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Research Article

Biocontrol of *Tuta absoluta* for sustainable tomatoes production in Lebanon

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Abstract

Since 2010, Lebanese tomatoes production has been threatened by the tomato leaf miner, *Tuta absoluta* (Meyrick) (*Lepidoptera: Gelechiidae*). In this context, this study aimed to evaluate the effect of six safe biological treatments (*Bacillus thuringiensis*, orange essential oil, pepper & garlic extract, pepper extract, garlic extract, and olive soap) in the management of *Tuta absoluta* on Lebanese tomatoes in organic open field conditions. Plants were treated after the first mines of this pest had appeared on leaves. We then compared the significant ability of six treatments to reduce infestation on leaves and weight loss of tomatoes fruits, in comparison with the untreated control. The results revealed that *Bacillus thuringiensis* treatment presented the lowest impact on tomato leaf infestation reduction and was the most effective treatment in protecting the tomatoes plants, with least reduction in weight loss of tomatoes fruits. The orange essential oil resulted as the second most effective treatment, followed by pepper and garlic extract mixed with organic olive oil soap, pepper extract mixed with organic olive oil soap, garlic extract mixed with organic olive oil soap, and organic olive oil soap. Therefore, the first two treatments are relatively effective and economically viable to organically control *Tuta absoluta*.

Keywords: Biological Pest Control; Ecological Balance; Food Safety; Organic Agriculture; Sustainable Agriculture; *Tuta absoluta*

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Introduction

Tomatoes (*solanum Lycopersicum mill*) are one of the most widely farmed and consumed vegetables in the world, they belong to the nightshade family, *Solanaceae*. According to FAOSTAT [1], the world's yearly tomato production is around 186,821,216 million metric tons: Asia producing share 54.4 %, America 17.5 %, Europe 15.7 %, and Africa 11.9 %. In addition, China was the world's greatest tomato producer in 2020, with an estimated production of 37,649,822.3 million metric tons, followed by the United States, India, Turkey, Egypt, and Italy [1]. On a global scale, the tomato (*Lycopersicon esculentum*) is becoming increasingly important for fresh crop consumption, including a primary component in many prepared foods, and studying the fundamental principles of plant growth and development. Moreover, it is high in nutrients such as vitamins, minerals, and antioxidants, all of which are necessary for a healthy human diet and can be grown in both open fields and greenhouses [2]. In Lebanon, tomatoes are one of the most produced agricultural commodities, with an average annual production of 305,300 tons over an area of 5,000 hectares in 2020 [1]. It is the first important vegetable crop followed by cucumber and onions with a production of 120,093 tons and 69,159 tons respectively [1]. However, their production has been hampered by several biotic and environmental restrictions.

Pests and illnesses are prominent examples of such restrictions, as they diminish yields and the quality of marketable crops, and some are directly linked to tomato damage and productivity losses. One of them is *Tuta absoluta* [3]. *Tuta absoluta*, also known as *tomato leafminer*, is recognized as a significant threat to tomato production, in both greenhouse and open field circumstances. The moth originated in South America and had since moved to Europe, North Africa, Asia, and the Middle East respectively [4]. Moreover, it affects tomatoes grown for both fresh and processed markets, with larvae causing up to 100 % losses when no effective control strategies are used [5]. *Tuta absoluta* has a high reproductive capacity, with the ability to produce up to 12 generations per year under ideal conditions [6]. In addition, insecticide resistance has been facilitated by the extensive and regular use of pesticides on this pest, both in its native range and in newly invaded areas [7]. In Lebanon, unfortunately, the farmers' primary method of *Tuta absoluta* control is blanket spraying with insecticides every 4 – 5 days per season, with a minimum and a maximum number of sprays of 8 to 25 sprays, respectively [8]. This method is certainly harmful to both humans and the environment [9]. For this, the development of control strategies based on the use of bio-insecticides as alternatives to synthetic insecticides should be supported, due to the significant effects of pesticides on insect pests, low mammalian toxicity, low persistence in the environment, and biodegradability [10].

In this direction, this research aimed to assess the effectiveness of various biological treatments of *Tuta absoluta* on Lebanese tomato variety Heirloom and compare it with the control as follows: *Bacillus thurigiengis* (Treatment 1); Orange essential oil (Treatment 2); Pepper extract mixed with organic olive soap (Treatment 3); Pepper and garlic extract mixed with organic olive soap (Treatment 4); Garlic extract mixed with organic olive soap (Treatment 5); Organic Olive soap (Treatment 6); and Control (Treatment 7).

Materials and Methods

Experimental Site Description: From April to August 2022, we conducted a field open trial at the Lebanese Agricultural Research Institute (LARI) in Qleiat - Keserwan station, North Beirut, at 992 m above sea level, located at Latitude: 33° 96′ 37.33″ N, and a longitude of 35° 71′ 43.69″ E. A general view of the experimental field can be seen in Figure 1.

Figure 1: Experimental field at the early stage of the growth production of tomatoes. Source: Michel Frem's photo.

In terms of climatic conditions, the region of Mount Lebanon has a Mediterranean climate characterized by hot and dry summers from June to September and cool and rainy winters from December to mid-March, with an average annual temperature of 15˚C [11]. Summers along the shore are hot and humid, with temperatures reaching 35°C in August. However, because of the sea's cooling impact, the daily temperature range is narrower than it is inland. January is the coldest month, with temperatures ranging from 5 to 10 ˚C. At the seaside, the average annual rainfall is between 700 and 1,000 mm. Approximately 70% of the country's typical rainfall comes between November and March and is concentrated during only a few days of the rainy season, dropping in large cloudbursts or intense storms. Inland Lebanon receives more precipitation (1,600 mm) than the coast, including snow in the highlands. Figures 2 and 3 depict the meteorological data collected from a weather station located in LARI, Qleiat. As seen below, the mean average temperature is shown by a line graph coloured in blue. In the graph, the lowest temperature was in January 2021 and 2022 with a temperature of 9 ˚C and 6 ˚C respectively. The highest temperature was detected in August 2021 with an average temperature of 25 ˚C, and in July 2022 with an average temperature of 22 ˚C. The Figure 3 depicts the average precipitation for each month of the years 2021 and 2022. The maximum precipitation was recorded in the months of January 2021 and 2022, with 328 mm and 307 mm, respectively. Furthermore, there was no precipitation from August to May in 2021. However, there was precipitation in the summer season of 2022, with the lowest recorded precipitation being 2.4 mm in April 2022.

Statistical Experimental Design: We based the experimental on a randomized complete block design with seven treatments of the extracts and *Bacillus thuringiensis* replicated three times as shown in Figure 4. We intercropped tomato plants cv. Heirloom with celery plants over an area of 120 m2 area. Each plot was 1.2 m long and 4.2 m wide and contained 5 rows. Each row contained 4 tomato plants intercropped with 1 celery plant with a total of 10 plants/ plot respectively for tomato and celery. Each variable was subjected to the univariate analysis of variance, and when significant, the means were

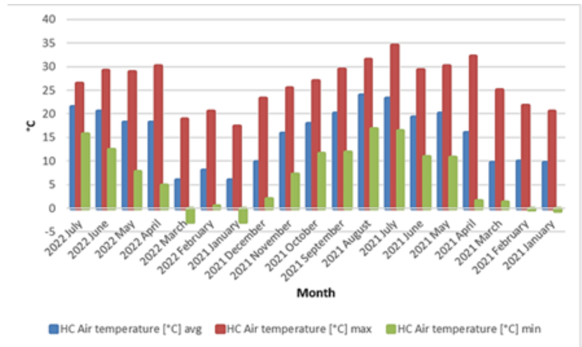

Figure 2: Monthly air temperatures (°C). Source: Our elaboration from the weather station of LARI.

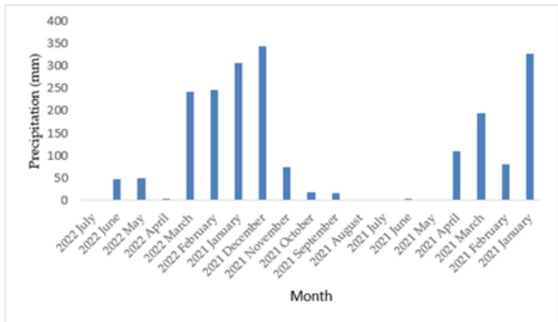

Figure 3: Monthly precipitation (mm) of the experimental site. Source: Our elaboration from the weather station of LARI.

compared to 5% using Tukey's test. In addition, IBM SPSS statistics software (version 23, 2018) was used for all statistical analyses. As such, we sued the following treatments applications:

Treatment 1: *Bacillus thuringensius* (i.e., 20 g of javelin + 200 g of sugar + 200 mL of citric acid per 20 L of water), opting for a synergetic effect. As *Bacillus* affects the larvae of *Tuta absoluta*, the sugar mixed with *Bacillus* would increase the ingestion of the bacterium while citric acid would accentuate the degradation of the digestive tube of the *larvae*;

Treatment 2: Orange essential oil (i.e., 100 mL per 20 L of water);

Treatment 3: Pepper extract mixed with organic olive oil soap (250 mL + 100 g of organic olive oil soap per 20 L of water);

Treatment 4: Mixture of pepper and garlic extracts (125 g of pepper extracts+100 g of garlic extracts+ 100 g of organic olive oil soap per 20 L of water);

Treatment 5: Garlic extract mixed with organic olive oil soap (100 mL+ 100 g of organic olive oil soap per 20 L of water);

Treatment 6: Organic olive oil soap (100 g per 20 L of water);

Treatment 7: Control

Planting Pest Surveillance and Monitoring: As preventive measures against diseases, we dusted all young tomato plants (Figure 5) with yellow sulphur powder till reaching the flowering stage to protect them from potential pests and diseases. In fact, numerous sulphur compounds were advised in numerous Integrated Pest Management

Figure 4: Experimental design of the field.

(IPM) publications for reasons of environmental safety programs for risk management in particular, edible plants (such as fruit trees and vegetables) from plant pathogenic illnesses and insect and mite infestations [12]. In addition, several studies suggested that the use of sulphur, especially as dustable powder, could be considered as a tool in *Tuta absoluta* management strategies [13]. For monitoring, we used cylindrical containers (Figure 6) filled with water to 1/3, located in the ground close to the ground to trap *Tuta absoluta* male moths, starting the second week of planting tomato plants. We counted the number of male moths of *Tuta absoluta* captured by the trap for each week by eliminating those already captured previously. We renewed the capsules of pheromone for *Tuta absoluta* every 4 weeks. We randomly placed three of these containers in the concerned Blocks. We observed the traps weekly starting from 11th May 2022. As such, we started harvesting the tomatoes fruits on 14th July 2022. Continuously, we recorded the health status of the tomato plants were recorded each week, mentioning any abnormalities and insect attacks as well as the possible presence of the *tomato leafminer*, *Tuta absoluta*.

Figure 5: Tomato plant dusted with powder sulfur

Treatments and Data Collection: The application of the treatments was done by manual spraying with a backpack sprayer every week regularly over a period of two months. The first treatment began three weeks after planting on 21st June. The sampling was done in each basic plot of the 8 plants. Three homogenous plants were selected from each plot. All infected leaves of *Tuta absoluta* were counted with the aid of a glass lens that reflected the leaflets' underside. Moreover, the infected and non-infected fruits were counted and weighted [14].

Figure 6: *Tuta absoluta* male moths captured

To calculate the rate of infection the simple formula of dividing the number of mined leaves of the treated plant by the number of mined leaves of the control was used. The reduction %age in leaves of *Tuta absoluta* was calculated according to the following equation [15].

$$\text{Infestation reduction (\%)} = \frac{A - B}{A} * 100$$

Where: A: number of larvae or mine blotches on leaves in control, and B: number of larvae or mine blotches on leaves in treatment.

To calculate the percentage of the weight loss of infested fruits on tomato by the *Tuta absoluta* infestation, the following formula was [15].

$$\text{Fruit weight loss (\%)} = \frac{\text{Weight of infected fruits}}{\text{Weight of non infected fruits} + \text{Weight of infected fruits}} * 100$$

Preparation of Botanical Extracts and Treatments Application: For the garlic aqueous extract, 250 g of garlic was weighed and then crushed. The crushed garlic was soaked in one litre of distilled water for 2 hours. Lastly, the garlic extract was filtered in the container. For the chili pepper aqueous extract,100 g of chili pepper was weighed and then crushed. The crushed pepper was boiled with 2 litres of distilled water for 1 hour. Lastly, the pepper extract was filtered in the container [14]. Regarding the orange essential oil, it was prepared in VWaste start-up facility. The schematic diagram (Figure 7) of the screw press machine cross-section below explains the key parts the machine contains a variable pitch screw press, connected to the screw shaft and gearbox. The screw is inserted into the machine pressing cage. At the top of the machine, there is a feed hopper. At the bottom of the pressing cage, there are nozzles. All machine components are made from food-grade stainless steel, such as 18/10, and 18/8, among others. For the oil separation from the emulsion, a lab centrifuge is needed that can provide speeds higher than 5000 rpm. The orange peels are inserted from the feed hopper. The peels are guided towards the screw press inside the machined cage. The variable pitch screw provides a gradual pressure increase on the peels, which is necessary to ensure efficient extraction of oil emulsion from the peels. The oil emulsion falls from the nozzles at the bottom of the cage and is collected into jars. The emulsion is put inside the centrifuge tubes, then the centrifuge is separated at >5000 rpm, for >10 mins. After centrifugation, the oil will float on top of the emulsion, which is collected with syringes into the final packaging for usage.

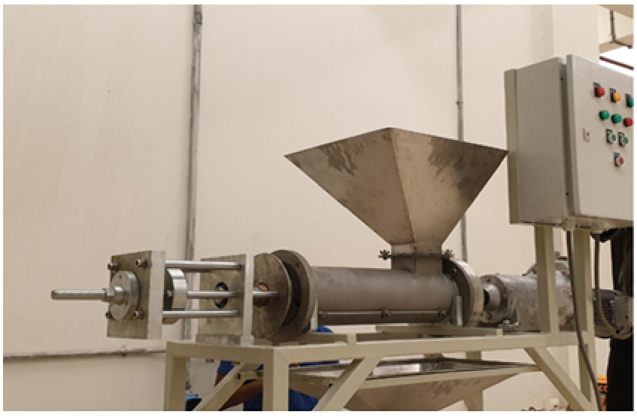

Figure 7: Orange essential oil preparation machine. Source: Rita Sfeir's photo.

Results

Effect of organic treatments on the reduction of tomatoes leaves infestation: Among all the different organic treatments, the analysis of variance (Table 1) demonstrated a very high significance among the means of the reduction of infestation by *Tuta absoluta* on tomatoes leaves. Regarding the disease incidence, the post hoc Tukey's Honest Significant Difference (HSD) test divided the population of treatments into four homogenous subsets (Table 2). Therefore, the tomatoes plants treated with *Bacillus thuringiensis* (Treatment 1) were least affected, whereas the non-treated plants were highest affected by the attack of *Tuta absoluta* based on the reduction of tomatoes leaves infestation.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	185787.15	1	185787.146	37.77	.025
	Error	9843.50	2.00	4919.275(a)		
Treatment	Hypothesis	46004.78	6	7667.464	13.98	.000
	Error	6651.75	12.12	548.590(b)		
Replication	Hypothesis	9871.66	2	4935.830	9.04	.004
	Error	6730.48	12.33	545.859(c)		
Treatment * Replication	Hypothesis	6603.66	12	550.305	1.60	.100
	Error	38424.43	112	343.075(d)		

Table 1: Univariate analysis of variance: Effect of treatments on the reduction of tomatoes leaves infestation (in %). a .996 MS (Replication) + .004 MS (Error); b .992 MS (Treatment * Replication) + .008 MS(Error); c .979 MS (Treatment * Replication) + .021 MS (Error); d MS (Error).

Furthermore, the post hoc Tukey's HSD test (Table 2; Figure 8) showed also that *Bacillus thuringiensis* was able to control effectively the infestation of *Tuta absoluta* on tomatoes leaves. There was no statistically difference between the latter (Treatment 1), orange essential oil (Treatment 2) and the mixture of pepper and garlic extract mixed with organic olive soap (Treatment 4). As such, this homogenous subset presents a value of p = .13. Also, Table 2 reveals also that Treatments 2, 3, 4 and 5 constitute another homogeneous group (p = .63). In addition, tomatoes plants treated with organic olive soap (Treatment 6) is highly affected by the infestation, after the control, but their reduction of infestation does not significantly differ from other plants treated with: pepper extract mixed with organic olive soap (Treatment 3), pepper and garlic extract mixed with organic olive soap (Treatment 4) and, garlic extract mixed with organic olive soap (Treatment 5) as shown also in Table 2.

Treatment	N	Subset			
		1	2	3	4
Treatment 7: No treatment/ Control	21	.00			
Treatment 6: Tomatoes plants treated with organic olive soap	15		30.12		
Treatment 5: Tomatoes plants treated with garlic extract mixed with organic olive soap	19		39.44	39.44	
Treatment 3: Tomatoes plants treated with pepper extract mixed with organic olive soap	19		39.87	39.87	
Treatment 4: Tomatoes plants treated with pepper and garlic extract mixed with organic olive soap	20		46.51	46.51	46.51
Treatment 2: Tomatoes plants treated with orange essential oil	20			49.63	49.63
Treatment 1: Tomatoes plants treated with Bacillus thuringiensis	19				62.41
Sig.		1.00	.104	.63	.13

Table 2: Univariate analysis of variance: Effect of treatments on the reduction of tomatoes leaves due to the infestation by *Tuta absoluta* (in mean %).

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares, the error term is Mean Square (Error) = 343.075. a Uses Harmonic Mean Sample Size = 18.808. b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed. c Alpha = .05.

Effect of organic treatments on the weight loss of tomatoes fruits infestation: Regarding the effect of organic treatments on the weight loss of tomatoes fruits infestation by *Tuta absoluta*, the analysis of variance showed a very high significance (Table 3). Across all the different organic treatments, *Bacillus thuringiensis* (Treatment 1) was the most effective treatment in protecting the tomatoes plants, with a least reduction in weight loss of tomatoes fruits due to the infestation by *Tuta absoluta*. The orange essential oil (treatment 2) resulted as the second most effective treatment. Furthermore, the pepper and garlic extract mixed with organic olive soap (Treatment 4), the pepper extract mixed with organic olive soap (Treatment 3), the garlic extract mixed with organic olive soap and, the organic olive soap are

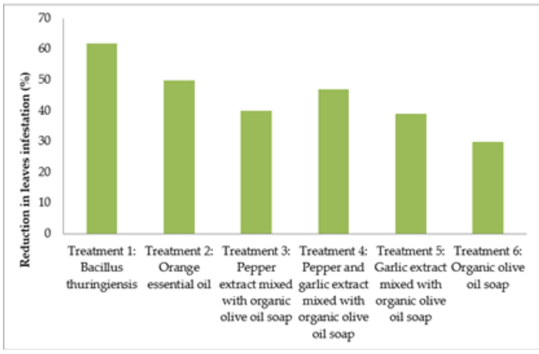

Figure 8: Mean reduction of Tuta absoluta infestation incidence (in %) on Lebanese tomatoes leaves as affected by the different organic treatments. Values marked with the same letter are not statistically different, according to the Tukey's HSD test (P≤ .05).

classified as the third, fourth, fifth and sixth most effective treatments, respectively in terms of the weight loss of tomatoes fruits infestation by *Tuta absoluta*.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	254790.127	1	254790.127	304.874	.003
	Error	1671.444	2	835.722(a)		
Treatment	Hypothesis	65961.540	6	10993.590	17.346	.000
	Error	7605.556	12	633.796(b)		
Replication	Hypothesis	1671.444	2	835.722	1.319	.304
	Error	7605.556	12	633.796(b)		
Treatment * Replication	Hypothesis	7605.556	12	633.796	4.110	.000
	Error	16193.333	105	154.222(c)		

Table 3: Univariate analysis of variance: Effect of treatments on the weight loss of tomatoes fruits due to the infestation by Tuta absoluta (in mean %).

[a] MS (Rep); [b] MS (Treatment * Replication); [c] MS (Error)

Furthermore, the post hoc Tukey's HSD test (Table 4) showed also that there was no statistically difference between *Bacillus thuringiensis* (Treatment 1) and orange essential oil (Treatment 2). Also, the mixture of pepper and garlic extract mixed with organic olive soap (Treatment 4) appears to form d distinctive subset group and present a value of p = 1.00. In addition, Table 4 reveals also that Treatments 3, 5 and 6 constitute another homogeneous group (p = .903). Consequently, Figure 9 recapitulates the distribution of the various organic treatments according to their effectiveness in terms of the reduction on the weight loss of tomatoes fruits, compared to the untreated control in the management of *Tuta absoluta* on Lebanese tomatoes.

Treatment	N	Subset			
		1	2	3	4
Treatment 1: Tomatoes plants treated with Bacillus thuringiensis	18	14.72			
Treatment 2: Tomatoes plants treated with orange essential oil	18	14.83			
Treatment 4: Tomatoes plants treated with pepper and garlic extract mixed with organic olive soap	18		32.11		
Treatment 3: Tomatoes plants treated with pepper extract mixed with organic olive soap	18			56.17	
Treatment 5: Tomatoes plants treated with garlic extract mixed with organic olive soap	18			57.17	
Treatment 6: Tomatoes plants treated with organic olive soap	18			60.94	
Treatment 7: No treatment/Control	18				78.83
Sig.		1.00	1.00	0.90	1.00

Table 4: Homogeneous subset post hoc Tukey's HSD test: Effect of treatments on the weight loss of tomatoes fruits due to the infestation by Tuta absoluta (in mean %).

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares.

The error term is Mean Square (Error) = 154.222. a Uses Harmonic Mean Sample Size = 18.000. b Alpha = .05.

Discussion

The results obtained in tomato open-field cultivation reveal that it is possible to reduce the tomato leaf miner impact by applying *Bacillus thuringiensis*. The potential of *Bacillus thuringiensis* formulates in controlling *Tuta absoluta* was clearly demonstrated in laboratory tests [16-20]. Moreover, when compared to non-treated controls, a research undertaken in Spain to investigate the effect of *Bacillus thuringiensis* on *Tuta absoluta* revealed great effectiveness in minimizing the damage at high infestation levels. As indicated in the results above (Figure 7), where *Bacillus thuringiensis* reduced *Tuta absoluta* on leaves by 60%, while (Figure 8) revealed a 15% reduction in weight loss of tomatoes. In addition, it was the most effective treatment compared to others. *Bacillus thuringiensis*, also found to be quite effective in decreasing the damage caused by the first, second, and third *Tuta absoluta* larval instars [21]. Furthermore, another study found evidence that first instar larvae were the most susceptible to *Bacillus thuringiensis* and that it could keep *Tuta absoluta* below economic thresholds [22]. Moreover, a research evaluated the effectiveness of *Bacillus thuringiensis* against *Tuta absoluta* and found that it caused substantial mortality in all three larval instars [23]. The study's findings support the larvicidal action of *Bacillus thuringiensis*

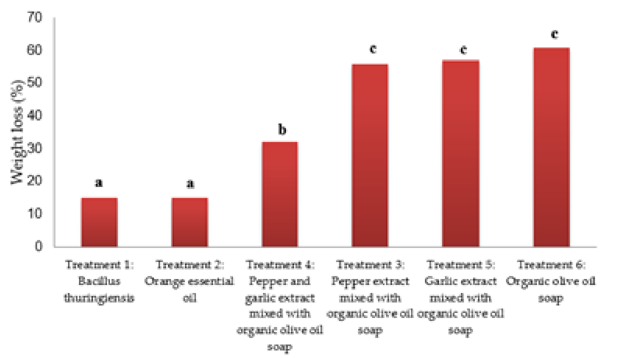

Figure 9: Mean weight loss of tomatoes fruits due to the infestation by Tuta absoluta (in mean %) as affected by the different organic treatments.

Values marked with the same letter are not statistically different, according to the Tukey's HSD test (P≤.05).

var. Kurstaki suspension against *Tuta absoluta* and highlight it as a potentially safe tool for use in integrated pest control in agricultural settings [22]. In addition, the results of tomato open-field cultivation show that applying orange essential oil can also help in reducing the impact of *tomato leaf miners*. According to studies, with researchs experimented with the essential oils extracted from *Citrus aurantium* and Citrus limon peels against third instar larvae of both pest species. The analysis by gas chromatography showed that limonene was the principal constituent of *Citrus aurantium* essential oils (88.57%) and Citrus limon (70.46%). Fumigant toxicity tests showed that *Citrus aurantium* oil was more toxic (LC50 was 14.68 µl/l air than Citrus limon (LC50 was 24.33 µl/l air for *Tuta absoluta*). The mortality rate of *Tuta absoluta* increased with the increase in essential oils dose. Hence, the essential oils of the two Citrus were found to be toxic, this could be useful for the investigation of new natural insecticidal compounds [24]. The efficacy of essential oil extracted from Citrus limon (Rutaceae) peels against *Tuta asboluta* was investigated in this experiment. Limonene was found to be the most abundant ingredient in the gas chromatography analysis, accounting for 52.80% of the total. This study found that essential oil linked with nanoparticles cause the death of 12 % of eggs, 66 % and 52% of larvae for translaminar toxicity, and 30 % and 40 % of larvae for ingestion toxicity after 72 hours at a dosage of 40 mg/ml [25]. Studies revealed that plant extracts are potential larvicides of *Tuta absoluta* when prepared and applied appropriately. These findings were consistent with the data given in (Figure 8) above, where orange essential oil exhibited a 15% in weight loss and was the most effective among other treatments, in contrast to leaf infestation in (Figure 7), which had only 50% on the reduction of leave infestation. Finally, essential oils of orange have been tested as pesticides against a variety of pests. This interest could be due to their widespread availability at reasonable prices. Orange essential oil is frequently produced as a byproduct of the citrus juice industry, and the cold-pressing technique makes orange essential oil extraction less expensive than other methods.

In this study, garlic and pepper extract mixed with organic olive soap extract showed relative moderate effect to control *Tuta absoluta* as shown by Figure 16, which this treatment resulted as 47% infection incidence on tomato leaves and 32% of weight loss due to infestation of *Tuta absoluta* (Figure 7). However, a similar study was conducted to determine if garlic (*Allium sativum*) and chili (*Capsicum annum L*) extracts may be used to control red spider mite in tomatoes. The results revealed that a combination of garlic and chilli was the most effective, followed by garlic and finally chilli [26]. On the other hand, a study carried out on tomatoes revealed that botanicals neem oil is effective in suppressing *Tuta absoluta* and has shown the greatest reduction in larval population [27].

According to this study, treating the *Tuta absoluta* with pepper and organic olive soap had little to no effect on it. This was consistent with (Figures 7 and 8), in which pepper experienced a 40% reduction in leaf infection and a 56% in weight loss due to *Tuta absoluta* infestation. However, studies included the effect of the water extract of *Capsicum annuumers* on some aspects of the life of the matrix *Tuta absoluta*, as a result of the destructive damage caused by this pest to the tomato crop in Iraq, three concentrations were used for the pepper extract (1%, 2%, and 4%), and studied the effect of these concentrations on egg hatching and the highest rate of hatching suppression 96.7% when using the pepper extract at a concentration of 4% and after 24 hours of laying eggs. Moreover, research evaluated the effect of *Capsicum annuumers* water extract on numerous aspects of the matrix *Tuta absoluta's* life. There were three concentrations of pepper extracts used: 1%, 2%, and 4%. As a consequence, the effect of various concentrations on egg hatching was investigated, with the highest rate of hatching suppression (96.7 %%t) when employing the pepper extract at a concentration of 4% and after 24 hours after egg laying [28]. The pepper *Capsicum annuum L*. aqueous fruit extracts were tested against the four larval stages of the *tomato leafminer Tuta absoluta* in a study. The results demonstrated that *Capsicum annuum* extracts were particularly efficient against *Tuta absoluta* larvae. The death rate was less than 25% after 24 hours, compared to more than 50% after 48 and 72 hours. Therefore, the extract used in this toxicological test was *Capsicum annuum*, which had a positive toxicological impact on *Tuta absoluta* larvae [29].

Garlic had no effect on the pest in this trial. Figures 6 and 7 indicated a 39% and 57% on leaf infestation, and in weight loss caused by the infestation, respectively. In accordance with Hussein et al. [30] discovered a significant drop in *Tuta absoluta* population after tomato plants were treated with garlic extract. *Tuta absoluta* was reduced moderately throughout this investigation due to the extraction procedure, which influences the presence of certain volatile oil that gives garlic its biological qualities.

The findings of this study agreed with those of Ghanim and Abdel Ghani [31], who found that *garlic* had a little effect on *Tuta absoluta* second instar larvae in the laboratory but had a moderate effect in the greenhouse. Furthermore, a research was carried out on three natural plants, *clove*, *parsley*, and *lavender*, as well as three commercial monoterpenoils (eugenol, isoeugenol, and cincol), which were tested against *Tuta absoluta*. At 30 µl/l water concentration, clove, eugenol, and isoeugenol oils induced significant reductions in egg hatchability for both one- and four-day-old eggs. Furthermore, increased clove oil concentration triggered a histological impact on the body wall of the larvae [32]. A study was carried out to investigate the efficiency of aqueous extracts of *Allium sativum* (*garlic*), *Allium cepa* (*onion*), and *Cloeme Arabica* made by infusion on various pests that infect tomato plants by spraying them for biological control. The results revealed that all of these extracts had a toxic effect on the studied insects, equivalent to chemical pesticides. In contrast, the data revealed that the dosages and time flow had a noticeable influence on the death rate. The death rate was 100% for *Tuta absoluta* and *Aphis gossypii* when employing direct spraying [33]. Hussein et al. [30] obtained similar results with additional pests, reporting that a good aqueous solution of *garlic* will successfully control *worms*, *beetles*, and *thrips in cowpea*.

The organic olive soap was highly affected by the infestation of *Tuta absoluta*. However, for almost 200 years, soap has been used to control insects. There has recently been a surge in interest in and use of these items. This shift is the result of a greater understanding of how to utilize soaps most effectively, as well as a desire to experiment with insecticides that are easier and safer to apply than many currently available options. It is still unclear how soaps and detergents kill insects. In most situations, control is achieved by disrupting the insect's cell membranes. Soaps and detergents may also remove the protective waxes that coat the insect, resulting in death due to excessive water loss [34]. Moreover, some studies had a positive effect in controlling other insects. A study suggests that native soap is an effective bio-pesticide against cowpea insect pests [35].

Conclusion

Tuta absoluta is one of the most harmful insect pests of several cultivated and non-cultivated host plants, particularly tomato plant *Solanum lycopersicum L*. Chemical insecticides are mainly used to manage the *tomato leaf miner*. However, their excessive use has led to several problems. Biological management remains an eco-friendly alternative for controlling of this pest. It relies on using bacteria, *entomopathogenic fungi*, animals, and plants. Plant extracts are easy to applicate and have low costs. Several species, plant parts and extracts forms are used. Biological effects of these extracts are due probably to their major components that affect vital physiological functions such as neurophysiology and respiration. This study is the assessment of the performance of organic treatments in Lebanon on *Tuta absoluta*. The results obtained here suggest that *Bacillus thuringiensis* treatment presented the lowest impact on tomato leaf infestation reduction and, was the most effective treatment in protecting the tomatoes plants, with at least reduction in weight loss of tomatoes fruits. The orange essential oil resulted as the second most effective treatment, followed by: (i) pepper and garlic extract mixed with organic olive oil soap, (ii) pepper extract mixed with organic olive oil soap, (iii) garlic extract mixed with organic olive oil soap, and (iv) organic olive oil soap used alone. As such, *Bacillus thuringiensis* and orange essential oils are relatively effective and economically viable to organically control *Tuta absoluta*.

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