I_M > 1$). However, Z coefficient determined that in all the dates, this predatory mite had a random distribution ($1.96 \geq Z \geq -1.96$), with the exception of November 10, when there was an aggregated distribution ($Z > 1.96$), coinciding with I_M. The I_M and Z tests resulted in different types of distribution for *E. mesembrinus*. With I_M, the mite's distribution had a regular pattern ($I_M < 1$), while Z test determined that this mite was randomly distributed ($1.96 \geq Z \geq -1.96$). Regarding phytophagous mites' *A. lycopersici* and *T. merganser* showed aggregated distribution ($I_M > 1$ and $Z > 1.96$) in all the sampling dates, with the exception of February 03 and September 15, respectively (Table 1).

At CP site, the eriophyde *A. lycopersici* showed an aggregated distribution pattern in all the sampling dates ($I_M > 1$ and $Z > 1.96$), except on March 03, when the distribution was at random ($1.96 \geq Z \geq -1.96$); while *T. merganser* presented aggregated distribution in most sampling dates; with some exceptions, in which the pattern was at random. The predatory mite *A. similoides*, showed a randomized distribution pattern in most sampling dates ($I_M < 1$ and $1.96 \geq Z \geq -1.96$), but it was aggregated in some dates ($I_M > 1$ and $Z > 1.96$) and, *E. mesembrinus* was randomly distributed in all the dates in which this species was observed (Table 1).

At OA site, the predatory mite *A. similoides* was distributed at random ($1.96 \geq Z \geq -1.96$) (on the dates in which this species was observed, but the distribution was aggregated in one date ($I_M > 1$ and $Z > 1.96$). Meanwhile, phytophagous mites, *A. lycopersici* and *T. merganser* had aggregated distribution patterns ($I_M > 1$ and $Z > 1.96$) in most dates, but in two dates they had random distribution (Table 1). There were discrepancies between and Z adjusted goodness of fit test, because in those dates, we found only one individual of those mite species.

Spatial distribution of mite species by Pequin chili *pepper phenological stages*

In the three sampling sites (AC, CP and OA), almost all predatory and phytophagous mite species had aggregated distribution patterns in Pequin chili pepper phenological stages. At AC site, the I_M and I_D tests determined that the predatory mite *M. (M.) negundinis* had an aggregated pattern ($Z > 1.96$) at leaf production, flowering, fructification and maturation stages of Pequin chili pepper plant. Predatory mite *E. mesembrinus* presented different distribution patterns. At leaf production, flowering, and fructification stages, this mite had a random pattern ($1.96 \geq Z \geq -1.96$) and it showed an aggregated pattern at the maturation stage. Phytophagous mites had an aggregated pattern in the four phenological stages of *C. annuum* var. *glabriusculum* (Table 2). At CP site, the predatory mite *M. (M.) negundinis* showed an aggregated pattern in four phenological stages of Pequin chili pepper, while *E. mesembrinus* had an aggregated pattern ($Z > 1.96$) at leaf production and fructification, and it had a random pattern ($1.96 \geq Z \geq -1.96$) at flowering. Phytophagous mites, *A. lycopersici* and *T. merganser* showed an aggregated pattern ($I_D > 1$, $I_M > 1$, $Z > 1.96$) (Table 3). At OA site, predatory mite (*A. similoides*) and phytophagous mites' *A. lycopersici* and *T. merganser* showed an aggregated pattern ($Z > 1.96$) in the four phenological stages recorded for Pequin chili pepper plant (Table 4).

Date	Altas Cumbres				Cañón de la Peregrina				Ojo de Agua		
	M. (M.)E. m. n	*E. m.*	*A. l.*	*T. m.*	*A. s.*	*E. m.*	*A. l.*	*T. m.*	*A. s.*	*A. l.*	*T. m.*
03-feb-17	0.00 **-0.50**	--	0.00 **-0.30**	2.16 **7.07**	--	--	4.87 **16.65**	2.86 **3.90**	--	0.00 **-0.20**	--
17-feb-17	0.00 **-0.20**	--	--	8.17 **17.92**	--	--	21.67 **126.07**	4.52 **10.90**	--	5.28 **76.32**	--
03-mar-17	--	--	--	4.46 **38.08**	--	--	0.55 **0.63**	0.55 **-0.63**	--	--	--
17-mar-17	--	--	2.95 **7.79**	7.69 **9.37**	--	--	25.40 **73.21**	--	--	2.57 **149.04**	--
31-mar-17	0.91 **-0.10**	--	5.93 **439.81**	18.42 **67.94**	0.00 **-0.20**	--	3.90 **44.67**	4.44 **3.44**	--	1.84 **75.78**	--
14-apr-17	0.00 **-1.60**	--	3.06 **75.51**	2.38 **2.90)**	0.00 **-0.30**	--	2.02 **7.42**	0.00 **-0.20**	--	1.40 **32.91**	--
28-apr-17	0.95 **-0.07**	0.00 **-0.20**	20.35 **227.12**	11.11 **10.11**	0.00 **-0.20**	--	4.95 **5.52**	--	--	2.09 **24.32**	16.67 **4.70**
12-may-17	0.00 **-0.30**	--	9.09 **27.51**	--	--	--	5.78 **22.47**	--	--	2.78 **1.60**	--
26-may-17	0.00 **-0.40**	--	35.10 **395.62**	20.00 **9.50**	0.00 **-0.70**	0.00 **-0.50**	7.17 **75.24**	--	--	4.07 **10.14**	--
09-jun-17	1.82 **0.90**	0.00 **-0.20**	36.05 **690.40**	15.54 **37.80**	8.33 **2.93**	0.00 **-0.20**	4.48 **35.88**	--	--	3.01 **24.13**	10.00 **4.50**
23-jun-17	0.00 **-1.00**	--	2.99 **288.58**	12.76 **57.60**	--	--	7.58 **809.45**	--	0.00 **-0.20**	1.57 **5.33**	4.39 **4.75**
07-jul-17	0.00 **-1.10**	--	3.35 **331.33**	8.86 **39.29**	--	0.00 **-0.20**	2.68 **282.77**	--	--	0.00 **-0.60**	0.00 **-0.20**
21-jul-17	--	--	--	--	--	--	1.63 **20.54**	0.00 **-0.60**	--	0.76 **-0.29**	--
04-aug-17	1.11 **0.11**	--	11.69 **80.20**	5.54 **14.54**	1.39 **0.35**	0.00 **-0.20**	5.28 **51.82**	5.69 **12.20**	--	3.12 **7.21**	--
18-aug-17	1.39 **0.35**	0.00 **-0.20**	20.86 **48.64**	11.26 **47.18**	0.00 **-0.20**	--	3.20 **60.31**	19.58 **29.73**	0.00 **-0.90**	8.33 **2.93**	--
01-sep-17	0.00 **-0.30**	--	22.13 **28.02**	15.38 **18.70**	0.00 **-0.20**	--	14.57 **199.55**	10.00 **9.00**	2.75 **2.45**	--	0.00 **-0.20**
15-sep-17	1.11 **0.11**	--	21.43 **14.30**	0.00 **-0.80**	--	--	4.98 **25.84**	15.95 **31.40**	0.00 **-1.00**	7.04 **20.54**	--
29-sep-17	--	--	--	--	--	--	1.94 **4.43**	0.79 **-0.58**	--	16.67 **6.27**	33.33 **19.40**
13-oct-17	0.00 **-0.40**	--	16.67 **10.97**	17.78 **16.78**	--	--	2.86 **2.79**	14.82 **44.22**	0.00 **-0.30**	0.00 **-0.20**	50.00 **9.80**
27-oct-17	0.91 **-0.10**	--	1.75 **2.69**	--	--	--	7.63 **13.26**	38.89 **34.10**	1.43 **1.15**	6.41 **7.03**	50.00 **9.80**
10-nov-17	2.17 **2.92**	--	12.99 **63.55**	9.80 **39.59**	1.78 **0.63**	--	5.55 **32.33**	50.00 **29.40**	0.95 **-0.10**	4.01 **10.24**	--

M.(M.)n.: *Metaseiulus* (*Metaseiulus*) *negundinis*, E.m.: *Euseius mesembrinus*, A.l.: *Aculpos lycopercisi*, T.m.: *Tetranychus merganser*, A.s.: *Amblyseius similoides*

TABLE 2. Variance-to-mean ratio (Index of dispersion), Morisita index and Z coefficient (bold letters) for predatory and phytophagous mites at different phenological stages of *Capsicum annuum* var. *glabriusculum* in Altas Cumbres, Tamaulipas, Mexico.

Phenological stage	Species	N	m	S^2	S^2/m	I_D	I_M
Leaf production	*M. (M.) negundinis*	110	6.88	28.78	4.19	62.8 **5.82**	1.44 **8.53**
	E. mesembrinus	9	0.56	0.66	1.18	17.67 **0.56**	1.33 **0.53**
	A. lycopersici	4741	296.31	246770.63	832.81	12492.08 152.68	3.63 **2206.12**
	T. merganser	501	31.31	795.16	25.39	380.92 **22.22**	1.73 **64.81**
Flowering	*M. (M.) negundinis*	43	6.14	24.48	3.98	23.91 **3.60**	1.43 **4.90**
	E. mesembrinus	3	0.43	0.62	1.44	8.67 **0.85**	2.33 **1.07**
	A. lycopersici	1530	218.57	277154.29	1268.03	7608.16 **120.04**	5.97 **2033.09**
	T. merganser	149	21.29	450.24	21.15	126.91 **12.62**	1.82 **32.53**
Fructification	*M. (M.) negundinis*	72	9.00	57.71	6.41	44.89 **5.87**	1.53 9.61
	E. mesembrinus	3	0.38	0.55	1.48	10.33 **0.94**	2.67 **1.25**
	A. lycopersici	214	26.75	677.64	25.33	177.33 **15.23**	1.80 **42.78**
	T. merganser	154	19.25	361.93	18.80	131.61 **12.62**	1.81 **31.36**
Maturation	*M. (M.) negundinis*	62	8.86	67.14	7.58	45.48 **6.22**	1.65 **10.73**
	E. mesembrinus	2	0.29	0.57	2.00	12.00 **1.58**	7.00 **3.21**
	A. lycopersici	139	19.86	347.14	17.48	104.89 **11.17**	1.72 **26.62**
	T. merganser	122	17.43	391.29	22.45	134.70 **13.10**	2.06 **34.68**

General spatial distribution

Results of the variance-to-mean ratio (S^2/m), the index of dispersion (I_D), as well as Morisita Index (I_M) and Z adjusted goodness of fit test for I_D and I_M regarding predatory and phytophagous mite species observed at AC, CP and OA are shown in Table 5. Table 6 shows the species observed at CP and OA sites. At AC site, the variance-to-mean ratio was greater than one for the predatory and phytophagous mites, with the exception of *A. coffeae* and *Euseius* sp. The I_D and I_M determined that predatory mites *P. reventus*, *P. mexicanus*, *A. coffeae*, *Euseius* sp. and *E. mesembrinus* had random distribution patterns ($1.96 \geq Z \geq -1.96$) and *M. (M.) negundinis* had an aggregated pattern; while phytophagous mites *A. lycopersici* and *T. merganser* had aggregated distribution patterns (Table 5).

TABLE 3. Variance-to-mean ratio (Index of dispersion), Morisita index and Z coefficient (bold letters) for predatory and phytophagous mites at different phenological stages of Capsicum *annuum* var. *glabriusculum* in Cañón de la Peregrina, Tamaulipas, Mexico

Phenological stage	Species	N	m	S^2	S^2/m	I_D	I_M
Leaf Production	*A. similoides*	35	2.19	6.56	3.00	45.00 **4.10**	1.88 **5.46**
	E. mesembrinus	11	0.69	1.96	2.85	42.82 **3.87**	3.78 **5.41**
	A. lycopersici	4432	277.00	225595.60	814.42	12216.37 **150.92**	3.75 **2157.4**
	T.merganser	138	8.63	105.45	12.23	183.391 **13.70**	2.23 **29.98**
Flowering	*A. similoides*	16	2.29	9.24	4.04	24.25 **3.65**	2.22 **5.20**
	E. mesembrinus	4	0.57	0.95	1.67	10.00 **1.16**	2.33 **1.43**
	A. lycopersici	2652	378.86	339055.48	894.94	5369.66 **100.31**	3.02 **1434.04**
	T.merganser	107	15.29	109.57	7.17	43.01 **5.96**	1.35 **9.98**
Fructification	*A. similoides*	23	2.88	12.70	4.42	30.91 **4.26**	2.09 **6.25**
	E. mesembrinus	2	0.25	0.50	2.00	14.00 **1.69**	8.00 **3.50**
	A. lycopersici	755	94.38	7065.41	74.87	524.06 **28.77**	1.69 **129.44**
	T. merganser	148	18.50	94.29	5.10	35.68 **4.84**	1.20 **7.22**
Maturation	*A. similoides*	14	2.00	7.67	3.83	23.00 **3.47**	2.31 **4.89**
	E. mesembrinus	0	0.00	0.00	--	--	--
	A. lycopersici	634	90.57	8107.95	89.52	537.12 **29.46**	1.84 **142.17**
	T.merganser	122	17.43	99.29	5.70	34.18 **4.95**	1.23 **7.59**

At CP site, the values of Z test for I_D and I_M regarding pedatory mites *T. aripo*, *G.* (*G.*) *annectens*, *M.* (*M.*) *negundini* and *P. paludis* were found within a Z range of 1.96 to -1.96, indicating that the distribution patterns of these mite species are randomized; while the phytophagous mites have aggregated distribution patterns (Table 6). At OA site, predatory mite *A. similoides* and phytophagous mites, *A. lycopersici* and *T. merganser* showed aggregated distribution patterns ($I_D >$ 1, $I_M > 1$ and Z > 1.96) (Table 6).

Table 7 shows Iwao's regressions for different predatory and phytophagous mites. At AC site, predatory mites *P. mexicanus*, *M.* (*M.*) *negundinis* and *E. mesembrinus* had α values equal to zero (t-student test), indicating that one individual was the basic component and β values were lower than 1 for *P. mexicanus* and *E. mesembrinus* indicating that their patterns were regular; while parameter b

of Taylor's regression showed an aggregated pattern (b > 1). While in *M. (M.) negundinis,* α sign was negative, indicating that this mite competes for food (for instance pollen or preys), and β value was greater than 1, indicating aggregated distribution patterns, contrasting with parameter b of Taylor's power, indicating a random pattern (b=1). Regarding phytophagous mites, *A. lycopersici* and *T. merganser*, α values were greater than 0, suggesting that the colonies or clump were the basic components of these populations and that they felt attracted to the plant (+α). The value of β from Iwao's regression and the value of b from Taylor were greater than one, indicating that the units were aggregated at Pequin chili pepper leaves in this study that lasted ten months.

TABLE 4. Variance-to-mean ratio (Index of dispersion), Morisita Index an Z coefficient (bold letters) for predatory and phytophagous mites at different phenological stages of *Capsicum annuum* var. *glabriusculum* in Ojo de Agua, Tamaulipas, Mexico

Phenological stage	Species	N	m	S^2	S^2/m	I_D	I_M
Leaf production	*A. similoides*	26	1.63	15.98	9.84	147.54 **11.79**	6.30 **24.37**
	A. lycopersici	3399	212.44	119529.46	562.66	8439.86 **124.64**	3.48 **1489.76**
	T.merganser	27	1.69	12.90	7.64	114.63 **9.76**	4.83 **18.29**
Flowering	*A. similoides*	33	4.71	36.90	7.83	46.97 **6.38**	2.28 **11.29**
	A. lycopersici	95	13.57	205.95	15.18	91.05 **10.18**	1.90 **22.9**
	T.merganser	11	1.57	4.62	2.94	17.64 **2.62**	2.16 **3.42**
Fructification	*A. similoides*	84	10.50	96.29	9.17	64.19 **7.72**	1.69 **14.47**
	A. lycopersici	126	15.75	241.36	15.32	107.27 **11.04**	1.80 **25.27**
	T.merganser	13	1.63	3.98	2.45	17.15 **2.25**	1.85 **2.75**
Maturation	*A. similoides*	84	12.00	91.33	7.61	45.67 **6.24**	1.48 **10.73**
	A. lycopersici	92	13.14	218.14	16.60	99.59 **10.80**	2.03 **25.29**
	T.merganser	13	1.86	4.14	2.23	13.38 **1.86**	1.62 **2.14**

At CP site, the values of α and β for predatory mite *E. mesembrinus* were zero and less than 1, indicating that the colonies were formed by single individuals and that they had a regular distribution pattern respectively; but the value of b was equal to 1, indicating a random pattern. While for *A. similoides* the values of α and β were equal to 0 and equal to 1, indicating that one individual was the basic component of the colony and also the basis for the significant degree of randomized colonies, respectively; matching the results obtained by Taylor's regression (b=1). Regarding phytophagous mites, *A. lycopersici* and *T. merganser*, α values were lower than 0, indicating that each colony was formed by one individual and *β* values were greater than 1, indicating an aggregated distribution

pattern. Taylor's power determined that *A. lycopersici* had an aggregated pattern (b > 1) and *T. merganser* had a random pattern (b=1) (Table 7).

At OA site, α and β values were equal to zero and greater than 1 for *A. similoides*, *A. lycopersici* and *T. merganser*, indicating that the basic component was an individual and the units were aggregated at the time when we observed the predator and the phytophagous mites. Therefore, Taylor's regressions were significant and showed that *A. lycopersici* had a significant degree of colony agglutination (b > 1), while *A. similoides* and *T. merganser* had a random and a regular pattern, respectively.

TABLE 5. Spatial distribution parameters of predatory and phytophagous mites on *Capsicum annuum* var. *glabriusculum* in Altas Cumbres, Tamaulipas, Mexico, using variance-to-mean ratio, index of dispersion (I_D), Z coefficient to test the goodness of fit (bold) and Morisita Index (I_M).

Mite species	N	m	S^2	S^2/m	I_D	I_M
Predators						
Proprioseiopsis reventus	1	0.048	0.05	1.05	21.00 **0.24**	--
Phytoseius mexicanus	5	0.238	0.30	1.27	25.42 **0.89**	2.10 **0.85**
Metaseiulus (Metaseiulus) negundinis	160	7.619	43.35	5.69	113.81 **8.84**	1.56 **13.83**
Amblyseius coffeae	3	0.143	0.13	0.94	18.79 **-0.11**	0.00 **-0.46**
Euseius sp.	2	0.095	0.09	0.99	19.89 **0.06**	0.00 **-0.31**
Euseius mesembrinus	9	0.429	0.57	1.34	26.89 **1.09**	1.75 **1.04**
Phytophagous mites						
Aculpos lycopersici	4843	230.619	207325.57	899.00	17979.92 **183.39**	4.57 **2669.51**
Tetranychus merganser	564	26.857	706.97	26.32	526.47 **26.20**	1.934 **81.29**

Association among species

In the three sampling sites, we found some mite species associated to other species at different degrees (Table 8). At AC site, predatory mite *M.* (*M.*) *negundinis* was associated with *A. lycopersici* and *T. merganser*. The two latter phytophagous were also associated together. The highest degree of association was observed between *M.* (*M.*) *negundinis* and *A. lycopersici*. At CP site, the highest degree of association was between *T. merganser* and *A. lycopersici*, followed by *A. similoides* and *A. lycopersici*. At OA site, we found an association between *A. similoides* and *A. lycopersici*, but the degree of association was low (Table 8). The values of the association indexes among predatory and phytophagous mites ranged from low to moderate, but they were always significant, according to x^2 test. This result indicates a predator-prey relationship; which in the case of phytophagous-phytophagous association, the relationship is based on the same food resource.

Association among different mite species and the phenological stages of Pequin chili pepper

At AC and CP sites, we observed phytoseiidae mite species with low abundance and rare occurrence, including one or two individuals of *P. reventus* and *Euseius* sp. that were found at Pequin chili pepper leaf production stage. We found five individuals of *P. mexicanus* at the leaf production stage and two individuals at flowering. *Amblyseius coffeae* was found in the four stages (leaf

production, flowering, fructification and maturation) with three, two, one and one individuals respectively. At CP site, *T. aripo*, *G.* (*G.*) *annectens*, *M.* (*M.*) *negundinis* were observed during the leaf production stage, with one, two and three individuals respectively; and *P. paludis* was found at leaf production, fructification and maturation stages with one individual in every stage.

TABLE 6. Spatial distribution parameters of predatory and phytophagous mites on wild plants of *Capsicum annuum* var. *glabriusculum* in Cañón de la Peregrina and Ojo de Agua, Tamaulipas, Mexico, using variance-to-mean ratio, Index of dispersion, Morisita Index and y Z coefficient to test the goodness of fit (bold letters).

Mite species	Number of mites	Average	Variance	Ratio V/M	I_D	I_M
Cañón de la Peregrina						
Predators						
Amblyseius similoides	45	2.143	7.355	3.43	68.65 **5.47**	2.08 **7.49**
Typhlodromalus aripo	1	0.048	0.050	1.05	21.00 **0.24**	--
Galendromus (Galendromus) annectens	2	0.095	0.095	0.99	19.89 **0.06**	0.00 **-0.31**
Metaseiulus (Metaseiulus) negundinis	3	0.143	0.095	0.66	13.26 **-1.09**	0.00 **-0.46**
Euseius mesembrinus	11	0.524	1.629	3.11	62.20 **4.91**	4.96 **6.73**
Phytoseius paludis	2	0.095	0.095	0.99	19.89 **0.06**	0.00 **-0.31**
Phytophagous mites						
Aculpos lycopercisi	4650	221.429	187401.397	846.33	16926.58 **177.75**	4.48 **2501.98**
Tetranychus merganser	234	11.143	127.818	11.47	229.42 **15.18**	1.89 **32.09**
Ojo de Agua						
Predators						
Amblyseius similoides	87	4.143	62.24	15.02	300.47 **18.27**	4.14 **42.11**
Phytophagous mites						
Aculpos lycopercisi	3486	166.000	100557.96	605.77	12115.42 **149.42**	4.35 **1799.66**
Tetranychus merganser	37	1.762	11.29	6.41	128.18 **9.77**	3.88 **16.43**

Chi-square test showed that a sampling error could not explain the proportional difference, and therefore there is a clear interaction among mite species and the Pequin chili pepper phenological stages. In the three sampling sites, the mite species (predatory and phytophagous) were associated to phenological plant stages. At AC site, species *M.* (*M.*) *negundinis*, *A. lycopersici*, *T. merganser* and *E. mesembrinus* were found associated to Pequin chili pepper phenological stages (χ^2=1027; df=9; P < 0.0001). While at CP site, we found *A. similoides*, *E. mesembrinus*, *A. lycopersici* and *T. merganser* (χ^2=454; df=9; P < 0.0001) associated with phenological stages of Pequin chili pepper; and at OA site, we found *A. similoides*, *A. lycopersici* and *T. merganser* (χ^2=1024; df=6; P < 0.0001) associated with Pequin chili pepper phenological stages.

TABLE 7. Spatial distribution of phytoseiidae and phytophagous mites on *Capsicum annuum* var. *glabriusculum* in Altas Cumbres, Cañon de la Peregrina and Ojo de Agua, Tamaulipas, Mexico, using Taylor's power law and Iwao's patching regression analysis

Mite species	Iwao			Taylor		
	$\alpha \pm SE$	$\beta \pm SE$	R^2	$a \pm SE$	$b \pm SE$	R^2
Altas Cumbres						
Predators						
Proprioseiopsis reventus	---	---	---	---	---	---
Phytoseius mexicanus	0.001 ±0.001	0.6905 ±0.062	0.864[***]	-0.000 ±0.001	1.001 ±0.001	0.999[***]
Metaseiulus (Metaseiulus) negundinis	-0.0824 ±0.053	1.476 ±0.272	0.606[***]	0.023 ±0.063	1.029 ±0.035	0.978[***]
Amblyseius coffeae	---	---	---	---	---	---
Euseius sp.	---	---	---	---	---	---
Euseius mesembrinus	0.001 ±0.001	0.568 ±0.053	0.856[***]	-0.001 ±0.001	1.002 ±0.001	0.999[***]
Phytophagous mites						
Aculpos lycopercisi	15.819 ±8.413	3.296 ±0.852	0.440[**]	2.191 ±0.234	1.655 ±0.115	0.915[***]
Tetranychus merganser	1.451 ±1.036	5.863 ±1.375	0.488[**]	1.390 ±0.254	1.251 ±0.261	0.546[***]
Cañón de la Peregrina						
Predator						
Amblyseius similoides	0.001 ±0.030	1.452 ±0.445	0.359[*]	0.015 ±0.035	1.001 ±0.013	0.996[***]
Typhlodromalus aripo	---	---	---	---	---	---
Galendromus (Galendromus) annectens	---	---	---	---	---	---
Metaseiulus (Metaseiulus) negundinis	0.003 ±0.001	-0.050 ±0.064	0.030[ns]	-0.687 ±0.341	-0.225 ±0.259	0.038[ns]
Euseius mesembrinus	0.001 ±0.001	0.270 ±0.035	0.758***	-0.001 ±0.003	1.010 ±0.002	0.999[***]
Phytoseius paludis	---	---	---	---	---	---
Phytophagous mites						
Aculpos lycopercisi	4.062 ±6.090	4.247 ±0.648	0.692[***]	1.681 ±0.188	1.778 ±0.137	0.898[***]
Tetranychus merganser	0.477 ±0.756	7.180 ±2.418	0.316[**]	0.740 ±0.279	1.061 ±0.160	0.697[***]
Ojo de Agua						
Predators						
Amblyseius similoides	-0.013 ±0.030	1.317 ±0.174	0.750[***]	0.013 ±0.030	1.010 ±0.021	0.991[***]
Phytophagous mites						
Aculpos lycopercisi	1.077 ±1.107	1.984 ±0.159	0.891[***]	1.274 ±0.126	1.443 ±0.060	0.967[***]
Tetranychus merganser	0.127 ±0.163	7.575 ±2.222	0.379[*]	0.068±0.100	0.879±0.052	0.935[***]

[*] P < 0,05; [**] P < 0,001; [***] P<0,0001; [ns]: non-significant;

TABLE 8. Association among predatory and phytophagous mites on leaves of *Capsicum annuum* var. *glabriusculum* in Altas Cumbres, Cañón de la Peregrina and Ojo de Agua, Tamaulipas, Mexico

Species	χ^2	Ochiai Index	Dice Index	Jaccard Index
Altas Cumbres				
M. (M.) negundinis - A. lycopersici	9.5321**	0.2560	0.2473	0.1411
M. (M.) negundinis - T. merganser	4.3531*	0.1266	0.1239	0.0660
T. merganser - A. lycopersici	7.5776**	0.1914	0.1860	0.1025
Cañón de la Peregrina				
*A. similoides*A. lycopersici*	4.3915*	0.0847	0.0496	0.0254
A. similoides - T. merganser	0.7658 NS	0.0302	0.0273	0.0138
E. mesembrinus - A. lycopersici	2.057 NS	0.0301	0.0097	0.0048
E. mesembrinus - T. merganser	0.0867 NS	0.0295	0.0173	0.0087
T. merganser - A. lycopersici	3.8879*	0.2278	0.1832	0.1008
E. mesembrinus - A. similoides	0.0086 NS	0.0465	0.0377	0.0192
Ojo de Agua				
A. similoides - A. lycopersici	15.711***	0.0873	0.0758	0.0394
A. similoides - T. merganser	0.7182 NS	0.0000	0.0000	0.0000
T. merganser - A. lycopersici	0.0494NS	0.0931	0.0448	0.0229

* Significant if P < 0.05. ** Significant if P < 0.01. *** Significant if P < 0.0001. NS: Non-significant.

Standardized residuals showed that mite species (predatory and phytophagous) were associated in a positive ($r_i > 2$) and negative ($r_i < -2$) ways to a particular phenological stage of Pequin chili pepper (Figure 2). At AC site, *M. (M.) negundinis* was found positively associated to fructification ($r_i = 14.60$) and maturation (15.18) stages; and was negatively associated to leaf production (-11.11) and flowering (-2.91) stages of Pequin Chili pepper. On the other hand, phytophagous mite *A. lycopersici* was positively associated to leaf production (14.58) and flowering (5.62), but it was negatively associated to fructification (-21.42) and maturation (-21.05). *Tetranychus merganser* was positively associated to fructification (15.50) and maturation (14.75), but it was negatively associated to leaf production (-9.88) and flowering (-4.60). On the other hand, *E. mesembrinus* was associated to the fructification stage (2.15) (Figure 2A).

At CP site, *A. lycopersici* was negatively associated to fructification (-15.08) and maturation (-12.48), but it was positively associated to leaf production (10.87) and flowering (5.64). Regarding *T. merganser*, this mite was positively associated to fructification (14.30) and maturation (12.77) and it was negatively associated to leaf production (-11.20) and flowering (-4.96). While predator *A. similoides* was positively associated to fructification (4.96) and maturation (2.52), but it was negatively associated to flowering (-2.53) and leaf production (-2.07). On the other hand, *E. mesembrinus*, was not associated to any plant phenological stage ($|r_i| < 2$) (Figure 2B).

At OA site, *A. lycopersici* was negatively associated to maturation (-23.90), fructification (-21.44) and flowering (-11.27), and it was positively associated to leaf production (34.98). *Tetranychus merganser* was positively associated to flowering (6.04), maturation (5.93) and fructification (5.18) and it was negatively associated to leaf production (-10.31). Furthermore, predator *A. similoides* was negatively associated to leaf production (-33.67) and it was positively associated to maturation (23.61), fructification (21.26) and flowering (9.37) (Figure 2C)
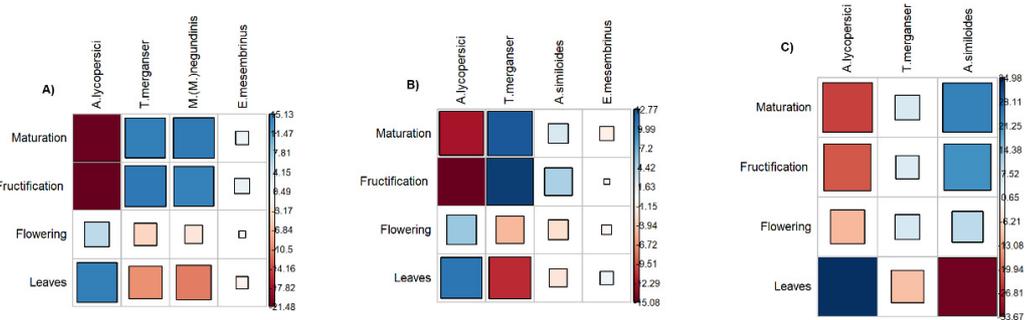
FIGURE 2. Association among predatory and phytophagous mites in four phenological stages of *Capsicum annuum* var. *glabriusculum* in A) Altas Cumbres, B) Cañón de la Peregrina and C) Ojo de Agua, Tamaulipas, Mexico. The positive standardized residuals are in blue and they represent positive association between rows and columns. The negative standardized residuals are in red and they represent negative association between rows and columns.

Discussion

Fruit picking of *Capsicum annuum* var. *glabriusculum* by local people is an anthropogenic activity disrupting the ecosystem and leading to a partial or total loss of leaves and/or plants of Pequin chili pepper (Monjarás-Barrera 2020). Leaf loss affects the abundance and diversity of mite species that use those leaves as substrate to reproduce, find shelter, for feeding or as prey hunting grounds (O'Connell *et al.* 2010; Walter & Proctor 2013). The observations indicate that many Phytoseiidae species prefer pubescent leaves to establish themselves and the presence of trichomes increases their abundance, as well as oviposition (Roda *et al.* 2001; Schmidt 2013). Therefore, the abundance of most phytoseiidae species such as *P. reventus*, *Euseius* sp., *A. coffeae*, *P. mexicanus* at AC, and *T. aripo*, *G.* (*G.*) *annectens*, *M.* (*M.*) *negundinis* and *P. paludis* at CP was lower, because the leaves of *C. annuum* var *glabriusculum* are glabrous (Monjarás-Barrera *et al.* 2019). On the other hand, species from *Euseius*, *Typhlodromalus* and *Phytoseius* genera apparently supplement their nutritional requirements by feeding on foliar cells. These mites pierce the cells to absorb water from their cytoplasm. Besides, several species of *Phytoseius* live on pubescent leaves (McMurtry *et al.* 2013; Tixer 2018). Furthermore, some species of *Proprioseiopsis* prefer inhabiting the soil and leaf-litter and when they are seen on aerial plant parts (on leaves), is because they are looking for prey to feed from (McMurtry *et al.* 2013). In the case of *G.* (*G.*) *annectens*, the low density found on *C. annuum* L. var. *glabriusculum* coincides with the results reported by Hoddle *et al.* (1999). They found very few individuals on the leaves of *Persea americana* (Miller) that used in the control of *Oligonychus punicae* (Hirst).

At the three experimental sites (AC, CP and OA), the predatory mite species that were observed more frequently on Pequin chili pepper leaves by collection date, presented a random distribution pattern in almost every date (Figure 1, Table 1). The observed distribution pattern for a given species is determined largely by the behavior and the mobility, as well as by the quick changes in the number of individuals along a specific timeline (Davis 1994). All the predatory species recorded in this study are generalist predators, meaning that they feed from different sources, bee pollen, leaf exudates and fungi, and they move throughout the plant and other habitats searching for food (McMurtry *et al.* 2013). Nevertheless, plant architecture plays an important role, because after being modified by herbivores' attacks, leads to changes in the richness and abundance of the predatory species, promoting dispersion and modified distribution patterns (Demite *et al.* 2013; Santamaria *et al.* 2018).

Phytophagous mites, *A. lycopersici* and *T. merganser* showed aggregated patterns in almost all the collection dates, as well as in the four phenological stages of Pequin chili pepper (Table 1–7). This type of pattern is typical in *Tetranychus* spp. (Jones 1990; García-Mari *et al.* 1991; Taylor 2019). Nevertheless, variations in spatial distribution (from aggregate to random) throughout the time depend on the behavior (low mobility), food, shelter and environmental conditions (Greco *et al.* 1999; Rahmani *et al.* 2010; Darbemamieh *et al.* 2012). Furthermore, when the plant offers protection and it is also a food source, *A. lycopersici* and *T. merganser* form groups in order to protect them from their predators, resulting in aggregated distribution (Taylor 2019). However, competition for the same food promotes dispersal among mites in search for new food sources (Mitchell 1970; Clotuche *et al.* 2013).

Iwao classified different distribution patterns (Iwao 1970; Davis 1994; Taylor 2019). Therefore, according to the parameters estimated (α, β) in this study, *M.* (*M.*) *negundinis* (at AC), *A. similoides* (at CP and OA), *T. merganser* (at CP and OA) and *A. lycopersici* (at CP and OA) presented aggregated patterns (α=0, β > 1). *E. mesembrinus* (at AC and CP) and *P. mexicanus* showed more regular than randomized patterns (α=0, β < 1), and we found *A. lycopersici* (at AC) forming aggregated colonies, indicating that this eriophyde responds to characteristic forms of reproduction and dispersion (α > 0, β > 1) (Table 7). The different spatial patterns observed in one or several mite species at several sampling sites are quite probably the result of interactions between the environment and demographic activities, including birth, death and mobility. Darbemamieh *et al.* (2012) studied these behavioral variations. This group of researchers stated that variations in spatial distribution along time depend on the behavior (low mobility), food sources and environmental conditions (temperature and relative humidity), leading to shifts from aggregated to random distribution patterns. These interactions can also be result of the mites' evolutionary answers, many of which depend on density. Therefore, there is feedback among density-dependent behavior, the habitat and the species living there (Taylor 2019).

Some reports regarding preys of *A. similoides* and *M.* (*M.*) *negundinis* include tetranychids and eriophyids (Acari: Tetranychidae, Eriophyidae) (Schuster & Pritchard 1963; Charlet & McMurtry 1977), coinciding with the association indexes among *M.* (*M.*) *negundinis*-*A. lycopersici*, *M.* (*M.*) *negundinis*-*T. merganser* at AC, and *A. similoides*-*A. lycopersici* at CP and OA, where the indexes were moderate or low, indicating a predator-prey relationship among them. Therefore, *A. lycopersici* and *T. merganser* are part of the diet of those predatory mites. Meanwhile, *E. mesembrinus* was not associated to any phytophagous species in the sites where we found it. However, some studies have proven probable association of this mite with *Euseius mesembrinus* in order to control Tetranychidae species (Abou-Setta & Childers 1989; Landeros *et al.* 2004). McMurtry *et al.* (2013) mentioned that the species from *Euseius* genus feed themselves from pollen mainly and sometimes from certain phytophagous mites and insects. Phytophagous species, *T. merganser* and *A. lycopersici* were associated at AC site, but such association was not found at CP and OA. Regarding this point, Odum and Barret (2006) noted that when two species feed from the same source, they could co-exist if their morphologies, growth rates, nutritional requirements, mortality causes and sensitivity to certain plant secondary metabolites are different; such as *T. merganser* and *A. lycopersici* over *C. annuum* L. var. *glabriuculum*.

Predatory mites were negatively associated with leaf production and flowering stages. Just like Schmidt (2013) mentioned, phytoseiidae prefer pubescent leaves with trichomes, and the host plant does not have those traits. Likewise, negative interactions between the predatory community and the host plant may arise as they start competing for resources such as pollen in the flowering stage and for space. Under the principle of competition, DeBach (1966), mentioned that strongly related species cannot co-exist in the same ecological niche; whereas later, Hurlburtt (1968) stated that these factors are related to the co-existence and the anatomic similarity of species. He found that

moderately similar species are found next to different species; while very similar species were rarely or never found together. These patterns of co-existence explain the fact that very different species can become adapted to different habitats and can use other type of resources; while similar species are always in intense competition. Therefore, biology and diet preferences can explain the presence or the lack of competition among predators (Camporese & Duso 1995). Consequently, a factor that influences positively in the predatory community is the plant capacity to provide shelter and supplementary food (Carrillo *et al.* 2015). This shelter depends largely on the architecture and the domatium development as plant defense mechanisms. However, phytophagous mites induce morphological changes that sometimes can harm plants and supply predators with better access to their prey (Lesna *et al.* 2005; Aratchige *et al.* 2007). On the other hand, the production of nectar, exudates and pollen, provide supplementary food to predatory mites, as plants trigger out these additional defense mechanisms to face herbivores 'attacks (Dicke & Sabelis 1988; Sabelis *et al.* 2005, 2007). The positive relation with the fructification and maturation stages is due to the mites' search for prey and supplementary food; because in the plant phenology both stages overlap, providing more food during flowering. This behavior was stronger in *M. (M.) negundinis* and *A. similoides* species and was weaker in *E. mesembrinus*, probably because *Euseius* species have a broader range of food sources, in comparison to *Amblyseius* and *Metaseiulus* species that are considered generalist predators (McMurtry *et al.* 2013).

The associations among phytophagous mites and the phenological stages of the plant went in opposite directions, that is, when *A. lycopersici* was positively associated to a phenological stage of the plant, *T. merganser* was negatively associated and vice versa, indicating that the populations of *A. lycopersici* displaced the populations of *T. merganser*, since the eriophyids population was larger than the tetranychids population and they eat the same food and therefore compete for the same resource. Van Leeuwen et al. (2010) observed that the populations of phytophagous *A. lycopercisi* were favored when cultivated plants of *C. annuum* L. grew under water stress. This phenomenon is related to wild populations of *C. annuum* L. var. *glabriusculum* that are under constant water stress due to the lack of rainfall for long periods of time (Periódico Official 2016; CONAGUA, 2019).

According to these results, we can accept the hypothesis that the abundance and the distribution patterns of predatory and phytophagous mites relate to different phenological stages of Pequin chili pepper, including leaf production, flowering, fructification and maturation. Furthermore, we concluded that mites associated to *C. annuum* L. var. *glabriusculum* plants growing in less disturbed and/or preserved areas, play a crucial role in understanding the behavior and the population's regulation of the species. These mites can provide us with information about the ecosystem stability and allow us to learn about the importance of preserving vegetation as a substrate and as reservoir to those species. Pequin chili pepper plants growing in natural areas do not produce flowers at the same time, due to the environmental conditions where they develop. Besides, these plants became an important food source for the generalist predatory mites. Predatory mites balance their diet with different resources, including prey, pollen, nectar and plant exudates, leading to different distribution patterns of the phytophagous mites living in the same natural areas.

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