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Variabilidad espacial de *Mycena Citricolor*: Berkeley y Curtis, 1887, en dos municipios cafetaleros del Estado de México

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Spatial variability of Mycena Citricolor Berkeley and Curtis, 1887, in two coffee-growing municipalities of the State of Mexico

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Abstract:

Coffee cultivation is one of the most important crops in the world, one of the main diseases of coffee is rooster's eye, at high infestation rates can cause leaf defoliation and low crop yields, the objective of the present study was to determine the type of spatial variability of the disease “rooster's eye” caused by the fungus Mycena citricolor Berkeley & Curtis (Agaricales: Mycenaaceae), in the coffee crop, using spatial statistics (Spatial Analysis by Distance Indexes “SADIE” and Geostatistics), the experiment was conducted in the municipalities of Sultepec and Temascaltepec in the State of Mexico from March to August 2022, where two plots of 0.5 hectares per municipality were established in 50 quadrants, taking four plants per quadrant, evaluating 36 leaves per plant, from which it was obtained that the presence of the disease is present in all months, however, the percentage of infestation varied according to climatic conditions such as temperature, relative humidity and precipitation, with respect to the SADIE indices, the Ia and *Ja* values indicate a spatial distribution in aggregates distributed in several centers, with respect to geostatistics, all the theoretical models of the semivariograms were adjusted to the spherical model, and maps were generated using the ordinary kriging method to determine the spatial behavior of rooster's eye in the different samplings, the use of spatial statistics helps to determine the behavior of the disease being a good tool that can change the strategies of conventional or traditional agriculture, since the application of inputs is not carried out in a homogeneous manner, but rather according to the quantification of spatial and temporal variability, allowing producers to carry out integrated disease management programs for the benefit of the environment.

KEYWORDS

Rooster's eye, SADIE, geostatistics, spatial distribution, coffee, semivariogram, nugget, plateau, index

List of Abbreviations

SADIE	Spatial Analysis By Distance Indixies
Co	Nugget
C	Plateau
MEE	Mean Estimation Errors
ESM	Mean Square Error
RMSE	Dimensionless Mean Square Error

1 Introduction:

Coffee plays a fundamental role in social relations and has become one of the most important commodities in the Latin American market, coffee growing is a pillar of the economy in many tropical countries [1]. Worldwide coffee is one of the most consumed and valued products, in 2013 total production reached 8.7 million kilograms while in 2015 global consumption was 9.1 billion kilograms, coffee is the second most important product in the world, after oil, generating annual earnings of close to 10 billion dollars [2]. This crop has a significant impact on the world economy and continues to be an important source of income for many countries. Currently, 70 countries produce coffee worldwide. Three of them account for around 55% of world production: Brazil (32-34%), Vietnam (12-13%) and Colombia (8-9%), The International Coffee Organization (ICO) estimates that in 2010, the sector employed 26 million people in 52 producing countries [3].

Mexico produces coffee of the arabica variety, with a national production of approximately 944 thousand tons of coffee beans annually. (pino et al.,2022) [4]. Coffee production in Mexico is fundamental for small coffee growers, since the production and sale of grain has historically generated economic income for subsistence and a viable alternative to improve the living conditions of this segment of society [5]. However, coffee cultivation in Mexico faces challenges that affect coffee growers, such as the “rooster's eye” disease caused by the fungus *Mycena citricolor* Berkeley & Curtis (Agaricales: Mycenaaceae), this disease causes defoliation and a decrease in coffee yield, although it does not kill the plant [6]. The disease is more intense in times of rain, high relative humidity, cloudiness and low temperatures [7]. The disease infestation begins with circular or oval spots on the upper side of the leaf, develop from dark brown spots of undefined border, lesions may appear light brown, grayish or reddish brown in color [8], severe defoliation can affect both young and old leaves, resulting in fruit drop, the death of primary and secondary shoots and stems and in more severe cases the death of the plant [9], the economic impact of this disease is significant, if not prevented and controlled in time, can generate losses of 75 %, in tropical zones [10]. In order to control the disease, it is essential to carry out cultural management, such as pruning, in order to stimulate the growth of new tissues, improve crop yields, facilitate internal aeration of plants and control fungal diseases in coffee plantations [11]. Likewise, the monitoring of rooster's eye is an important strategy for good management and control of this type of phytosanitary problems, for proper monitoring, it is necessary to establish sampling points that generate reliable data for the preparation of maps indicating the distribution of these organisms [40]. In this context, the present work used spatial statistical methods (SADIE Index and Geostatistics), these methods provide direct measures of variability and spatial dependence in real time. The SADIE (Spatial analysis by distance indices) method is an important tool that allows us to calculate special patterns in data sets with minimum effort, allowing a uniform distribution of the study variable to be obtained at all sampling points [12]. In addition, the SADIE Indices allow the analysis of spatial patterns of individual variables and of pairs of variables that can be taken at the same coordinates, which facilitates the analysis of long-term variables [13]. One of the main advantages of using SADIE is the ability to be able to use count data and consider the location of two dimensions, which provides more robust results than if only the frequencies per sample unit are considered [14]. On the other hand, geostatistical analyses provide an important tool for interpreting the spatial behavior of the study variables. [15]. In this context, the geostatistical analysis starts with the structural analysis, which corresponds to the analysis of the experimental semivariogram, being able to obtain a theoretical semivariogram, Facilitating the creation of maps that are useful for visualizing the spatial location of an object. facilitating real-time decision making [16]. The purpose of this research was to determine the type of spatial variability of the disease “eye of rooster” caused by the fungus Mycena citricolor Berkeley & Curtis (Agaricales: Mycenaaceae), in coffee cultivation in two municipalities of the State of Mexico, using spatial statistics (Spatial Analysis by Distance Indexes “SADIE” and Geostatistics). In addition, density maps of the spatial distribution of rooster's eye disease were created, identifying the area infested by this organism.

2 Materials and methods

The present study was conducted in four coffee plots located in two municipalities of the State of Mexico (Sultepec and Temascaltepec), the municipality of Sultepec is located in the eastern region of the State of Mexico, at an altitude of 2,297 meters above sea level, its geographic coordinates are longitude 99°57'55“, latitude 18°51'26”, regarding the municipality of Temascaltepec, it is also located in the eastern region of the State of Mexico, at an altitude of 2,200 meters above sea level, its geographic coordinates are: longitude 100° 02' 29", latitude 19° 02' 36", these data are provided by the National Institute of Statistics and Geography (INEGI, 2020) [17]. The selected plots had an average age between 5 and 15 years, with Caturra and Typica coffee varieties, the agronomic management of the plots was similar.

The plots were established on an area of 0.5 hectares each, for sampling the quadrant methodology was used, which consists of dividing each plot into 50 quadrants, in each quadrant, four plants were selected to carry out the sampling, each plant was divided into three strata (high, medium and low) and four bandolas were selected per stratum, one for each cardinal point, in each bandola three leaves were selected at random obtaining a total of 36 leaves per plant where the presence or absence of the fungus in each leaf was recorded [4]. In addition, each plant was georeferenced using a Trimble SPS361 receiver, allowing to obtain the precise coordinates to subsequently analyze the spatial distribution of fungus [18, 13]. Sampling was carried out every two weeks from March to August 2022, which allowed the evaluation of the dynamics of the fungus at different times of the coffee cycle. The data obtained were subjected to a kurtosis test and coefficient of variability to determine if they were normal [13].

2.1 Spatial Analysis by Distance indixies (SADIE).

SADIE is a spatial distribution analysis software tool developed by Dr. Joe N. Perry, Department of Entomology and Nematology, Rothamsted Experimental Station (UK), its main objective is the creation of spatial models describing the distribution of individuals in a given area, using an index associated with the aggregation of a random deviation test in an algorithm [19] [20] for the calculation of the distance-based index for regularity the index Ia and Ja is used which is based on the distance of the clustering in the disease population, its count is contained in the aggregation index Ia with its Pa (probability of aggregation) and aggregation index Ja, with its relation called Qa (probability of clustering), the sample is spatially aggregated if $Ia > 1$, the sample is spatially random if $Ia = 1$, and the sample is regular if $Ia < 1$, on the other hand, if the index $Ja = 1$ it represents spatially random data and $Ja < 1$ regular samples. Los valores del índice Ja ayudan a corroborar los resultados obtenidos con el índice Ia [21] El programa utilizado para poder determinar los valores y también las probabilidades en ambos índices es SADIE 1.22 [22].

2.2 Geostatistics

To evaluate the spatial structure of the sampling data, experimental semivariograms were performed using Variowin 2.2 software (Software for 2D spatial data analysis, New York, USA). This software allows exploring the special variability of the samples Pannatier, Y. [23]. In each experimental semivariogram, they are fitted in different theoretical models to describe spatial variability, such as the spherical, Gaussian, exponential model, among others, during the interactive fitting process the following parameters were evaluated nugget (Co) represents small-scale random variability, plateau (C) indicates large-scale structured variability and range or range (a) defines the maximum distance of the spatial correlation [56, 4]. In addition, the following statistical parameters were evaluated to validate the models, the mean estimation errors (MEE), the mean square error (MSE) and the dimensionless mean square error (RMSE) to validate the model and with them to assess accuracy [24].

2.3 Spatial dependence level.

Spatial dependence allows to describe the distribution of values in space, to quantify the correlations or redundancies of information between values measured at different sites Emery [25]. In order to evaluate the relationship between the data, the level of spatial dependence must be determined where the nugget and pot effect relationship is used and expressed as a percentage.Where if the percentage is less than 25% the spatial dependence is high, if the percentage is higher than 26 % to 75 % it is moderate and 76% the spatial dependence is low [26].

2.4 Mapping and infested area

For the creation of accurate and detailed maps, the interpolation method known as ordinary kriging was used, this method allows estimating values at non-sampled points in an impartial and objective manner, providing a valuable tool for the spatial representation of variables, the main advantages of ordinary kriging is that it provides a measure of the uncertainty error associated with the estimated surface, this allows the reliability of the results to be assessed, providing a more complete view of the spatial distribution of the variable in the study[27]. This technique allows the unbiased estimation of values associated with points that were not sampled. Vieira [28]. The Surfer 16 program (Surface Mapping System, Golden Software Inc., Golden, CO) was used to generate the maps. (Martínez, et.al, .2023) [29]. With the generated maps, the infestation percentage is calculated [30, 31].

3 Results

3.1 Measurement of climatic factors

Data collected in the municipalities of Sultepec and Temascaltepec revealed that the highest incidence of the disease occurs during the months of July and August. on the other hand, the months of May and June showed less presence of the disease, due to high temperatures and low rainfall, understanding the phenology of the crop and local climatic conditions allows forecasting periods of high disease incidence and developing management strategies and timely control, this can prevent economic losses due to low crop yields. With data obtained from the Sultepec and Temascaltepec weather stations, we can indicate that in the municipality of Sultepec the average temperatures ranged between 22.5ºC in March and 26ºC in August, compared to the case of the municipality of Temascaltepec, average temperatures varied between 22.8ºC and 23.9ºC during the same months (Table 1), regarding the percentage of relative humidity in the municipality of Sultepec, it ranged between 44.2% (minimum) and 76.2% (maximum) in the months of May and August, respectively, while for the municipality of Temascaltepec the relative humidity was 35% in March and 95% in August (Table 1), finally, with respect to precipitation, the following data were obtained in the municipality of Sultepec, rainfall in the month of March was 0 Pmm and 268 Pmm in the month of June, in the municipality of Temascaltepec, rainfall was 6.21 Pmm in March and 229.92 Pmm in July (Table 1). In order to have an efficient management of coffee cultivation, it is necessary to highlight the importance of considering climatic factors and the need to constantly monitor weather conditions in order to implement control measures.

Table 1: Temperature (T), Humidity percentage (H %) and Precipitation (P mm) of the municipalities of Sultepec and Temascaltepec, State of Mexico, [30]

Sultepec				Temascaltepec			
Months	**T**	**H%**	**P mm**	**Months**	**T**	**H%**	**P mm**
March	26	48.8%	0	March	23.9	35%	6.21
April	28.2	50.3%	45.6	April	25.3	35.4%	6.6
May	28.1	44.2%	55	May	25.1	84.2%	143.21
June	25	69.2%	268	June	23.5	56.1%	32.31
July	23	75.1%	200.11	July	22.8	77.9%	229.92
August	22.5	76.2%	244.6	August	22.8	93%	211.72

3.2 SADIE (Spatial Analysis by Distance Indexes).

In relation to the values of the *Ia* index in the municipality of Sultepec and Temascaltepec, it was identified that the spatial distribution of the disease is distributed within the plots in an aggregated form, the values of the *Ia* index in the municipality of Sultepec varied between 1.25 and 1.85 while in the municipality of Temascaltepec the *Ia* was between 1.25 and 1.79 (Table 2), indicating that the total of the samples taken with respect to the *Ia* index was significantly higher than one, with respect to its probability *Pa* indicated that the spatial distribution of the disease is of an aggregate type. The *Ja* index in the municipality of Sultepec is between 1.03 and 1.19, while in the municipality of Temascaltepec, it is between 1.03 and 1.19, the values are between 1.04 and 1.19, with respect to their probability Qa indicating that the distribution of Mycena citricolor occurs in several aggregation centers Table 2.

(Table 2) Value of indices *Ia* and *Ja* and their respective probabilities *Pa* and *Qa* in rooster's eye disease *Mycena citricolor* Berkeley & Curtis (Agaricales: Mycenaaceae) in the municipalities of Sultepec and Temascaltepec, State of Mexico.

Sultepec plot 1	I_a	P_a	J_a	Q_a	*%SI*	**Sultepec plot 2**	I_a	P_a	J_a	Q_a	*%SI*
March 1	1.31	0.012s	1.07	0.213ns	95	March 1	1.33	0.011s	1.08	0.164ns	89
March 2	1.39	0.003s	1.04	0.128ns	95	March 2	1.27	0.016s	1.15	0.257ns	90
April1	1.45	0.014s	1.17	0.271ns	96	April1	1.57	0.019s	1.05	0.195ns	90
April 2	1.25	0.010s	1.12	0.161ns	95	April 2	1.50	0.009s	1.12	0.141ns	90
May 1	1.51	0.017s	1.15	0.178ns	96	May 1	1.71	0.017s	1.14	0.311ns	88
May2	1.36	0.002s	1.02	0.293ns	96	May2	1.28	0.008s	1.19	0.277ns	91
June 1	1.49	0.015s	1.13	0.227ns	95	June 1	1.85	0.010s	1.06	0.157ns	90
June 2	1.63	0.018s	1.18	0.133ns	95	June 2	1.80	0.013s	1.11	0.328ns	90
July 1	1.28	0.013s	1.11	0.238ns	94	July 1	1.73	0.015s	1.17	0.209ns	89
July 2	1.59	0.016s	1.19	0.201ns	95	July 2	1.46	0.010s	1.09	0.282ns	90
August 1	1.33	0.011s	1.14	0.142ns	94	August 1	1.66	0.012s	1.13	0.179ns	91
August 2	1.42	0.005s	1.03	0.170ns	96	August 2	1.61	0.014s	1.10	0.350ns	90

Temascaltepec plot 1	I_a	P_a	J_a	Q_a	%SI
March 1	1.44	0.009s	1.15	0.152ns	85
March 2	1.27	0.012s	1.08	0.237ns	84
April1	1.58	0.015s	1.13	0.133ns	84
April 2	1.73	0.006s	1.10	0.196ns	83
May 1	1.40	0.019s	1.18	0.273ns	84
May2	1.55	0.014s	1.06	0.301ns	83
June 1	1.76	0.005s	1.09	0.369ns	76
June 2	1.67	0.013s	1.19	0.326ns	77
July 1	1.62	0.018s	1.12	0.145ns	76
July 2	1.51	0.017s	1.04	0.284ns	77
August 1	1.25	0.004s	1.17	0.246ns	76
August 2	1.32	0.011s	1.06	0.169ns	76

Temascaltepec plot 2	I_a	P_a	J_a	Q_a	%SI
March 1	1.26	0.007s	1.06	0.160ns	88
March 2	1.44	0.010s	1.10	0.312ns	89
April1	1.70	0.015s	1.05	0.208ns	89
April 2	1.39	0.012s	1.15	0.273ns	88
May 1	1.63	0.006s	1.13	0.348ns	89
May2	1.48	0.008s	1.07	0.371ns	90
June 1	1.30	0.017s	1.19	0.190ns	89
June 2	1.73	0.011s	1.18	0.388ns	88
July 1	1.77	0.013s	1.12	0.259ns	89
July 2	1.32	0.009s	1.16	0.367ns	89
August 1	1.79	0.019s	1.14	0.172ns	89
August 2	1.52	0.014s	1.08	0.297ns	90

ns: not significant at 5%; s: significant at 5%; ns

3.3 Geostatistics

With the biweekly sampling, it was possible to model and map the spatial behavior of *Mycena citricolor* in the four coffee plots of the present study, the percentage of infestation will also be calculated for each sampling done per plot. Among the results, 48 experimental semivariograms were obtained, as well as 48 theoretical semivariograms, the geostatistical parameters, allowing the validation of the experimental semivariograms, which were fully adjusted to the spherical model, as detailed in Table 3 The range indicates the maximum distance at which there is a spatial relationship between the data; the range values presented for the plots in the municipality of Sultepec and Temascaltepec show the following values, in the case of the municipality of Sultepec in plot one, the range or reach was between 7.37 and 14.83 meters for the months of March and April, respectively, These values are shown in Table 3. In the semivariograms of the theoretical models obtained, it was determined that the nugget effect was equal to zero in all the samples taken, as detailed in Table 3, this value represents the experimental error indicating that the sampling scale was adequate, finally, the values of the plateau for plot one in the municipality of Sultepec ranged between 4.83 and 24.73 in the months of May and August, respectively (Table 3).

3.4 Level of spatial dependence

The level of spatial dependence consists of dividing the value of the nugget effect by the value of the plateau, the level of spatial dependence of Mycena citricolor populations in all cases was high (Table 3), indicating that the disease populations depend on each other and their level of aggregation is high.

Table 3: Parameters of the theoretical models fitted to the semivariograms of the disease samples**,** Rooster's eye *(Mycena citricolor* Berkeley & Curtis; Agaricales: Mycenaaceae) in coffee plots in the municipalities of Sultepec and Temascaltepec, State of Mexico.

Sultepec plot 1	Half	Variance Sample	Model	Nugget	Meseta	Plateau	S.D.
March 1	**6.86**	**5.09**	**Spherical**	**0**	**9.767**	**13.2**	**high**
March 2	**6.45**	**4.24**	**Spherical**	**0**	**12.91**	**7.37**	**high**
April1	**5.45**	**3.39**	**Spherical**	**0**	**5.93**	**14.18**	**high**
April 2	**5.11**	**3.33**	**Spherical**	**0**	**5.74**	**14.83**	**high**

May 1	4.73	2.53	Spherical	0	4.83	13.75	high
May2	4.99	2.96	Spherical	0	5.46	13.61	high
June 1	5.38	4.59	Spherical	0	10.08	12.74	high
June 2	5.86	7.51	Spherical	0	16.49	13.63	high
July 1	6.56	8.55	Spherical	0	19.38	11.98	high
July 2	7.43	10.15	Spherical	0	19.15	12.10	high
August 1	7.81	10.44	Spherical	0	22.79	13.48	high
August 2	8.23	11.57	Spherical	0	24.73	13.69	high

Sultepec plot 2	half	Variance Simple	Model	Nugget	Meseta	Plateau	S.D.
March 1	3.86	4.48	Spherical	0	9.40	8.74	high
March 2	3.60	4.35	Spherical	0	9.29	9.40	high
April1	3.33	3.77	Spherical	0	8.59	9.56	high
April 2	3.02	3.17	Spherical	0	6.01	9.09	high
May 1	2.89	2.83	Spherical	0	7.56	9.15	high
May2	3.08	3.34	Spherical	0	6.84	9.22	high
June 1	3.72	4.68	Spherical	0	8.30	9.12	high
June 2	4.35	7.85	Spherical	0	13.52	9.34	high
July 1	4.86	9.76	Spherical	0	18.75	8.65	high
July 2	5.41	12.02	Spherical	0	22.75	9.15	high
August 1	5.73	12.94	Spherical	0	25.22	10.16	high
August 2	6.01	14.28	Spherical	0	28.45	9.11	high

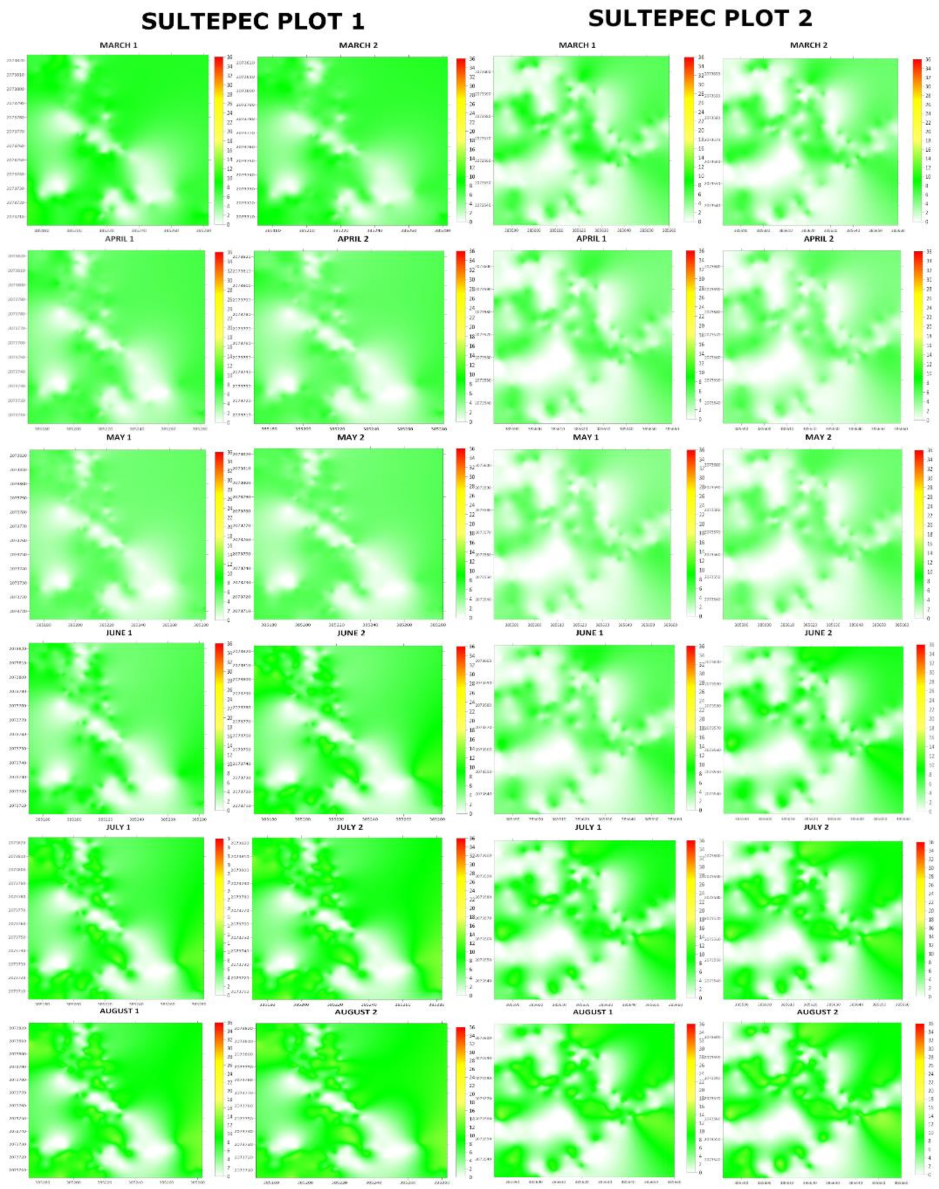
Temascaltepec Plot 1	Half	Variance Simple	Model	Nugget	Meseta	Plateau	S.D.
March 1	3.86	4.48	Spherical	0	9.40	8.74	high
March 2	3.60	4.35	Spherical	0	9.29	9.40	high
April1	3.33	3.77	Spherical	0	8.59	9.56	high
April 2	3.02	3.17	Spherical	0	6.01	9.09	high
May 1	2.89	2.83	Spherical	0	7.56	9.15	high
May2	3.08	3.34	Spherical	0	6.84	9.22	high
June 1	3.72	4.68	Spherical	0	8.30	9.12	high
June 2	4.35	7.85	Spherical	0	13.52	9.34	high
July 1	4.86	9.76	Spherical	0	18.75	8.65	high
July 2	5.41	12.02	Spherical	0	22.75	9.15	high
August 1	5.73	12.94	Spherical	0	25.22	10.16	high
August 2	6.01	14.28	Spherical	0	28.45	9.11	high

Temascaltepec Plot 2	Half	Variance Simple	Model	Nugget	Meseta	Plateau	S.D.
March 1	6.16	5.33	Spherical	0	7.63	11.87	high
March 2	6.09	4.5	Spherical	0	6.47	11.96	high
April1	5.56	4.23	Spherical	0	6.27	11.34	high
April 2	5.23	3.51	Spherical	0	5.16	11.56	high
May 1	4.96	3.29	Spherical	0	4.75	12.11	high
May2	4.49	3.27	Spherical	0	4.59	10.91	high
June 1	5.89	5.59	Spherical	0	9.29	12.58	high
June 2	6.52	7.65	Spherical	0	13.60	11.61	high
July 1	6.91	8.04	Spherical	0	14.33	11.62	high
July 2	7.77	9.20	Spherical	0	16.28	12.86	high

August 1	**8.321**	**10.09**	**Spherical**	**0**	**17.07**	**12.11**	**high**
August 2	**8.98**	**11.27**	**Spherical**	**0**	**18.56**	**12.16**	**high**

3.5 Surface estimation (maps).

Using the Ordinary Kriging method, 48 incidence maps were generated, to evaluate and visualize the spatial distribution of the rooster's eye disease in coffee plots, these maps reveal the presence of well-defined aggregation points indicating specific foci within the plots where the disease is concentrated, likewise to visually represent the behavior of the infestation level on the maps, different colors were used, white indicating no disease presence in contrast to red which represents the highest aggregation (Figure 1), with the maps generated, it is possible to identify the biweekly behavior of the disease in the coffee crop with respect to the samplings carried out; this information is crucial for the agricultural management of the coffee crop.



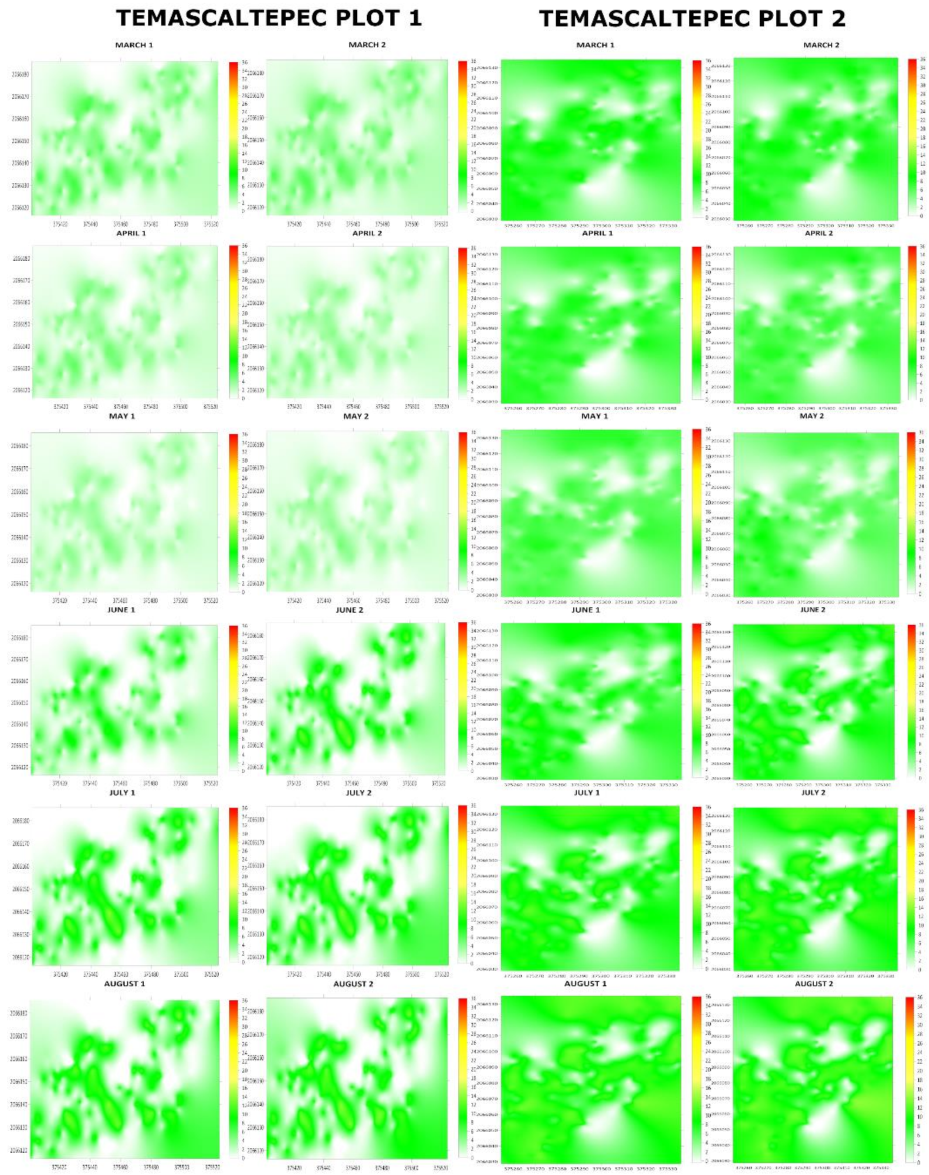


Figure 1: Modeling and mapping of the spatial distribution of rooster's eye (Mycena citricolor Berkeley & Curtis; Agaricales: Mycenaaceae) in coffee plots in the municipalities of Sultepec and Temascaltepec, State of Mexico.

3.6 Infested surface

The percentage of infestation of *Mycena citricolor* was identified through the generation of maps using the Ordinary Kriging Technique, noting that in no case was there a 100% infestation although in some cases the percentage of infestation is strong, with respect to the municipality of Sultepec, in plot one there was a percentage of infestation that varied from a minimum of 94% in July and August to a maximum of 96% as detailed in (Table 4), on the other hand, in the municipality of Temascaltepec in plot two, there was a variation in the percentage of infestation that ranges from 88 % in May to 91 % in August, as shown in (Table 4).

Table 4: Percentage of infestation and non-infestation of walleye in Sultepec and Temascaltepec.

Sultepec					
Parcela 1	**Infestad %**	**Not infested %**	**Plot 2**	**Infestad %**	**Not infested %**
March 1	95 %	5 %	March 1	89 %	11 %
March 2	95 %	5 %	March 2	90%	10 %
April1	96 %	4 %	April1	90 %	10 %
April 2	95 %	5 %	April 2	90 %	10 %
May 1	96 %	4 %	May 1	88 %	12 %
May2	96 %	4 %	May2	91 %	9 %
June 1	95 %	5 %	June 1	90 %	10 %
June 2	95 %	5 %	June 2	90 %	10 %
July 1	94 %	6 %	July 1	89 %	11 %
July 2	95%	5 %	July 2	90 %	10 %
August 1	94 %	6 %	August 1	91 %	9 %
August 2	96 %	4 %	August 2	90 %	10 %

Temascaltepec					
Parcela 1	**Infestad %**	**Not infested %**	**Parcela 2**	**Infestad %**	**Not infested %**
March 1	85 %	15 %	March 1	88 %	12 %
March 2	84 %	16 %	March 2	89 %	11 %
April1	84 %	16 %	April1	89 %	11 %
April 2	83 %	17 %	April 2	88 %	12 %
May 1	84 %	16 %	May 1	89 %	11 %
May2	83 %	17 %	May2	90 %	10 %
June 1	76 %	24 %	June 1	89 %	11 %
June 2	77 %	23 %	June 2	88 %	12 %
July 1	76 %	24 %	July 1	89 %	11 %
July 2	77 %	23 %	July 2	89 %	11 %
August 1	76 %	24 %	August 1	89 %	11 %
August 2	76 %	24 %	August 2	90 %	10 %

4 Discussion

4.1Measuring climatic factors

The data obtained allow us to understand the climatic factors that favor the presence of the rooster's eye disease in coffee crops, like pests, this disease requires specific conditions in order to develop, so the epidemiological triangle indicates that there must be a dynamic balance between three elements: host (coffee plant), agent (*Mycena citricolor*) and environment, According to [31] and [32], *Mycena citricolor)* occurs when the relative humidity exceeds 75 %, and the temperature is between 20 and 22 ºC, on the other hand, Acuna,V. [33] points out that for the disease to develop and spread, relative humidity must be higher than 80 %, with a minimum temperature of 20ºC, [34] also identifies the following agronomic factors associated with the disease: excess shade, high relative humidity and lack of ventilation in the crop, Finally, [35] points out that low altitudes and temperatures ranging from 22 to 24ºC can increase the presence of (*Mycena citricolor*) disease.

4.2 SADIE (*Spatial Analysis by Distance Indixes).*

The results obtained with indices *Ia* and *Ja* with SADIE allow us to conclude that the spatial distribution of rooster's eye disease is of an aggregated type, characterised by the presence of several centres of aggregation, this can be clearly observed in the maps obtained with the ordinary Kriging methodology (Figure 1), in this sense [36] suggests that an aggregate distribution allows the implementation of agronomic management methods, more environmentally friendly, as the spatial variability is known and targeted actions can be taken, on the other hand, [37] points out in his work "larvae of Lepidoptera" that these show a spatial distribution in aggregates since the resulting values obtained with the SADIE methodology were 1.46 and 1.62 in the *Ia* and *Pa* indices, respectively, on the other hand, [38] points out that the impact of plant cover on the presence of biological control agents in vineyards has an aggregate spatial distribution in the plots, since the index *Ia* > 1. Similarly, with respect to the *Ja* index, [39] in his study of soldier worms, found *Ja* index values greater than one in the localities studied, which confirmed the aggregation of populations of fall armyworms, and also obtained maps with the Kriging method that show patches or groups of insect populations, Similarly,[40] found *Ja* index values greater than one in the distribution of leaf damage caused by red spider mites in avocado, suggesting the existence of several centers of aggregation of the pest within the plot, likewise there are more studies with findings of spatial distribution in phytosanitary problems in different crops and natural environments with indices *Ia* and *Ja* with SADIE , such as:[41] in their study of the population structure and spatial distribution of black oak, in forest fragments, [42] in work on the spatial distribution of thrips in avocado crops,[43], in his research on the spatial distribution of *Frankliniella occidentails* in blackberry (Rubus sp.) crops, among other studies.

4.3 Geostatistics

Geostatistics performs analysis and modeling of spatial variables with data at specific locations using coordinates [42], the use of geostatistics in the present work, allowed us to model the spatial structure of *Mycena citricolor*, adjusting in its totality the theoretical semivariograms to the spherical model, according to [44] in his work on Spatial modeling of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in peel tomato, the spherical model indicates the presence of the pest, suggesting the existence of aggregation centers that were originated by climatic conditions, , on the other hand [45] indicates that the spatial distribution with spherical models manifests patches or clusters at specific points within the study plots. Likewise, the cross-validation statistics approved the mathematical validation of the adjusted models, which is very important because it allows us to affirm that the results obtained are highly reliable. Regarding the nugget effect, it was equal to zero in all samples. Having a null nugget effect at the sampling sites allows us to affirm that the scale of the study was adequate and that there was no sampling error [46], [47], with the results obtained we can infer that the spatial structure, depends on climatic factors such as temperature, relative humidity and precipitation that are found according to the season of the crop in relation to its phenology [30, 31, 32, 33, 34]. On the other hand, the range in which the data are correlated was calculated in meters, this spatial correlation indicates that coffee plants at a certain distance from an infected plant are more likely to be infested than plants farther away (2024) [46],[48] indicates that the values of the incidence *Sporisorium reilianum* (Kühn) Langdon and Fullerton), range values in his study ranged from 143.24 to 1671.3 meters, Finally, Ruiz, E. G., [49] in the Geostatistical analysis of the spatio-temporal distribution of *"Lobesia Botrana"* (Lepidoptera: Tortricidae) in Roja Alta (Spain) indicates that in his study the range values varied between 7.9 and 28 kilometers. Using geostatistics, it was found that the geospatial structure of *Mycena citricolor* is aggregated; this type of information is useful to optimize the use of agricultural inputs based on the quantification of spatial and temporal variability, and to carry out management programs.

4.4 Level of spatial dependence

In all cases, there was high spatial dependence, a variable is considered to have strong spatial dependence if its value is less than 25 %, high spatial dependence ensures that the aggregation found will be maintained over time, creating stable ecological niches, likewise [50] mentions that in the spatial distribution of Thrips tabaci in Quibor that within their results points out that the nugget effect in relation to the plateau value was less than 25 % which indicates a strong spatial dependence in the results. On the other hand, [51], in his work on Spatial modeling of the dispersion of *Megalurothrips usitatus* (Bagnall) (Thysanoptera: Thripidae) in *Phaseolus vulgaris*, indicates that the spatial dependence was high in samples two to six and moderate in samples seven, eight and nine, showing that when the crop passes the flowering stage, the population density increases despite the application of management measures. Finally,[52] in Spatial distribution of *Bactericera cockerelli Sulc* egg populations, In the level of spatial dependence obtained a percentage of less than 25 % for all semivariograms, which would emerge that the egg populations depend on each other and that the level of aggregation is high.

4.5 Estimation of the infested area (maps).

Density maps were made using the ordinary Kriging technique, identifying that there are samples with a higher percentage of infestation, however, no case of *Mycena citricolor* infested 100% of the study plots, according to Lara Díaz 2019[53] the ordinary kriging method in the creation of spatial distribution maps, facilitating detection in areas of high infestation and optimizing integrated management efforts. On the other hand, [54] carried out a spatial analysis of the populations of *Scirtothrips perseae nakahara* in the avocado crop, identifying multiple aggregation centers, these are visualized on infestation maps, which can be used to implement control and prevention measures, on the other hand, [55] [56] indicate that the generation of maps through the ordinary kriging technique is useful to identify green areas with a high percentage of infestation, allowing a more effective control and a reduction in economic costs.

5 Conclusions

Rooster eye disease is present all year round, the incidence of the disease varies from month to month, this correlates to changes in temperatures and relative humidity, so it is important to continuously monitor the distribution of the disease and implement effective control measures.

In SADIE, indixes *Ia* and *Ja* in the samplings were significantly greater than one, which demonstrates that the distribution of the disease in the coffee crop is of an aggregate type and that it is arranged in several centers of aggregation.

On the other hand, geostatistics was able to explain the spatial distribution of *Mycena citricolor* , presenting itself with a spatial behavior in aggregates, being in specific centers, the spatial distribution was adjusted only to the spherical model, allowing to explain the spatial variability of the disease.

With the maps generated with the Krigeado technique, the aggregation centers of *Mycena citricolor* can be visualized as they interpolate and describe the spatial continuity, This allows us to know in real time how the spatial continuity is being carried out, having a predictive capacity, allowing us to carry out preventive and focused control actions, in order to maintain low levels of infestation.

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