



PEST–PREDATOR DYNAMICS AND THEIR EFFECTS ON FLOWER ABORTION IN GREENHOUSE TOMATO PLANTS

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Abstract

This is because insect pests often influence greenhouse tomato production, but the interactions among the abundance of the pests, the predators, and the damage inflicted by the pests, and their effects on reproductive performance have not been fully studied under controlled cultivation settings. This study examined temporal patterns in pest and predator populations and evaluated their associations with plant damage and flower abortion in greenhouse tomato plants. Observational plant-level data collected from greenhouse compartments over five sampling weeks were analyzed. The final dataset consisted of 800 observations obtained by integrating pest, predator, and flower datasets using shared plant identifiers. Descriptive statistics were used to summarize biological variables, while Pearson correlation analysis and multiple linear regression were applied to assess relationships among pests, predators, plant damage indicators, and reproductive traits. Pest and predator populations were highest during the early sampling period and declined in later weeks. Necrotic rings showed the strongest positive correlation with flower abortion ($r = 0.403$). Regression analysis indicated that necrotic rings and sampling week were significant predictors of flower abortion, whereas pest abundance showed weaker associations. These findings suggest that plant damage indicators and temporal dynamics play an important role in reproductive loss in greenhouse tomato systems.

Keywords: tomato production, greenhouse agriculture, insect pests, biological control, crop yield

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a horticultural crop that is commonly grown globally and is a valuable model species in the areas of plant development, physiology of stress, and food science. Through its economic and biological significance, it has been a focus crop in research and commercial production systems of agriculture [1]. Nevertheless, to sustain a constant tomato production is still not easy because there are growing demands of climate variability, pests, and sustainability issues within the contemporary agricultural system [2]. Specifically, it has been estimated that increased temperatures and environmental stressors could have a huge impact on tomato production in the next few decades, and this could decrease the world's production unless measures are taken to adapt to the management issues [3]. This has contributed to the development and expansion of controlled farming systems, including greenhouses, due to the increasing demand for tomatoes. Such systems enable growers to manage the environment and prolong production time, and hence improve the stability of yield and quality of the crop. Nevertheless, there are also significant environmental and resource implications of greenhouse production systems, such as energy consumption and the presence of greenhouse gases related to intensive cultivation levels [4]. This has led to the sustainability of the production of greenhouse tomatoes in the modern day horticulture becoming a priority. The sustainable strategies of greenhouse cultivation should be aimed at the acquisition of maximum output with minimal alterations in the atmosphere and minimal consumption of resources [5]. Energy-efficient greenhouse management and technological advances have been proposed as one of the key solutions to improve the sustainability and resilience of these production systems, in particular, in regions with high energy demands due to climatic control [6]. Despite the advantages of greenhouse farming, pest attacks have been one of the biggest restrictions to the production of tomatoes in the controlled setting. The greenhouses offer favorable environment that favors the fast growth and multiplication of the insect pests as a result of the controlled climate in the greenhouses. Naturally occurring enemies in greenhouse environments and biodiversity are important in maintaining the population of pests and the ecology [7]. Greenhouse crop management sustainability has therefore been based on Combinatory approaches to pest management (IPM). These methods are a combination of the biological control, surveillance, and cultural methods to reduce the application of chemical pesticides despite pests being properly maintained at low levels [8]. Whiteflies and the tomato leafminer (*Tuta absoluta*) are just some of the many pests that have been found to be destructive to greenhouse tomatoes. These pests may be very economically detrimental through feeding on plant tissues, plant pathogen transmission, and decreasing plant vigour and productivity. Whiteflies are also reported to cause weakness of plants by sucking sap and may facilitate the growth of secondary infections, and the larvae of *Tuta absoluta* only feed on leaves and reproductive tissues, resulting in severe damage to tomato crops [9]. Due to the prevalence of these pests, effective methods of management have become a central issue of study. The ability of wild tomato accessions to these insect pests has also been discussed recently, and it has been emphasized that, through an integrated approach, a combination of host resistance and ecological pest control measures is necessary [10]. Natural enemies have been used as a significant part of IPM programs in greenhouse crops through biological control. Zoophytophagous mirid predators are actively applied in tomato farming due to their potential to consume not only plant tissues, but also pest species, which makes them able to colonize and survive within the greenhouse ecosystems. Some of the species that have been reported to be effective biological control agents against a number of greenhouse pests include *Macrolophus pygmaeus* and *Dicyphus errans* [11]. The population of them in the greenhouse systems may result in suppression of pests by having a direct preying effect on the pest populations as well as preventing a stable population of predators in the crop environment. Those studies that investigate the ecological behavior of mirid predators have also demonstrated that plant traits and crop species may affect predator attraction and reproduction success, and consequently, their performance as a biological control agent [12]. Though many studies have concerned the pest control methods and biological control agents in greenhouse tomato production, very few studies have addressed the mutual relationships between pest abundance, predator presence, plant damage indicators, and plant

reproductive outcomes in a similar experimental context. Specifically, insufficient consideration has been paid to the behavior of pest predation and destruction of vegetation in determining the impact of repugnant factors on reproductive behavior like abortion of flowers in greenhouse environments. These relationships are significant to understand since the traits of reproduction have a direct impact on the growth of fruits and the general yield of crops. Hence, the current research was done to examine the correlations among pest populations, predator abundance, signs of plant damage, and flower abortion in tomato plants under greenhouses. The experiment was a time series investigation of the dynamics of pest and predator populations, correlations between pest abundance, predator presence, plant damage and reproductive traits, and factors related to flower abortion by use of plant-level data of observational conditions in controlled greenhouse compartments.

2. Materials and Methods

2.1 Study system and experimental design

The research was undertaken by the observational data involving the interaction of greenhouse tomato pests and predators under the conditions of controlled compartments [13]. The plants were observed in various greenhouse compartments and tunnels for five weeks of sampling. The study took place at the plant level and recorded observations that were repeated, and allowed measuring the abundance of the pests, the presence of predators, the indicator of plant damage and the reproductive characteristics. The last dataset contained 800 plant observations, which were seen as the result of the combination of pest, predator, and plant reproductive datasets through using common identifiers (week, compartment, tunnel, and plant ID). Every observation was the measurement of a particular plant within a particular sampling week.

2.2 Biological variables recorded

Numerous biological variables were registered to define the pest pressure, the abundance of predators, plant loss, and reproductive output. The abundance of pests was measured using the number of Tuta larvae (*Tuta absoluta*) and whiteflies spotted per plant. The abundance of predators was measured based on the numbers of two zoophytophagous mirid species, *Macrolophus pygmaeus* (Total MP) and *Dicyphus errans* (Total Derrans). Plant damage was assessed by counting the number of necrotic rings, which are visible as feeding damage on plant tissues. The plant reproductive performance was evaluated by estimating the total number of flowers per plant and the number of aborted flowers per entire sampling time.

2.3 Data preparation

A combination of pest, predator, and flower-level datasets was done using common identifiers at the plant level. Data sets were analyzed using records that had common identifiers. Before statistical analysis, variables were verified for completeness and consistency. All the numerical variables were considered as continuous counts/abundance data.

2.4 Statistical analysis

They were summarized using descriptive statistics, which summarized pest abundance, predator presence, plant damage and reproductive variables. Pest and predator temporal trends were analyzed by determining the weekly mean abundance, and represent changes over the five weeks of sampling. Pearson correlation coefficients were used to test a pair-wise relationship among pests, predators, plant damage indicators, and reproductive traits. To analyze the relationship between factors and flower abortion, the number of aborted flowers was taken as a response variable, and the multiple linear regression analysis was carried out. The predictor variables were: pest abundance (whiteflies), predator abundance (Total MP) and sampling week. Ordinary least squares regression was used to estimate model coefficients, standard errors and statistical significance. Each of the statistical tests was assessed according to the significance of $p < 0.05$.

3. Results

3.1 Descriptive statistics of pest, predator, and plant reproductive variables

The final dataset contained 800 observations of plants. Table 1 shows the descriptive statistics of the major biological variables. Tuta larvae mean abundance was 1.60 and whiteflies 3.33, with a standard deviation of 2.10 and 2.85, respectively. The average predator abundance of the *Macrolophus pygmaeus* (Total MP) and *Dicyphus errans* (Total Derrans) was 2.67 ± 2.80 and 0.55 ± 1.01 individuals, respectively. The vegetation had an average of 7.93 ± 1.67 flowers, and 1.42 ± 1.54 aborted flowers were observed within the sampling period. The average ring of necrosis was 4.08 ± 4.06 with a total of 0 to 22.

Table 1. Descriptive statistics of pest, predator, plant damage, and reproductive variables.

Variable	Mean	Min	Median	Max
Tuta larvae	1.596	0	1.00	17
Whiteflies	3.326	0	2.67	14
Total MP	2.669	0	2.00	15
Total Derrans	0.550	0	0.00	6
Necrotic Rings	4.076	0	3.00	22
Total Flowers	7.932	1	8.00	16
Aborted Flowers	1.418	0	1.00	7

3.2 Temporal dynamics of pest and predator populations

The abundance of pest and predator patterns was assessed over the 5 weeks of sampling (Figure 1). The highest density of pests was seen within the first two weeks and among whiteflies and Tuta larvae, with a significant drop in the second through the third week, after which the density levels returned to relatively lower levels. The same was the case with predator populations. *Macrolophus pygmaeus* (Total MP) was most abundant at the onset of the experiment but reduced after the second week, but the abundance of *Dicyphus errans* (Total Derrans) was constant over the entire time of the sampling period.

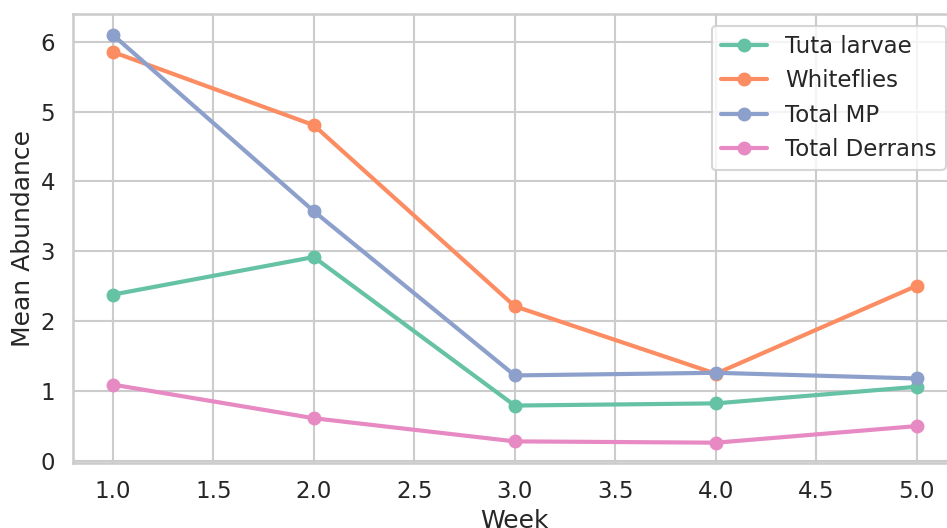


Figure 1. Temporal dynamics of pest and predator populations across sampling weeks.

3.3 Correlations among pests, predators, plant damage, and reproductive traits

Correlation analysis was used to test the relationships between pests and predators, the use of plant damage indicators, and reproductive traits (Table 2, Figure 2). The whiteflies and Total MP were found to have a moderate positive correlation ($r = 0.388$), whereas Tuta larvae and Total MP were found to be weakly correlated ($r = 0.236$). The most positive correlation with flower abortion was necrotic

rings ($r = 0.403$). The pest abundance variables had negative interactions with necrotic rings, and the pest abundance to the total flower production were weakly correlated.

Table 2. Correlation matrix among pest abundance, predator abundance, plant damage, and reproductive variables.

Variable	Tuta larvae	Whiteflies	Total MP	Total Derrans	Necrotic Rings	Total Flowers	Aborted Flowers
Tuta larvae	1.000	0.273	0.236	0.036	-0.342	-0.060	-0.180
Whiteflies	0.273	1.000	0.388	0.145	-0.435	-0.046	-0.289
Total MP	0.236	0.388	1.000	0.159	-0.462	-0.085	-0.315
Total Derrans	0.036	0.145	0.159	1.000	-0.157	-0.097	-0.083
Necrotic Rings	-0.342	-0.435	-0.462	-0.157	1.000	0.037	0.403
Total Flowers	-0.060	-0.046	-0.085	-0.097	0.037	1.000	0.296
Aborted Flowers	-0.180	-0.289	-0.315	-0.083	0.403	0.296	1.000

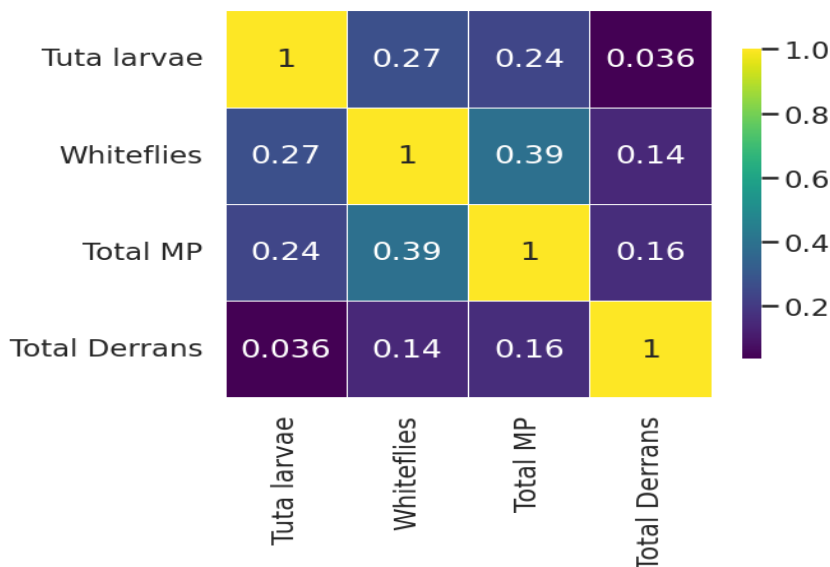


Figure 2. Correlation heatmap showing relationships among pest populations, predator abundance, plant damage indicators, and reproductive traits.

3.4 Drivers of flower abortion

Several linear regression was conducted to assess factors which were related to flower abortion (Table 3). The last model was statistically significant ($F(4,795) = 52.01, p < 0.001$) and had 20.7% variance in flower abortion ($R^2 = 0.207$). There was a significant and positive relationship between necrotic rings and flower abortion ($0.078, p < 0.001$), and sampling week had a significant and positive correlation with the rate of abortion ($0.214, p < 0.001$). The abundance of the whitefly was also negatively correlated with flower abortion, but marginally so ($\beta = 0.039, p = 0.052$), whereas predator abundance (Total MP) was not ($\beta = 0.040, p = 0.072$).

Table 3. Multiple linear regression model predicting flower abortion.

Variable	Coefficient (β)	Std. Error	t-value	p-value	95% CI
Intercept	0.697	0.212	3.286	0.001	0.281 – 1.114
Whiteflies	-0.039	0.020	-1.947	0.052	-0.079 – 0.000

Total MP	-0.040	0.022	-1.799	0.072	-0.083 – 0.004
Necrotic Rings	0.078	0.017	4.660	<0.001	0.045 – 0.110
Week	0.214	0.055	3.900	<0.001	0.106 – 0.321

Figure 3 shows the relationship between key predictors and flower abortion, with regression plots showing the positive relationship between plant damage and the rate of abortion and the weaker relationships between pest and predator abundance.

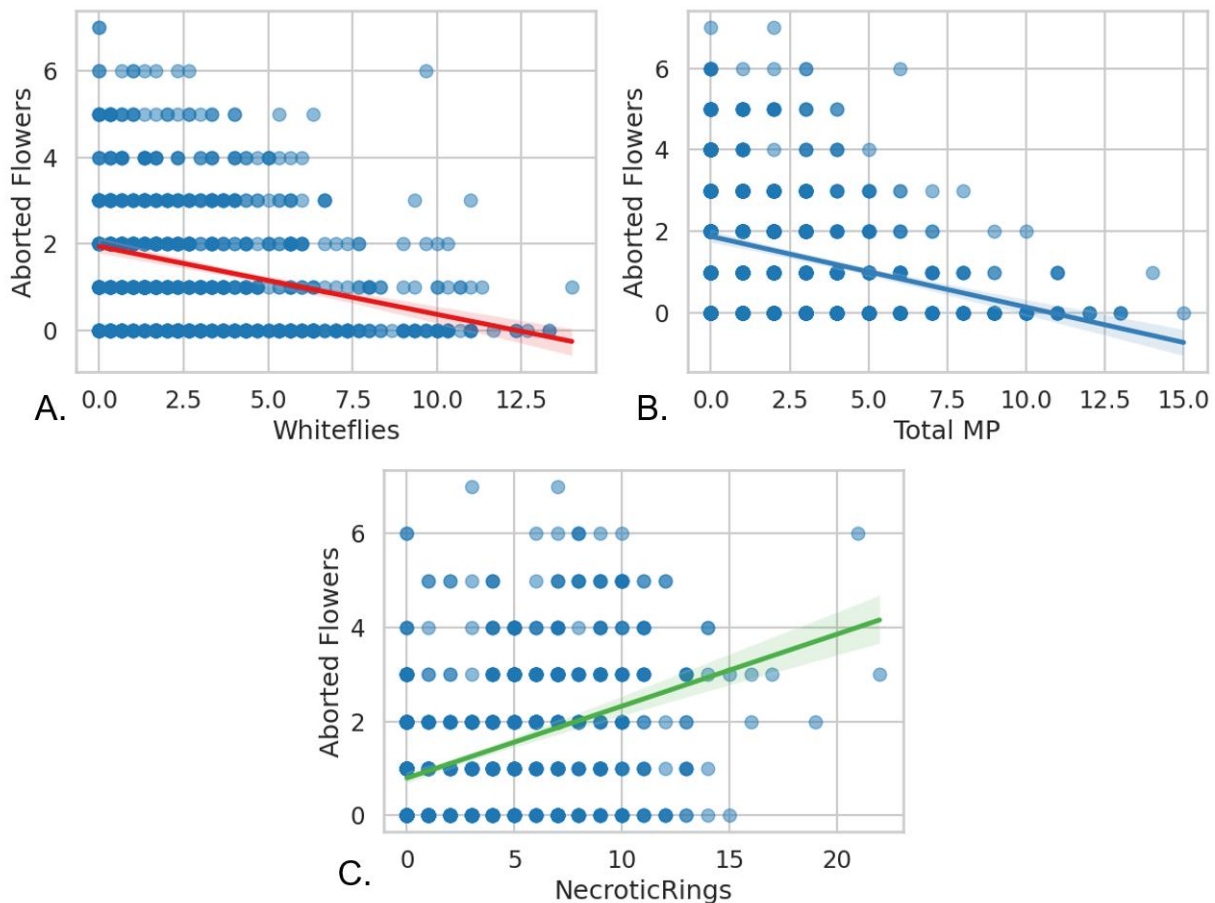


Figure 3. Drivers of flower abortion in greenhouse tomato plants. (A) Relationship between whitefly abundance and the number of aborted flowers. (B) Relationship between predator abundance (*Macrolophus pygmaeus*, Total MP) and flower abortion. (C) Relationship between plant damage (necrotic rings) and flower abortion.

4. Discussion

The findings show that there was evident temporal variation of pest and predator populations across the weeks of the sample. Pest densities were at their strongest in the first weeks of the observation period, and in the second and later weeks, the trend was the same but less pronounced in predator populations. These trends indicate that pest populations can be set up early in the crop development and then level off as ecological interactions in the greenhouse environment evolve. These dynamics observed indicate that insect population dynamics in managed cultivation systems are complex because the level of plant growth and the interaction of ecology may have a profound effect on the abundance of pests and predators. Correlation analysis showed that there were moderate positive relationships between pest abundance and the presence of predators, especially between whiteflies and *Macrolophus pygmaeus*. This association suggests that the population of predators can react to the presence of prey sources in the crop environment. But the comparatively low correlation coefficients for a number of variables imply predator-prey relationships in greenhouse tomato systems

are not necessarily linear, and some ecological and environmental processes might have an effect on the same. The regression analysis also indicated that the indicators of plant damage and sampling time were more strongly correlated with flower abortion as compared to pest abundance on its own. The strong correlation between necrotic rings and flower abortion is a good indication to believe that cumulative stress or tissue damage in plants may have a key role in reproductive behaviour. The correlation at positive between sampling week and flower abortion, also showing that there can be a reduction in the plant reproductive performance with time in the crop cycle. On the other hand, the abundance variables of pests were less related to flower abortion when the plant damage and the time were included in the model, which suggests that reproductive responsiveness may be an integrated effect of stress on plants and not directly acting by pests.

The tomato pest population changes in the current analysis are consistent with those of earlier studies that explain the dynamic nature of pest in the tomato cropping system. Studies of the animal populations within tomato production systems have demonstrated that pest populations can significantly fluctuate over time in the crop cycle and that initial populations can tend to increase with population adjustment linked to environmental factors and associated predators [14]. The mentioned dynamics are especially prevalent in the greenhouse context, where the development stages of crops and the availability of resources may affect pest development and maintenance. The predator-prey interactions between whiteflies and the mirid predators also concur with the results of the past ecological research. It has been experimentally established that resources of plants and floral feeding can affect predator relationships and enhance the efficiency of biological controls by mitigating aggressive relationships among natural enemies [15]. On the same note, it has been reported that zoophytophagous mirids like *Macrolophus pygmaeus* have been useful as a biological control measure in the greenhouse tomato farm, with the predators playing a significant role in the sustainability of pests in the crop [16]. The preventive biological control strategies recognize the significance of timely predator settlement in greenhouse crops. It can be better to introduce predators prior to the build-up of pest populations to harmful degrees to boost pest management and stabilize the ecological relationships within greenhouse production frameworks [17]. Such strategies are justified by the temporal trends that are apparent in the current analysis because the abundance of predators seemed to be correlated with the occurrence of pests in the crop.

The close correlation between plant damage and reproductive results that the analysis found also indicates the results of previous studies discussing the behavior of mirid feeding. Zoophytophagous mirids can feed both on plant tissues and prey, and the extent of plant destruction may depend upon tomato cultivars and predator species [18]. Such interactions have shown that there is a complex existence of predators in greenhouse ecosystems where beneficial species may also cause the control of pests and destruction of plants simultaneously. The predator performances have also been observed to be conditional on the ecological environment and prey abundance when the performance of biological control agents is studied. Indicatively, the study on the assessment of the mirid predators in tomato systems has indicated that the pest suppression by the predators may vary depending on the level of prey and environment in the crop setup [19]. One of the reasons why the abundance of the predator had a relatively weak direct relation with the abortion of the flower as seen by the regression model, could be this variability. It has also been emphasized by previous research work that approaches of integrated pest management are significant in the management of tomato pests. Monitoring systems, traps and biological control measures in the greenhouse production systems are normally integrated to reduce the impact of the major pests such as whiteflies and tomato leaf miners, *Tuta absoluta* [20]. The insects have been largely observed as a great threat to tomato production due to their leaching nature and their high reproduction rate [21]. The life history studies have also shown that the growth and reproductive potential of *Tuta absoluta* is not only dependent on the host plant being investigated but also on the environment, and this may influence the degree of pest population as well as crop destruction [22]. These results support the fact that numerous ecological parameters need to be considered when analyzing the effects of pests in greenhouse-cropping systems.

These findings indicate that plant damage indicators and pest and predator abundance should be taken into consideration during the assessment of crop health in a greenhouse tomato production system.

Observing observable vegetation damage might offer useful data on how plants are stressed and could be losing their reproductive organs, which the pest cannot identify. These results also justify further progress in the integrated pest management strategies, which use biological control agents, along with the monitoring and crop management practices. The relationships between the pests, predators and the plant response can be used to make improved decisions in greenhouse crop protection programs because the knowledge of such interactions is available.

These results have a number of limitations which should be considered when interpreting them. This was the analysis of observational data within a relatively narrow sampling period, and the environmental factors such as the temperature, humidity and the nutrient availability were not added to the statistical models. These may affect the insect population and the reproduction of plants in the greenhouse systems. Potential future directions of research must also incorporate larger-scale follow-ups and a longer duration of the study, as well as incorporate more aspects of the environment to understand the nature of pest-predator interactions and plant reproductive outcomes. Such experiments that would control the abundance of the predators or pest pressure would also offer more objective ideas of causal relationships among the biological control agents and the performance of the plants. Moreover, the addition of fruit set and yield variables in the analyses would enhance a better understanding of the effects of the pest predator interactions on the ultimate crop productivity of tomatoes.

5. Conclusion

There was a definite temporal change in the abundance of pests and predators in greenhouse tomato plants, with more abundance observed in the early period of sampling and less in the later period. Plant damage was the most strongly linked variable between flower abortion and the abundance of pests alone. More specifically, the necrotic rings were found to be the most significant predictor of the flower abortion, and sampling week also demonstrated a significant positive correlation with reproductive loss. The abundance of whiteflies had only a weak correlation with flower abortion, and the abundance of predators was not significantly related to the abortion in the last model. Such results suggest that the apparent plant damage can be a more informative signal of the reproductive stress when compared to pest counts in greenhouse tomato systems. Real-time observation of the plant damage and pest and predator populations could thus increase the quality of crop status monitoring and make more effective decisions on pest management. Despite the fact that the analysis was conducted on the basis of observation data that was gathered during a short period of time, it gives valuable evidence that reproductive responses of tomato plants are determined by a combination of various interacting factors. More research that includes extended periods of sampling, environmental factors and effects on yields would assist in explaining the processes that relate pest-predator relationships, plant damages and crop performances.

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