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GEOTECHNOLOGIES APPLIED IN THE MONITORING OF MEALYBUGS IN THE CULTURE OF BLACK PEPPER

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VITÓRIA DA CONQUISTA – BA
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GEOTECHNOLOGIES APPLIED IN THE MONITORING OF MEALYBUGS IN THE CULTURE OF BLACK PEPPER

Dissertation presented to the State University of Southwest Bahia, as part of the requirements of the Graduate Program in Agronomy, area of concentration in Crop Science, to obtain the title of Master.

Advisor: Prof. Dr. Odair Lacerda Lemos

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I DEDICATE

First to God; to my parents (Silvio and Josefa), for all the support; family, friends, colleagues and life mentors.

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I DEDICATE

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RESUMO

FREIRE, D. S. GEOTECNOLOGIAS APLICADAS NO MONITORAMENTO DE COCHONILHAS NA CULTURA DA PIMENTA-DO-REINO. 2022, 57p. (Dissertação: Mestrado em Agronomia; Área de concentração: Fitotecnia)*

A pipericultura brasileira tem destaque no cenário mundial, sendo caracterizada pela importância socioeconômica que exerce, no entanto, o manejo da pimenta-do-reino ainda é pouco tecnificado no Brasil e há escassez de pesquisas para a cultura. Insetos, como as cochonilhas (Hemiptera: Coccoidea), têm dificultado o manejo fitossanitário. As cochonilhas destacam-se como uma espécie de praga de importância na pipericultura, algumas são transmissoras de virose e pode causar prejuízos à especiaria. Apesar dos danos e de sua importância fitossanitária, são poucos os estudos de tecnologias para o monitoramento de cochonilhas na pimenta-do-reino que auxiliam na tomada de decisão. Assim, este estudo objetivou avaliar o padrão de distribuição espacial e temporal de cochonilhas e características fitotécnicas da cultura da pimenta-do-reino com o uso de geotecnologias aplicadas, bem como relatar as espécies de cochonilhas que ocorrem na pipericultura no estado da Bahia. O primeiro estudo do padrão de distribuição espacial de infestação das cochonilhas na pimenta-do-reino indica ser aleatório e apresenta probabilidades de ocorrência mais favoráveis nas estações do verão e primavera, podendo ser períodos críticos para o manejo. As características fitotécnicas de área foliar, massa seca de pimenta-do-reino e espectrais de GLI indicaram ter zonas de manejo semelhantes. A espécie cultivada, *Piper nigrum,* é registrada pela primeira vez como hospedeira de *D. gracilis;* e *P. longivalvata* é relatada, no estado da Bahia, associada às plantas de pimenta-do-reino. Logo, as geotecnologias apresentaram ser potenciais ferramentas para o cultivo de pimenta-do-reino, atribuindo zonas de manejo, otimizando o monitoramento de cochonilhas e o acompanhamento do desenvolvimento da cultura.

Palavras-chave: Coccoidea; distribuição espacial; *Piper nigrum*; zonas de manejo.

ABSTRACT

FREIRE, D. S. GEOTECHNOLOGIES APPLIED IN MONITORING OF MEALYBUG IN THE BLACK PEPPER CULTIVATION. 2022, 57. (Dissertation: Master Science in Agronomy; Area of concentration: Crop Science)*

Brazilian pipericulture is prominent in the world scene, and is characterized by the socioeconomic importance it exerts, however, the management of black pepper is still little technical in Brazil and there is a scarcity of research for the black pepper crop, hindering phytosanitary management. The mealybugs stands out as a pest of importance in pipericulture, some species can be transmitting viruses and can cause too much damage to the spice. Despite its phytosanitary importance, there are few studies and technologies for the integrated management of mealybugs in black pepper, which help monitoring and decision-making. Thus this study showed: to report the first records of *Dysmicoccus gracilis* on *Piper nigrum* and, *P. nigrum* as a host plant of *Protopulvinaria longivalvata* in the state of Bahia. And, to evaluate the pattern of spatial and temporal distribution of cochineals and phytotechnical characteristics in the culture of black pepper with the use of applied geotechnologies. The cultivated specie *Piper nigrum* is recorded for the first time as host of *D. gracilis* and, *P. longivalvata* is reported associated instead in the state of Bahia, on black pepper plants. The first study of the spatial distribution pattern of mealybug infestation in black pepper indicates that it is random and has more favorable probabilities of occurrence in the summer and spring seasons, indicating that they are critical periods for management. The phytotechnical characteristics of leaf area, dry pepper weight, and GLI spectral, indicated similar management zones. Therefore, geotechnologies presented potential tools for the cultivation of black pepper, assigning management zones, optimizing the monitoring of mealybugs and monitoring the development of the crop.

Keywords: Coccoidea; spatial distribution; *Piper nigrum*; management zones.

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LIST OF ABBREVIATIONS AND INITIALS

%	Percentage
ºC	Degrees Celsius
AP	Precision Agriculture
a	Range
ADE	Spatial dependency evaluator
C	Partial Sill
C0	Nugget
Co+C	Partial
CP1	Main component 1
CP2	Main component 2
DPM	Dry Pepper Mass
GLI	*Green Leaf Index*
GSD	*Ground Sampling Distance*
IPM	Integrated pest management
IV	Vegetation Index
kg^{-1}	Kilograms
LA	Leaf Area
LST	*Land Surface Temperature*
m^2	Square meters
mm	Milimeters
NDVI	*Normalized Difference Vegetation Index*
RGB	*Red, Green and Blue*

SUMMARY

GENERAL INTRODUCTION

The black pepper is one of the main spices grown in the world, represents a link in the production chain on several continents, and participates in commercial structures of import, export, also exercising its importance in the world cuisine.

The cultivation of black pepper in the Brazilian territory occurs mainly in the North, Southwest and Northeast regions, allocating most of the production to the foreign market. Brazil is prominent in the world scene, being the largest non-Asian producer and presenting better production techniques (Lourinho et al., 2014).

Brazilian pipericulture is characterized by socioeconomic importance, constituting one of the main sources of family income, such as Pará, which employs more than 70.000 people and produced 35.000 tons (Filgueiras, 2012; Vidal, 2020). The states of Espírito Santo and Bahia are also highlights in the national economic scenes. In 2020, the state of Espírito Santo produced 67.594 tons of spice and Bahia 9.691 tons (Vidal, 2020; Galeano and Vandernas, 2021).

The management of black pepper is not very technical in Brazil and the production chain is going through difficulties due to the lack of technical assistance, low technology, improvement of processing (Filgueiras et al., 2009), in addition to the incidence of insect pests. Despite its importance, there is a low of research for the black pepper crop, making it difficult to access information in the phytosanitary management of this crop (Ribeiro et al., 2019).

Several phytosanitary problems are observed in the culture of black pepper, mainly caused by mites and insects, among these stinks bugs and the beetle *Longitarsus nigripennis, Cydia hemidoxa* and the thrips *Liothrips karnyi,* in addition to aphids and mealybugs that can cause productivity losses of up to 88% (Gupta, 2012; Daba et al., 2016; Ribeiro et al., 2019; Nair, 2020).

The mealybugs stands out as one of the pests of importance in pipericulture, because it is a transmitter of virus (Bhat and Rao, 2020) and causes other damage to the spice. The mealybugs are hemipterans of normally whitish coloration, have a mouthmouth sucking with which they feed on the sap of plants (Williams and Hodgson, 2014). These insects are mostly polyphagous, host in forest and agricultural species (Mansour et al., 2017).

The mealybugs feed on sap, as well as the injection of toxins, causing wilting, falling shoots and leaves, besides favoring the association of fuliginous fungi, decreasing photosynthesis (Mibey, 1997; Lemos et al., 2014; Selvarajan et al., 2016).

A virus of importance in mealybug-transmitted pipericulture is the badvirus PYMoV (Piper Yellow Mottlevirus), which can cause production losses. The main symptoms of PYMoV badvirus are mottled chlorosis, whitening ribs, leaf deformation, dwarfism and fruit reduction (Duarte et al., 2000).

Despite its phytosanitary importance, there are few studies for the integrated management of mealybugs in black pepper that assist in monitoring and decision making. For the development of an integrated pest management program (IPM), it is essential to know the spatial distribution of the insect pest (Pedigo, 1994), and to identify demographic and behavioral responses to the environment (Vinatier et al., 2011).

Sampling is a basic and essential component in the IPM that contributes to the knowledge of the population level and other characteristics (Lima et al., 2017). With monitoring, it is possible to understand fluctuation, a characteristic that is essential for the definition of control strategies throughout the cultivation period (Telli and Yiğit, 2019).

The characterization of insect dispersion and the development of sampling plans contribute to quantify infestation and damage levels, facilitating management. However, the sampling system requires a method that is direct and easy to implement (Gutierrez-Coarite et al., 2019), optimizing the monitoring execution time (Prager et al., 2014).

Together with the IPM, geotechnologies are tools that help in the knowledge and explanation of pest behaviors in various aspects. Geotechnologies are composed of solutions in hardware, software and others that together are powerful tools for decision making (Rosa, 2005). One of the recent solutions of geotechnologies is the use of remotely piloted aircraft in agriculture, which have become increasingly evident, in view of the various agricultural applications, especially in remote sensing in the context of precision agriculture, assisting farmers in planning and decision-making (Barbedo and Koenigkan, 2018; Andrade et al., 2019), through the yield forecast (Kefauver et al., 2017), biomass estimation (Liu et al., 2019), plant height (Holman et al., 2016), identification of weeds, insect pests and diseases (Zhang et al., 2019).

Part of these applications, through the acquisition and processing of images of aerial or orbital platforms, is through vegetation (IV) indices, which are mathematical formulas that, based on combinations of bands within the electromagnetic spectrum, allow to observe and understand changes and spectral behavior of vegetation (Carneiro et al., 2019; Klouček et al., 2019).

Another resource of geotechnologies is geostatistics that, when applied to the IPM, allows to understand the spatial and temporal heterogeneity of pests, through spatial distribution (Pinchao and Munõz, 2019), characterizing the dispersion, identification of the spatial dependence of insects (Galdino et al., 2017) and detection of spatial variability (Pazini et al., 2015). These methods assist in pest management programs, indicating areas that require greater attention for monitoring (Martins et al., 2018) or that should be treated, known as management zones.

One of the geostatistical methods that assists in understanding pest behavior is interpolation. A method of estimating value in locals not sampled in geographic space, such as kriging interpolation, which is considered one of the most useful and advantageous methods applied to pest management (Fernández and Ribes-Dasi, 2014). Ordinary kriging is already used for pests of economic importance in oat crops (Dal Prá et al., 2011), rice (Pazini et al., 2015), fig (Pasini et al., 2015) and others.

In this context, geotechnologies, applied to the integrated management of mealybugs in pipericulture, can help identify spectral responses of the attack and a sampling plan. Thus, the dissertation was organized into two articles, which aimed to evaluate the spatial and temporal distribution pattern of mealybugs and phytotechnical characteristics of the black pepper crop with the use of applied geotechnologies, as well as to report the species of mealybugs that occur in pipericulture in the state of Bahia.

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ARTICLE I

Geotechnologies applied in the monitoring of mealybug in the black pepper cultivation*

*Situation: Submitted

Geotechnologies applied in the monitoring of mealybug in the black pepper cultivation

Geotecnologias aplicadas no monitoramento de cochonilhas na cultura da pimenta-do-reino

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ABSTRACT

The knowledge of the population behavior of insect pests within the agricultural system represents an important strategy in the development of integrated pest management. This study aimed to evaluate the spatial and temporal distribution pattern of mealybug and phytotechnical characteristics in black pepper culture with the use of applied geotechnologies. The study was conducted in commercial cultivation of black pepper in the municipality of Porto Seguro - BA. In an area of 26 hectares, used a grid with 96 points. Notes were assigned according to the infestation of the mealybugs, according to the presence, formation of colonies and/or dispersion in the plant. The data were grouped according to the season and submitted to the Lilliefors test at 5%. The ordinary kriging method was used for the Green Leaf Index, dry pepper weight, leaf area and indicator kriging for infestation data. Drone images were used to calculate the aerial GLI index and to obtain the leaf area of each plant. With landsat 8 satellite images, the vegetation index and surface temperature were obtained. The climatics data were associated with, phytotechnical, spectral and monitoring variables, using principal component analysis, where it revealed that cochineal infestation levels are directly associated with the summer season and the NDVI and GLI index. It was observed that the insect presents random distribution. The spatial-temporal distribution of GLI and the maximum indices occur in the winter and spring seasons. From the probability of occurrence map, the spring and summer seasons presented more favorable conditions for the occurrence of mealybug in the planting of black pepper

Key words: Spatial distribuition. Pipericulture. Kriging. Vegetation index.

RESUMO

O conhecimento do comportamento populacional dos insetos-praga, dentro do sistema agrícola, representa uma importante estratégia no desenvolvimento do manejo integrado de pragas. O objetivo do trabalho foi avaliar o padrão de distribuição espacial e temporal de cochonilhas e as características fitotécnicas da cultura da pimenta-do-reino com o uso de geotecnologias aplicadas. O estudo foi conduzido em cultivo comercial de pimenta-do-reino, no município de Porto Seguro, Bahia, Brasil. Foi utilizada uma área comercial de 26 hectares, utilizado um grid com 96 pontos. Foram atribuídas notas de acordo com a infestação das cochonilhas, com a presença, formação de colônias e/ou dispersão na planta. Os dados foram agrupados por estação do ano e submetidos ao teste de Lilliefors a 5%. Utilizou-se o método de krigagem ordinária, para o índice de folha verde, massa de pimenta seca, área foliar e krigagem indicadora para dados de infestação. Foram utilizadas imagens de drone para cálculos dos índices GLI aéreo e para obtenção da área foliar de cada planta. Com as imagens do satélite Landsat 8, foram obtidos o índice de vegetação e a temperatura de superfície. Os dados climáticos foram associados com as variáveis fitotécnicas, espectrais e do monitoramento, utilizando análise de componentes principais, quando se verificou que os níveis de infestação da cochonilha estão diretamente associados com a estação do verão e com os índices NDVI e GLI. Observou-se que o inseto apresenta distribuição aleatória. A distribuição espacial-temporal do GLI e as máximas dos índices ocorrem nas estações de inverno e primavera. A partir do mapa de probabilidade de ocorrência, as estações de

primavera e verão apresentaram condições mais favoráveis para a ocorrência de cochonilhas no plantio de pimenta-do-reino

Palavras-chave: Distribuição espacial. Pipericultura. Krigagem. Índice de vegetação

INTRODUCTION

The population behavior of insect pests within the agricultural system represents an important strategy in the development of integrated pest management (MIP) that aims to employ a set of techniques that aim to keep the population below the level of economic damage (GALLO et al., 2002). Through population monitoring, it is possible to identify the fluctuation and behavioral aspects of the insect, in view of the development of crops and the environment (GAZOLA et al., 2019), and determine the levels of damage and control.

Among the species of insect pests in agricultural production systems, mealybugs are characterized as pests of economic importance in several agricultural crops, such as pipericulture (COCCO et al., 2020; FINCH et al., 2020). These insects, through sap sucking, toxin injection, as well as association with fungi (NEDUNCHEZHIYAN et al., 2011; OLIVEIRA et al., 2014), threaten the health of plants. In this sense, the knowledge of population trends, in the temporal and environmental aspects of this group of insects, helps in the successful management and reduction of losses (TELLI & YIĞIT, 2019), as it has been studied in grape cultures (EL-GAYED et al., 2020), citrus (YAVUZ et al., 2021) and cassava (GAZOLA et al., 2019).

Efficiency in pest management requires timely identification and intervention that, through sampling, through traditional methods, assist in decision making, however, these resources are time-consuming and can present low accuracy (RANJAN & VINAYAK, 2020). The Geographic Information System (GIS) brought a new dimension to the IPM, seeking to optimize and aggregate the decision (RANO et al., 2022). Precision agriculture allows to know the spatial-temporal variability of several parameters that influence the productivity and health of crops, from the collection of data by sensors and platforms (PEDERSEN & LIND, 2017).

The precision agriculture has been applied to the IPM for several pests and crops, through artificial intelligence (TOSCANO-MIRANDA et al., 2022), studies on spatial distribution by interpolation methods, such as kriging (DUARTE et al., 2015) and spectral sensing (PRABHAKAR et al., 2013).

Precision agriculture (PA) techniques involve the collection and management of data and information, obtained by remote sensing, satellites or drones, and processed by information technologies (HUANG et al., 2018) that, in turn, support the implementation of precise and sustainable actions (RAJMIS et al., 2022). The management zones represent, in precision agriculture, subareas that require different practices in crop management based on the needs of insums, such as application of nutrients or insecticides (FULTON & PORT, 2018; FILHO et al., 2020).

Agricultural technologies are still little widespread in the crop of black pepper (*Piper nigrum* L.), despite playing an important socioeconomic role in the world and in Brazil, because they have a consumer market demanding quality standards for bioproducts (DALAZEN et al., 2022). Studies on technologies and management of mealybugs in black pepper culture are scarce. Thus, this work aims to evaluate the spatial and temporal distribution pattern of mealybugs and phytotechnical characteristics in black pepper culture with the use of applied geotechnologies.

MATERIALS AND METHODS

The study was conducted during the period from January 2021 to January 2022, in commercial cultivation of black pepper (*P. nigrum*), cv. Bragantina, located at the geographic coordinates 16°49'7.52"S and 39°18'0.27"W, with 68 meters of altitude, in the municipality of Porto Seguro, BA, extreme South of Bahia. The study area was 26 hectares, conducted in drip irrigation system, in a spacing of 3.40 m x 1.80 m.

The experimental site was previously georeferenced and the data processed in GIS software, Quantum GIS 3.16, and a sample mesh was generated in a regular grid, with spacing between the sampling points of 50 meters, based on the planting line, totaling 96 points (Figure 1).

The sampling protocol of mealybug species is nonexistent in the literature and, for this study, was developed based on qualitative evaluation, with attribution of notes, according to the pest infestation, observing the presence and formation of colonies or dispersion of mealybugs in the plant, being carried out monthly monitoring of three plants per sample point, totaling 288 plants, which were collected for subsequent taxonomic identification in the laboratory.

The assigned notes were based on the methodology of NAGRARE et al. (2011) and adapted for pepper culture: 0 – Absence of mealybug; 1 - Dispersed mealybugs without colony formation; 2 - Grouped mealybugs with beginning of colony formation; 3 - Grouped mealybugs with colony formation less than 2 cm; 4 - Mealybugs grouped with colony formation greater than 2 cm and/or beginning of formation in the bunches; 5 – Infestation with distributed colonies and formation of colonies greater than 2 cm in the clusters and presence of fumagina.

The acquired data were grouped according to the season (autumn, winter, spring, summer) and submitted to the Lilliefors normality test at 5% in SPSS Statistics software. Then, they were integrated into GIS environments, in ArcGis 10.6 software, and submitted to descriptive data analysis.

The spatial-temporal distribution by season (summer 21, autumn 21, winter 21, spring 21 and summer 22) was obtained by studying the semivariogram and adjusted by the theoretical models, allowing estimating the coefficients of the semivariogram: nugget effect (C0); landing (C0+C); partial level (C); and range (a). After adjustment, data were interpolated using the ordinary kriging method for the attributes: GLI (Green Leaf Index), DPM (Dry Pepper Mass) and LF (Leaf area). For the probability of occurrence map, the indicator kriging was performed, based on the infestation data. The spatial dependence index was also calculated according to the evaluator proposed by DALCHIAVON et al. (2012): C/(C0+C) x 100, in which a 20% ≤ ADE is considered, indicating spatial attribute with very low dependence; 20% < ADE ≤ 40%, attribute with low dependence; 40% < ADE ≤ 60%, attribute with medium dependency; 60% < ADE ≤ 80%, high dependency attribute; and ADE ≥ 80%, attribute with very high spatial dependence.

For remote aerial sensing, four flights were performed in the area, according to the seasons: summer 21, autumn 21, winter 21 and spring 21. The drone, model Phantom 4 Pro, equipped with RGB camera (Red, Green and Blue), obtained a GSD (Ground Sampling Distance) of 5 cm. The acquired images were processed in Pix4D software, and orthomosaics were generated.

To verify the spectral responses of plants under stress of cochineal attack, the maximum, average and minimum values of GLI (Green Leaf Index) indices were calculated for aerial and orbital images; NDVI (Normalized Difference Vegetation Index) and LST (Land Surface Temperature) on the Google Earth Engine platform, using landsat 8 satellite images. The leaf area attribute (LA) was acquired through orthomosaic processing and delimitation of the area of each plant in square meters (m^2).

The black pepper harvest was carried out in July 2021 and January 2022, when the fruits of three plants were harvested at each sampling point. The harvested grains were dried in a greenhouse for 7 days, at 70ºC, to obtain the parameters of dry mass of pepper in kg^{-1}.

Climatic data of temperature (maximum, average and minimum) in degrees Celsius (ºC), relative humidity (%) and precipitation (mm) of the experimental area were obtained monthly through a weather station, model Davis Vantage Pro 2, installed in the property. Multivariate analysis of main components was performed, seeking to associate the climatic, phytotechnical, spectral and mealybug monitoring variables in XLSTAT software.

RESULTS AND DISCUSSION

In the principal component analysis, the first two CP1 and CP2 components were extracted, which are responsible for explaining 93.20% of the variability contained in the set of the 14 original variables, with individual contributions of 54.52% and 38.68% for the first (CP1) and second (CP2) components, respectively (Figure 2).

Visualizing the projections represented by the variables and the position of the seasons in the quadrants, in the CP1 and CP2 axes, in the two-dimensional graph (Figure 2), it is evident that the levels of mealybug infestation are directly associated with the summer season. Rainfall, on the other hand, is directly correlated with the spring season in 2021, when it provided a reduction in infestation.

Analyzing the two-dimensional plane, referring to the positive correlation of the variables and the main component - CP1, in order of importance and by the highest correlation coefficients (r-pearson), it is observed that the variables: minimum vegetation index - NDVImin (0.92), maximum vegetation index - NDVImax (0.91), average surface temperatures - LSTmed (0.91), orbital green leaf index- GLI_orbital (0.90), average vegetation index - NDVImed (0.90), maximum surface temperatures - LSTmax (0.84), cochineal infestation level-INFEST (0.78), minimum surface temperatures - LSTmin (0.77) and Relative Humidity (RH) (0.66) are directly associated (Table 1). On the other hand, rainfall and infestation index showed a negative correlation (-0.90), indicating that rainfall has a direct effect on the control of the cochineal population (Table 1).

The increase in surface temperature favors the development of the species, as well as the increase in LST can also promote, with a migration of mealybugs from the soil surface to the aerial part of the plant, as there is a strong correlation between infestation levels and vegetation (NDVI) and green leaf index (GLI-orbital). The increase of these indicators of vegetation vigor may be providing a microclimate effect and, consequently, the mealybugs migrate more easily to the area part of the plant.

KUMAR et al. (2013), when studying the effects of temperature and relative humidity in the Phenacoccus solenopsis life table, found that the temperature of 35 ± 1 °C and 65% RH is the most favorable combination for optimal population growth. Chong et al. (2008), studying Maconellicoccus hirsutus, observed that the increase in temperature accelerated the development of Females of M. hirsutus up to a maximum rate of 29°C. For the second main component, the temperatures: minimum - Tmin (0.95), maximum - Tmax (0.93) and mean (0.99), and infestation level (0.61) showed positive correlations (Table 1), with air temperatures (Tmin, Tmax and Tmed) associated with the level of infestation of the cochineal, in the spring and summer seasons, due to the location of the variables at the top of CP2 (Figure 1). The Green Leaf Index (GLI_aéreo) showed a negative correlation (-0.89) with CP2.

In the geostatistical analysis (Table 2), for each attribute a semivariogram was generated, and the best model that fit for most variables was Gaussian, except for infestation in the autumn season whose best model was exponential. According to Seidel & Oliveira (2014), the Gaussian model of semivariogram is the one with the greatest force of spatial dependence, evidencing that the data have a strong spatial dependence. The range of spatial dependence of the samples is an important information to assist in the definition of sampling. The maximum distance found between the attributes of remote sensing, GLI between stations, ranged from 168.16 to 266.64 meters. For the phytotechnical variables, leaf area (LA) and dry mass of black pepper (DPM), the maximum range was 143.38 meters. For infestation variables, a range variation of 86.31 to 352.87 meters is observed between seasons, suggesting that this insect may present different spatial arrangements of its distribution in the field, depending on the season and environmental conditions.

From the application of geostatistical methods, it is possible to reduce the number of samples due to the knowledge of maximum distance between attributes. In this study, the sampling grid was 50 meters between the points, allowing a detection of the spatial distribution of mealybug in black pepper, however, it can be optimized for a grid of up to 90 meters. According to VALERIANO & PRADO (2001), sampling can be performed with spacings lower than the maximum range found, without loss in sample representativeness, thus reducing costs and optimizing the monitoring operation.

Another important evaluation is the spatial dependence index, which represents the relationship of how much spatial dependence is, quantified by the semivariogram model, and contributes to data variability (PAZINI et al., 2015). The variables of stational GLI presented an ADE from low to high spatial dependence by the methodology of DALCHIAVON et al. (2012). The phytotechnical attributes of leaf area and dry mass pepper showed moderate spatial dependence. Cochineal infestation showed very low spatial dependence. In summary, the attributes GLI autumn and GLI summer and cochineal infestation did not present spatial dependence.

In the case of infestation of mealybugs *D. gracilis* and *P. longivalvata*, the low spatial dependence obtained by geostatistics indicates that the behavior of these insects may be random. In other studies with mealybugs, the spatial distribution pattern varied according to the insect species and host. GÓNGORA-CANUL et al. (2018), when studying the spatial distribution of *Paracoccus marginatus* in jatropha, also identified a random dispersion pattern, however, CHELLAPPAN et al. (2013), when they also studied *P. marginatus*, observed that this species presented spatial distribution behaviors uniformly, aggregated and randomly, depending on the host and environment. Other studies conducted for other species of mealybugs, such as *Praelongorthezia praelonga* in citrus (GOUVEIA et al., 2020) and *Pseudococcus viburni* in cotton (CANÁRIO et al., 2016), showed an aggregate distribution.

The spatial distribution of insects is dependent on the quality of habitat and environmental conditions that influence the behavior of the insect (SILVA et al., 2017), corroborating the correlations found for the species *D. gracilis* and *P. longivalvata* in black pepper.

Among the phytotechnical attributes, the leaf area represents an important evaluation parameter, since plants with greater leaf area have a larger surface of light interception, which may result in a higher photosynthetic rate (TAIZ et al., 2017).

Some nondestructive methods have been validated in pipericulture to estimate leaf area for monitoring the development of varieties (PARTELLI et al., 2007). From the geoprocessing of aerial images, it was possible to isolate the leaf area of each plant and understand the spatial-temporal dynamics (Figure 3). It was observed that the black pepper plants have different leaf area development for each season of the year, and in the autumn season, it observed a variation between 1.18 m^2 and 2.35 m^2; in winter, a variation of 1.50 m^2 and a maximum of 2.56 m^2, reaching, in spring, the maximum of 2.81m^2. In the summer, there was a decrease in the leaf area of black pepper, with a variation of 1.19 m^2 to 2.58m^2, which may have been influenced by the reduction of rainfall and temperature increase, impacting the vigor of the plants.

Compared to the spatial-temporal distribution of the spectral index (Figure 4), it is observed that the highest values occur in the winter and spring seasons (ranging from 0.22 to 0.26; 0.17 to 0.29, respectively), and the lowest values in the autumn and summer seasons (ranging from 0.12 to 0.18 and 0.13 to 0.18, respectively).

After harvesting and drying the black pepper, the dry mass attribute of black pepper kg^{-1} was obtained (Figure 5). It was observed that the maximum dry mass was 4.29 kg and the minimum dry mass was 1.36 kg of dry black pepper/plant. It can be noted that the lowest values found for DPM occur in a zone at the center of the study area, which is the same region with low GLI index (Figure 4) and leaf area (Figure 3). The low productivity at the center may have been influenced by the characteristics of the rugged topography of the terrain, which differs from the marginal areas, evidencing a possible management zone to be introduced.

From the development of predictive distribution through indicator kriging, which allows mapping as a probability of exceeding a predetermined limit, it was observed that it was possible to identify the regions with probability of risks for the occurrence of mealybugs in a given season (Figure 6). In this case, it was found that, despite being likely to occur in different places, the behavior of higher occurrence is marginal in the area of pepper. This behavior may be related to the low movement capacity of female mealybugs, which is the easily visualized genus, because they do not have wings, different from males that are winged insects (ROSS & SHUKER, 2009).

The indicator kriging represents a tool that has been used in integrated pest management (BRENNER et al., 1998), making it possible to identify the zones of probabilities of occurrence (Table 3). From the maps modeled by the indicator kriging (Figure 6), it was observed that, during the summer seasons 2021 and autumn 2021, the model estimated that 61.84% and 65.63% of the area under study had low to moderate risk of infestation (<50%) and only 38.11% and 34.37% of the respective areas presented risks above 50%, indicating a possible directed management.

Subsequently, in the winter seasons 21, spring 21 and summer 22, the mealybug gradually increased the presence in the study area, as well as the probability of occurrence, and the spring and summer seasons had the highest probabilities of occurrence in relation to the previous seasons, reaching a moderate to high risk area (>50%) of 38.89%, in the spring; and 43.43% in the summer. By mapping the displacement behavior and gradually increasing the occurrence of the presence of the cochineal, it is possible to define cochineal management strategies in critical seasons that favor the development of the insect.

The spring and summer seasons presented more favorable conditions for the occurrence of mealybugs in the planting of black pepper. In comparison, in summer 21 and summer 22, there was an increase in the risk zone above 50%; in parallel, there was a decrease in areas of low to moderate probability (<50%) that remained similar, indicating a possible adaptation of these recent species of mealybugs in the culture of black pepper over time and environmental factors.

CONCLUSION

The infestation of the species of mealybugs *P. longivalvata* and *D. gracilis* in black pepper indicates to be random and is more likely to occur in the summer and spring seasons;

The phytotechnical characteristics of leaf area, dry mass of black pepper and GLI spectra indicate similar management zones;

Geotechnologies are potential tools for the monitoring of mealybugs in the cultivation of black pepper, determining management zones and monitoring the development of the crop

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript.

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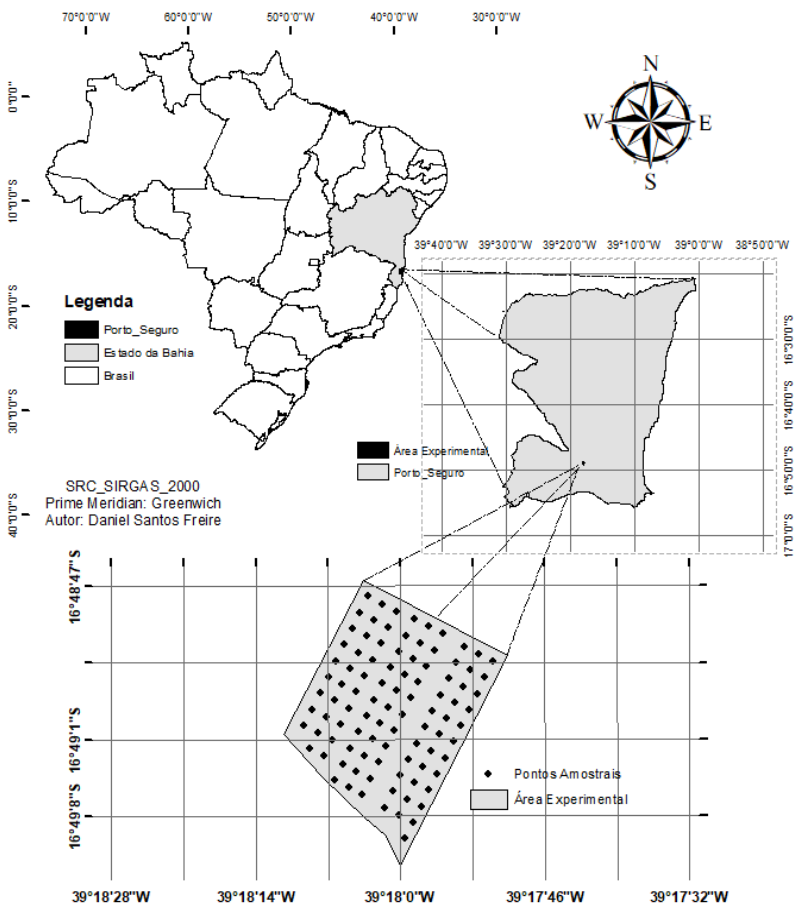

Figure 1. Location map of the experimental area and sampling mesh with distribution of georeferenced points

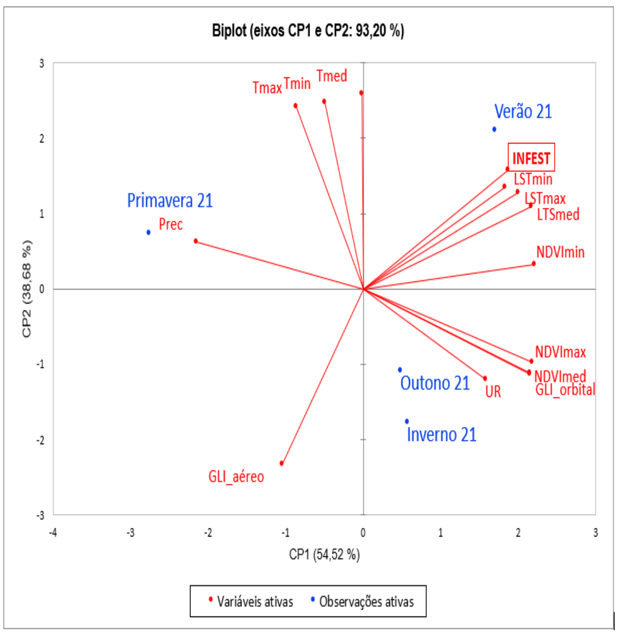

Figure 2 - Analysis of main components in Black Pepper, according to the seasons.

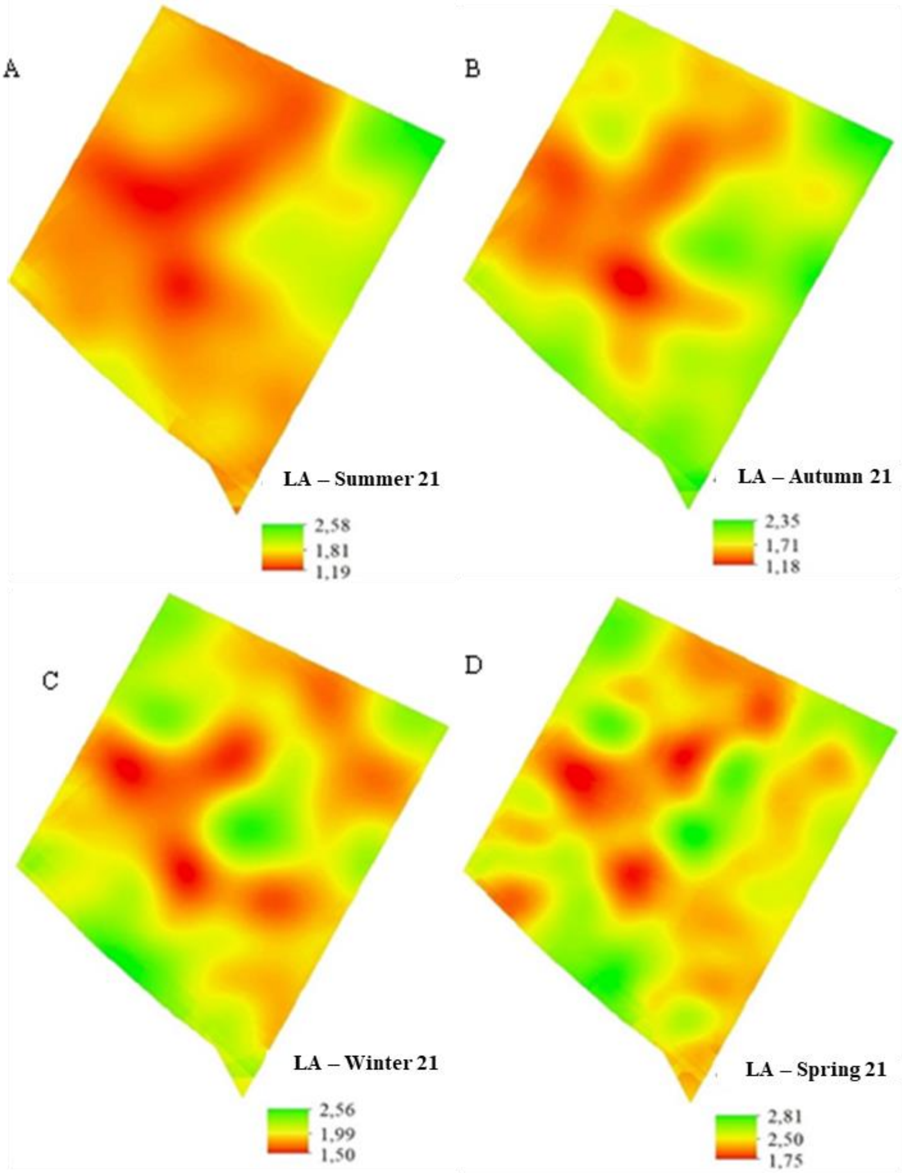

Figure 3. Thematic map of the spatial distribution of the leaf area of black pepper in different seasons

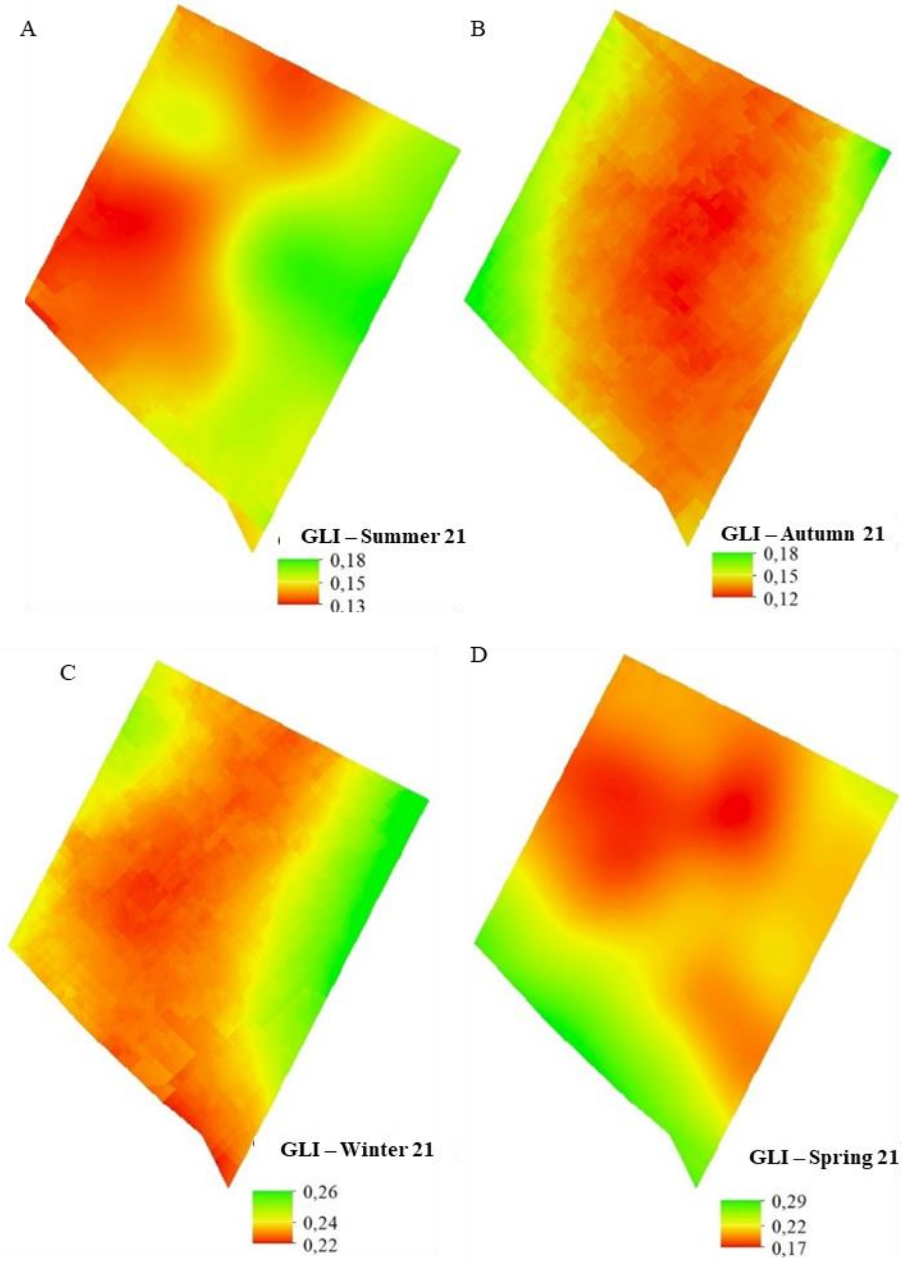

Figure 4. Thematic map of the spatial distribution of the spectral index GLI in black pepper, in different seasons.

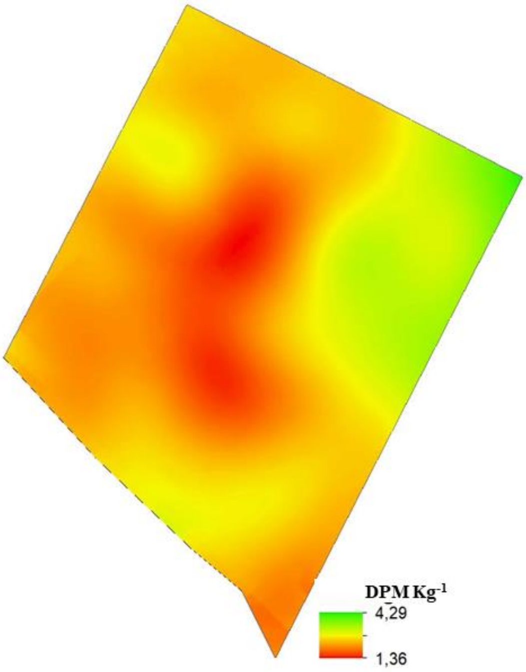

Figure 5. Thematic map of the spatial distribution of the dry mass of black pepper in different seasons.

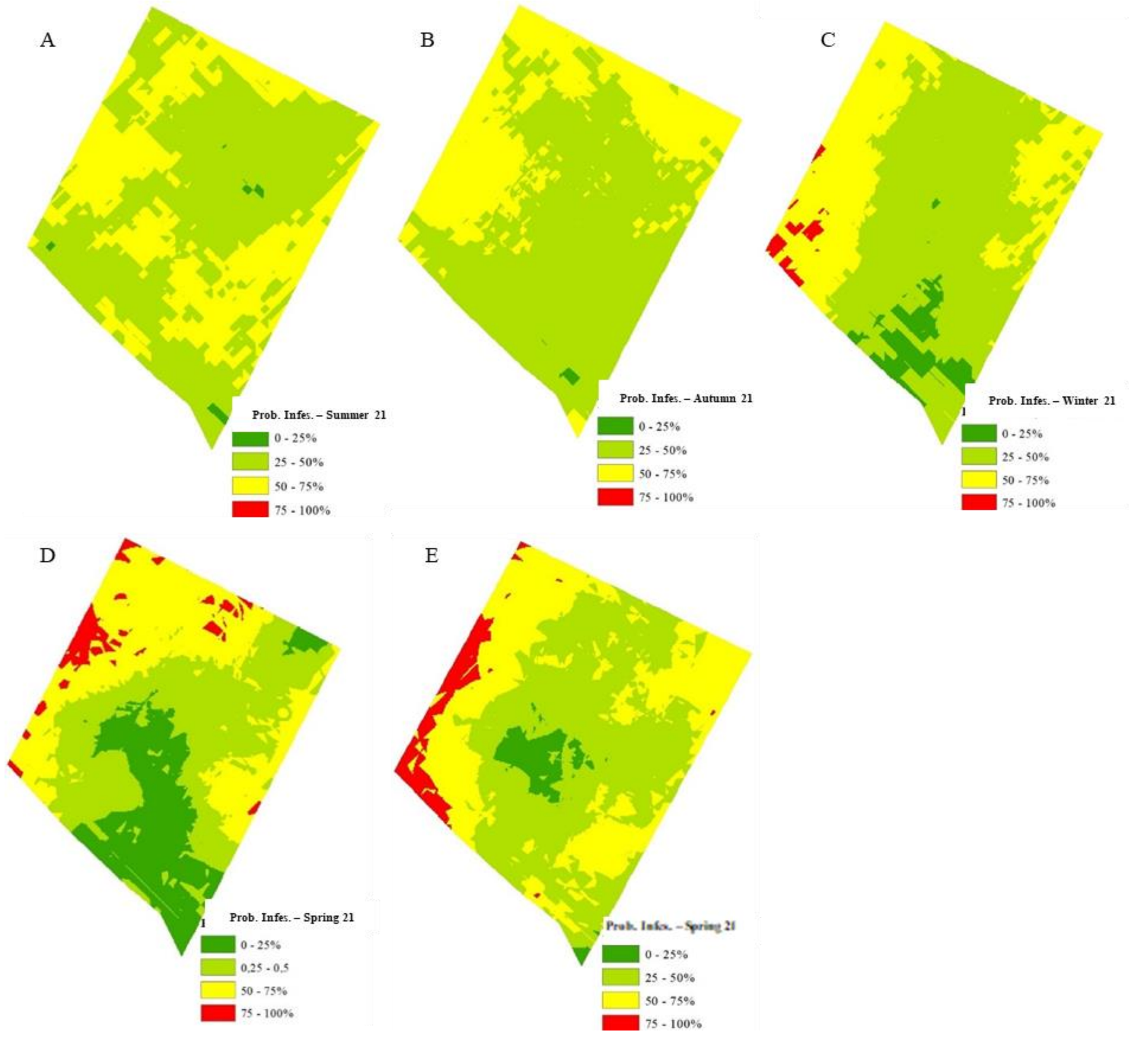

Figure 6. Thematic map of the spatial distribuition of the probability of occurrence of mealybug in black pepper in different seasons.

Table 1 - Linear correlation coefficients (r-pearson) between the variables and the first two main components (CP1 and CP2) related to the seasons

Variables	Correlation coefficients - Pearson	
	CP1 (54,52%)*	CP2 (38,68%)
Minimum air temperature (Tmin)	-0,21	**0,95**
Maximum air temperature (Tmax)	-0,36	**0,93**
Average air temperature (Tmed)	-0,01	**0,99**
Relative Humidity (RH))	**0,66**	-0,46
Rainfall (Prec))	**-0,90**	0,24
Minimum Surface Temperature (LSTmin)	**0,77**	0,52
Maximum Surface Temperature (LSTmax)	**0,84**	0,49
Average Surface Temperature (LSTmed)	**0,91**	0,42
Minimum Vegetation Index (LSTmin)	**0,92**	0,13
Maximum Vegetation Index (LSTmax)	**0,91**	-0,37
Average Vegetation Index (LSTmed)	**0,90**	-0,43
Green Leaf Index - Orbital (GLI_orbital)	**0,90**	-0,44
Green Leaf - Aerial Index (GLI_aéreo)	-0,44	**-0,89**
Infestation Level (Infest)	**0,78**	**0,61**

Value referring to the percentage of variability of the original set of data retained by the respective main components. Bold correlations (>0.60 in absolute value) were considered in the interpretation of the main component.

Table 2 - Estimated parameters for experimental semivariogram for spectral, phytotechnical and cochineal infestation variables in the culture of black pepper

Variable	Model	C0	C	C0+C	ADE	a (m)	Error mean
Variáveis espectrais							
GLI Autumn	Gaussiano	0,000	9,700	9,700	37,259	171,470	0,000
GLI Winter	Gaussiano	0,000	1,825	1,825	99,998	202,705	0,000
GLI Spring	Gaussiano	0,0003	0,0002	0,001	99,995	168,16	-0,00002
GLI Summer	Gaussiano	0,0002	0,0001	0,0003	33,33	266,64	0,0002
Variáveis fitotécnicas							
AF Autumn	Gaussiano	0,049	0,041	0,090	45,556	127,200	0,004
AF Winter	Gaussiano	0,059	0,072	0,131	55,172	108,840	-0,002
AF Spring	Gaussiano	0,026	0,068	0,094	72,340	90,520	-0,001

AF Verão	Gaussiano	0,052	0,053	0,105	50,429	112,010	-0,001
Summer	Gaussiano	0,1623	0,1617	0,324	49,907	143,38	0,0108
Variáveis de infestação							
Infestation Autumn	Exponencial	0,250	0,001	0,251	0,398	86,306	-0,003
Infestation Winter	Gaussiano	0,242	0,010	0,252	3,968	352,870	-0,010
Infestation Spring	Gaussiano	0,218	0,022	0,240	9,167	97,105	-0,010
Infestation Summer	Gaussiano	0,240	0,011	0,251	4,382	104,850	-0,010

C0 - nugget, C - partial sill, C0+C - partial, a - range, ADE - Spatial dependence index

Table 3 - Zones of probability of occurrence of cochineals in the culture of black pepper, modeled by indicator kriging

	Occurrence probability zones (ha)			
	0 - 25%	26 - 50%	51 - 75%	76 - 100%
Summer 21	0,13	16,19	10,07	0,00
Autumn 21	0,06	17,28	9,05	0,00
Winter 21	1,60	16,00	8,42	0,38
Spring 21	5,95	10,19	9,20	1,07
Summer 22	1,23	13,71	10,12	1,35

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ARTICLE II

First record of *Protopulvinaria longivalvata* (Hemiptera: Coccidae) and *Dysmicoccus gracilis* (Hemiptera: Pseudococcida) associated with black pepper in southern Bahia, Brazil*

*Situation: Submitted

First record of *Protopulvinaria longivalvata* (Hemiptera: Coccidae) and *Dysmicoccus gracilis* (Hemiptera: Pseudococcida) associated with black pepper in southern Bahia, Brazil

Primeiro registro de *Protopulvinaria longivalvata* (Hemiptera: Coccidae) e *Dysmicoccus gracilis* (Hemiptera: Pseudococcida) associadas a pimenta-do-reino no Sul da Bahia, Brasil

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ABSTRACT

This work records, for the first time, *Dysmicoccus gracilis* infesting *P. nigrum* plants and the occurrence of *Protopulvinaria longivalvata* in the state of Bahia. The samples of mealybugs were collected in black pepper plants, in a commercial plantation located in the municipality of Porto Seguro - BA, southern Bahia. *Piper nigrum* is first reported as host of *D. gracilis* and, *P. longivalvata* is reported associated instead in the state of Bahia, on black pepper plants.

Keywords: mealybugs, *Piper nigrum*, record.

RESUMO

Este trabalho registra, pela primeira vez, *Dysmicoccus gracilis* infestando plantas de P. nigrum e a ocorrência de *Protopulvinaria longivalvata* no estado da Bahia. As amostras de cochonilhas foram coletadas em plantas de pimenta-do-reino, em um plantio comercial localizado no município de Porto Seguro, sul da Bahia. *Piper nigrum* é relatada pela primeira vez como hospedeira de *D. gracilis,* e *P. longivalvata* é relatada associada, no estado da Bahia, a plantas de pimenta-do-reino.

Palavras-chave: cochonilhas, *Piper nigrum*, registro.

INTRODUCTION

Black pepper (*Piper nigrum* L., Piperaceae), a plant of Asian origin, is one of the main spices of economic interest in Brazil (IBGE, 2018). The country is considered the largest producer of grain in the ocident, and the second largest exporter in the world (VIDAL, 2020). The states of Espirito Santo, Pará and Bahia represent more than 90% of the production of national pepper, playing an important socioeconomic role (GOMES FILHO, 2017; SILVA JUNIOR et al., 2022).

Despite the increasing production in the country, pipericulture faces phytosanitary challenges, especially with the attacks of mealybugs (Hemiptera: Coccoidea) (LEMOS & CELESTINO FILHO, 2009). In the world, 36 species of mealybugs associated with P. nigrum have been recorded: Asterolecaniidae (1);. Cerococcidae (1); Lecanodiaspididae (1); Monophlebidae (1); Xenococcidae (1), Diaspididae (9); Coccidae (11); Pseudococcidae (11) (GARCÍA MORALES et al., 2016). In Brazil, four species associated with black pepper were recorded: the coccydeo *Protopulvinaria longivalvata*, Green, 1909, in the states of Espírito Santo and Pará (MARTINS et al., 2013; LEMOS & CELESTINO FILHO, 2009); and pseudococcídeos, *Pseudococcus elisae* Borchsenius, 1947 and *Planococcus minor* Maskell, 1897 in the state of Pará (DUARTE et al., 2000; SOUSA et al., 2011).

This work records for the first time *Dysmicoccus gracilis* infesting *P. nigrum* plants and the occurrence of *P. longivalvata* in the state of Bahia, Brazil.

Samples of mealybugs of the families Coccidae and Pseudococcidae were collected on fruits, roots, leaves and stems of 10 black pepper plants, in a commercial plantation located at the geographic coordinates 16°49'7.52"S and 39°18'0.27"W, with an altitude of 68 meters in the municipality of Porto Seguro, Bahia, Brazil. The collected insects were stored in test tubes containing 70% alcohol and identified by the author (A.L.B.G.P.). The species *D. gracilis* was identified based on the key proposed by GRANARA DE WILLINK (2009), while the species *P. longivalvata* based on the work of WILLIAMS & WATSON (1990).

The mealybugs samples collected on the adaxial and abaxial faces of black pepper leaves and branches were identified as *P. longivalvata* (Figure 1); and those of the pseudococcyd, obtained on the bunches, roots, branches and stem, identified as *D. gracilis* (Figure 2). *Piper nigrum* is first recorded as host of D. *gracilis*; and, *P. longivalvata* is reported associated for the first time in the state of Bahia, in black pepper plants.

The black pepper plants infested by both species of mealybugs showed a low vigor aspect. However, the leaves infested with *P. longivalvata* were covered by fumagina (Figure 1).

Protopulvinaria longivalvata was described in 1909 from specimens collected on *P. nigrum* in Sri Lanka (GREEN, 1909) and is currently distributed in 15 countries, located mainly in the Eastern, Afrotropical and Neotropical regions (GARCÍA MORALES, 2016). This coccyde is a polyphagous species known for infest 26 species of host plants, distributed in 20 genera and 14 families. In Brazil it was registered in *Persea americana* Mill., *Nectandra* sp. and *Laurus nobilis* L. (Lauraceae), *Camelia* sp., (Theaceae), *Gardenia jasminoides* (Rubiaceae) in Rio Grande do Sul (COSEUIL & BARBOSA, 1971); Citrus sp. (Rutaceae) (SILVA et al., 1968) and *P. nigrum* in the states of Espírito Santo and Pará (LEMOS & CELESTINO FILHO, 2009).

The genus Protopulvinaria includes two other species, all originating in Asia, being *P. longivalvata* and *P. pyriformis* known to Brazil (WYCKHUYS et al., 2013; GARCÍA MORALES, 2016). Adult females of both species are characterized by a pyriform and flattened body, with the narrowest part towards the head. They measure approximately 3 mm in length and have marginal areas of the body sclerotized. The presence of the ovissack can be seen through a whitish area around the body of these insects. The predominant coloration is reddish in the younger forms of *P. longivalvata* and yellowish in *P. pyriformis,* however, the older females of both species have brown coloration, being difficult to separate the species in the field. Microscopically, they resemble having the anal plates in the center of the body and the anterolateral margin of the an anal plates visible longer than the posterolateral margin. *Protopulvinaria longivalvata* differs by having smaller and less divided marginal bristles (long and visibly divided into *P. pyriformis*), shorter and less conspicuous dorsal bristles (long and conspicuous in *P. pyriformis*) and usually 8 or less submarginal tubers (usually 10 or more) in *P. pyrformis*.

The two species of Protopulvinaria distributed in Brazil have common host plants, however only *P. longivalvata* is associated with *P. nigrum*. According to LEMOS & CELESTINO FILHO (2009) this is the most common cochineal species in black pepper crops in the state of Pará, occurring on leaves, branches and shoots this species was also predominant in relation to D. *gracilis* in the present study. In the dry periods of the year, black pepper leaves very infested by *P. longivalvata* become flaccid and wither.

The genus Dysmicoccus Ferris is represented by 139 described species, 13 of which are recorded in Brazil. This genus includes several polyphagous species, considered pests of several plants of economic importance, including some that are vectors of viruses, such as *D. brevipes* (Cockerell), transmitter of virus in pineapple (SETHER et al., 1998). This species is the only species previously recorded on P. nigrum in Asia (WILLIAMS, 2004).

Adult females of Dysmicoccus species are macroscopically similar because they present with oval body, covered by white pharinaceous secretion and with lateral wax filaments ranging from 6 to 17 pairs around the body; 17 in *D. gracilis*. Microscopically, *D. gracilis* is very similar to *D. grassii* (Leonardi) for presenting translucent pores in the femur and tibia, ventral tubular ducts on the body margin, head, thorax and abdomen and discoidaal pores associated with the eye, although sometimes absent; but *D. gracilis* has multillocular pores in the chest and discoidal pores around the eyes in a sclerosated ring, while *D. grassii* has few discoidal pores associated with the eye and no multilocular pores in the thorax (WILLINK GRANARA, 2009).

Dysmicoccus gracilis was described from specimens collected in *Mangifera indica*, in the state of Bahia, Brazil (GRANARA DE WILLINK, 1999). Other host plant species were associated with *D. gracilis*, for example *Schinus terebinthifolius* Raddi (Anacardiaceae) in Brazil, *Vismia* sp. (Hypericaceae) in Guyana and *Ficus* sp. (Moraceae) in Costa Rica (GRANARA DE WILLINK, 1999). Subsequently, the species was recorded on roots and aerial part of conilon coffee plants (*Coffea canephora* L., Rubiaceae) in the states of Bahia and Espírito Santo (SANTA CECÍLIA et al., 2007; WILLINK'S GRANARA, 2009).

The sampled black pepper plants showed no symptoms of viruses, although the two species of cochineals are not yet recorded as transmitters of viruses in this crop.

CONCLUSION

For the first time, the species *D. gracilis* and the occurrence of *P. longivalvata* in black pepper in the state of Bahia, Brazil, are recorded for the first time. The registration of these species of mealybug associated with black pepper in the state of Bahia may help the producing community and researchers to develop monitoring and management strategies for these species, in order to avoid future losses.

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DECLARATION OF CONFLICTS OF INTEREST:

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed for the idealization and writing of the paper.

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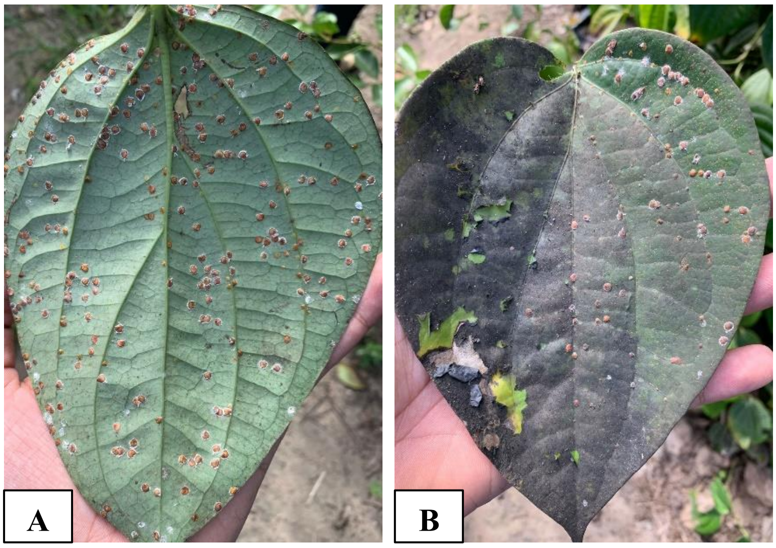

Figure 1. *Protopulvinaria longivalvata* on black pepper leaves in the municipality of Porto Seguro, Bahia, Brazil: A) Abaxial face; B). Adaxial face.

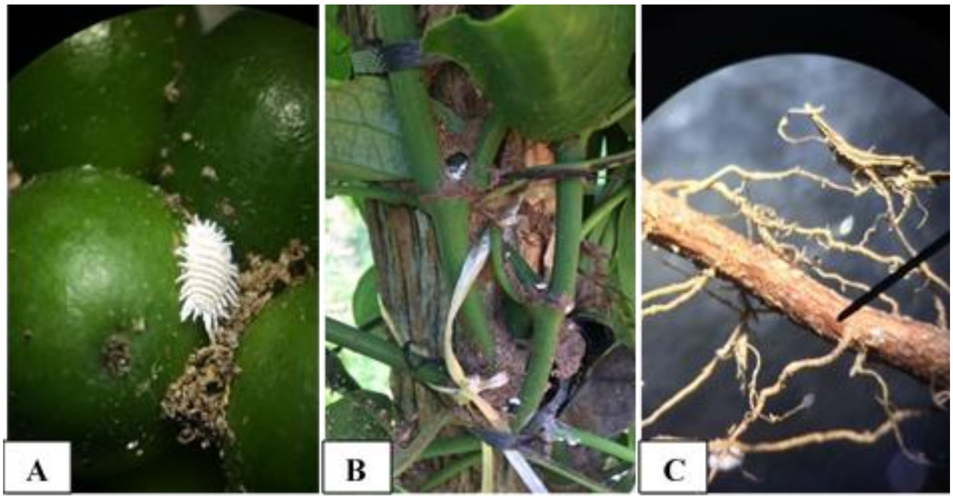

Figure 2. *Dysmicoccus gracilis* on different structures of black pepper plants, in Porto Seguro, Bahia, Brazil A) fruits; B) branches; C) roots

FINAL CONSIDERATIONS

The results obtained in this study are relevant indicators of the importance of continuous monitoring of mealybugs in black pepper culture, since reports of the first occurrence of a new species associated with the crop can help other research and the producing community to identify future injuries to pipericulture and assist them in monitoring management.

The methodology developed for monitoring these species of mealybugs was essential to understand their spatial behavior, characterized by random distribution, which may hinder the establishment of management strategies, such as management zones.

From the technical-scientific view, the first study to use applied geostatistical methods in the monitoring of mealybug in the culture of black pepper stands out, representing an important tool in the integrated management of pests.

Therefore, the results presented in this work will allow the participants of the black pepper production chain to continue assessing the risks of this species to the crop, so that they can develop new monitoring strategies.