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Full Length Research Paper

Path analysis to evaluate the direct and indirect effects of climatic variables in the development stages of *Tuta absoluta* (Lepidoptera: Gelechiidae) in tomato (*Solanum lycopersicum* L.)

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The objective of this study was to evaluate the influence of climatic variables on the population dynamics of the tomato moth *Tuta absoluta* (Meyrick, 1917), (Lepidoptera: Gelechiidae) through correlations and path analysis, on the main variable in organic and conventional tomato crops (*Solanum lycopersicum* L., Solanaceae). We studied the effects of the pheromone (used Delta traps) on insect phase sampling in two areas of agricultural with tomato cultivation in Alagoas, Northeast Brazil: latitude 09º81´76´´, longitude 36º59´42´´, during the agricultural years 2015-2017. The experimental design was completely randomized with two treatments with 60 replicates. In the path analysis, the main variables were adults, eggs, caterpillars and mines. Rainfall, relative humidity, temperature, wind speed, and solar radiation were explanatory and correlated variables. In the path analysis we observed that rainfall, relative humidity, and solar radiation were the variables of greatest influence on the population dynamics with direct effects in the organic system with correlation coefficients r = 0.83, r = 0.52 and r = 0.45 respectively. The following variables showed negative correlations: wind r = -0.43, and temperature r = -0.19. In the conventional system r = 0.80, r = 0.43 and r = 0.41, for the same variables. The wind speed variable had a negative effect of r = -0.38, and the temperature had a negative effect of r = -0.13. We observed that climatic conditions are variables conditioning the development of insect infestation in the tomato crops studied.

Key words: Integrated pest management, horticulture, food, agriculture.

INTRODUCTION

For crop systems that are subject to insect infestation, it is critical to implement pest management programs, including monitoring of insect pests, predators, parasitoids, natural enemies, and pollinators that occur in agroecosystems (Haji et al., 2002).

Cultivation of the tomato (*Solanum lycopersicum* L., Solanaceae), cited in several works such as those of Peralta et al. (2005); Souza and Lorenzi (2008) has broad scope for both natural consumption and for processing in industry. Worldwide, there is no other vegetable with such economic importance and versatility in terms of consumption and consumer acceptance across social strata (Filgueira, 2003).

For the tomato (*S. lycopersicum*), one of the pests that is a problem for the farmer is the tomato moth (*Tuta absoluta*). According to Gravena and Benvenga (2003), peaks of moth population occur during prolonged droughts and during winter. In rainy seasons, the population density decreases, and increases if the crop is irrigated with central pivot systems.

The tomato moth is present during the entire crop cycle, depending on the planting season, which lasts an average of 110 days. Santos et al. (2008b) argue that chemical treatment for purposes of integrated pest management can cause insect populations to become resistant. The choice of treatments and insecticide mixtures for tomato crops are planned according to the phenological stage and meteorological conditions favorable to pest attack (Gravena and Benvenga, 2003).

Techniques for monitoring insects in tomato culture have been established in Brazil. Synthetic pheromones have been used both for mass collection and for decision-making regarding integrated pest management. Tomato moth sampling is the principal tool of the field pest inspector. Sampling is accomplished via various technologies and strategies, including the use of traps containing synthetic pheromones (Bento, 2000).

The control of *T. absoluta* is managed by farmers using chemical products, usually successive applications with insecticides. The use of pheromone-based strategies is recognized as an important control technique for *T. absoluta* (Cocco et al., 2013; Megido et al., 2013). Major advances have been made in the field of semiochemicals to deal with *T. absoluta*, particularly sex pheromones (Desneux et al., 2010). The reproductive biology of *T. absoluta* supports the use of male annihilation as an effective control method for the reproduction of this pest, since males emerge before females, and females mate several times (Garzia et al., 2012).

Wright (1921), initiated path analysis studies, emphasizing the direct and indirect effects of the explanatory variables on the main ones. Evaluation of simple correlations between variables is the initial step. Although the correlations are important for quantifying the magnitude and direction (negative or positive correlation) of factor influences, they do not accurately uncover cause-and-effect relationships among variables.

Path analysis is also called “walking analysis”. The study of simple correlations between the variables makes it possible to measure associations, without drawing conclusions regarding cause and effect. Therefore, this analysis makes no inferences regarding the type of association between variables (Coimbra et al., 2005).

According to Cruz et al. (2004), path analysis is used to verify whether the direct or indirect effects of the explanatory variables (A1, A2... An) on the main variable (B) should or should not be considered in a study. If the path coefficient of a given explanatory variable is numerically smaller than the coefficient of the residual variable, it means that this independent variable only indirectly explains changes in B. In other words, this variable alone is not able to explain variations in B. It can be important only when analyzed in conjunction with other variables. A path coefficient numerically greater than the coefficient of the residual variable demonstrates that there is a direct effect of the explanatory variable on the main variable.

There are no data regarding the influence of population fluctuations of *T. absoluta* in Alagoas on cultivation of vegetables and tomato (*Solanum lycopersicum* L.). In addition, there are no data regarding the influence of meteorological parameters and insect phases on the effects of synthetic pheromones. The objective of this study was to perform a path analysis of the climatic elements, identifying their direct and indirect effects on the population dynamics of *T. absoluta* in tomato cropping systems in the agreste region of Alagoas, Brazil; for the decision of integrated pest management.

MATERIALS AND METHODS

Study area

This study was carried out in two tomato cultivation areas, in Alagoas, Northeast Brazil, latitude 09°81'76'', longitude 36°59'42''. In agricultural areas, the soil is predominantly eutrophic red-yellow latosol (EMBRAPA, 2009). The climate is Köppen classification As', (tropical and hot), with temperature ranging between 23 and 32°C. Rainfall in fall/winter ranges between 500 and 1,000 mm. Meteorological data were gathered from the database of the National Institute of Meteorology (INMET), published by the Secretariat of Water Resources of Alagoas - SEMARH (SEMARH Alagoas, 2017).

Two conventional and organic cultivation systems were evaluated. In the organic cultivation the management is carried out with the application of natural products in the soil and in the conventional crops the handling is made the use of synthetic products in the soil and in the crops. These were configured as single rows separated by one and a half meters, approximately 25 m in length and divided into rectangular experimental areas.

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Figure 1. Tomato crops conventional and organic system in the agreste region of Alagoas (research period 2015-2017).
Source: Author's photo. (2015-2017).

Areas were equivalent to 1.5 ha. The period of study spanned four crops during the agricultural years 2015-2017 (Figure 1A and B).

Monitoring of *T. absoluta* adults in delta traps, using the ISCAlureTuta® pheromone

For the monitoring of adults, two traps of the Delta type with latex septa impregnated with ISCAlureTUTA® sex pheromone were used, with a wire support structure in the longitudinal direction for the placement of the pheromone at opposite vertices. The pheromone has as its main component ((E, Z, Z)-3,8,11-tetradecadienyl acetate (1.4 g/kg), available in latex septa (natural rubber - 998.6 g/kg) the same component used by Roda et al. (2015) for crops in Panama and Florida.

ISCAlureTuta® is a specific and selective attractant for male tomato moths (*Tuta absoluta*). When used with Delta plastic traps, it identifies the presence of the pest as well as assisting in decision-making by providing accurate data regarding insect population fluctuation. By capturing a large number of moths, the traps can be used to exert effective population control (Figure 2A and B). ISCAlures are pheromone evaporators, impregnated with rubber septa. Release is controlled and constant, similar to that of the target insect. They are often used for identification, measurement of population fluctuation, and for mass capture. The pheromone attracts males into the Delta trap where they are stuck in a paper receptacle (ISCA Tecnologias, 2017).

Insects were collected for monitoring every seven days, for a total of sixty collections/year. The research period was from September 2015 to February 2017. For analysis of the data on population fluctuation of the target insect and its stages of development, we considered meteorological parameters including rainfall, relative humidity, temperature, wind, and solar radiation. The rubber septa with the pheromone were replaced every thirty days, and the bottoms (floor) of the Delta trap were changed, as the glue would remain unsealed after the installation of the traps. The insects caught in the traps were counted and removed with the aid of a forceps every seven days, and were placed in jars with 70% alcohol.

Experimental design

The experimental design was completely randomized with two areas (Delta trap + pheromone traps) with 60 replicates. The Delta traps were fixed on bamboo stalks at a height of about twenty centimeters above the plants. According to the phenological stage, the traps were moved vertically. Data analysis was performed using GENES Software (Cruz, 2006).

Adult catch data for Delta traps with ISCAluteTuta ® pheromone, along with the average number of eggs, caterpillars and mines found in the plant were correlated with the following climatic variables: rainfall, relative humidity, temperature, wind, and solar radiation. These were interpreted using Pearson correlation matrices. Direct and indirect effects were evaluated by path analysis.

In path analysis, the main variables considered were adults, eggs, caterpillars, and mines. The explanatory and correlated variables were precipitation, relative humidity, temperature, wind speed and solar radiation. Prior to path analysis, we performed multicollinearity diagnosis to determine whether the correlations between the explanatory variables would affect the results of path analysis. If so, measures were taken to mitigate the problem. Correlation matrices, multicollinearity diagnoses, and trail analysis

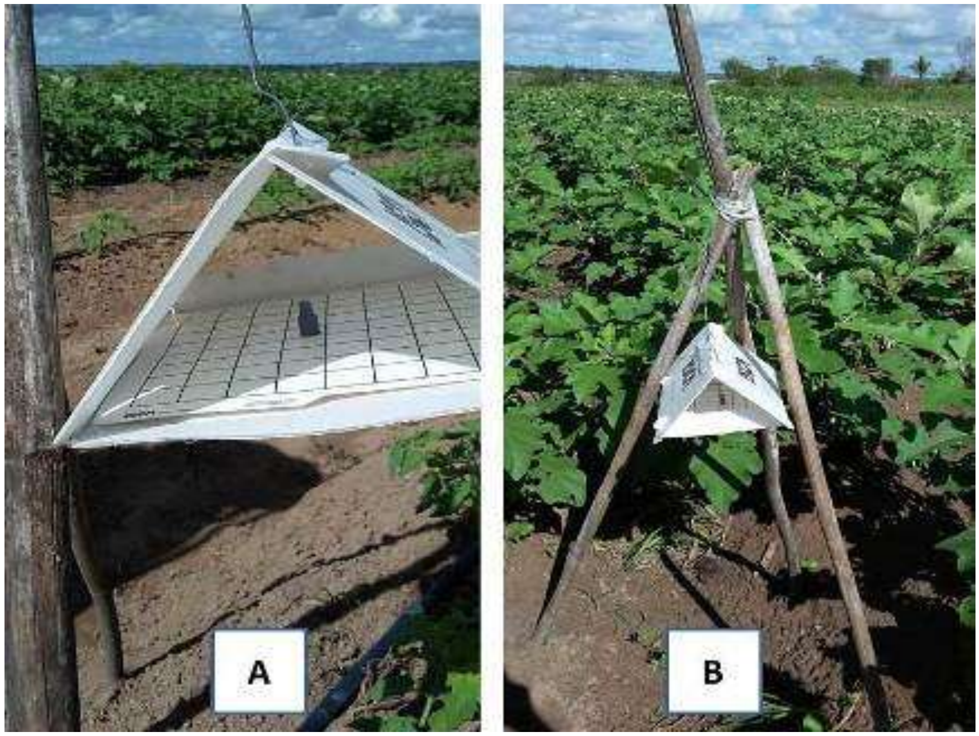

Figure 2. Traps (Delta) with the rubber septum of the pheromone IscalureTuta®. A (Conventional farming) and B (Organic farming).
Source: Author's photo. (2015-2017).

including illustrative casual diagrams, were executed using Excel spreadsheets and GENES software (Cruz, 2006).

Monitoring of insect phases in tomato

In both agricultural areas, we monitored insect phases in the plant every 15 days from 45 to 150 days after emergence (DAE). We used five plants randomly selected by zigzag walking in the tomato rows in a 40 × 50 m area. We used four sampling procedures for *T. absoluta*: three leaves of the apical third (eggs, caterpillars and mines), three leaves (eggs, caterpillars and mines) and an entire plant (eggs, caterpillars and mines), five fruits collected per plant in the upper part were taken to verify the presence of eggs, injuries, or mines. The experimental design was completely randomized with two treatments (conventional and organic) and ten replicates (collections). Samples were taken to the laboratory and observed with stereoscopic loupes at 80x magnification (adapted from Gomide et al., 2001).

RESULTS AND DISCUSSION

Evaluation of *T. absoluta* phases in tomato

Monitoring showed the presence of the insect in its egg and caterpillar stages, as well as damage to the plants through the mines throughout the crop cycle (45 to 150 DAE). *T. absoluta* has a life cycle of 36 to 38 days. Therefore, it can complete three generations in one crop cycle (Guedes and Picanço, 2012). The monitored parts of the plant were as follows: apical third, middle third and whole plant, and fruits of 2 to 3 cm in diameter (Figure 3A to E). The apical and middle third had the highest incidence of oviposition and damage. The tomato moth prefers these areas for its habitat and niche. First-instar caterpillars invade these areas (OEPP/EPPO, 2005; Guenaoui, 2008).

Oviposition is the most important phase with respect to decision-making regarding pest control. According to Gomide et al. (2001), sampling methods that monitors the presence of eggs has advantages over other methods. The leaves of the tomatoes are where the insect lives during the first stages of life. *T. absoluta* caterpillars develop in the mined leaves and tomato fruits. The most reliable evaluation for the monitoring of population levels are performed on the leaves (EPPO/IOBC/FAO/NEPPO, 2011).

Picanço et al. (2007) reported that *T. absoluta* first instar larvae cause crop losses of up to 100% by attacking tomatoes leaves, flowers, stems, and especially fruits. In the leaf, the larvae feed on the mesophyll, leaving the epidermis intact. The leaf mines resemble an irregular patch with finger-like extensions, easily differentiable from mines made by *Liriomyza trifolii* (Burgess, 1880) (Diptera: Agromyzidae). Larvae can make several mines on the same leaf or may penetrate

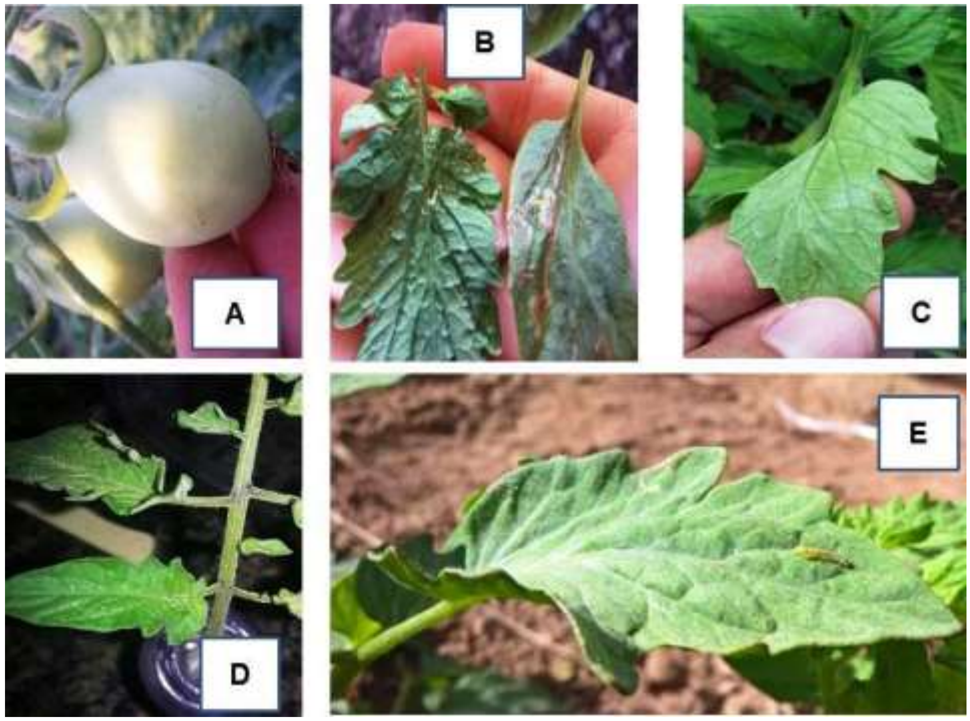

Figure 3. Eggs, caterpillars and mines on tomato leaves.
Source: Author's photo (2015-2017).

Table 1. Mean of the variables monitored and analyzed in tomato plants (*S. lycopersicum* L.) (2015-2017), with the standard deviation.

Variables searched	Pointer leaves		Leaves of the middle third		Whole plant		Fruits (eggs) 2 cm	
	Org	Conv	Org	Conv	Org	Conv	Org	Conv
Eggs	32±2.3^{a}	66±5.6^{a}	80±6.7^{a}	91±8.7^{a}	30±2.4^{b}	78±4.8^{a}	18±2.2^{a}	30±3.4^{a}
Mines (injury)	23±1.8^{b}	42±4.7^{b}	54±3.6^{b}	78±6.5^{a}	66±5.7^{a}	48±3.9^{b}	17±2.1^{a}	12±2.5^{b}
Caterpillars	19±2.1^{b}	35±4.9^{b}	41±2.9^{b}	36±2.6^{b}	54±3.9^{a}	43±2.7^{b}	7±0.9^{b}	18±1.3^{b}

Caption: Organic (Org), Conventional (Conv.). Means not followed by the same letter differ significantly in the column by the Tukey test at 5% probability. Source: survey data.

other leaves, including the stem (Estay and Bruna, 2002).

In this study, the mean numbers of eggs, caterpillars and mines monitored in the two cultures were significantly different by the Tukey test at 5% probability (Table 1). In the conventional system, the averages were higher than in the organic system. In solanaceous crops in the region of Sardinia, Italy (Mediterranean climate), 11.3% of leaves had mines, with 2.7 mines/leaf (Delrio et al., 2012). Studies in the Mediterranean reported high pest infestation on tomato leaves (3.8 mines/leaf) and fruits (27% of damaged fruits). Eggs, larvae, and adults were detected over two consecutive winters, suggesting that *T. absoluta* can develop continuously throughout the year under natural conditions (Cocco et al., 2015) (Table 1).

Garzia et al. (2012) report that *T. absoluta* can be found in the plants during the entire development cycle. During the fruiting period, the infestation is more substantial because of less effective control of the caterpillars inside the fruits. This coincides with the harvest period, when insecticide treatment decreases. The observation of caterpillars in the leaves of the tomato is explained by the fact that they were changing mines in the leaf. We hypothesized, therefore, that temperature influences this behavior, because the time chosen for this monitoring was after 3 pm

Benvenga et al. (2007) reported a significant correlation between the number of traps and the increase in *T. absoluta* attack on tomatoes cultivated in a protected environment. Cabello et al. (2010) suggested that there is a need to regularly monitor the plants to detect the presence of caterpillars, since their presence and number

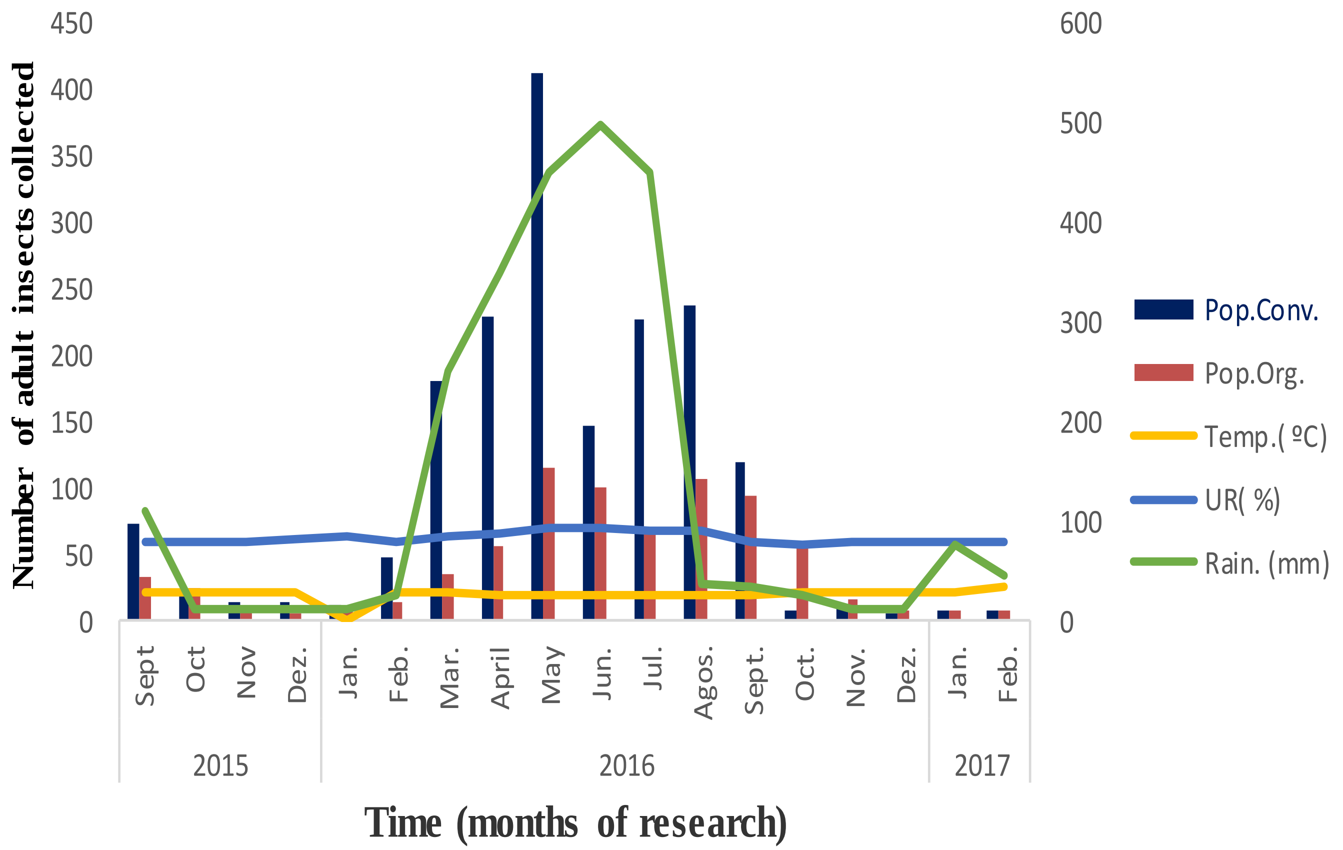

Figure 4. Population fluctuation of *Tuta absoluta* with the Delta trap with IscalureTuta® pheromone in the agreste region of Alagoas and the monitoring of climatic variables (Sept / 2015-Fev / 2017).
Source: Search (2015-2017).

do not always correlate with the number of adults caught in the traps.

Torres et al. (2001) report that the behavior of the tomato moth may be related to the increase of temperature inside the mine exposed to the sun. Another hypothesis is that the accumulation of excrement inside the mine results in deprivation of food for mesophyll of the source leaf. The population fluctuation of *T. absoluta* throughout the study (2015-2017) ranged from 5 to 15 insects per day found in the trap. We verified that the occurrence of the moth of the tomato did not reach the level of 25 caterpillars per plant, which is the limit for the control, according to Gravena and Benvenga (2003) and Cely et al. (2010).

This fact can be attributed to the management by the farmer in the application of chemical products in the conventional system and in the organic system, with the application of natural products, as well as the planting of other crops in the area at the end of the harvest. Bacci (2006) stated that in regions where the practice of crop rotation was adopted, seasonality influenced the presence of pest insects.

Evaluation of the adult *T. absoluta* in the delta trap with the pheromone ISCAlureTuta®

In the monitoring of the insect with the use of the pheromone, the population of males accumulated was a total of 6,623 insects in the conventional system, and 2,270 insects in the organic system. This suggests that the insect is endemic in Alagoas. The population fluctuation of the tomato moth in Alagoas in the months with lower temperature was higher than that of periods with high temperature, with a mean of 415 in the winter period (Figure 4). Bacci (2006) reported some pest peaks in the winter months, in the state of Minas Gerais, since in tomato crops the pest is present there throughout the year. The adoption of the practice of monitoring the populations of insect pests throughout the crop cycle is fundamental for decision-making regarding control, particularly with respect to reducing the use of insecticides (Marsaro et al., 2010).

Al-Zaidi (2010) used the combined effect of pheromones and light on traps for mass capture. They obtained significant results, suggesting that the combined approach may be an important strategy for integrated pest management that will decrease the number of individuals in the insect population in tomato or solanaceous crops.

According to Santos (2007), pest monitoring is fundamental for pest control, since it allows monitoring the incidence and the damage done by the pests, facilitating the timing of decision-making in pest control. Our data collected from the adults in the traps showed that population fluctuations of the tomato moth (*T. absoluta*) in regions are atypical with respect to changes in the demographic density of the species in crops regulated by climatic conditions. Santos et al. (2008a) concluded from their study that, at the end of the crop cycle, there was a greater capture of adults in the traps because of favorable climatic conditions to the insect and because of decreased application of insecticides.

In similar conditions using pheromone in the Mediterranean, Cocco et al. (2015) showed that male catches and leaf infestation were low in winter and increased steadily in the spring, up to 797.3 males/ trap/week and 6.4 mines/leaves, respectively. In open field conditions, males were caught throughout the year with a peak in early September, concurrently with the highest average daily temperatures.

In order to emphasize the climatic aspects, Alvarenga (2004) reported that when tomatoes are cultivated in a protected environment, the low relative humidity of the air and the high temperatures provoke an increase of transpiration rate, leading to closure of stomata, reduction of the pollination rate, abortion of flowers and, consequently, lower production.

Wind is a mechanism used by plants to attract potential pollinating insects, with the olfactory information being an important stimulus (Vainstein et al., 2001). Other abiotic factors influence visit rates: the combination of high values of luminosity and temperature favors visits. Barbosa et al. (2016) showed that relative humidity of the air and low temperatures, wind and low insolation influence certain insects such as those of the family Apidae.

Gravena and Benvenga (2003), affirmed that peaks of population fluctuation occur in prolonged droughts and in the winter. The population density decreases during rainy periods. In Alagoas, during the study period, population peaks were observed in May to September in the two tomato crops and in the fallow area, where the relative humidity (RH) was an average of 85% and temperature (T) an average of 28°C with a daily photoperiod of 12 h. We exchanged rubber septa containing pheromone every 30 days and counted adults caught in the traps every 7 days. Adults remain in the leaves until dusk. In this study, greater adult flying activity was observed around the trap, compared with other schedules. During the day, adults remained in the tomatoes, in the face of the leaves. At dusk, they demonstrated hectic flight over the flowers and leaves.

The biology and ecology of pests are objects of study worldwide, especially in Europe and Africa. These studies estimate climactic suitability for various pests and potential spread of pests on a regional and global scale. Some studies demonstrate insect adaptation (Bacci et al., 2006). The evidence suggests that temperature and humidity influence *T. absoluta* population growth, while the pest's ability to survive conditions of cold, hot, humid and dry stress are the main characteristics that define its forms of adaptation (Tonnang et al., 2015).

Correlation analysis of the studied variables

Data from Pearson's simple correlation coefficients (Tables 2 and 3) suggest that high correlation coefficients between independent variables other than zero were statistically significant. In Table 2, the results of the simple correlation matrix (r) between the studied variables point to the coefficients (r) with the highest significance among the biotic and correlated variables observed in the development stages of the insect. Among the climactic (abiotic) variables, the coefficients revealed the following positive correlations: precipitation (r = 0.80), relative humidity (r = 0.43), solar radiation (r = 0.41); and the following negative correlations: temperature (r = -0.13), and wind (r = -0.38). The extraction of the correlation matrix allows the selection of the most significant variables, which have a prominent role in the interpretation of the study proposal. Benvenga et al. (2007) in a similar study, found a positive correlation between the number of insects and productivity. Bacci (2006) also observed this effect of correlations among climatic variables.

Fernandes et al. (2009), in studies of *Leucoptera coffeella* (Guérin-Mèneville, 1842) (Lepidoptera: Lyonetiidae) in coffee crops, performed path analysis and showed that the environmental variables most influencing the intensity of attack of this pest were rainfall (r = 0.69), air temperature (r = -0.40), and solar radiation (r = -0.44). Some of these coefficients were different from those found in this study.

The correlation coefficients were calculated for each main variable in combination with the independent variables. They were interpreted according to the model proposed by Franzblau (1958) in which: 0-0.19 are null or negligible; 0.2-0.39 are low; 0.4-0.59 are moderate; 0.6-0.79 are accentuated; and 0.81-1.00 are high (Pereira, 2015).

These correlation coefficients, although useful for quantifying the magnitude and direction of factor influences in the determination of complex characters, do not provide precise relative magnitudes of the direct and indirect effects of these factors (Cruz and Carneiro, 2006). When the main variable shows significant correlations with other variables, path analysis may be employed to identify variables with significant correlations

Table 2. Pearson's simple correlation coefficients among the variables evaluated in the population survey of *T. absoluta* in the agreste region of Alagoas - conventional crop (period 2015-2017).

Variables	Eggs	Caterpillars	Mines	Adults	Rain.	UR	Temp	Wind.	Rad
Eggs	-								
Caterpillars	0.95*	-							
Mines	0.90*	0.94*	-						
Adults	0.78*	0.74*	0.64*	-					
Rain.	0.66*	0.61*	0.52*	0.80*	-				
UR	0.41*	0.42*	0.49*	0.43*	0.45*	-			
Temp	-0.13*	-0.15*	-0.20*	-0.13*	-0.04^{ns}	-0.33*	-		
Win.	-0.16*	-0.19*	-0.09^{ns}	-0.38*	-0.25*	-0.39*	0.53*	-	
Rad	0.49*	0.43*	0.42*	0.41*	0.52*	0.02^{ns}	0.37*	0.23*	-

* significant at the 5% probability level (p <0.5). ns - not significant (p> = 0.5), by the t test.* Equipe Estatcamp (2014). Rainfall (Rain.); Relative humidity (RH); Temperature (Temp.); Winds (Win.); Radiation (Rad.).

Table 3. Pearson's simple correlation coefficients among the variables evaluated in the population survey of *T. absoluta* in the agreste region of Alagoas - organic crop (period 2015-2017).

Variables	Eggs	Caterpillars	Mines	Adults	Rain.	UR	Temp	Win.	Rad
Eggs	-								
Caterpillars	0.49*	-							
Mines	0.44*	0.91*	-						
Adults	0.32*	-0.04^{ns}	0.05^{ns}	-					
Rain.	0.19*	-0.05^{ns}	0.09^{ns}	0.83*	-				
UR	0.40*	0.16*	0.20*	0.52*	0.45*	-			
Temp	0.01^{ns}	-0.09^{ns}	-0.24*	-0.19*	-0.04^{ns}	-0.33*	-		
Win.	-0.20*	0.24*	0.19*	-0.43*	-0.25*	-0.39*	0.53*	-	
Rad	-0.02^{ns}	-0.30*	-0.30*	0.45*	0.52*	0.02*	0.37*	0.23*	-

* significant at the 5% probability level (p <0.5). ns - not significant (p> = 0.5), by the t test . Equipe Estatcamp (2014). Rainfall (Rain.); Relative humidity (RH); Temperature (Temp.); Winds (Win.); Radiation (Rad.).

with the basic variable, as well as those that have greater direct effects in the desired direction (Júnior et al., 2003).

In the organic system, the independent variables with greatest correlations with the population dynamics, represented by the catch of adults of *T. absoluta*, were rainfall, relative humidity, and solar radiation (r = 0.83, r = 0.52 and r = 0.45, respectively, Table 3). The variables temperature and wind velocity also correlated, although with negative module value (r = -0.19 and r = -0.43, respectively). In other words, these variables may exert an indirect effect on the adult population in the region of tomato cultivation in Alagoas, in the opposite direction to the way the main variable behaves.

Direct and indirect effects were evaluated by path analysis

The data displayed in Tables 4 and 5 refer to the results obtained from path analysis, exploring the correlations of the explanatory variables and their direct and indirect effects on the main variable, the values of the coefficients of determination, and the effects of the residual variables. The dependent and main variables in the two crops: eggs, caterpillars, mines and adults, correlated with the independent variables: rainfall, relative humidity, mean temperature, wind speed, and solar radiation, and also correlated with each other. They explain the direct and indirect effects on the population dynamics of *T. absoluta*.

The high population density of *T. absoluta* during the winter period from May to September (rainy months) is attributed to the lack of proper management of the crop remnants and to the direct and indirect effects of the climatic elements on this pest, observed in the two systems of cultivation. The reduction of density from November to April (comprising the drought months) is attributed to crop rotation and the increase of wind speed and air temperature, as well as to solar radiation. These may be the causes of the seasonal cycles of population growth. The decline of populations correlated with the direct and indirect negative effect of temperature on *T. absoluta* (Bacci, 2006; Barbosa et al., 2016).

Table 4. Direct and indirect effects of biotic and abiotic variables in the conventional system on the number of adults of *T. absoluta*.

Detail	Rainfall	UR	Temp.(°C)	Winds	Rad.
Direct effect on number of eggs	0.4057	0.1650	-0.2134	0.0362	0.3519
Indirect effect by RAIN	-	0.1852	-0.0189	-0.1015	0.2139
Indirect effect by UR	0.0753	-	-0.0546	-0.0656	0.0035
Indirect effect by TEMP	0.0099	0.0707	-	-0.1133	-0.0792
Indirect effect by WINDS	-0.0090	-0.0144	0.0192	-	0.0086
Indirect effect by RAD	0.1855	0.0076	0.1305	0.0838	-
Pearson's Correlation (r)	0.6674	0.4141	-0.1372	-0.1604	0.5825
Coefficient of determination (R^2)			0.53		
Effect of residual variable			0,67		
Direct effect on number caterpillars	0.3590	0.1939	-0.1939	0.0048	0.3102
Indirect effect by RAIN	-	0.1639	-0.0167	-0.0898	0.1893
Indirect effect by UR	0.0885	-	-0.0642	-0.0771	0.0042
Indirect effect by TEMP	0.0090	0.0642	-	-0.1029	-0.0719
Indirect effect by WINDS	-0.0012	-0.0019	0.0025	-	0.0011
Indirect effect by RAD	0.1635	0.0067	0.1151	0.0739	-
Pearson's Correlation (r)	0.6188	0.4268	-0.1572	-0.1911	0.5068
Coefficient of determination (R^2)			0.46		
Effect of residual variable			0,72		
Direct effect on number mines	0.1634	0.3676	-0.3069	0.1548	0.4047
Indirect effect by RAIN	-	0.0746	-0.0076	-0.0408	0.0862
Indirect effect by UR	0.1678	-	-0.1218	-0.1462	0.0080
Indirect effect by TEMP	0.0143	0.1017	-	-0.1629	-0.1139
Indirect effect by WINDS	-0.0387	-0.0615	0.0821	-	0.0368
Indirect effect by RAD	0.2133	0.0088	0.1501	0.0964	-
Pearson's Correlation (r)	0.5201	0.4912	-0.2041	-0.0987	0.5182
Coefficient of determination (R^2)			0.48		
Effect of residual variable			0.71		
Direct effect on number of adults	0.6612	0.0409	-0.0143	-0.2237	0.1254
Indirect effect by RAIN	-	0.3018	-0.0309	-0.1654	0.3486
Indirect effect by UR	0.0186	-	-0.0135	-0.0162	0.0008
Indirect effect by TEMP	0.0006	0.0047	-	-0.0076	-0.0053
Indirect effect by WINDS	0.0559	0.0889	-0.1187	-	-0.0533
Indirect effect by RAD	0.0661	0.0027	0.0465	0.0298	-
Pearson's Correlation (r)	0.8024	0.4390	-0.1309	-0.3831	0.4460
Coefficient of determination (R^2)			0.68		
Effect of residual variable			0.55		

* Significant by t-test, 5% probability.

According to Araujo et al. (2011), the main meteorological elements that provide energy for evaporation and removal of water vapor from evaporating surfaces are solar radiation, air temperature, relative humidity, wind speed, and decreased vapor pressure. Of these, solar radiation is the most important element for the evaporative demand of the atmosphere. When the direct and indirect effects of the biotic variables were observed with indirect pathway of the meteorological conditions, some of these variables correlated, depending on the stage of development, namely: eggs x caterpillars, mines x caterpillars as a function of the adult of *T. absoluta* collected in the traps in the two crops. For the abiotic variables with indirect pathways, the correlations were: temperature x winds, relative humidity x precipitation, and solar radiation causing a negative effect on the average temperature (Gravena and Benvenga, 2003).

According to Nogueira et al. (2012), when interpreting correlations, three aspects should be considered: magnitude, direction, and significance. Estimation of positive correlation coefficient indicates the tendency of one variable to increase when the other also increases,

Table 5. Direct and indirect effects of biotic and abiotic variables in the organic system on the number of adults of *T. absoluta*.

Detail	Rainfall	UR	Temp.(°C)	Winds	Rad.
Direct effect on number of eggs	0.0399	0.4295	0.2815	-0.1442	-0.1211
Indirect effect by RAIN	-	0.0182	-0.0018	-0.0100	0.0210
Indirect effect by UR	0.1961	-	-0.1423	-0.1708	0.0093
Indirect effect by TEMP	-0.0131	-0.0932	-	0.1494	0.1044
Indirect effect by WINDS	0.0360	0.0573	-0.0765	-	-0.0343
Indirect effect by RAD	-0.0638	-0.0026	-0.0449	-0.0288	-
Pearson's Correlation (r)	0.1951	0.4092	0.0160	-0.2040	-0.0495
Coefficient of determination (R^2)			0.22		
Effect of residual variable			0.88		
Direct effect on number caterpillars	0.2656	0.2519	-0.1187	0.6037	-0.5484
Indirect effect by RAIN	-	0.1212	-0.0124	-0.0664	0.1400
Indirect effect by UR	0.1150	-	-0.0835	-0.1002	0.0054
Indirect effect by TEMP	0.0055	0.0393	-	-0.0630	-0.0440
Indirect effect by WINDS	-0.1510	-0.2401	0.3204	-	0.1438
Indirect effect by RAD	-0.2892	-0.0119	-0.2035	-0.1307	-
Pearson's Correlation (r)	-0.0541	0.1604	-0.0977	0.2434	-0.4339
Coefficient of determination (R^2)			0.35		
Effect of residual variable			0,80		
Direct effect on number mines	0.5166	0.1589	-0.3047	0.6984	-0.6298
Indirect effect by RAIN	-	0.2358	-0.02415	-0.1292	0.2724
Indirect effect by UR	0.0725	-	-0.0526	-0.0632	0.0034
Indirect effect by TEMP	0.0142	0.10099	-	-0.1617	-0.1130
Indirect effect by WINDS	-0.3320	-0.2777	0.3707	-	0.1664
Indirect effect by RAD	-0.1747	-0.0137	-0.2337	-0.1500	-
Pearson's Correlation (r)	0.0966	0.2042	-0.2444	0.1943	-0.4506
Coefficient of determination (R^2)			0.48		
Effect of residual variable			0.71		
Direct effect on number of adults	0.6086	0.1194	-0.0759	-0.2412	0.2139
Indirect effect by RAIN	-	0.2778	-0.0284	-0.1522	0.3209
Indirect effect by UR	0.0545	-	-0.0395	-0.0475	0.0026
Indirect effect by TEMP	0.0035	0.0251	-	-0.0403	-0.0281
Indirect effect by WINDS	0.0603	0.0959	-0.1280	-	-0.0574
Indirect effect by RAD	0.1128	0.0046	0.0794	0.0509	-
Pearson's Correlation (r)	0.8397	0.5228	-0.1924	-0.4303	0.5028
Coefficient of determination (R^2)			0.78		
Effect of residual variable			0.45		

* Significant by t-test, 5% probability.

and negative correlations indicate tendency of one variable to increase while the other one decreases. Table 4 displays the direct and indirect effects on the main independent variables (climatic elements), and explains the population dynamics, such as variable "eggs", which contributed 53% to the remaining adults in the crops (R^2 = 0.53). For the "caterpillar" variable, there was a 46% participation in this increment of adults (R^2 = 0.46). The damage caused by *T. absoluta* on tomato leaves through the mines was 48% (R^2 = 0.48). Climatic elements directly influenced 68% (R^2 = 0.68), precipitation contributed to the presence of the adult in the conventional crop. One can also raise the hypothesis of the absence of natural enemies by the systematic application of insecticides.

According to Bacci (2006), the population dynamics of *T. absoluta* depend on climatic factors in a direct way. Winds favor the dispersion of adults and rain promotes egg and caterpillar mortality. Temperature affects development, and insect reproduction indirectly affects natural enemies. It can be inferred that precipitation in Alagoas may impair the management of *T. absoluta*.

The application of chemical products may be affected by the amount of rainfall, because water dilutes the product in the tomato leaves, causing inefficiency of the handling.

Siqueira et al. (2001) discussed the application of synthetic products and the resistance of *T. absoluta* in tomato crops according to this approach. Bacca et al. (2006) point out that, in Minas Gerais, precipitation negatively affected the population dynamics of *T. absoluta*, since rain impairs flight and reduces encounters between partners, reducing reproduction. However, their data differ from the data in the present study. Climatic variations can directly or indirectly influence phytophagous insects in terms of oviposition, feeding, growth, development, reproduction, and migration (Kamata, 2000; Hopkins and Memmott, 2003).

In conventional cultivation, the residual coefficients with higher values on the direct effect were the “caterpillar” variable (0.72), followed by the “mines” variable (0.71), as these coefficients were higher than the path value. The effects of the explanatory variables are indirect on the main variable. Caterpillars survive by feeding on the mesophyll of the leaves or other parts of the tomato, in conjunction with the permanence of the adult of *T. absoluta* in the crop region. Therefore, within the mesophyll, caterpillars may not suffer directly from climate actions or from integrated pest management.

The data in Table 5 of the organic system have different coefficients than those of the conventional system, although both existed under identical climatic conditions. The presence of adult *T. absoluta* under the influence of climatic variables is due to the fact that in organic management, with agroecological bias, there are host species present. The application of natural products in the management may induce resistance, as evidenced by the higher coefficient (R^2 = 0.78). The indirect effects of the climatic variables contributed 78% to the presence of the insect during the crop cycles. Bacci (2006) stated that climatic elements influence the population of *T. absoluta* because it affects their natural enemies.

In the variable “eggs” which requires attention of the farmer to control, there was no substantial percentage (R^2 = 0.22), representing 22% of the increment of adults in the organic system. Following the development of the insect, caterpillars gave a coefficient of (R^2 = 0.35), meaning a contribution of 35% at this stage for the adult phase. This crop was controlled by natural products. The “mines” coefficient of determination (R^2 = 0.48), suggested substantial damage to the tomato. This is an important stage of *T. absoluta* for the following phase. Gonring (2004) deals with the sequence of *T. absoluta* events in tomatoes from the presence of adults in oviposition, caterpillars, mines, and fruit boring.

The highest direct effect (DE), corroborated by the residual coefficient greater than that of the path was on the number of eggs (0.88), followed by the DE for the caterpillar variable (0.80). These variables are responsible for the adult endemism of *T. absoluta* in tomato cultivation in Alagoas. As Balzan and Moonen (2012) argue, the results show relatively higher harvest damage for tomatoes transplanted later in the season and harvested in late August through early September, and greater damage to fruits caused by this pest during the second year of the study, both for conventional and organic crops. In Europe (Italy), the biological and chemical pest management strategies for *T. absoluta* control adopted by farmers in the region are continuously reviewed and discussed (Riudavets et al., 2016).

Conclusions

In Alagoas-Brazil, *T. absoluta* population peaks in the winter months. We recommend placing traps with the pheromone IscalureTuta® during this period, to inhibit mating and thereby to control the insect population. Path analysis made it possible to estimate the correlation coefficients between meteorological and biotic variables on the population dynamics of *T. absoluta*. We demonstrated the direct and indirect effects of the explanatory variables on population dynamics. When the determination coefficients (R^2) are higher in the path analyses, they indicate that the climatic components explain a great part of the variation in the population dynamics of *T. absoluta*. By the analysis of the direct effects of the meteorological variables on the biotic variables, adult number was the variable that best correlated with climatic variations. This demonstrates the value of substantial planning for integrated pest management. Studies that disregard the variables of solar radiation, temperature, relative humidity, and wind speed can lead to spurious results. Further studies of the management tactics to combat this pest should take into account insect cycles and the elements related to the seasonal impacts on their populations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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