Article

Spatial behavior of the branch borer in avocado using the SADIE method in the State of Mexico

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Abstract

Avocado presents different phytosanitary problems that affect its good development and decrease production, one of these problems is the branch borer (*Copturus aguacatae*), an insect that generates damage by boring the pith of the branch and, in large infestations, causes abortion of flowers and breaking of branches, it is also considered a pest of quarantine interest. The populations of this insect and the economic importance it represents makes it important to implement studies that allow knowing the spatial distribution of the borer within the avocado orchards, in order to apply control measures that are effective. The objective of this study was to analyze the spatial distribution of *Copturus aguacatae* in avocado using the technique of Spatial Analysis by Distance Indices. The short-term spatial-temporal stability of the pest was determined with the association index of Spatial Analysis by Distance Indices, the results showed that the populations of the branch borer are distributed in an aggregate way within the study areas in several centers, with the density maps elaborated using the Kriging technique, the aforementioned distribution was corroborated. It was not possible to determine a spatial and temporal stability of the insect populations at all sampling dates. Infestations did not occur on 100% of the area of the avocado plots, which is important since, in this way, control measures can be directed on specific areas of infestation.

Keywords: infestation maps, infested area, kriging.

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Introduction

The avocado (*Persea americana* Mill.) is the fourth most important fruit in the world (FAO, 2019). Its world production is estimated at 4.2 million tonnes, with Mexico being the main one with an average annual production of 1 107 135.16 t in 134 322.12 ha (SIAP, 2019), according to these data, there has been an increasing trend in cultivated area and production volume, with a predominance of the Hass variety, which stands out for its demand worldwide (Naamani, 2007). According to data from SIAP (2019), the main producing state is Michoacán, followed by Nayarit, Morelos and the State of Mexico.

On the other hand, avocado presents a great diversity of pests, among them, the branch borer (*Copturus aguacatae* Kissinger), which is native to Mexico and has only been reported attacking avocado (*P. americana*) and its different varieties (García *et al*., 1986). *Copturus aguacatae* is found in all avocado plantations in Mexico, affecting them considerably, with losses of approximately 2 to 3 t ha^{-1} (Sánchez *et al*., 2012), the presence of this pest represents an obstacle to the export of the fruit, as it is classified as a pest of quarantine interest, this situation generates economic losses since the avocado, instead of being exported and sold at high prices, has to be marketed locally at prices different from export prices (Urías, 2007).

In Mexico, the regulation of this pest is established in the official Mexican standard NOM-066-FITO-2002 (SAGARPA, 2005), which has specifications for the phytosanitary management and movement of avocado, which is applied under the phytosanitary campaign of regulated avocado pests (De Dios Ávila *et al*., 2016).

Adults of *Copturus aguacatae* are rhomboid-bodied and measure 3.77 to 5 mm long and 2 to 2.5 mm wide, black to reddish, with small white, red, orange and black scales that give it reddish-brown tones; females are bigger than males (SENASICA, 2010). The attack is detected by the presence of small white dots of powdery consistency on the branches (García *et al*., 1967). The damage consists of lesions produced by the larvae that bore through the epidermis until they reach the pith of the branch; likewise, adults cause lesions on tender shoots, in which females oviposit. These damages cause the defoliation of the plant, causing the abortion of flowers and fruits, and consequently the decrease in production (Talavera and Padilla, 2003).

The monitoring of pest populations is a very important procedure to be able to carry out an adequate management, since with this one can have an overview of how it is distributed within the study plots (Esquivel and Jasso, 2014). In order to properly use the information derived from monitoring, it is necessary to establish sampling points that generate reliable data (Maldonado *et al*., 2017) with which, in this case, the spatial behavior of *C. aguacatae* can be visualized.

The infestation of this pest makes it important to implement activities that allow knowing its location within the plots; therefore, the objective of this work was to determine the spatial analysis of *Copturus aguacatae* in avocado using SADIE tools.

Materials and methods

The study was carried out in two avocado-producing municipalities in the State of Mexico: Coatepec Harinas and Donato Guerra. In each municipality four plots of two hectares each were established, each plot was divided into quadrants of 20x20 m to have a total of 50 quadrants per plot. Under the quadrant sampling method, 25 were taken at random and from each quadrant, two trees were selected at random to have a total of 50 trees per plot, giving a total of 200 trees per municipality (Figure 1). It was verified that the plantations were avocado of the Hass variety (the age of the trees was seven years) and that they did not apply agrochemicals for pest control. In these plots, the presence of the pest was identified by visualizing small white dots of powdery consistency on the branches (García *et al*., 1967).

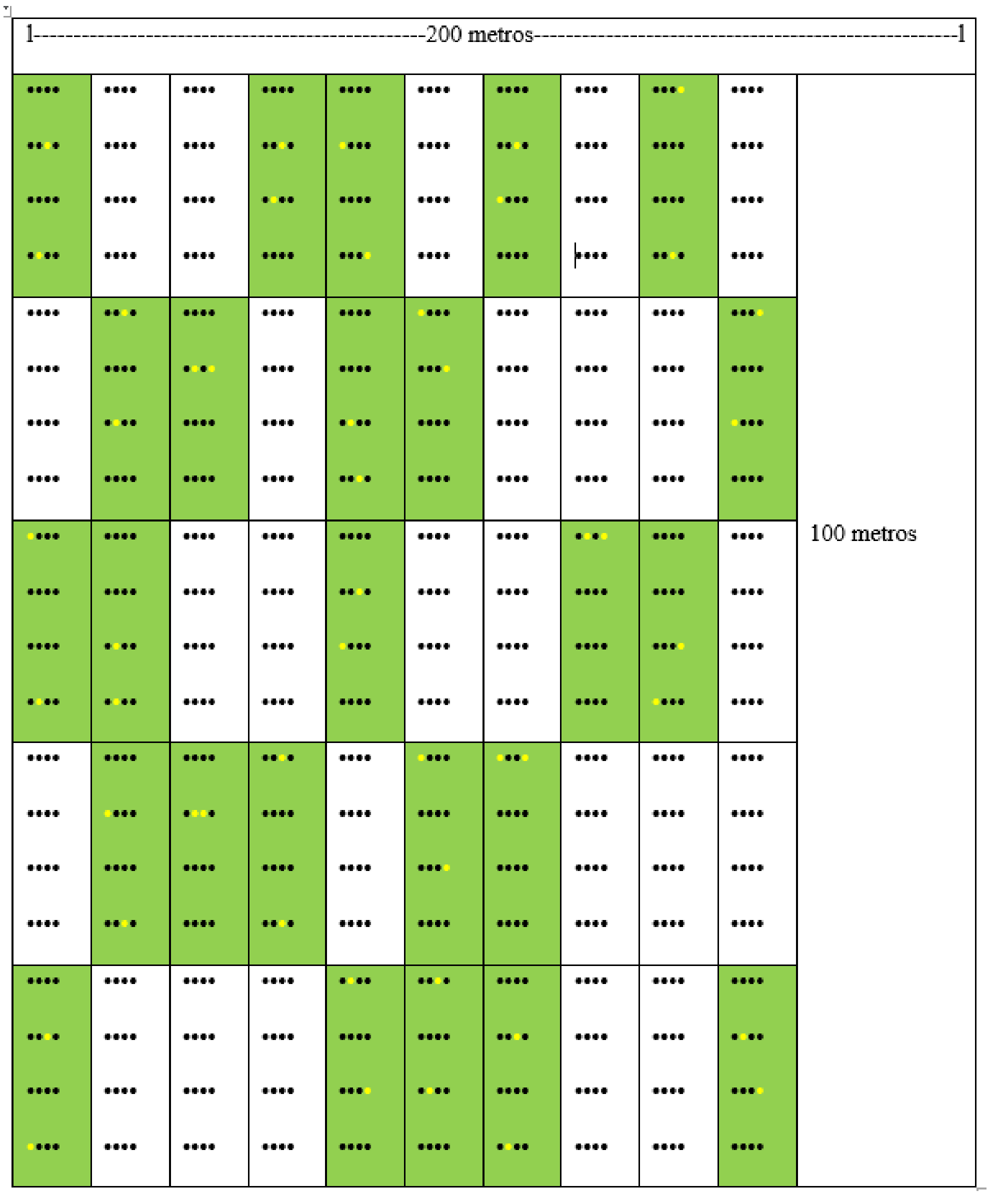

Figure 1. Representation of field sampling for data interpolation.

Each sampled tree was tagged and georeferenced using a differential global positioning system (DGPS). The samplings were carried out on the 1st and 15th of each month from January to December 2019 and for the sampling of the adults of *C. aguacatae,* blue plastic bands of 60 cm long by 20 cm wide were placed (Gasca-Corona and Equihua-Martínez, 1999), provided with adhesive called Spider plus.

The bands were checked on the 1st and 15th of each month to count captured adults and hung again for further samplings. A plastic band was placed in the three strata of the tree (low, medium and high strata) for each cardinal point, having a total of 12 traps per tree.

Spatial analysis by distance indices (SADIE)

SADIE has been developed by Dr. Joe N. Perry of the Department of Entomology and Nematology at Rothamsted Experimental Station (United Kingdom). This tool identifies the spatial model for two-dimensional data, with an associated index of aggregation and a test for the deviation of randomness based on an attraction algorithm, which incorporates a biological model for the dispersion of individuals from an origin in which each individual is assigned a dynamic territory. Perry (1995) developed and extended the use of the distance index for regularity (I_a) for establishing the spatial structure of insect populations. In addition, he introduced two diagnostic diagrams to aid interpretation and a new index to estimate the number of clustering foci of a population, the J_a index.

Elaboration of maps

The interpolation of values was performed through ordinary kriging that allows the estimation without bias of values associated with points that were not sampled, the estimates obtained were represented in the form of a map for each sampling date using the Surfer 9 program (Surface Mapping System, Golden Software Inc., Golden, CO).

Spatial and temporal stability

To carry out the comparison between the different maps obtained with kriging, the Im index (association index) of SADIE was used to establish the spatial-temporal stability (Perry Klukowsky, 1997). This comparison of sampling dates can give us indications of the spatial temporal dynamics of the insect, more specifically of the possibility of finding a numerical stability in space and time. If Im > 0, it is indicative that there is an association or a spatial-temporal stability between the maps. The determination of the stability was carried out with the SADIE 1.22 program.

Results

With the data obtained, it was possible to generate the spatial modeling and mapping of *C. aguacatae* populations in avocado orchards. The population means of the insect in the municipality of Coatepec Harinas were 7.42 individuals per tree in June in its second sampling, this infestation value being the highest recorded in all the sampling months, while the infestation with the lowest density was in November in the first sampling. It is worth mentioning that in the second sampling of November and in December, there was no longer the presence of adults of *C. aguacatae*.

As for the municipality of Donato Guerra, the months that registered the greatest presence of adults were May and June, the latter with a mean of 6.05 insects per tree and the month with the lowest presence of borer was September with an average of 0.29 adults per tree, in this municipality there was no longer the presence of the insect in October, November and December.

The results obtained with the application of the SADIE indices in the municipality of Coatepec Harinas showed the values between 1.3 the lowest and 1.77 the highest. For the municipality of Donato Guerra, the lowest value was 1.29 and the highest was 1.74 (Table 1), in all cases the I_a index was significantly greater than one, this with respect to its probability P_a, which indicates an aggregate spatial distribution of *C. aguacatae* in avocado in all the samplings carried out for the two municipalities. In the second sampling in November and the two in December, there was no capture of *C. aguacatae*.

Table 1. Value of the I_a and J_a indices and their respective probabilities P_a and Q_a in the populations of *Copturus aguacatae* in Coatepec Harinas and Donato Guerra 2019.

Sampling	Coatepec Harinas				Donato Guerra 2017			
	I_a	P_a	J_a	Q_a	I_a	P_a	J_a	Q_a
January 01	1.4	0.1 s	1.08	0.145 ns	1.4	0.007 s	1.1	0.135 ns
January 15	1.5	0.002 s	1.15	0.168 ns	1.3	0.011 s	1.2	0.184 ns
February 01	1.4	0.005 s	1.21	0.155 ns	1.6	0.014 s	1.1	0.143 ns
February 15	1.6	0.017 s	1.18	0.185 ns	1.3	0.014 s	1.2	0.167 ns
March 01	1.3	0.008 s	1.2	0.206 ns	1.4	0.005 s	1.3	0.208 ns
March 15	1.6	0.011 s	1.25	0.166 ns	1.7	0.009 s	1.2	0.236 ns
April 01	1.7	0.007 s	1.16	0.217 ns	1.4	0.01 s	1.1	0.133 ns
April 15	1.5	0.006 s	1.14	0.158 ns	1.6	0.008 s	1.1	0.219 ns
May 01	1.7	0.009 s	1.1	0.249 ns	1.6	0.015 s	1.1	0.153 ns
May 15	1.6	0.016 s	1.13	0.193 ns	1.5	0.017 s	1.1	0.178 ns
June 01	1.8	0.01 s	1.18	0.252 ns	1.6	0.006 s	1.2	0.227 ns
June 15	1.3	0.003 s	1.2	0.149 ns	1.4	0.012 s	1.1	0.159 ns
July 01	1.7	0.005 s	1.24	0.271 ns	1.7	0.008 s	1.2	0.252 ns
July 15	1.8	0.003 s	1.09	0.174 ns	1.6	0.004 s	1.2	0.269 ns
August 01	1.7	0.004 s	1.09	0.257 ns	1.7	0.015 s	1.1	0.277 ns
August 15	1.4	0.012 s	1.09	0.266 ns	1.7	0.006 s	1.3	0.272 ns
September 01	1.5	0.013 s	1.23	0.221 ns	1.3	0.012 s	1.2	0.213 ns
September 15	1.3	0.008 s	1.21	0.21 ns	1.7	0.005 s	1.2	0.148 ns
October 01	1.8	0.01 s	1.16	0.137 ns	-	-	-	-
October 15	1.6	0.012 s	1.11	0.246 ns	-	-	-	-
November 01	1.7	0.009 s	1.07	0.234 ns	-	-	-	-

As for the J_a index, the values in the municipality of Coatepec Harinas were 1.07 the lowest and 1.25 the highest, while in the municipality of Donato Guerra, values between 1.08 and 1.25, respectively, were obtained (Table 1). This index (J_a) in all the samplings of the two municipalities was not significantly greater than one, this taking into account its probability Q_a, this result confirms the aggregation found by the I_a index and also having data that were not significantly greater than one allows determining that the spatial distribution of the insect within the avocado orchards is concentrated in more than one aggregation center.

Infestation maps showed that adult populations of *C. aguacatae* were located in aggregation centers; that is, its location is in specific points, within the avocado orchards. In the municipality of Coatepec Harinas in January, February, March and April (1), the aggregation centers were located in the central and left part of the map; however, in April (15), May, June, July and August, the aggregation centers are distributed throughout the map, having infestations both in the central left and right parts and upper and lower parts and finally, in September and October (1), the aggregation centers were located in the upper left part of the map and in October (15) and November, the aggregation centers were located in the central and lower part of the map (Figure 2).

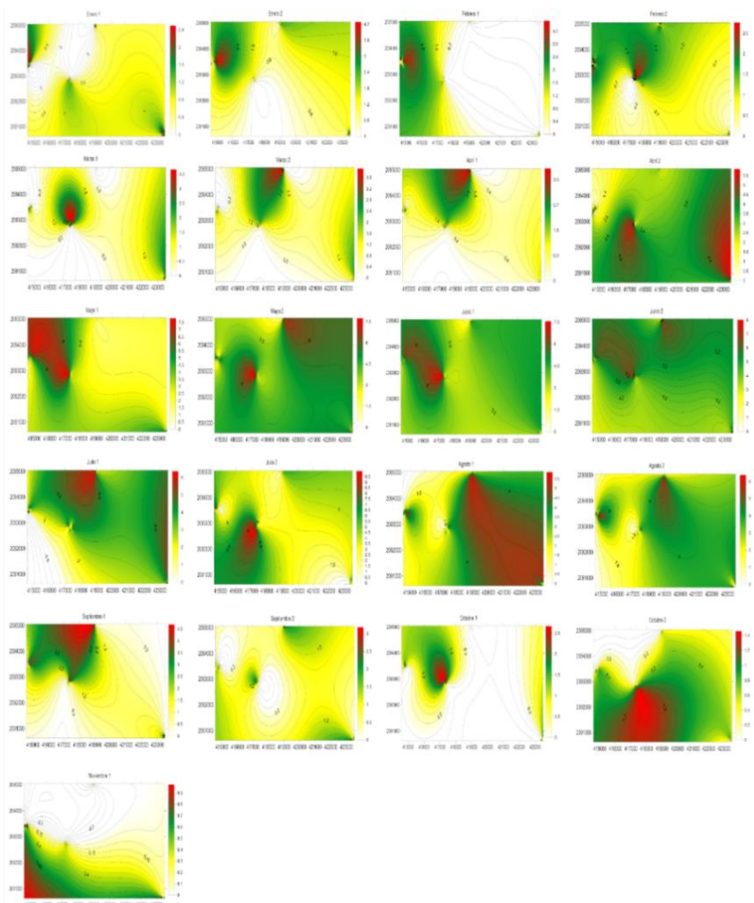

Figure 2. Density maps of *Copturus aguacatae* populations in avocado in Coatepec Harinas.

As for the municipality of Donato Guerra, the most marked aggregation centers were located in the central left part of the maps; however, in some cases aggregation centers were also found in the right area of the map, as was the case of January (15) and August (15) (Figure 3). In the density maps obtained with the kriging technique, the aggregation centers of the populations of *C. aguacatae* are observed, this type of graphic representations can be given a use by means of which the different control measures, whether chemical, biological, mechanical, etc., can be directed precisely towards the points of infestation.

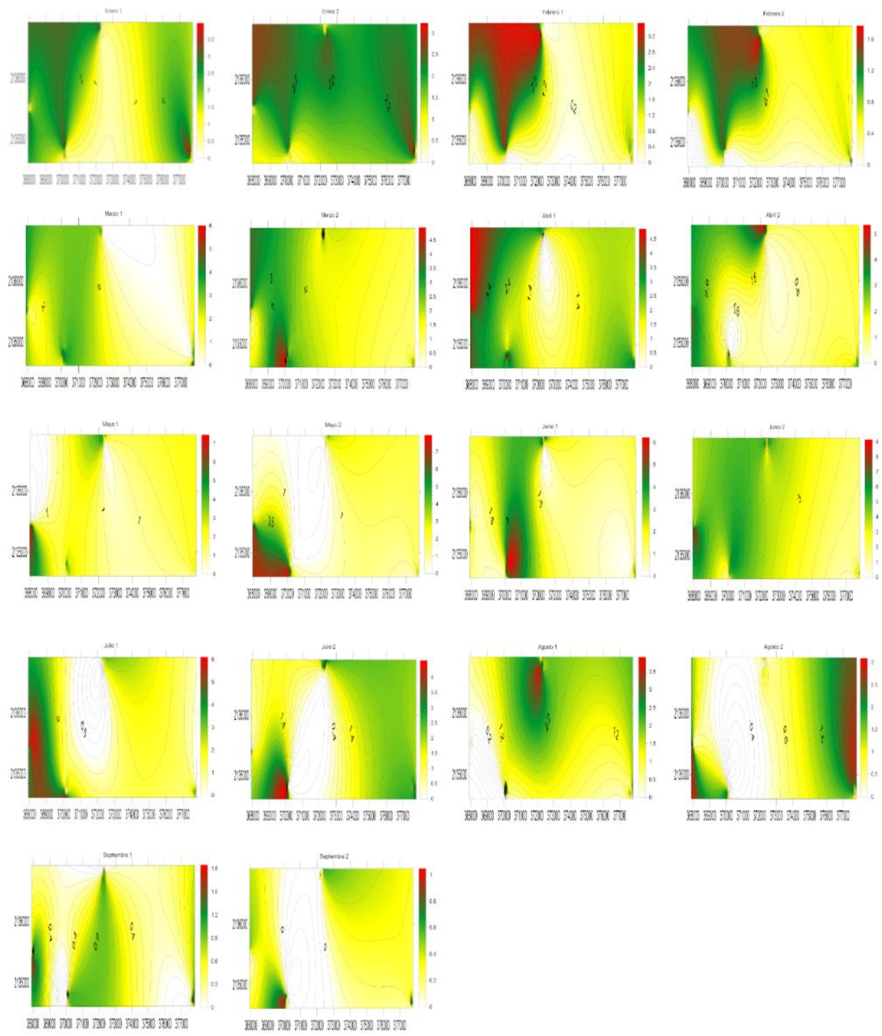

Figure 3. Density maps of *Copturus aguacatae* populations in avocado in Donato Guerra.

Infested area

In the municipality of Coatepec Harinas, the percentages of infestation of 100% only occurred in May and June; however, in July and August, high percentages were also obtained with a variation of 86% to 99% of infestation, on the other hand, the months in which low infestation levels were obtained were February (1) with 41% and October with 40% of infestation, it is worth mentioning that, in the second sampling of November and the whole month of December, the presence of *C. aguacatae* was not found, so no results of these samplings are shown.

For the municipality of Donato Guerra, the samplings of January (15), March (15) and June (15) were the ones in which 100% of infested area was obtained, in the other samplings the percentages of infestation decreased, with that obtained in March (1) being the lowest percentage, with 64% of infestation (the infestation ranges were between 64% the lowest value and 100% the highest value).

These percentages of infestation are important to determine the degree of incidence of the insect in the avocado plots and, in this way, take the necessary actions to carry out a management of the pest and, according to the months in which there is a greater or lesser percentage of infestation, the different control measures that help lower the populations of the pest insect must be applied.

Spatial and temporal stability

In the municipality of Coatepec Harinas, the comparisons between sampling dates indicated that March 01 *vs* March 15, March 15 *vs* April 01, April 15 *vs* May 01, May 01 *vs* May 15, May 15 *vs* June 01, June 01 *vs* June 15, July 15 *vs* August 01, August 01 *vs* August 15 resulted in an I_m index greater than 0, indicating that there was no significant difference, that is, a spatial association was detected between the maps compared, so it was possible to detect a short-term spatial-temporal stability of the populations of *C. aguacatae* between those dates compared. However, in the other comparisons made, it was not possible to detect spatial stability (Table 2).

For the municipality of Donato Guerra, it was only possible to detect spatial-temporal stability in the dates compared January 01 *vs* January 15, February 01 *vs* February 15, April 01 *vs* April 15, April 15 *vs* May 01 and June 01 *vs* June 15, since an Im index with values greater than zero was obtained, in the other dates compared, the values of this index were not greater than zero, so it is indicative that there is no spatial-temporal stability of *C. aguacatae* within the avocado orchards (Table 2).

Table 2. Comparison of maps with the I_m index of SADIE for the municipalities of Coatepec Harinas and Donato Guerra.

Compared samplings	Coatepec Harinas	Donato Guerra
	Im	Im
January 01 *vs* January 15	-0.24	0.29
January 15 *vs* February 01	-0.15	-1.77
February 01 *vs* February 15	-2.45	2.75
February 15 *vs* March 01	-0.19	-0.46
March 01 *vs* March 15	1.27	-0.18
March 15 *vs* April 01	1.68	-3.28
April 01 *vs* April 15	-0.33	2.08
April 15 *vs* May 01	1.67	4.05
May 01 *vs* May 15	2.06	-0.44
May. 15 *vs* June 01	1.2	-0.21
June 01 *vs* June 15	3.11	2.93
June 15 *vs* July 01	-3.82	-2.86
July 01 *vs* July 15	-1.6	3.61
July 15 *vs* August 01	2.23	-1.13
August 01 *vs* August 15	1.91	-1.7

Compared samplings	Coatepec Harinas	Donato Guerra
	Im	Im
August 15 *vs* September 01	-3.44	-2.94
September 01 *vs* September 15	-1.56	-2.07
September 15 *vs* October 01	-3.62	-
October 01 *vs* October 15	-2.88	-
October 15 *vs* November 01	-1.36	-

Values of Im >0 indicate spatial association.

The short-term spatial-temporal stability in the populations of *C. aguacatae* was detected only in some comparisons between dates sampled for the two municipalities, on the other dates no spatial stability was found. This phenomenon can be explained because the environmental conditions were very variable during the sampling season, which favored the movement of *C. aguacatae* to certain areas where there were possibly micro climatic conditions that favored its development, another possibility may be that the size of the plot's influences, in which it is not possible to detect similarities in the way the insect aggregates.

Discussion

The use of the SADIE methodology has had positive results in the study of biological organisms and their spatial distribution, as indicated by (Ferguson *et al*., 2000; Thomas *et al*., 2001; Alexander *et al*., 2005; Winder *et al*., 2005; Conrad *et al*., 2006; Ramírez-Dávila and González-Andujar, 2007). The spatial distribution of *Copturus aguacatae* within the avocado orchards in the municipalities of Donato Guerra and Coatepec Harinas in the State of Mexico indicated that *C. aguacatae* appeared in the form of patches in specific geographical points within the crop for the two municipalities studied, these results agree with what was determined by Reay-Jones (2012), who found that the populations of *Oulema melanopus* Linnaeus (leaf beetle in wheat) are found in an aggregate spatial structure, both eggs, larvae and adults. Maldonado *et al*. (2017) showed that thrips populations are distributed in aggregate form in different aggregation centers within avocado orchards, on the other hand, Ramírez *et al*. (2013) also determined the aggregate spatial structure of thrips in different aggregation centers in avocado plantations in Michoacán, Mexico.

This type of work has also been successfully applied in studies of parasitic plants, as was done by Ramírez and Porcayo (2009), who studied the spatial distribution of *Arceuthobium* sp. (dwarf mistletoe) using SADIE indices and found an aggregate spatial structure distributed in different aggregation centers, and in corn diseases as indicated by Ramírez *et al*. (2011), who found that *Sporisorium reilianum* ((Kühn) Langdon and Fullerton) is distributed in corn plots in an aggregate manner, being located in several aggregation centers.

The spatial behavior of the populations of *C. aguacatae* in aggregate form allows suggesting that they can be managed and therefore reduced by applying control measures to the aggregation centers or specific points in which the pest is located and thus avoid generalized or full coverage applications, which leads to savings in inputs, visualizing the foci of infestation through the generated maps. This is consistent with Rong *et al*. (2006); Esquivel and Jasso (2014), who, respectively, proposed the management of *Locusta migratoria manilensis* Linnaeus (migratory locust) and *S. exigua* Hübner (armyworm) in corn at specific points of presence of the pest.

With the use of infestation maps, it can be suggested to producers to carry out an integrated management of the pest, in which control methods can be used, such as biological control where entomopathogenic fungi such as *Beauveria bassiana* Bassi or *Metarhizium anisopliae* Sorokin can be used (Coria *et al*., 2007), parasitoid insects such as *Urosigalphus avocadoae* Gibson (Hernández *et al*., 2009) can also be used, which has high specificity of larvae, so it is useful in the management of these populations.

Both entomopathogenic fungi and parasitoids would be applied in the months where adult populations are smaller and in this way regulate future populations, if these alternatives do not work effectively, cultural control is used, with the use of sanitary pruning in which the branches have to be incinerated to eliminate eggs and larvae of the pest and taking into account that avocado producers in the State of Mexico tend to reduce the use of agrochemicals, chemical control with the product Malathion in foliage applications would be taken as a last option.

The calculation of the infested area based on the density maps indicates that the pest was not distributed in 100% of the studied area, so the infestation of the insect does not occur uniformly. These types of results agree with those found by Quiñones *et al*. (2015), who found that thrips populations in gladiolus did not infest 100% of the plot and these were in aggregate form at specific points of infestation, Esquivel and Jasso (2014) conducted a study of spatial distribution and mapping of armyworm in six localities in the State of Mexico in corn and found that in none of the localities, there was an infestation area of 100% and the maximum percentage reached was 94%; Jimenez *et al*. (2013) reported that populations of *Frankliniella occidentalis* Pergande (Thysanoptera: Thripinae) in husk tomato are not distributed in all plots.

Contrary to this, Jiménez *et al*. (2008) determined the spatial distribution and mapping of *Curculio elephas* Gyllenhal (Coleoptera: Curculionidade) in *Quercus ilex* Linnaeus, they made four density maps, one for each year, using the inverse distance method as interpolator of the Surfer 7 program, these maps indicate that the insect was located throughout the plot with an aggregate spatial distribution.

The spatial-temporal stability of the spatial distribution of *C. aguacatae* in avocado was obtained with the I_m index of SADIE, with which comparisons were made between dates sampled for the two municipalities, in which spatial stability was found only in the months of greatest infestation, finding spatial stability of pests within a crop is interesting since in this way a prediction can be made and, with it, direct control measures towards future areas of infestation and specific geographical points that require management and thus open the door to precision agriculture techniques in pest control.

These types of studies have also been conducted by Maldonado *et al*. (2017), who found spatial stability of thrips in avocado only on certain sampling dates, these dates correspond to the months in which the highest incidence was found. Esquivel and Jasso (2014) found that the armyworm in corn has short-term spatial-temporal stability. Ramírez *et al*. (2011) found that *Sporisorium reilianum* in corn had spatial stability at some sampling dates and at others such stability was not found. Ramírez and Porcayo (2009) found that the larvae of the green mosquito *Jacobiasca lybica* Bergenin & Zanon (Homoptera: Cicadellidae) had short-term spatial and temporal stability in a vineyard in Andalusia Spain.

Conclusions

It was possible to determine the spatial distribution of *Copturus aguacatae* within the avocado orchards in the municipalities of Donato Guerra and Coatepec Harinas in the State of Mexico, using the SADIE indices (Ia and Ja), which indicated that *C. aguacatae* appeared in the form of patches in specific geographical points within the crop.

The use of this type of techniques to establish the spatial structure of pest insects is of great importance, since, in this way, the population distribution and fluctuation of organisms within crops can be known. The foregoing can help the implementation of integrated management programs of the studied pest and be able to direct the different control measures, whether biological, cultural, physical, chemical, etc., towards specific areas of infestation, which will result in the reduction of the use of agrochemicals, less environmental impact, also prevent pests from generating resistance and producers will benefit from having a greater economic benefit.

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