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Understanding Greenhouse Tomato (*Solanum lycopersicum* L.) Growers' Perceptions for Optimal *Phthorimaea absoluta* (Meyrick) Management—A Survey in Greece

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Abstract: The tomato (*Solanum lycopersicum* L.) leafminer, *Phthorimaea absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is an extremely invasive pest and is threatening tomato production worldwide. Several strategies have been developed and implemented for managing *P. absoluta*. Effective pest control strategies based on integrated pest management (IPM) schemes include different cultural practices and techniques. This study seeks to (a) examine the perspectives, attitudes, and opinions of greenhouse tomato producers in Greece regarding different methods of *P. absoluta* management and (b) to determine whether the perceived damage caused by *P. absoluta* could be predicted by the implementation of various control management strategies. A questionnaire was employed to ascertain the views and beliefs of the participants. The questionnaire comprised five-point Likert scale questions. Principal component analysis (PCA) and binary logistic regression analysis were applied to examine the relationship between the reported perceived insect damage and the utilization of control techniques. The study findings indicate that greater adoption of alternative control methods and higher levels of adherence to preventive measures against *P. absoluta* are associated with a perception of reduced levels of damage. Conversely, individuals with a strong reliance on pesticides use are more likely to perceive a higher level of damage. Ultimately, as tomato growers are trying to deal with *P. absoluta*, more education and research on other alternatives could help the reduction of chemical use, promoting more environmentally friendly practices. The findings highlight integrated pest management over pesticides for sustainable tomato production. This can guide future research and extension efforts to develop tailored *P. absoluta* management approaches for Greek greenhouse growers and similar environments.

Keywords: crop protection; chemical alternatives; farming practices; grower attitudes; preventive measures; chemical control; pest resistance; cultural methods

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1. Introduction

The tomato leafminer, *Phthorimaea absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is a South American moth and is one of the most destructive pests of tomato [1]. Recently *P. absoluta*, referred to as "*Tuta absoluta*", has been re-classified under its original genus, *Phthorimaea* [2]. In Europe, this pest was first identified in eastern Spain in late 2006 and has subsequently spread throughout the Mediterranean Basin and Europe. Since its initial detection, the pest has caused severe damage to tomato crops in invaded areas, and it is currently regarded as a significant agricultural threat to European and North African tomato production [3]. The larvae of the tomato leafminer create mines and galleries in tomato plants, which impair the plant's photosynthetic capacity and reduce yield. The larvae can also attack fruits, and secondary pathogens can invade galleries, leading to fruit rot. The pest directly feeds on the growing tip, halting plant development. This affects tomatoes for fresh market and processing, causing losses and affecting the visual aspect of harvested products, reducing market value [1,3]. The presence of *P. absoluta* was initially documented in Greece in June 2009 [4]. It rapidly spread throughout most of the country, causing a significant negative impact on tomato cultivation [5].

Prevention is key for effective greenhouse crop pest control. Methods to achieve this include using insect-proof netting, ensuring plant material is free of insects, and installing a vestibule at the greenhouse entrance [5,6]. Other cultural methods to control *P. absoluta* include removal and destruction of infested plant parts and weed control [7]. However, crop residue management remains inadequate, further complicating control efforts [8]. Furthermore, the management of wild host plants near crop fields is a key component of IPM schemes [3,9].

Effective strategies to control pests have been implemented, including integrated pest management (IPM) that involves conserving native natural enemies [10–15]. However, insecticide applications remain a prominent pest control method in many cases [16]. *Bacillus thuringiensis* (Bt) is a widely used biological control agent; however, it demonstrates different levels of efficacy depending on its interaction with chemical insecticides, highlighting the importance of timing and application strategies in pest management. *Phthorimaea absoluta* represents a significant challenge in pest control due to its ability to cause substantial damage and its tendency to acquire resistance to several insecticides [4]. Since 2010, *P. absoluta* populations in Greece have been monitored as part of our continuous resistance monitoring program [16]. Following its initial detection in Europe, the insect was soon found to be resistant to pyrethroids. Moderate resistance to indoxacarb, emamectin benzoate, and spinosad has also been reported in Europe and the Mediterranean [16–22]. There has also been a notable increase in the prevalence of resistance to diamide insecticides [18,21–23].

Pheromone mating disruption is an effective control measure for closed greenhouses, reducing adults population and damage. This approach is less effective in open greenhouses, typical in Mediterranean areas [1]. Cocco et al. showed this can be improved with highly insulated greenhouses, reducing immigration of gravid females and establishing populations [23].

It has been demonstrated that mass trapping can be an effective method of reducing the overall *P. absoluta* population levels and pest pressure [24]. However, mass trapping is likely to be most effective when used in conjunction with recommended insecticides [3]. Caparros Megido et al. have reported evidence of deuterotokous parthenogenesis on *P. absoluta* [25], which could have significant implications for the efficacy of sex pheromone management strategies [24].

The use of natural enemies such as *Macrolophus pygmaeus*, despite their effectiveness to some extent, is underutilized, even though they are a great alternative to chemical pesticides. The limited use of these methods requires excessive and systematic education and training on the benefits of biological control. Combining knowledge with biological methods will reduce both crop and environmental damage [26]. Cost-effective integrated pest management (IPM) strategies in Mediterranean horticulture focus on biological controls, solarization, crop rotation, and targeted pesticide use. These methods reduce pest populations while minimizing chemical inputs, supporting sustainable farming practices and protecting ecosystem health [27].

This study had two main objectives. First, it aimed to examine the perspectives, attitudes, and opinions of greenhouse tomato producers in Greece regarding different methods of *P. absoluta* management. Second, it was designed to determine whether the perceived damage caused by *P. absoluta* could be predicted by the implementation of various control strategies for *P. absoluta* management.

2. Materials and Methods

2.1. Data Collection

The procedure of collecting data was assisted through the utilization of a questionnaire hosted on Google Forms and thereafter disseminated via email and social media. Furthermore, the survey was distributed via internet agricultural news forums, electronic newspapers, and QR codes posted at agricultural fairs. The questionnaire was accompanied by a concise document that outlined the study's aims, a statement of consent, a privacy statement that adhered to the regulations set forth by the General Data Protection Regulation (GDPR), and the identities and contact information of the researchers.

2.2. Participants

The study focused on greenhouse tomato growers in Greece (Figure 1), targeting a population of 6646 individuals. This estimate was based on data received from the Greek Payment Authority of Common Agricultural Policy in 2023 (https://www.opekepe.gr/ (accessed on 26 April 2024). The required sample size for the survey, considering the target population, was determined to be 264, ensuring a 90% confidence level with a 5% margin of error. This calculation was based on the methodology for calculating sample size in survey research, as outlined by Serdar et al. [28].

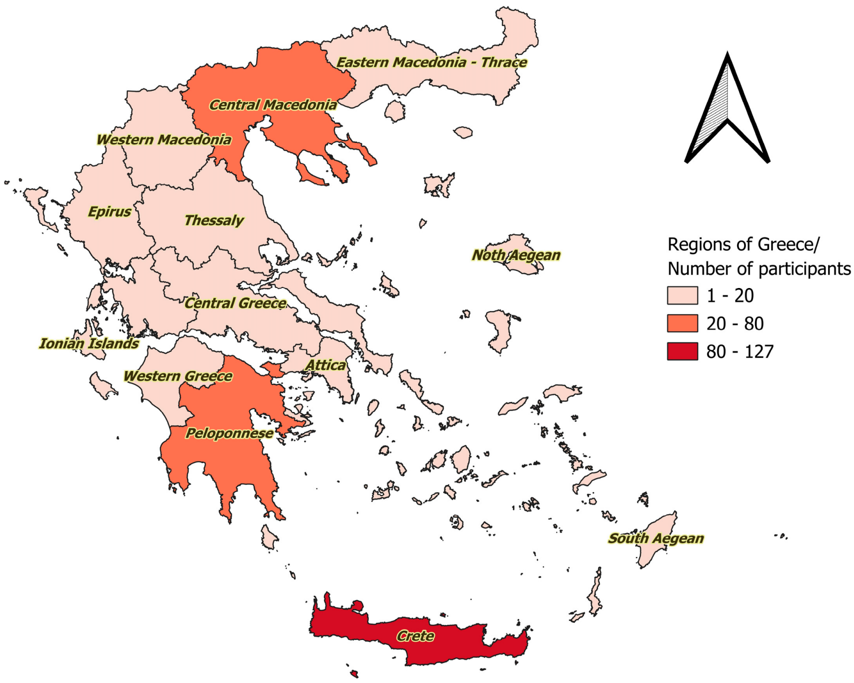

Figure 1. Regional distribution of participants across Greece, categorized by the number of participants per region. The color gradient represents the number of participants: light orange (1–20), orange (20–80), and dark red (80–127).

The survey, conducted from 1 May to 30 June 2023, consisted of 26 questions partitioned into two distinct sections. The initial section consisted of nine descriptive questions regarding the sociodemographic characteristics of the participants and the key elements of their crops, whilst the subsequent section encompassed a set of 17 closed five-point Likert scale items. The aforementioned items included the documentation of data related to the surveillance of *P. absoluta*, with the participants' perspectives on the present state of plant protection and infestations caused by the pest. Furthermore, the acquisition of technical knowledge pertaining to plant protection was documented. The participants were instructed to express their level of agreement with the assertions using a five-point Likert scale. The scale ranged from 1, representing strong disagreement, to 5, representing strong agreement. Additionally, participants were asked to rate the frequency of their engagement in specific behaviors on a five-point scale. A rating of 1 indicated never, a rating of 2 indicated seldom, a rating of 3 indicated occasionally, a rating of 4 indicated frequently, and a rating of 5 indicated always.

2.3. Data Analysis

The initial stage of the study involved a descriptive statistical analysis of the data obtained from the questionnaire. The data were presented and interpreted using the median, in accordance with the approach proposed by Simoglou and Roditakis (2022) [29]. The Kruskal–Wallis test was employed for the analysis of ordinal variables in three or more groups, whereas the Mann–Whitney U test was used for cases involving the analysis of ordinal variables in two groups. Chi-squared test was used to determine whether there is a significant association between ordinal variables. Table 1 summarizes the comparisons made on ordinal variables of participants' perceptions.

Table 1. Statistical comparisons of the participants' perceptions between two or more independent groups.

Principal Components as Dependent Variables	Independent Groups Tested		Statistical Test Performed
PC3—'Prevention'	'Education level'	i. Secondary education ii. Higher education	Mann–Whitney U test
PC3—'Prevention'	'Perceived damage'	i. 0–30% level of damage ii. 31–100% level of damage	Mann–Whitney U test
'Perceived damage' as a binomial variable (i. 0–30% and ii. 31–100% level of damage)	'Number of chemical applications per growing season'	i. 0–40 applications ii. 41–100 applications	Chi-squared test
PC3—'Prevention'	'Cultivated area'	i. <0.5 ha ii. >0.5 ha	Mann–Whitney U test
PC3—'Chemicals'	'Cultivated area'	i. <0.5 ha ii. >0.5 ha	Mann–Whitney U test
PC3—'Prevention'	'Quality system implementation'	i. Organic farming ii. Integrated crop management iii. None	Kruskal–Wallis test (Dunn's test with Bonferroni correction as a post-hoc)
'Release of natural enemies attitude'	'Quality system implementation'	i. Organic farming ii. Integrated crop management iii. None	Kruskal–Wallis test (Dunn's test with Bonferroni correction as a post-hoc)

Principal component analysis (PCA) was employed to reduce the number of interrelated variables to a smaller set of composite variables, which capture the essential information structure. A criterion of an eigenvalue threshold greater than one was employed to determine the number of principal components (PCs) to be retained. The introduction of oblique rotation resulted in the simplification of the PC loads, with each variable load allocated to an individual PC. Only variables with loadings of 0.60 or higher were included in the final analysis. The suitability of the PCA procedure was evaluated using the Kaiser–Meyer–Olkin (KMO) test, which quantifies the sampling adequacy of the dataset on a scale of 0 to 1. A value closer to 1 indicates that the variables are influenced by a similar set of factors, thereby suggesting that principal component analysis may be a suitable technique for analyzing the data. This allows for an evaluation of the suitability of the data for reduction in dimension through the implementation of principal component analysis. To further explore the relationships between the variables and assess the suitability of the data for PCA, we performed a Bartlett's test of sphericity. The Bartlett's test of sphericity is a statistical test that examines the entire correlation matrix and determines the presence of correlations among the variables. It provides a statistical significance value, indicating that the correlation matrix contains significant correlations among at least some of the variables [30].

For original scale-variable loadings on a single PC, the McDonald's omega reliability coefficient of internal consistency was computed and documented, following Simoglou et al. [31]. A single measure was obtained for each PC by combining variables loading on a single PC and creating composite scores for subsequent analysis [30].

Moreover, as the Bartlett's test offers insight into the overall correlation structure but does not elucidate the specific nature of the relationships between individual variables, we conducted a Spearman's rank-order correlation analysis to complement this analysis. It is a non-parametric measure that assesses the strength and direction of monotonic relationships between variables.

A binary logistic regression analysis was conducted to identify potential predictors for the dependent variable, which was defined as the perceived damage to greenhouse farming caused by *P. absoluta* in the preceding year. The model incorporated sociodemographic variables and characteristics that were identified by PCA as possible predictors. The odds ratios (ORs) and corresponding 95% confidence intervals (CIs) have been computed and are displayed. The statistical significance of each independent variable in the model was assessed using the Wald test. Performance metrics, such as accuracy and the area under the ROC curve (AUC), are employed to assess the predictive accuracy of a logistic regression model. Accuracy is defined as the proportion of correctly classified objects. AUC measures the degree of differentiation between true positive and false positive values. AUC values greater than 0.5–1 indicated an optimal fit of the model [31].

Statistical analyses were performed using Jamovi 2.4.2 [32] and Jasp 0.17.3 [33], both of which are based on the R programming language.

3. Results

3.1. Characteristics of Survey Participants

A total of 270 respondents from across all Greek regions participated in the survey. The sample population consisted of greenhouse tomato growers aged 18 and older. Table A1 provides the sociodemographic details of the respondents. The majority of respondents were male (88.1%). The sample was representative of all age groups. The respondents were predominantly located in the southern region of Greece (68.9%), with 14.2% residing in the central region and 16.3% in the northern region. Most participants had attained at least a high school education. The sample was well-balanced between groups with varying experience and cropping area. Finally, approximately half of the participants implemented an integrated crop management system. Ten percent of the participants were organic farmers, while the remaining approximately 40% did not apply any quality management system (Table A1). A Jasp 0.18 power analysis indicated that a sample size of 270 can be used to detect effect sizes as low as 0.2 or greater with a probability of at least 0.906, provided that a two-tailed criterion for detection with a maximum Type I error rate of $\alpha = 0.05$ is employed.

3.2. Participants' Perspectives on the Significance of Greenhouse Tomato Pests

The response distribution of participants to the research question regarding the significance of various insect pests of greenhouse tomatoes was established as follows. Participants exhibited a robust level of agreement (median = 5) regarding the significance of *P. absoluta*, with a total of 92.9% of participants indicating this level of agreement. In contrast, a median value of 4 was recorded in response to questions about whiteflies, mites, and thrips. A total of 71.1%, 67.7%, and 58.0% of participants exhibited the same level of agreement, respectively. The remaining cases, namely those pertaining to foliar chewing caterpillars, leafminers, Mediterranean tomato gall midges, and wireworms, demonstrated no evidence of disagreement or agreement in terms of central tendency (median = 3) (Table 2).

Table 2. Participants' response frequencies (%) to the five-level Likert scale question about the perceived significance of greenhouse tomato pests (N = 270) (IQR: interquartile range).

Original Variables (5-Point Likert Scale Statements)	1 Strongly Disagree	2 Partly Disagree	3 Neither Disagree/ Nor Agree	4 Partly Agree	5 Strongly Agree	Median	IQR
Perceived significance of greenhouse tomato pests: *Tuta absoluta*	5.2	1.5	0.4	2.6	90.3	5	0
Whiteflies	7.8	5.2	15.9	28.1	43	4	2
Mites	9.3	6.3	17	34.1	33.3	4	2
Thrips	11.2	9.7	21.2	30.5	27.5	4	2
Foliar chewing caterpillars	16	11.5	24.9	29	18.6	3	2
Leaf miners (*Lyriomyza* spp.)	15.2	15.9	24.8	30.7	13.3	3	2
Mediterranean tomato gall midge (*Lasioptera tomaticola*)	26.3	14.8	14.8	28.5	9.3	3	3
Wireworms (*Agriotes* spp.)	25.3	16.4	24.2	21.2	13	3	3
Scale reliability (McDonald's ω): 0.898							

3.3. Participants' Views on Control Measures Against *Phthorimaea absoluta*

Subsequently, respondents were questioned regarding the frequency of their use of control techniques to manage the primary greenhouse tomato pest, *P. absoluta*. The data depicted in Table A2 demonstrate a considerable degree of yearly implementation of control measures, which included the use of non-infested propagating material, the application of authorized pesticides, the elimination of endemic hosts, and the establishment of insect nets at greenhouse openings, with a median value of 5. Furthermore, respondents consistently report implementing various control measures to prevent pest infestations in their tomato crops on an almost annual basis. These measures include the removal of infested plant parts as early as possible, the use of biological insecticides, avoiding growing a second crop of tomatoes in a greenhouse where the current crop has been infested, and mass trapping of adults (median = 4). Respondents were also asked to indicate their disposal practices for crop waste. The respondents were also asked whether they buried the residues, or if they disposed of them appropriately, covering them with plastic sheeting. The data suggest that this method is not a common practice, as the median value is 3. A comparable outcome was observed at the level of central tendency, with a median value of 3, in the case of a reverse statement, i.e., the deposition of residues in the open air without burial. Moreover, other control measures were also not commonly employed by participants to control *P. absoluta*. These included the application of pheromone mating disruption technique (median = 3), the construction of a vestibule at the greenhouse entrance, the introduction of natural enemies (median = 2), or the establishment of predator-attracting plants (median = 1).

The participants were requested to provide a subjective evaluation of the damage caused to their crops by *P. absoluta* during the previous growing season. The primary variable, "damage", was categorized into six levels, ranging from 0% to total destruction. At the central tendency level, growers reported a damage level corresponding to 10–20% of their crop (median = 2).

3.4. Variables That Predict the Participants' Perceived Crop Damage Caused by *Phthorimaea absoluta*

A quantitative approach was employed to assess the predictive value of various control techniques utilized by tomato producers to manage *P. absoluta*. Principal component analysis (PCA) and logistic regression analyses were applied to examine the relationship between the reported perceived insect damage and the utilization of control techniques by tomato producers.

3.4.1. Principal Components Underlying the Participants' Attitudes

The initial 26 variables were subjected to a principal component analysis, which yielded six principal components (PCs) that collectively accounted for 66.0% of the variance. The adequacy measures of the principal component analysis (PCA), including the McDonald's omega reliability coefficient, Bartlett's test of sphericity, and the KMO measure of sampling adequacy test, were deemed suitable (Table A3). The Spearman's rank-order correlation analysis revealed a multitude of statistically significant correlations between the original variables. For example, with regard to the attitude of making informed decisions about the type of pesticide to apply, a robust positive correlation was identified between the attitude of obtaining information from the Internet and from social media ($\rho = 0.739$, $p < 0.001$). This suggests a strong monotonic relationship between these two variables. Similarly, the participants' perception of the efficacy of applying insect-proof screens in greenhouse openings was found to be positively correlated with their perception of the efficacy of vestibule entrances to the greenhouse ($\rho = 0.739$, $p < 0.001$). Additionally, there was a positive correlation between the perceived efficacy of releasing natural enemies and their perceptions of the efficacy of the pheromone mating disruption method ($\rho = 0.611$, $p < 0.001$). A total of six variables accounted for 15.901% of the variance in the first PC, representing the perceived significance of pests as reported by participants. Variables loading on the second PC included participants' perspectives on alternative control methods and accounted for 12.322% of the variance. The third PC related to prevention and accounted for 10.631% of the variance. The fourth PC was composed of variables pertaining to synthetic plant protection products use, which accounted for 9.855% of the variance. The fifth PC consisted of variables representing the influence of the internet and peer groups on participants' decisions regarding the use of pesticide formulations, which accounted for 8.880% of the variance. The sixth PC was correlated with the implementation of cultural methods by participants, which accounted for 8.423% of the variance.

The interrelationship among the six PCs is illustrated in Figure 2. The adoption of alternative control methods (PC2) follows a pattern that is roughly orthogonal to the reliance on chemical pesticides (PC4), suggesting a primarily negative association. Furthermore, the negative correlation between the perceived severity of insect pests—as well as the influence of online sources and the opinions of peers on decision-making process—and the acceptance of preventive measures is also evident.

In order to enhance the assessment of how the preventive measures (PC3—'prevention') affect the perceived damage by *P. absoluta*, several factors were examined. The Mann–Whitney U test was applied, setting 'prevention' as the dependent variable, and controlling for the original variable 'education'. For the purposes of the analysis, the variable 'education' was categorized into two groups: those with secondary education (comprising those with less than high school, high school, and technical education) and those with higher education (comprising those holding bachelor's, master's, and doctoral degrees in education). The findings indicated that individuals with higher levels of education exhibited a statistically significant degree of agreement with statements pertaining to the prevention strategies against the invasion of *P. absoluta* ($W = 4122.0$; $p = 0.007$; rB (rank biserial correlation) = 0.221, which can be considered a small effect size).

To investigate whether the level of commitment of farmers to preventive measures affects their perception of damage caused by *P. absoluta*, the original variable 'perceived damage' was divided into two levels with a binary effect. The first level reflected damage from 0–30%, while the second level reflected damage from 31% to complete disaster. The Mann–Whitney U test was applied, setting 'prevention' as the dependent variable, while controlling for the original variable 'perceived damage'. The findings indicated that participants who expressed a higher level of agreement with the implementation of preventive measures against *P. absoluta* exhibited a statistically significant reduction in their perceived damage compared to their counterparts ($W = 4842.000$; $p = 0.006$; rB = 0.264, a small effect size).

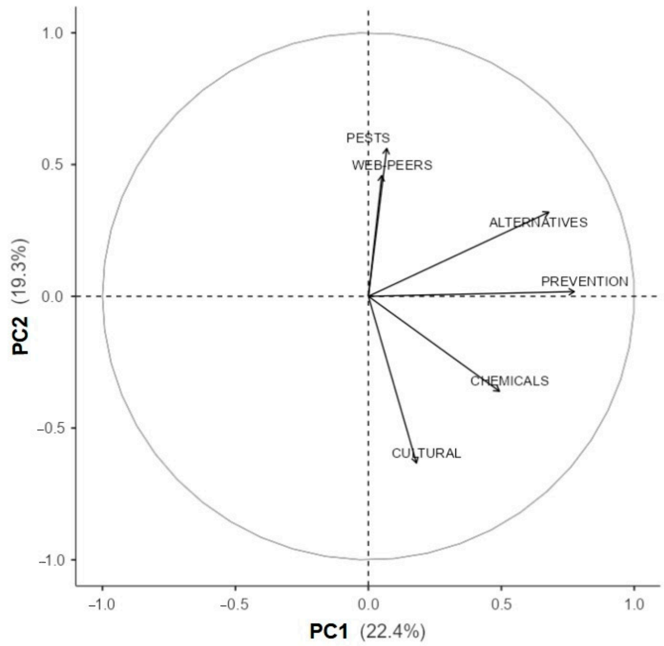

Figure 2. The relationship between the principal components extracted using PCA. The factor 'pests' is indicative of the perceived pest importance, while 'web-peers' represents the combined effect of web and peer influences on the choice of pesticides. The factors 'alternatives', 'prevention', and 'cultural' indicate a set of alternative control methods, preventive methods, and cultural approaches to pest control, respectively. The factor 'chemicals' encompasses the various options for chemical pesticide use. An inverse relationship between participants' compliance with alternative control methodologies and their tendency toward pesticide use is evident. Also, the perceived severity of insect pests and the influence of online sources and peer opinions are inversely correlated with the acceptance of preventive measures.

Furthermore, in order to investigate the relationship between the number of pesticide applications and the perceived damage, the original variable 'number of chemical applications per growing season (period from planting to the completion of fruit harvest)' was split into two levels. The low level reflected a range of 0 to 40 applications, while the high level reflected a range of 41 to 100 applications of pesticides per growing season. The results of the chi-squared test ($\chi^2 = 6.398$; df = 1; $p = 0.011$) indicated that a greater proportion of respondents reported low perceived damage in conjunction with a lower number of pesticide applications.

Similarly, the original variable 'cultivated area' was categorized into two levels, with the lower category representing cultivated area up to 0.5 hectares and the higher category representing cultivated area >0.5 hectares. A Mann–Whitney U test was employed, with 'prevention' set as the dependent variable and the binomial variable 'cultivated area' set as the independent variable. The findings revealed that those who reported cultivating a larger greenhouse tomato crop exhibited a statistically significant propensity to adopt the 'prevention' approach (W = 1342.000; $p < 0.001$; rB = 0.414, indicating a moderate effect size). Nevertheless, it becomes evident that a larger area of land under cultivation is linked to a higher level of adherence among participants in the use of plant protection products to control *P. absoluta*. The Mann–Whitney U test was used to analyze the relationship between the factor 'chemicals' as the dependent variable and the 'cultivated area' as the independent. It revealed that those who reported cultivating higher areas of greenhouse tomatoes demonstrated a higher and statistically significant tendency to use chemicals (W = 1284.000; $p < 0.001$; rB = 0.440, a moderate effect size).

The Kruskal—Wallis test demonstrated that the quality system adopted by the farmers (organic farming, integrated crop management, and no quality system) had a statistically significant impact on the participants' reported level of commitment to the 'prevention' approach ($\chi^2 = 26.365$; df = 2; $p < 0.001$; $\varepsilon^2 = 0.123$, indicating a moderate effect size). A post-hoc test using Dunn's test with Bonferroni correction indicated that those reporting high adherence to integrated crop management principles reported significantly higher implementation of prevention measures compared to those with no quality system ($p < 0.001$), while they did not differ significantly from the organic farmers ($p = 0.325$). However, organic farmers did not significantly differ from those with no quality system in adherence to 'prevention' ($p = 0.335$). The quality system implemented by the tomato producers also had a statistically significant impact on the participants' reported adherence to the release of natural enemies, specifically *Macrolophus* or *Nesidiocoris* ($\chi^2 = 16.741$; df = 2; $p < 0.001$; $\varepsilon^2 = 0.062$, indicating a moderate effect size). A post-hoc test using Dunn's test with Bonferroni correction indicated that organic tomato producers reported higher adherence to the implementation of releasing natural enemies compared to integrated crop management tomato producers ($p = 0.001$) or those with no quality system ($p < 0.001$).

3.4.2. Logistic Regression Model for Predictive Variables of Participants' Perceptions

A binary logistic regression analysis was conducted to ascertain whether any variables could predict participants' perceptions of damage to greenhouse tomato production caused by *P. absoluta*. The dependent variable focused on participants' responses to the question regarding the magnitude of damage to greenhouse tomato production caused by *P. absoluta* in the preceding year. An input procedure was employed to incorporate background sociodemographic variables and the six PCs previously retained from the PCA into the model as potential predictors. The model demonstrated satisfactory performance in terms of both accuracy and the AUC value (see Table 2), indicating that it exhibited a very good fit.

A significant Wald test, a negative regression coefficient (b), and an odds ratio (OR) value less than unity indicate that participants who report greater adoption of alternative control methods and higher levels of adherence to preventive measures against *P. absoluta* in the greenhouse are more likely to perceive reduced levels of damage to their greenhouse tomato crop (Table 2). Conversely, individuals with a strong reliance on pesticides use are more likely to perceive a higher level of damage to their greenhouse tomato production (OR: 1.735) (Table 2). No other PCs or background variables were found to be significant predictors and are therefore not supported in the model.

4. Discussion

The objective of this study was to examine the perspectives, attitudes, and perceptions of greenhouse tomato producers in Greece regarding the management of tomato leafminer, *P. absoluta*, a pest that has a significant impact on greenhouse tomato crops [4,9]. Additionally, the study aimed to assess the predictive value of implementing various control strategies for *P. absoluta* management in order to ascertain the extent of damage perceived by greenhouse tomato cultivators. This was facilitated through the implementation of multivariate statistical analysis on questionnaire data pertaining to the degree of crop damage reported by tomato growers caused by the pest.

The 26-item questionnaire was implemented to record the monitoring and management practices of *P. absoluta*, capture technical knowledge related to plant protection in greenhouse tomato cultivation, and gauge beliefs about the current state of plant protection in Greece.

A quantitative analysis of responses from survey participants regarding the perceived significance of pests affecting the greenhouse tomato crop revealed that the majority of participants (92.9%) either partly or strongly concurred that the tomato leafminer is a significant insect pest for the crop. Tomato leafminer *P. absoluta* is a challenging pest to control due to its potential for significant damage and its capacity to develop resistance to a range of insecticides [4]. The second most significant pests are whiteflies, followed by mites, thrips, and other pests related to tomatoes. The outcome is noteworthy as it appears that, at least in terms of perceived importance, *P. absoluta* is now ranked first by greenhouse tomato growers. In a previous survey of beliefs among growers in Crete, it was ranked second after the whitefly *Bemisia tabaci* (Gennadius) [9]. This shift in perception highlights the evolving challenges faced by tomato growers and the need for effective pest management strategies. It also underscores the importance of continued research and innovation in developing sustainable solutions for pest control in tomato crops.

Respondents of the present survey seem to consistently employ a range of fundamental methods for preventing and managing the pest. These measures include the utilization of high-quality propagative material, the application of authorized pesticides, the elimination of native hosts of the pest in the vicinity of the greenhouse, and the installation of insect-proof netting in the openings of the greenhouse.

The interviewees frequently engage in the early removal and destruction of infested fruit and shoots, which has the potential to impede the transmission of the infestation. Additionally, they regularly utilize biological pesticides as a feasible alternative. Furthermore, they often refrain from growing a second vulnerable crop in a greenhouse that already contains an affected crop. Finally, they often employ mass trapping as a method of pest management.

Nonetheless, the implementation of measures to ensure the appropriate and safe disposal of crop residues remains inadequate at the level of central tendency. In fact, they should be disposed of safely on an ongoing basis [8].

Furthermore, the results of this study demonstrate that the method of mating disruption against *P. absoluta* has been adopted by only a limited number of participants, despite its proven effectiveness [34] and official approval in Greece. The utilization of mating disruption has been demonstrated to be an efficacious methodology for the management of the tomato leafminer in greenhouse settings. It is recommended that it be incorporated into comprehensive IPM programs for tomatoes [24]. Additionally, with regard to the installation and utilization of a special double-entry vestibule at the greenhouse entrance, further work is required, as evidenced by our results. Double-entry doors should be used carefully to prevent pests from entering the greenhouse [8]. In IPM programs for *P. absoluta*, cultural control methods could be of particular value in greenhouses and should be employed. These methods comprise a range of practices, including optimized greenhouse structure, usage of double doors, the sealing of greenhouses with insect-proof netting to prevent the entry of pests, the selective removal and destruction of infested plant parts, the complete destruction of plants after harvest, and the management of wild hosts such as black nightshade (*Solanum nigrum* L.), silverleaf nightshade (*S. eleagnifolium* L.), devil's apple (*Datura stramonium* L. and *D. ferox* L.), and tree tobacco (*Nicotiana glauca* Graham) in the vicinity of the greenhouse [3,9].

As evidenced by previous research, the implementation of preventive measures to deter insect entry into the greenhouse is a crucial aspect in the pursuit of sustainable greenhouse tomato cultivation. The utilization of insect-proof screens represents the initial prophylactic measure to be employed in the control of *P. absoluta* in greenhouses [35]. The efficiency of mating disruption control can be improved by utilizing greenhouse facilities with high levels of isolation. Such greenhouses serve to prevent the immigration of mated females and to hinder the build-up of *P. absoluta* populations [24]. Our results indicated that those who expressed greater support for the implementation of preventive measures against *P. absoluta* exhibited a statistically significant reduction in perceived damage compared to those who held opposing views.

Additionally, the results indicated that the level of education of the tomato growers was significantly related to the adoption of preventive measures. Those with a higher educational level reported a significantly higher level of agreement toward prevention-related statements. This is consistent with Kinuthia et al. who found that education of the household head had a statistically significant positive influence on the intensity of uptake of mechanical and preventive methods in tomato pest management [36].

Our data indicate that further progress is required in the implementation of classical or conservation biological control, including the release of natural enemies such as *Macrolophus pygmaeus* and *Nesidiocoris tenuis* and the utilization of plant species that act as banker plants, for example *Thymelea hirsuta* (L.), *Dittrichia viscosa* (L.), and *Coriadrum sativum* L. [10,37], or oviposition deterrents, for example *Ocimum basilicum* L. [38]. The respondents to the survey demonstrated a clear aversion to the use of this strategy for the protection of greenhouse tomatoes. This suggests greenhouse tomato growers are either unaware or unconvinced of the effectiveness of conservation biocontrol. This lack of awareness or skepticism may be impeding the adoption of beneficial insect-based strategies in greenhouse tomato production. Educating growers on the benefits and effectiveness of conservation biological control should potentially lead to increased utilization of these methods in the future. Bionti et al. have reviewed research conducted in Europe that has demonstrated the efficacy of predatory mirids in achieving sustainable control through their use in field releases and/or plant nursery situations and/or through their incorporation into conservation strategies [1]. Also, a prevalent practice within the context of greenhouse tomatoes involves the application of *Bacillus thuringiensis* formulations in combination with synthetic insecticides. Nevertheless, this approach is not recommended due to potential antagonistic effects [39]. Instead, Desneux et al. proposed that in an effective IPM strategy, once *P. absoluta* is detected in monitoring traps, preventive measures such as *B. thuringiensis* should be initiated and could be integrated with predator and/or parasitoid releases. In the event of an outbreak, curative treatments with approved insecticides are suggested [3]. The establishment and maintenance of habitats within and surrounding tomato crops that supply food and provide shelter for oviposition and overwintering encourages the natural antagonists of *P. absoluta*. Habitat manipulation, as a conservation biological control approach that aims to conserve antagonist species, has the potential to contribute to safer and more effective control of invasive pests and should further be promoted [10–12,14,15].

The findings indicate that those who have cultivated greenhouse tomatoes on a large scale demonstrated a significantly higher level of commitment to implementing preventative measures. This can be attributed to factors related to the quality of greenhouse construction. The use of insect-proof nets is incompatible with low-tech greenhouse operations, as they have the potential to negatively alter the internal environment [15,40]. Consequently, alternative solutions must be sought in order to protect crops from pests in such contexts. Nevertheless, unscreened greenhouses permit the colonization of protected tomato crops by wild natural enemies from the external surroundings. Hence, conservation biological control is increasingly regarded as a supplementary or alternative strategy to commercial augmentative methods [11,14,15,41].

Additionally, the implementation of quality systems by farmers, which included the use of organic farming or integrated pest management (IPM), and the lack of a quality system exhibited statistically significant impacts on the magnitude of commitment expressed by participants to implement preventive measures. Individuals who demonstrated a robust dedication to integrated management principles were significantly more likely to adopt preventive measures than those who failed to adopt a quality system. Furthermore, the degree of compliance with the release of natural enemies reported by participants was found to be significantly influenced by the quality system employed by tomato growers. In particular, organic tomato growers employed classical biological control more frequently than IPM tomato growers or those lacking a quality system. Finally, the results showed that a higher number of respondents reported a low perceived level of damage while reporting a lower number of pesticide applications. This is consistent with previous research in Greece, where it was found that conventional greenhouse producers perceived the control of *P. absoluta* to be more difficult than did the organic producers [9]. Historically, control strategies against tomato leafminer have relied on the use of insecticides, which have led to the selection of insecticide-resistant *P. absoluta* populations and adverse effects on the majority of non-target arthropods present within the tomato agro-ecosystem [1,21,22].

Following the invasion of the insect in European countries, the emergence of pyrethroid resistance was soon identified, with moderate resistance to indoxacarb, emamectin benzoate, and spinosad also observed in Europe and the Mediterranean [16–19,21,22,42]. In addition, there is evidence of an upward trend in the prevalence of diamide resistance [18,21,23]. The results of this study indicate a significant inverse relationship between participants' compliance with alternative control methodologies and their tendency toward pesticide utilization, as evidenced in the PCA graph. This implies that there is considerable potential for further integration of all available control strategies in order to achieve more comprehensive and effective pest management. Implementing integrated pest management practices not only helps control *P. absoluta* in tomato production but also promotes a healthier ecosystem overall. By reducing reliance on chemical pesticides and encouraging the presence of natural enemies, farmers can achieve sustainable pest control while protecting themselves and the environment [43].

The regression model of this study indicates that a greater reliance on alternative control methods, including the use of biological insecticides, trapping techniques, the use of biological control agents, pheromone mating disruption, and the destruction of surrounding native hosts, is associated with a negative impact on participants' perceptions of damage to greenhouse tomato crops. Higher compliance with the implementation of preventive measures, such as the use of insect-proof screens in greenhouse openings and the construction of vestibules leading into the greenhouse, has a similar negative effect on perceived damage. Nevertheless, a more favorable attitude toward chemical control was found to be a positive predictor of the perceived damage to respondents' greenhouse tomato crops.

The above findings may suggest that participants may view chemical control as a more effective method of protecting their crops compared to the use of biological control agents with low adoption rates. It is therefore important for researchers and consultants to consider these attitudes when developing strategies for managing pest damage in greenhouse tomato crops. The aforementioned data must be taken into account when formulating integrated management programs that target the prevention of insect invasion. Rather than resorting to eradication, this objective could be accomplished by implementing alternative approaches, including the utilization of plant extracts or cultural practices and techniques [6,44]. Systematic monitoring and the reinforcement of a protective system, in addition to the application of plant protection products, contribute to this endeavor [6].

Understanding the perceptions and preferences of farmers can help tailor interventions that are more likely to be adopted and successful in protecting greenhouse tomato crops. Furthermore, additional research could investigate the reasons behind the preference for chemical control over other methods, in order to address any misconceptions or concerns that may exist. Education and outreach efforts may also be necessary to promote the benefits of preventive and alternative methods in managing tomato leafminer. It can be posited that the diffusion of IPM strategies may result in the establishment of sustainable pest control practices, which would entail a reduction in chemical reliance and the impact on non-target organisms. This approach enhances ecosystem health, biodiversity, and tomato crop quality, thereby providing an economically beneficial solution for tomato growers.

5. Conclusions

Tomato growers use on a consistent basis various methods to prevent and manage pests, including high-quality propagative material, authorized insecticides, the elimination of native hosts, and the instillation of insect-proof netting. They also often avoid growing a second vulnerable crop in a greenhouse and often use organic pesticides as an alternative. However, only a limited number of participants adopt measures for safe disposal of crop residues and mating disruption against *P. absoluta*. Education level significantly influences the adoption of preventive measures. The study shows an inverse relationship between compliance with alternative control methodologies and pesticide usage. Farmers with a significant area of greenhouse tomatoes showed greater commitment to prevention approaches. Quality systems like organic farming and integrated pest management also impact the commitment to preventive measures. Chemical control may be more accepted than other preventive measures with low adoption rates. The study's regression model shows that reliance on alternative control methods and preventive measures negatively affect perceived damage. However, a favorable attitude toward chemical control predicts positively farmers' perceived damage. Understanding farmers' perceptions and preferences can help tailor interventions for successful pest management. To sum up, while greenhouse tomato growers are trying to deal with *P. absoluta*, more education and research on other alternatives could help the reduction of chemical use, promoting more environmentally friendly practices to protect the crop.

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Appendix A

Table A1. Sociodemographic characteristics of the respondents (N = 270).

Demographic Variables		Frequency	Percentage
Gender	Female	32	11.9%
	Male	238	88.1%
Age	18–30	37	11.9%
	31–40	76	28.1%
	41–50	91	33.7%
	≥51	66	24.4%
Educational background	Less than high school	7	2.6%
	High school	113	41.9%
	Technical education	44	16.3%
	Bachelor's degree	80	29.6%
	Master's degree	24	8.9%
	Doctoral degree	2	0.7%
Residential geographical area	Northern Greece	44	16.4%
	Central Greece	38	14.2%
	Southern Greece	186	68.9%
Number of years in the profession	New farmers (up to 3 years)	17	6.3%
	4–10 years	48	17.8%
	11–20 years	62	23.0%
	21–30 years	50	18.5%
	≥31 years	30	11.2%
Greenhouse tomato cultivation area	<0.1 ha	41	15.2%
	0.1–0.2 ha	53	19.6%
	0.3–0.5 ha	109	40.4%
	0.6–1.0 ha	40	14.8%
	>1.0 ha	27	10.0%
Quality system implementation	None	107	39.6%
	Organic cultivation	27	10.0%
	Integrated crop management	136	50.4%

Table A2. Frequency of participants' responses (%) to the five-point Likert scale question about how participants had managed *Phthorimaea absoluta* in recent years (N = 270) (IQR: interquartile range).

Original Variables (Five-Point Likert Scale Statements)	1 Never	2 Rarely	3 A Few Years	4 Almost Every Year	5 Annually	Median	IQR
Using healthy seedlings (planting material with phytosanitary passport)	8.2	3.3	8.6	7.8	72.1	5	1
Application of approved chemical insecticides	11.2	3.7	8.9	8.9	67.3	5	1
Destruction of native hosts (weeds) in the surrounding area	4.8	7.1	11.9	14.9	61.3	5	1
Installation of insect-proof nets in the greenhouse openings	22.3	7.1	8.1	7.8	54.4	5	3
By removing and carefully destroying affected fruit, leaves and shoots at an early stage	9.7	8.2	11.9	20.4	49.8	4	2
Applying biological insecticides	9.3	8.9	13	19.7	49.1	4	2
Avoidance of planting a second susceptible crop in a greenhouse where an infested crop is already present	14.5	8.2	15,2	16	46.1	4	2
Mass trapping	19.3	11.9	16	20.4	32.3	4	3
Crop residue destruction by burial or plastic sheeting	35.3	11.9	16.7	11.2	24.9	3	3
Disposal of crop residues outside without burial	26.8	13	15.2	14.5	30.5	3	4
Pheromone confusion method	34.9	13.4	19	14.1	18.6	3	3
Installation of a vestibule at the entrance of the greenhouse	40.4	14.1	10.4	4.8	30.4	2	4
Release of natural enemies, in particular *Macrolophus* and *Nesidiocoris*	38.3	17.8	17.5	11.9	14.5	2	3
Planting predator attractants (e.g., *Thymelea hirsuta*, *Diettrichia viscosa*, various aromatic plants)	52.8	16.4	12.3	11.2	7.4	1	2
Scale reliability (McDonald's ω): 0.744							

Table A3. Results of the principal component analysis of the participants' perceptions on a number of statements using a five-point Likert scale.

Original Variables (Five-Point Likert Scale Statements)	Median (1)	IQR (2)	Principal Components						Uniqueness (3)
			PC1 Perceived Pest Significance	PC2 Alternative Control Methods	PC3 Prevention	PC4 Chemicals	PC5 Web and Peer Influence	PC6 Cultural Methods	
Perceived significance of tomato pests: Foliar-chewing larvae	3	2	0.808						0.328
Wireworms	3	3	0.796						0.290
Thrips	4	2	0.791						0.349
Mediterranean tomato gall midge	3	3	0.787						0.322

Table A3. *Cont.*

Original Variables (Five-Point Likert Scale Statements)	Median [(1)]	IQR [(2)]	Principal Components						Uniqueness [(3)]
			PC1 Perceived Pest Significance	**PC2** Alternative Control Methods	**PC3** Prevention	**PC4** Chemicals	**PC5** Web and Peer Influence	**PC6** Cultural Methods	
Leafminers	3	2	0.772						0.399
Mites	4	2	0.711						0.410
Tuta absoluta	5	0	0.687						0.477
Perceived efficacy of alternative control methods: Biological insecticides	4	2		0.796					0.394
Mass trapping	4	2		0.766					0.352
Releasing of natural enemies	4	2		0.749					0.398
Pheromone mating disruption method	3	3		0.708					0.357
Destroying surrounding native hosts (weeds)	5	2		0.602					0.472
Application of preventive measures: Insect screens in greenhouse openings	5	3			0.861				0.279
Vestibule entering the greenhouse	2	4			0.828				0.321
Perceived efficacy of preventive measures: Insect screens in greenhouse openings	4	2			0.716				0.259
Vestibule entering the greenhouse	4	2			0.600				0.279
Application of chemical insecticides	5	1				0.821			0.289
Perceived efficacy of chemical insecticides	5	2				0.809			0.299
Application before crop establishment: Chemical fungicides	3	3				0.761			0.382
Chemical insecticides	2	3				0.684			0.417
Choosing which formulation to use: From the web	1	2					0.904		0.178
Using social media (Facebook, YouTube, etc.)	1	1					0.879		0.198
Considering the experience of friends/peers	3	3					0.777		0.346

Table A3. *Cont.*

Original Variables (Five-Point Likert Scale Statements)	Median (1)	IQR (2)	Principal Components						Uniqueness (3)
			PC1 Perceived Pest Significance	PC2 Alternative Control Methods	PC3 Prevention	PC4 Chemicals	PC5 Web and Peer Influence	PC6 Cultural Methods	
Adoption of cultural measures: Previous crop residue removal	5	0						0.845	0.267
Preparing the soil properly	5	0						0.767	0.352
Weed removal	5	2						0.750	0.423
Sum of the squared loadings			4134	3204	2764	2562	2309	2190	
Scale reliability (McDonald's ω)			0.852	0.817	0.822	0.774	0.824	0.723	
Explained variance %			15,901	12,322	10,631	9855	8880	8423	
Cumulative variance %			15,901	28,223	38,854	48,710	57,590	66,013	
Bartlett's test of sphericity	X^2 = 2749.947; df = 325; $p < 0.001$								
KMO measure of sampling adequacy test	0.748								

(1): Median values of the distribution of participants' replies to the five-point Likert scale questions (1 = never to 5 = annually, or 1 = totally disagree to 5 = totally agree, whatever applicable). (2): Interquartile range. (3): Proportion of variance that is "unique" to the variable and not explained by the PCs. Uniqueness is equal to 1—communality. The lower the uniqueness is, the greater the relevance of the variable in the PC model. Note: Oblique "promax" rotation was used, and variable loadings > 0.6 and uniqueness < 0.5 were selected.

Table A4. Results of binomial logistic regression analysis examining prognostic factors for participants' perceived damage from Phthorimaea absoluta in the previous year.

Model Coefficients—Dependent Variable: Previous Year's Perceived Damage from *Phthorimaea absoluta*									
				Wald Test				95% Confidence Interval	
Predictor	Estimate, b	Standard Error	z	Statistic	df	*p*	Odds Ratio	Lower	Upper
(Intercept)	−1.336	1.002	−1.333	1.778	1	0.182	0.263	0.037	1.874
Alternative control methods	−0.438	0.173	−2.535	6.424	1	0.011	0.645	0.460	0.905
Prevention	−0.427	0.192	−2.224	4.945	1	0.026	0.653	0.448	0.951
Chemicals	0.551	0.251	2.200	4.839	1	0.028	1.735	1.062	2.836
Web and peer influence	0.117	0.176	0.665	0.442	1	0.506	1.124	0.796	1.588
Cultural methods	−0.196	0.173	−1.133	1.284	1	0.257	0.822	0.585	1.154
Quality assurance (organic cultivation)	−1.172	0.829	−1.413	1.996	1	0.158	0.310	0.061	1.574
Quality assurance (ICM)	−1.315	0.822	−1.600	2.559	1	0.110	0.269	0.054	1.345
Tomato cultivation	1.159	0.715	1.622	2.630	1	0.105	3.186	0.785	12.928
Perceived pest significance	0.239	0.185	1.287	1.657	1	0.198	1.270	0.883	1.826
Predictive measures: AUC = 0.709; Accuracy = 0.791									

b: Estimates represent the log odds of "Previous year's perceived damage from *P. absoluta* = 1" vs. "Previous year's perceived damage from *P. absoluta* = 0".

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