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The Fluctuations of the Whitefly (*Bemisia tabaci* Genn) Population on Potato Plants and their Sustainable Management with Bio-Insecticides

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ABSTRACT

Potato whitefly, *Bemisia tabaci* (Genn.), is one of the most common insects that injure potato plants affecting the quality of potato production in Egypt. In the present study, open field experiments were conducted to study the seasonal population fluctuation of whitefly (*Bemisia tabaci*, Genn.) nymphs and adults on potato (*Solanum tuberosum* L.) during two seasons 2021 and 2022 in the Qalubia Governorate (Egypt), under protected conditions and its correlation with the environmental factors: temperature (maximum and minimum), relative humidity, wind speed, and precipitation were observed. Also, the toxicity of different essential oils (EOs) namely camphor oil (*Cinnamomum camphora*), citronella oil (*Cymbopo gonnardus*, L), geranium oil (*Pelargonium graveolens* L.), eucalyptus oil (*Eucalyptus globulus* L.), Marjoram (*Origanum majorana*) and thyme oil (*Thymus vulgaris* L.) were examined separately and as mixtures with chitosan against both *B. tabaci*, nymphs and adults. These were compared with imidacloprid as a positive control. The population fluctuation study of *B. tabaci* showed the highest mean number of adults recorded at 1.13 adults/plant and 1.1 adults/plant on November 12, 2022. While the nymph population was 2.21 nymphs/plant on November 19, 2021, and 2.413 nymphs/plant in 2022. Adult and nymph populations showed a continuous decrease until December. There was a significant correlation between the *B. tabaci* population (nymph and adult) and wind speed, relative humidity, and precipitation during the 2021 season. In contrast, during the 2022 season, the *B. tabaci* population (nymph and adult) significantly correlated with all examined environmental factors, except for precipitation levels. Also, the study tested essential oils EOs, chitosan (Ch), and their mixtures on potato plants for their effectiveness against *B. tabaci* infestation. Results showed the tested emulsions had a slightly lower efficacy than the conventional synthetic insecticide, Imidacloprid, in controlling *B. tabaci* on potato fields. Thyme and citronella were the most effective in reducing *B. tabaci* adult populations, followed by camphor and geranium. The highest reduction percentage was caused by (thyme+Ch). Foliar spray of thyme, citronella, and camphor showed similar efficacy on *B. tabaci* nymphs. The (EOs+Ch) mixture was more effective than the EOs. Chitosan enhances the durability of essential oil emulsions and improves their adherence to leaf surfaces. Thyme and citronella oils effectively reduced *B. tabaci* adult populations, followed by camphor and thyme. Combining chitosan with thyme or citronella oils enhanced their effectiveness against *B. tabaci* adults.

Keywords: potato plant, *Bemisia tabaci,* population fluctuation, environmental factors, essential oils, chitosan

1. Introduction

Potato (*Solanum tuberosum* L.) is a modified underground swollen stem belonging to the family Solanaceae and native to South America. Potato rank as the fourth most important food crop, following rice, wheat, and maize. Also, it is one of the most significant food crops in the world and a perennial herb due to its superior value (Chau *et al.,* 2023). In 2022, the FAO reported a global potato production of 375 million tons, with Egypt contributing 6.1 million tons (FAOSTAT, 2022). Potato production

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suffers globally because of plant damage caused by different pests at different stages of the growth process. Ensuring the sustainability of potato production is a significant challenge for agricultural professionals worldwide. (Kroschel *et al.,* 2020). Amongst the sap-sucking insect pests damaging this crop, the whitefly, *B. tabaci* (Hemiptera: Aleyrodidae), a highly polyphagous insect pest, has become serious, causing heavy losses during certain years (Perring *et al.,* 2017; Perera and Senanayake, 2023). The high population of *B. tabaci* can remove significant amounts of phloem sap, reducing plant vigour. *B. tabaci* damage can occur in two ways: First, plant vitality is lowered through the loss of cell sap, and normal photosynthesis interferes with sooty mould growth on the honeydew excreted by *B. tabaci*. may also damage honeydew, reducing plant vigilance (Bohatá *et al.,* 2024). Different groups of insecticides have been recommended for the control of *B. tabaci*. Previous research has evaluated insecticides that are less toxic and more environmentally safe for controlling *B. tabaci*. In recent years, there have been significant advancements in insect control through innovative methods that decrease the reliance on synthetic pesticides. (Naveen *et al.,* 2017; Amour *et al.,* 2023). EOs used in insect pest management show promise as a sustainable and environmentally friendly alternative, particularly in the absence of safe options. EOs are known for their low toxicity towards non-target organisms, such as natural enemies and pollinators (Kumar *et al.,* 2022). Researchers have found that certain essential oils have insecticidal and repellent properties that can effectively control several Hemiptera (Saad et al, 2017; Wagan *et al.,* 2022; Li *et al.,* 2022). Research has indicated that certain plant oils may have limitations due to poor stability and water solubility, which can hinder their effectiveness as insecticides in field conditions (Campos *et al.,* 2019). To address this challenge, researchers are exploring ways to enhance the efficacy of EOs by developing more efficient formulations (Sharifian *et al.,* 2015; Hashem *et al.,* 2018; Massoud *et al.,* 2018).

Chitosan is an amino polysaccharide found in nature and can be extracted from various sources, including crustacean and insect exoskeletons and fungal cell walls. It is one of the most abundant polysaccharides found in nature (Huq *et al.,* 2022). Indeed, chitosan has been recognized for its potential as an alternative to traditional pest control methods. It possesses insecticidal and antimicrobial properties that make it effective in managing pests (Rajkumar *et al.,* 2020).

Chitosan's ability to inhibit the growth of certain microorganisms and repel or disrupt the life cycle of insects has made it a promising option for pest control applications. However, it is important to note that further research and development are still ongoing to fully explore and optimize its effectiveness in this regard (Rajkumar *et al.,* 2020; Keppanan *et al.,* 2024). Chitosan-treated essential oil emulsions show promise in reducing pest populations and reducing crop damage. To develop effective and sustainable management strategies for controlling *B. tabaci* as a vector of viruses, it is crucial to comprehend its population fluctuation with the prevailing climatic factors in the regions (Pathania *et al.,* 2020).

The study aimed to investigate the population fluctuation of *B. tabaci* in potato plants. Also, mixing chitosan with essential oil emulsions could enhance their stability, longevity, and adhesion to leaf surfaces. This approach offers a viable alternative to chemical pesticides, reducing environmental impact while promoting safer farming practices.

2. Material and Methods.

Two Experiments were carried out under field conditions on potato. Plants cultivated at mid-September (Nili plantation), on French Spunta variety during season (mid-September, October, November, December and Jan) months during two growing seasons of potato (2020-2021) and (2021-2022). All field experiments were carried out in Qalubiya Governorate (EL-Qanater Research Station Farm) Horticulture Research Institute, ARC, Egypt, is located at latitudes 30° 11′ 38.90″N and longitude 31° 6′ 56.10″E. Qalubia Governorate.

2.1. Population fluctuation

2.1.1. Seasonal incidence of *B. tabaci*

The experiment's design was arranged in a randomized complete block with three replicates; there were 18 plots; each plot area was measured at 18 m2 and divided into three rows, each 6 m long and 3 m wide. Potato tubers were deepened inside the row, each row at a 30 cm distance. The total cultivated area was 350 m2. The distance between each tuber was 30 cm**.** Weekly observations on *B. tabaci*, adults and immature were conducted on potato plants, Number of leaves Samples of (10 leaves per plant) from

Upper - medium - low were chosen randomly early in the morning before the whitefly adults tend to be more active, (Gameel, 1973).

2.1.2. The environmental factors

The effects of maximum temperature(ºC), minimum temperature (ºC), relative humidity (%), wind speed (m/s) and precipitation (mm/day) on the population density of *B. tabaci* were investigated during two consecutive seasons (2020-2021) and (2021-2022). On the other hand, the obtained values of the five environmental factors were taken as independent variables (x), i.e., mean maximum temperature (x_1), mean minimum temperature (x_2), mean percentage of relative humidity (x_3), wind speed (x_4), and precipitation (x_5). The correlation coefficient (r) was worked out between the incidence of *B. tabaci* and important environmental factors during the period to determine the weather's influence on population fluctuation. environmental factors were collected from automated weather stations in the Central Laboratory for Agricultural Climate, which was allocated to the experimental sites at the Agricultural Research Center, Giza, Egypt.

2.2. Evaluation of some bio-insecticides against *B. tabaci*

Different essential oils (EOs), namely camphor oil (*Cinnamomum camphora*), citronella oil (*Cymbopo gonnardus*, L), geranium oil (*Pelargonium graveolens* L.), eucalyptus oil (*Eucalyptus globulus* L.), marjoram (*Origanum majorana*), and thyme oil (*Thymus vulgaris* L.), were purchased from the National Research Center, oils extract unit, Cairo, Egypt. The EOs were examined separately and as mixtures with chitosan. Chitosan obtained from shrimp shells polysaccharide (B-1.4-Glucosamin) Low MW (1987 g/mol) were purchased from BIOTECH co., LTD. Dokki, Giza. Egypt. These were compared with imidacloprid, a positive control. Imidacloprid (Suncloprid® 35% S.C.) obtained from El-Nasr Company for Intermediate Chemicals, Giza, Egypt.

2.2.1. GC-MS analysis

The chemical analysis of the essential oils under studied (camphor, citronella, geranium, eucalyptus, and thyme) were analyses according to (Mohareb *et al.,* 2023) using a GC-TSQ mass spectrometer (Thermo Scientific, Austin, TX, USA) with a direct capillary column TG-5MS (30 m × 0.25 mm film thickness). By comparing the mass spectra of each peak to those in the library, the components were identified on their retention time, and the mass spectra were compared with those of the Wiley 09 and NIST 14 mass spectral databases (Stein, 2014).

2.2.2. Chitosan (Ch) characterization

Fourier transform infrared (FTIR) spectroscopy was used to identify the chemical structure of Chitosan polysaccharide. The FTIR spectra of the membranes were measured with a Jasco FT/IR6200 spectrophotometer. The spectra were the average of 50 scans recorded at a resolution of 4 cm^{-1} in the range from 4000 to 500 cm^{-1}. Burker tensor 37 spectrometers were used in this identification in the range of 400-4000 cm^{-1} using the technique of KBr pellet as 1.0 mg of samples was added to 100 mg KBr pressed, then exposed to infrared radiation (Wu *et al.,* 2012; Guo and Chen, 2014).

2.2.3. Preparation of chitosan solution, essential oils emulsion and their mixtures

Chitosan solutions were prepared from 2.0 g of chitosan and dissolved in 100 ml of sterile water containing 0.5 ml (v/v) glacial acetic acid. The mixture was dissolved using an overhead 40 °C stirrer at 6000 rpm for 30 minutes. The pH of the solution was 5.3, adjusted to 5.6 by adding either 1N NaOH or 1N HCl depending on the pH reading, using a digital pH meter (Madushani *et al.,* 2014; Zahid *et al.,* 2015), and completed to 1 L with water. Emulsion formation oil in water emulsion was prepared according to (Sugumar *et al.,* (2015) with little modification. It was prepared in a ratio of 1:1 v/v using essential oil (3%), tween 80 (3%), and water (94%). The emulsions were prepared by stirring at 6000 rpm for 30 minutes and completed with 1 L of water. Chitosan solution was mixed with essential oils emulsion in an equal ratio (1:1), according to Essa *et al.* (2019) and then was homogenized using magnetic stirring at 6000 rpm for 10 min.

2.2.4. Field experiments of the tested bio-insecticides

According to standard agricultural practices, the experiments were designed as randomized complete blocks of 13 plots (each treatment replicated three times). The treated plots were separated from each other by untreated rows as a barrier to prevent overlapping treatments. A knapsack sprayer (20 litres) was used, filled with the prepared concentration just before each treatment. The data were compared with imidacloprid, a positive control. Imidacloprid was applied at a rate of 75 g/100 L in water. Also, compared with the untreated plot as a negative control.

2.2.5. Sampling methods

Observations on the incidence of *B. tabaci* were made on the five randomly selected and tagged plants and transferred into paper bags to examine the nymph of whitefly by the stereomicroscope. Inspection of plants was carried out before spraying (zero time) and after 3, 5 and 10 days after application in both the sprays. The data obtained were computed for mean reduction percentage.

2.3. Statistical analysis

Population data of *B. tabaci* (nymphs and adults) and multiple environmental factors, viz., maximum, and minimum temperatures, the percentage of relative humidity, precipitation, and wind speed was subjected to statistical analysis to calculate the coefficient of correlation and regression as calculated by Senedcor and Cochran (1967). The data of controlling *B. tabaci* were subjected to investigated by the significance of mean differences between treatments and controls was compared statistically using analysis of variance (split-plot-plot ANOVA) at the 0.05% probability level, with individual pairwise comparisons using Tukey's multiple range tests at a 95% confidence level via Co-Stat software.

3. Results

3.1. Population fluctuation of *B. tabaci* during 2021 and 2022

The population of *B. tabaci*, including both nymphs and adults, infesting potato plants was recorded during the autumn of 2021 and 2022. This study investigated population fluctuations and their relationship with various environmental factors, such as maximum temperature, minimum temperature, relative humidity, wind speed, and precipitation. *B. tabaci* were the first detected in the fourth week of October for each season, two weeks after the opening of the first potato leaf. The mean numbers of nymphs per plants were 0.096 and 0.08 in 2021 and 2022, respectively, whereas the mean numbers of adults per plants were 0.18 and 0.2, respectively. On November 12, 2022 the maximum mean number of adult *B. tabaci* populations was 1.1 adults/plant and on November 19, 2021, the maximum mean number of adult *B. tabaci* populations reached 1.13 adults/plant. The whitefly nymph population reached a peak of 2.21 nymphs/plant on November 19, 2021, and 2.413 nymphs/plant in 2022. Adult and nymph populations showed a continuous declining trend. Until December, nymph populations decreased to 0.80 and 0.73 nymph/plant during the two studied seasons, and adults decreased to 0.56 and 0.61 adults/plant on December 24, 2021, and 2022, respectively (Figure 1A, B, C, D, and E). Environmental factors for the 2021 season (wind speed, relative humidity, and precipitation) are effective, but the maximum and minimum temperatures have not been affected. The weekly densities of the nymph and adult populations increased during the second fortnight of November 19, 2022, reaching a peak of 2.1 and 1.15 leaves/week. Relative humidity is 77.00% (Figure 1C), wind speed is 5.61 m/s (Figure 1D), and total daily precipitation is 7.00 mm (Figure 1E).

The 2022 season's environmental factors (maximum temperature, minimum temperature, wind speed, and relative humidity) were deemed effective factors in *B. tabaci* population fluctuation, while the amount of precipitation had no effect. During the second two weeks of November 19, 2022, nymph and adult population weekly densities increased until they peaked at 2.41 and 1.13 leaves/week, respectively. The maximum temperature recorded that day was 28.25°C (Figure 1A), the lowest was 12.00°C (Figure 1B), the relative humidity was 69.44% (Figure 1C), and the wind speed was 1.13 meters/second (Figure 1D).

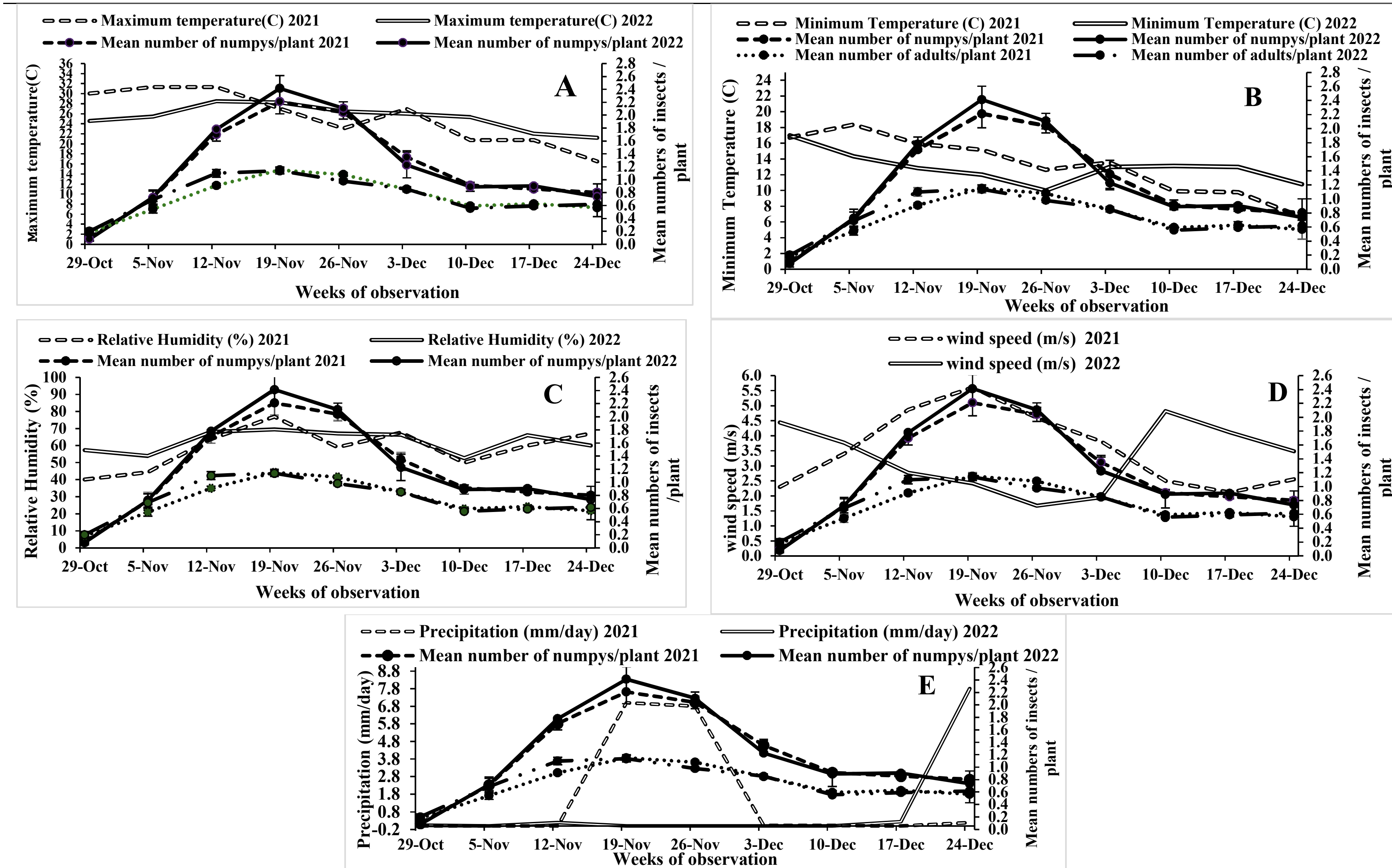

Fig. 1: Population dynamics of *B. tabaci* (mean ±SE) on potato plants in Qalubi Governorate, Egypt in 2021 and 2022 with (A) maximum temperature, (B) minimum temperature, (C) relative humidity, (D) wind speed, and (E) precipitation

The correlation coefficient was non-significantly positive between the *B. tabaci* population and maximum temperature for the nymphal and adult populations during 2021 but significantly negative with r = 0.683* and r = 0.682* for the nymphal adult population during 2022 (Table 1).

Table 1: Correlation coefficient of whitefly population on potato with weather parameters during years 2021 and 2022.

Weather parameters	Correlation Coefficients							
	2021				2022			
	Nymphs/ leaf		Adults/leaf		Nymphs/ leaf		Adults/leaf	
	r	P value	r	P value	r	P value	r	P value
Maximum temperature(°C)	0.046	0.905ns	0.002	0.994ns	0.683	0.0423*	0.682	0.0427*
Minimum Temperature (°C)	0.058	0.881ns	0.013	0.97ns	-0.673	0.0468*	-0.649	0.058ns
Relative Humidity (%)	0.741	0.022*	0.355	0.348ns	0.750	0.0199*	0.719	0.0288*
wind speed (m/s)	0.898	0.001***	-0.709	0.032*	-0.769	0.0152*	-0.795	0.104*
Precipitation (mm/day)	0.771	0.015*	0.423	0.255ns	-0.237	0.5388ns	-0.163	0.674ns

*Significant at 0.05% level of significance.

The minimum temperature also showed a non-significantly negative correlation with both populations during the first year, but the correlation was statistically significant (r = -0.673* and -0.649*) for the nymphs and adults populations during the second year, respectively. The relative humidity showed a positive correlation (r = 0.731) with nymphal. The relative humidity exhibited a positive correlation (r = 0.750 * and 0.791 *) with the nymphal and adult populations during 2022. Nymph populations had a highly significant positive correlation with wind speed (r = 0.898. Both nymphal and adult populations showed significant negative correlation with r = 0.769* and r = 0.795* in 2022. Precipitation does not exhibit any effect on nymphal and adult populations in the two studied seasons, except with nymphs being significantly positive (r = 0.771*) in 2021.

Regression studies of the *B. tabaci* population with environmental factors, viz., maximum temperature, minimum temperature, relative humidity, wind speed, and precipitation, were worked out (Table 2) with R_2 values of 0.537 and 0.650 for the nymphal and adult populations, respectively, for the year 2021. but the R_2 values of nymphal and adult populations increased to 0.969 and 0.951, respectively, during 2022. The R_2 values indicated that environmental factors contributed actively to the population fluctuation of whiteflies on potato plants especially during season 2022.

Table 2: Regression equation of whitefly population with weather parameters during years 2021 and 2022.

Whitefly population	2021		2022	
	Regression equation	R_2	Regression equation	R2
Nymphs	Y_1=0.125+0.043X_1-0.133X_2-004X_3+ 0.532X_4+0.044X_5	0.537	Y_2=-3.245+0.173X_1-0.237X_2+ 0.043X_3 +0.131X_4-0.026X_5	0.969
Adults	Y_2=0.310+0.075X_1-0.090X_2 +0.011X_3 -0.428X_4+0.103X_5	0.650	Y_2=-1.112+0.076X_1-0.073X_2 +0.013X_3 + 0.008X_4+0.009X_5	0.915

Y1= Whitefly nymph per leaf; Y2= Whitefly adults per leaf; X1= Maximum temperature (oC); X2= Minimum temperature (oC); X3= Relative humidity (%); X4= wind speed (m/s); X5=Precipitation (mm/day).
P<=0.05

3.2. Chemical composition of essential oils

The tested essential oils (thyme oil, geranium oil, citronella oil, marjoram oil, and camper oil) were identified by GC-MS. The main constituents of each of them are shown in (Table 3). With many oxygenated monoterpenes and sesquiterpene derivatives of essential oils, thyme oil has 15 components that were characterized, representing 99.72%. The main components were (+)-linalool (26.50%), myrcene (15.67%), thymol (13.76%), and 1,8-cineole (11.94%). Geranium oil had 13 components, with citronellol (28.99%), geraniol (14.8%), and selinenol (9.69%) being the predominant components. Citronella oil contains 10 components. The main components were E-citral (39.5%), Z-citral (37.17%), and p-cymene (17.5%). Marjoram oil had 13 components: terpinen4ol (30.93%), thuyan-4-ol (12.30%), and çTerpinene (11.96%). Camper oil's main components were: 1-p-Menthol (37.24%), 1,8-Cineole (27.78%), and Monoelaidin (13.39%).

Table 3: Chemical component (%) of thyme, geranium, citronella, marjoram, and camper essential oils

Components	Thyme oil %	Geranium oil %	Citronella oil %	Marjoram oil %	Camper oil %	RT (min)
A-camphene	0.45					5.20
3-Methyl-apopinene						5.87
alpha-Terpinene	4.53	1.19	0.50	7.69	19.78	6.37
Tetrahydro-m-cresol						6.49
Camphene					0.06	6.81
Sabinene	0.69			3.82		7.28
Menthen					0.96	7.80
Trans-Carane						7.95
á-Myrcene	15.67				0.69	8.08
Alpha-Pinene	1.07	10.18				8.11
alpha-Phellandrene					0.63	8.53
B-Pinene	2.03				0.13	8.96
1H Pyrazole, 1 vinyl					1.12	9.23
p-cymene	2.26		17.15	3.39		9.27
1,8-Cineole	11.94			5.97	27.78	9.45
β-cis-Ocimene			0.52		0.07	9.98
ç-Terpinene	0.13			11.96	5.09	10.35
1,2-Oxolinalool					0.06	10.91
linonene	8.10			3.06		11.27
(+)2Carene					0.47	11.29
(+)-Linalool	25.50	8.49	1.02	9.40	0.21	11.79
Menthone					-	11.94
exo-Fenchol					0.15	12.33
1-Terpinenol					0.40	12.95
Isopinocarveol					0.40	13.16
Isoborneol					0.24	14.05
Terpinen4ol	6.31			30.93	0.64	14.29
thuyan-4-ol				12.30		14.14
1-p-Menthol			0.75		37.24	14.86
Camphene					2.34	15.02
Isocitral			2.40			15.84
Thymol	13.76					15.92
trans-Verbenol			1.75			16.02
Menthol					-	16.07
Cyclohexanone, 5-methyl-2-(1-methylethyl)-, cis-		6.92				16.12
Carvacrol	2.47					16.71
Citronello		28.99				18.59
Pulegon					-	18.61
Z-Citral			37.17			18.91
linalyl acetate				3.45		18.99
Geraniol		14.8				19.45
methyl eugenol				1.97		19.56
Citronellyl formate		9.60				19.93
E-Citral			39.10			19.95
β-bisabolene				1.95		20.43
Longifolene			0.08		0.24	20.69
Geranyl ethanoate		4.21				20.80
Germacrene-d		1.99				26.2
Caryophyllene	0.81	1.59		2.87	0.06	26.40
Cubenene		1.40				27.45
Selinenol		9.69				30.45
N Hexadecanoic acid					0.88	33.07
13-Octadecenoic acid					0.66	33.50
-(-)trans-Myrtanyl acatate		0.93				34.05
Z-(13,14-Epoxy) tetradec-11-en-1-ol acetate					0.83	34.14
Carane					0.23	34.29
Monoelaidin					13.39	34.38
Octadecanoic acid					0. 98	34.94
alpha-Linoleic acid					0.59	35.13
Benzyl oleate					0.16	35.26
Heptacosane					0.78	35.45
Octadecanedioic acid					0.22	35.77

3.3. Chitosan Fourier transform infrared (FTIR) spectroscopy.

FTIR analysis for chitosan is shown in (Figure 2) which confirms the presence of different organic and inorganic groups. The spectra have characteristic bands for chitosan. FTIR spectrum of chitosan showed eight functional groups of O–H, N–H, C-H, N = C–N, N–H, $N–H_2$, C–H, C–O, and C–H which showed respective absorption bands viz., 3433-3259, 2923,2151-2360, 1656, 1566, 1405, 1322, 1156-1069-1028, and 894cm^{-1}.

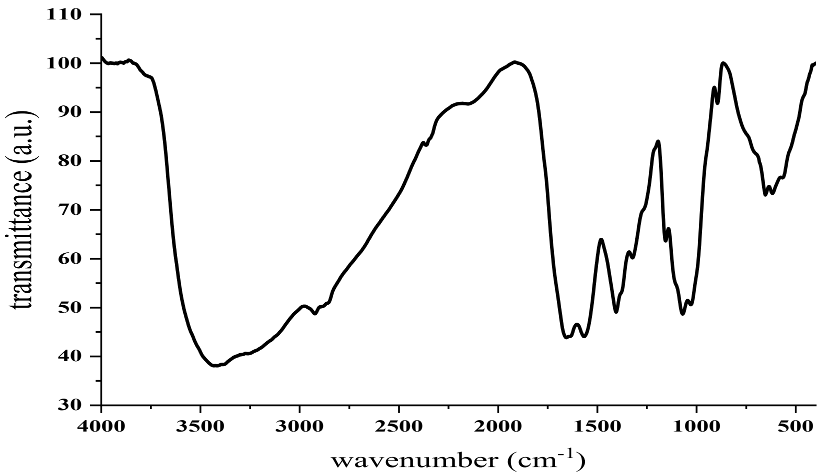

Fig. 2: FTIR spectra of chitosan.

3.4. Insecticidal activity tested essential oils, chitosan, and their mixtures against *B. tabaci*

The tested essential oils, chitosan, and their mixtures on potato plants intercropping by three spray applications revealed great variations in the effectiveness against the infestation of *B. tabaci* nymphs and adults under field conditions during the two successive seasons of 2020–2021 and 2021–2022. The obtained results indicated the following:

During season 2021, Figure 3 shows the percentage reduction of *B. tabaci* populations (adult and nymph) under three successive applications of the studied treatments at 3, 5, and 10 days. The initial effect (3 days after spraying) of (thyme+Ch). and (citronella+Ch) were superior in whitefly adult population reduction (75, 79, 66% and 74, 76, 61%, after 3, 5, and 10 days application, respectively followed by (camphor+Ch) and thyme (68, 72, 64 % and71,74, 59%). The lowest reduction percentage was (13,14,12%) caused by Ch (Figure 3a). Foliar application of (thyme+Ch). (citronella+Ch) and (camphor+Ch) showed a similar efficacy on whitefly nymphs (74,79,79% & 70,75,76% and 64,73,73% respectively). Furthermore, the general reduction percentage cleared that there were slightly significant differences between (thyme+Ch). (citronella+Ch) and (camphor+Ch) applications on both studied *B. tabaci* stages (adults and nymphs). Also, pelargonium (Ch) and marjoram (Ch) reduced toxicity against both whitefly stages. There is a significant difference between the reduction percentages of the tested oil emulsions and their mixers. The (EOs+Ch) mixture was more effective than EOs (Figure 3b). The results of the second application on adults (Figures 3c). In the second recording (thyme+Ch). was significantly higher treatment followed by (citronella+Ch) and camphor+Ch). In the percentage reduction of nymph populations (5 days after spraying), there were significant differences between (thyme+Ch). and (citronella+Ch) followed by (camphor+Ch) (Figures 3d). Also, in the third application, (Figure 3e) Regarding the effect five days after treatment, (thyme+Ch). (77%), and (citronella+Ch) (76%), were the highest impacts followed by thyme (74%), and citronella (67%), on whitefly adults. Also (Figure 3f) Regarding that the (thyme+Ch). emulsion had significantly higher reduction percentages against nymph populations (79%), followed by (citronella+Ch) (75%), and (camphor+Ch) (73%).

In the 2022 season, (Figure 4a) indicated that blending chitosan with thyme or citronella increased the effectiveness of both oils against whitefly adults. Initially, the efficacy of thyme and citronella oils was measured at 66% and 60%, respectively. However, when combined with chitosan, the efficacy of thyme and citronella oils rose to 73% for *B. tabaci* adults within three days after first spraying. The tested materials showed higher effectiveness against whitefly nymphs, with (thyme+Ch). and thyme demonstrating the highest reduction in *B. tabaci* populations at 82% and 77%, respectively. This

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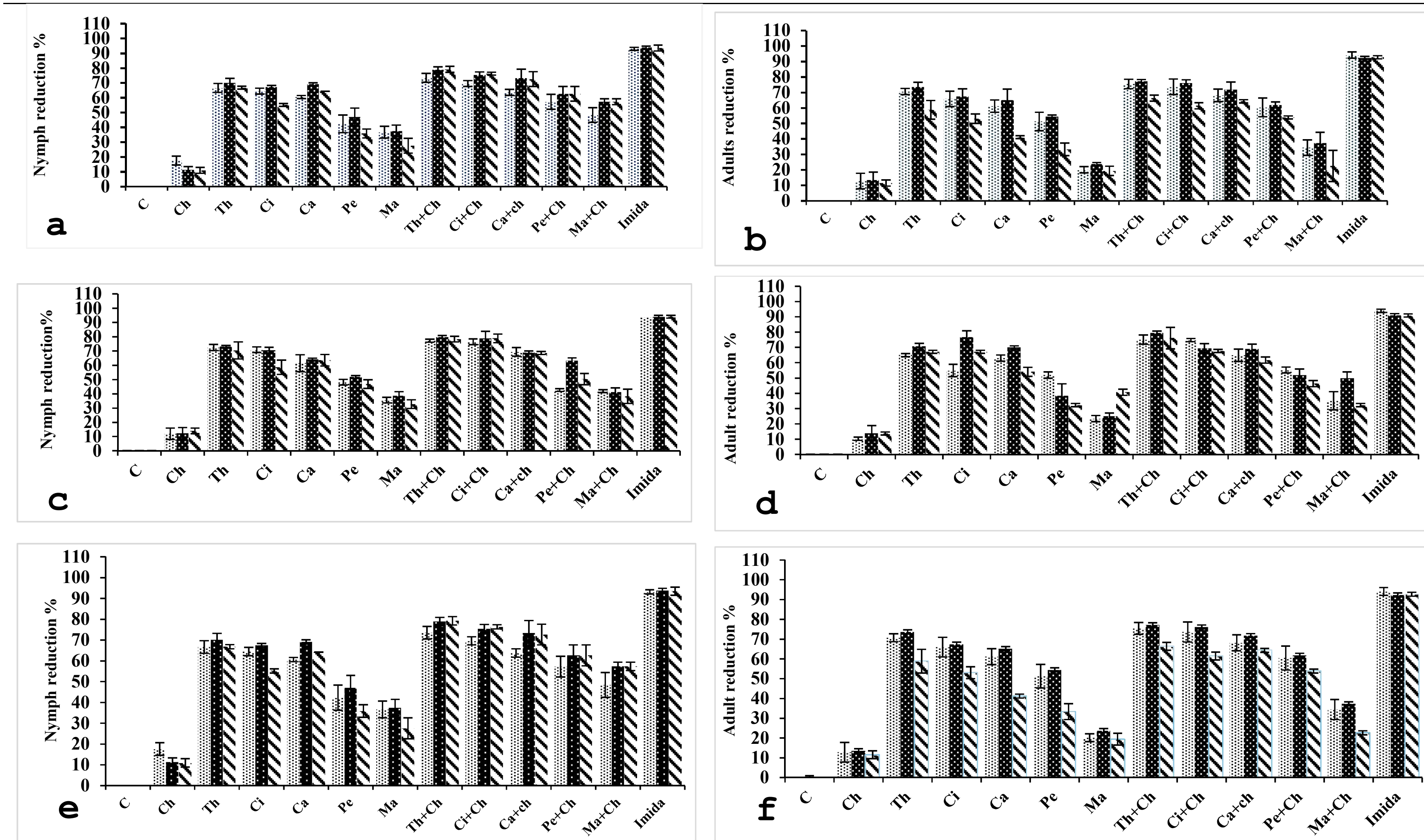

Fig. 3: Percentage reduction of *B. tabaci* populations adult and nymph (a&b) after first spray, (c&d) second spray and (e&f) third spray with tested essential oils, chitosan, and their mixtures during season 2021

Where, 3days, 5days, 10days, (c) control, (ch) chitosan, (Th) Thyme, (Ci) Citronella, (Ca) Camphor, (Pe) Pelargonium, (Ma) Marjoram, (Th+Ch) Thyme+ chitosan, (Ci+Ch) Citronella+ chitosan, (Ca+Ch) Camphor+ chitosan, (Pe+Ch) Pelargonium+ chitosan, (Ma+Ch) Marjoram+ chitosan, (Imida) Imidacloprid

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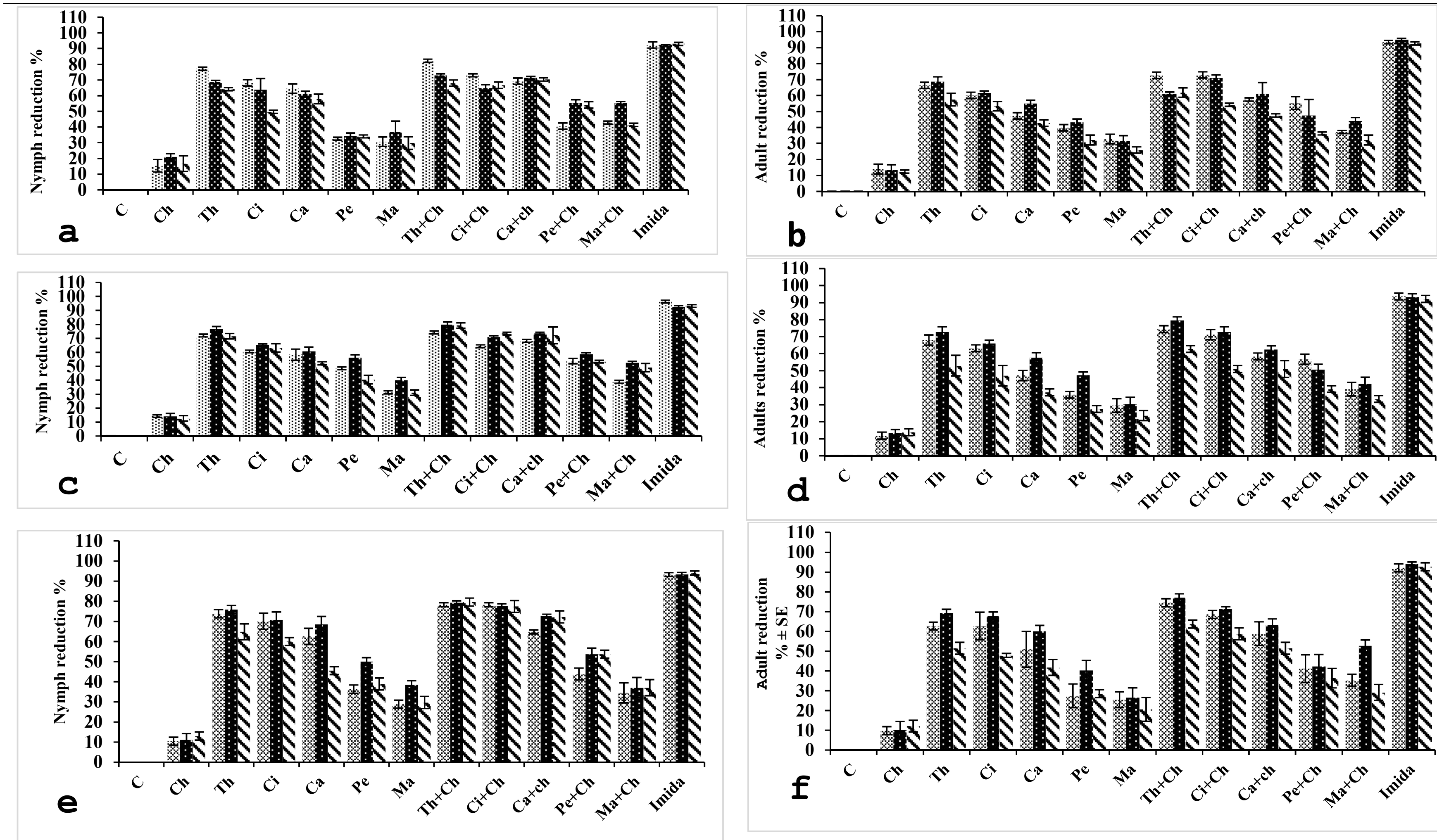

Fig. 4: Percentage reduction of *B. tabaci* populations adult and nymph (a&b) after first spray, (c&d) second spray and (e&f) third spray with tested essential oils, chitosan, and their mixtures during season 2022.

Where, 3days, 5days, 10days, (c) control, (ch) chitosan, (Th) Thyme, (Ci) Citronella, (Ca) Camphor, (Pe) Pelargonium, (Ma) Marjoram, (Th+Ch) Thyme+ chitosan, (Ci+Ch) Citronella+ chitosan, (Ca+Ch) Camphor+ chitosan, (Pe+Ch) Pelargonium+ chitosan, (Ma+Ch) Marjoram+ chitosan, (Imida) Imidacloprid.

reduction was comparable to the effectiveness of Imidacloprid, which achieved a 92% reduction in *B. tabaci* populations (Figure 4b). the second spray and three days after application of (thyme+Ch). spray yielded the highest efficacy, with an 80% reduction in *B. tabaci* (adult and nymph), followed by (citronella+Ch) 73% reduction in adults and a 71% reduction in nymph and thyme alone, achieving a 73% reduction in adults and 77% reduction in nymph for (Figure 4c& d). Finally, the third spray was a less effective spray against the adult population (Figure 4e). about nymph, there were no significant differences between (thyme+Ch). and (citronella+Ch) after 3,5 and 10 days after application followed by (camphor+Ch)

4. Discussion

The presence of *B. tabaci* firstly recorded in the fourth week of October 2020-21 and 2021-22 in Qalubiya Governorate, Egypt. Environmental factors (wind speed, relative humidity, and precipitation) affect the *B. tabaci* population fluctuation during the 2021 season. While environmental factors (maximum temperature, minimum temperature, wind speed, and relative humidity) for the 2022 season were found to be effective. The present findings agree with (Harshita *et al.,* 2019) from India who found that the *B. tabaci* in tomato began to appear during the third week of November in 2015–16 and the second week of November in 2016–17 during the investigation period and remained active throughout the cropping season. Also, (Berani and Patel, 2020) in India found the population fluctuation of the *B. tabaci* population on the brinjal plant peaked during the 4th week of November 2018–19 and the 5th week of October 2019–20.

The study found a significant negative correlation for the nymphal adult population in 2022. Relative humidity showed a positive correlation with nymphal populations, while wind speed had a significant positive correlation. Precipitation did not affect nymphal and adult populations in the two seasons studied. Regression studies showed that environmental factors significantly contributed to the population fluctuation of *B. tabaci* on potato plants in 2022.While there was a positive correlation between the *B. tabaci* population and temperature in other studies (Marabi *et al.,* 2017), but there was a negative correlation with relative humidity. Maximum temperature positively influenced the *B. tabaci* population, while wind speed and rainfall negatively affected it. According to (Subba *et al.,* 2017), the *B. tabaci* population did not have a significant negative correlation with temperature, rainfall, or relative humidity. While, the population fluctuation of *B. tabaci* are significantly influenced by temperature, as found by (Shah *et al.,* 2019). Abbas *et al*. (2023), found that temperature and relative humidity were positively correlated with *B. tabaci* populations, although the correlation was non-significant. Specifically, maximum, and minimum temperatures were negatively correlated with *B. tabaci* populations, while relative humidity showed a positive correlation (Abbas *et al.,* 2023). The impact of the environmental factors on *B. tabaci* populations can be analyzed and strategies developed by studying the trends and patterns observed between *B. tabaci* population fluctuation and environmental conditions.

On the other hand, the current study estimated the efficacy of thyme oil, geranium oil, citronella oil, marjoram oil, and camper oil emulsions and examined the combination of chitosan with these essential oils against stages (adults and nymphs) of *B. tabaci* in potato fields.

The major components of essential oils are typically highlighted for their bioactivity; it is also worth noting that minor constituents present in essential oils can play a significant role as well. These minor constituents may have synergistic effects with the major components. Some studies have found that the use of the whole essential oil produces a greater impact than that of the major components used together (Burt, 2004; Reichling *et al.,* 2009).

The results of FTIR analysis show that the IR spectra of chitosan showed a strong absorption band at 3433 and 3259 cm^{-1} due to OH and amine N-H symmetrical stretching vibrations (Arafat *et al.,* 2015; Wanule et al.,2014). Absorption peak at 2923 Cm^{-1} indicates the presence of CH stretch (Chen *et al.,* 2011). The absorption bond between 2360 and 2151cm^{-1} is due to stretching N=C=N in carbodiimide. FTIR analysis also shows α-chitin characteristic bands such as amide I band is split into two components at 1656 cm^{-1} and amide II band is observed at 1566 cm^{-1}. The absorption band at 1656 was due to C=O stretching (amide I) (de Queiroz Antonino *et al.,* 2017). The band observed at 1405cm^{-1} corresponds to the Asymmetric C-H group. 1322 cm^{-1} (symmetric C-H bending of CH2 group). The bands at 1156-1069 and 1028 cm^{-1} are attributed to Stretching C-O in polysaccharides. The C-H deformation of the β-glycosidic bond is centered at 894 cm^{-1} (Povea *et al.,* 2011).

The tested emulsions had a slightly lower efficacy than the conventional synthetic insecticide, Imidacloprid, in controlling *B. tabaci* on potato fields. Thyme emulsion exhibited the highest mortality rate and repellency against the *B. tabaci* followed by citronella and camphor but geranium and marjoram showed the lowest efficacy. Thyme oil has previously been reported to have a high level of suppression of *B. tabaci* populations (Li *et al.,* 2022; Kim *et al.,* 2011) The toxicity of thyme oil is due to its main components, linalool, myrcene, thymol and 1,8-cineole. At relatively high concentrations, these compounds may act as weak inhibitors of acetylcholinesterase activity against *B. tabaci* (Zarrad et al.,2017). Citronella oil demonstrated toxicity towards nymphs and a repellent effect on adults of *B. tabaci* (Saad *et al.,* 2017; Emilie et al.,2015). Citronella oil's main components were E-citral and Z-citral, which may be associated with a GABA receptor or through inhibition of AChE (Tak *et al.,* 2017). Essential oils from *C. camphora* showed high toxicity, deterrence repellency, and anti-oviposition effects against adult *B. tabaci* up to 72 h after exposure in the greenhouse environment (Wagan et al.,2022). The insecticidal effect of C. *camphora* oil at 2.0% v/v on *Trialeurodes vaporariorum*. *C. camphora* oil resulted in 49.7% egg mortality and 88.5% nymph mortality, respectively. For adults, 2.0% v/v of essential oil caused the highest mortality (40.0%) at 72 h. *C. camphora* oil resulted in lower mortality (49.4% and 40.0%) than the synthetic pesticide spiromesifen (0.05% v/v, 65.0% and 72.0%, respectively).

Conversely, this study examined a combination of chitosan and essential oils, such as thyme oil, geranium oil, citronella oil, marjoram oil, and camper oil, for their effects on *B. tabaci* in potato fields. The most effective treatment for *B. tabaci* stages (adults and nymphs) was thyme (Ch), followed by (citronella+Ch) and camphor (Ch). At the same time, (geranium+Ch) and marjoram (Ch) had lower adult and nymph reduction percentages. When all tested EOs are loaded into chitosan, they demonstrate increased effectiveness compared to when EOs are used alone. This suggests that combining EOs and chitosan enhances the properties of essential oils (Ibrahim *et al.,* 2022; Campos *et al.,* 2018). Chitosan provides a protective agent around the EOs from degradation in the field by light, heat, UV radiation and oxidation (Rajkumar *et al.,* 2020; De Oliveira *et al.,* 2018). Chitosan can improve the solubility of hydrophobic EOs in aqueous solutions, making them more readily available for controlling *B. tabaci* in potato fields (Sedlaříková *et al.,* 2019). Moreover, chitosan's derivatives with alkyl, benzyl, and alkyl groups showed good activity against insect pests due to improved solubility and enhanced activity compared to plain chitosan (Abenaim and Conti. 2023).

5. Conclusions

The study aimed to investigate the population fluctuation of *B. tabaci* in potato plants. Environmental factors (wind speed, relative humidity, and precipitation) significantly impact the population fluctuation of *B. tabaci*. In 2021, relative humidity and wind speed positively influenced nymph and adult populations, while precipitation did not. Regression data revealed that temperature and relative humidity had a positive correlation, while wind speed negatively affected *B. tabaci* populations. And develop effective control measures using bio-insecticides, specifically essential oil, and chitosan, to minimize health risks and environmental pollution. Research focused on stabilizing and durability of essential oil emulsions and improving their adherence to leaf surfaces through the incorporation of chitosan. The study sought to offer a viable alternative to chemical pesticides, thereby contributing to safer agricultural practices and reduced environmental impact. Essential oils like thyme, geranium, citronella, marjoram, and camper oil were identified and tested for their effectiveness against *B. tabaci* infestation. Thyme and citronella oils were the most effective in reducing *B. tabaci* adult populations, followed by camphor and thyme. Blending chitosan with thyme or citronella oils increased their effectiveness against *B. tabaci* adults.

References

Abbas, Q., A. Hameed, Q.A. Haider Karar, N. Muhammad, M. Hussain, U. Faheeem, T. Muhammad, A. Ahmad, M. Shahid, A. Hameed, and M. Iqbal, 2023. Seasonal abundance and population fluctuation of cotton whitefly (*Bemisia tabaci* L.) under spatio-temporal environment of South Punjab, Pakistan. JPAA, 8(1).

Abenaim, L., and B. Conti, 2023. "Chitosan as a Control Tool for Insect Pest Management: A Review." Insects 14(12):949. https://doi.org/10.3390/insects14120949

Amour, M., E.N. Wosula, L. Mrisho, C. Hoskins, D. Buss, T. Bruce, F. Stephano, and J.P. Legg, 2023. Efficacy of selected botanical oils against the cassava whitefly (*Bemisia tabaci*) and their effects on its feeding behaviour. Journal of Applied Entomology, 147(7): 473-485. https://doi.org/10.1111/jen.13128

Arafat, A., S.A. Samad, S.M. Masum, and M. Oniruzzaman, 2015. Preparation and characterization of chitosan from shrimp shell waste. International journal of scientific & engineering research, 6(5): 538-541.

Berani, N.K., and J.J. Patel, 2020. Population fluctuation of sucking insect pest of brinjal and its relationship with environmental factors. Journal of Entomology and Zoology Studies, 8(6): 1613-1617.

Bohatá, A., E.A. Folorunso, J. Lencová, L.S. Osborne, and J. Mraz, 2024. Control of sweet potato whitefly (*Bemisia tabaci*) using entomopathogenic fungi under optimal and suboptimal relative humidity conditions. Pest Management Science, 80(3): 1065-1075. https://doi.org/10.1002/ps.7837

Burt, S., 2004. Essential oils: their antibacterial properties and potential applications in foods a review. International journal of food microbiology, 94 (3): 223-253. https://doi.org/10.1016/j.ijfoodmicro.2004.03.022.

Campos, E.V., P.L. Proença, J.L. Oliveira, A.E. Pereira, L.N. de Morais Ribeiro, F.O. Fernandes, K.C. Gonçalves, R.A. Polanczyk, T. Pasquoto-Stigliani, R. Lima, and C.C. Melville, 2018. Carvacrol and linalool co-loaded in β-cyclodextrin-grafted chitosan nanoparticles as sustainable biopesticide aiming pest control. Scientific reports, 8(1): 7623. https://doi.org/10.1038/s41598-018-26043-x

Campos, E.V., P.L. Proença, J.L. Oliveira, M. Bakshi, P.C. Abhilash and L.F. Fraceto, 2019. Use of botanical insecticides for sustainable agriculture: Future perspectives. Ecological indicators, 105: (483-495). https://doi.org/10.1016/j.ecolind.2018.04.038

Chau, M.H., 2023. Evaluation of *Azospirillum brassilense* dose response on growth and yield of minitubers from apical rooted cuttings grown in coco-peat. Journal of Forestry Science and Technology, 15: 003-008. https://doi.org/10.55250/jo.vnuf.2023.15.003-008

Chen, G., J. Mi, X. Wu, C. Luo, J. Li, Y. Tang, and J. Li, 2011. Structural features and bioactivities of the chitosan. International journal of biological macromolecules, 49(4): 543-547. https://doi.org/10.1016/j.ijbiomac.2011.06.009

De Oliveira, J.L., E.V.R. Campos, A.E. L.E. Pereira, Nunes, C.C. Da Silva, T. Pasquoto, R. Lima, G. Smaniotto, R.A. Polanczyk, and L.F. Fraceto, 2018. Geraniol encapsulated in chitosan/gum arabic nanoparticles: A promising system for pest management in sustainable agriculture. Journal of agricultural and food chemistry, 66(21): 5325-5334. https://doi.org/10.1021/aCh.jafc.8b00331

de Queiroz Antonino, R.S.C.M., B.R.P. Lia Fook, V.A. de Oliveira Lima, R.Í. de Farias Rached, E.P.N. Lima, R.J. da Silva Lima, C.A. Peniche Covas, and M.V. Lia Fook, 2017. Preparation and characterization of chitosan obtained from shells of shrimp (*Litopenaeus vannamei* Boone). Marine drugs, 15(5): 141. https://doi.org/10.3390/md15050141

Edirisinghe, M., A. Ali, M. Maqbool, and P.G. Alderson, 2014. Chitosan controls postharvest anthracnose in bell pepper by activating defense-related enzymes. Journal of Food Science and Technology, 51: 4078-4083. https://doi.org/10.1007/s13197-012-0907-5

Emilie, D., M. Mallent, C. Menut, F. Chandre, and T. Martin, 2015. Behavioral response of *Bemisia tabaci* (Hemiptera: Aleyrodidae) to 20 plant extracts. Journal of economic entomology, 108(4): 1890-1901. https://doi.org/10.1093/jee/tov118

Essa, E.E., S.A. Mo'men, M.H. Rady, S.A. Ma'moun, E.M. Barakat, and M.S. Salama, 2019. Eucalyptus oil nano-emulsion encapsulated in chitosan beads as a new approach in control of *Culex pipiens* larvae. International Journal of Mosquito Research,6(5 Part A): 63-69. http://www.dipterajournal.com/pdf/2019/vol6issue5/PartA/6-5-14-241.pdf

FAOSTAT 2022. http://www.fao.org/faostat/en/#data "Production," "Crops and Livestocks," "crops primary"

Gameel, O.I., 1973. Field evaluation of insecticides for jassid, Empoasca lybica De Berg and whitefly, *Bemisia tabaci* (Genn.) control on cotton. Bull. Entomol. Soc. Egypt, Econ. Ser., 7: 113-122.

Guo, J.A. and B. Chen, 2014. Insights on the molecular mechanism for the recalcitrance of biochars: interactive effects of carbon and silicon components. Environmental Science & Technology, 48 :9103-9112. https://doi.org/10.1021/es405647e

Harshita, A.P., D. Saikia, and D. Anjumoni, 2019. Population fluctuation and management of whitefly, Bemisia tabaci in tomato ecosystem, Solanum lycopersicum L. Journal of Entomology and Zoology Studies, 7(2): 1232-1235.

Hashem, A.S., S.S. Awadalla, G.M. Zayed, F. Maggi, and G. Benelli 2018. *Pimpinella anisum* essential oil nanoemulsions against *Tribolium castaneum*-insecticidal activity and mode of action. Environ Scince Pollution Research Internathional, 25(19):18802–18812. https://doi.org/10.1007/s11356-018-2068-1

Huq, T., A. Khan, D. Brown, N. Dhayagude, Z. He, and Y. Ni, 2022. Sources, production and commercial applications of fungal chitosan: A review. Journal of Bioresources and Bioproducts, 7(2): 85-98. https://doi.org/10.1016/j.jobab.2022.01.002

Ibrahim, S.S., W.S. Abou-Elseoud, H.H. Elbehery, and M.L. Hassan, 2022. Chitosan-cellulose nanoencapsulation systems for enhancing the insecticidal activity of citronella essential oil against the cotton leafworm *Spodoptera littoralis*. Industrial Crops and Products, 184: 115089. https://doi.org/10.1016/j.indcrop.2022.115089

Keppanan, R., A. Karuppannasamy, B.C. Nagaraja, V. Thiruvengadam, S. Kesavan, Y.A. Dhawane, and A. Ramasamy, 2024. Effectiveness of chitosan nanohydrogel mediated encapsulation of EcR dsRNA against the whitefly, *Bemisia tabaci* Asia-I (Gennedius)(Hemiptera: Aleyordidae). Pesticide Biochemistry and Physiology, 198: 105712. https://doi.org/10.1016/j.pestbp.2023.105712

Kim, S.I., S.H. Chae, H.S. Youn, S.H. Yeon, and Y.J. Ahn, 2011. Contact and fumigant toxicity of plant essential oils and efficacy of spray formulations containing the oils against Band Q-biotypes of *Bemisia tabaci*. Pest Managment Scince, 67:1093–1099. https:// doi. org/ 10. 1002/ ps. 2152

Kroschel, J., N. Mujica, J. Okonya, and A. Alyokhin, 2020. Insect Pests Affecting Potatoes in Tropical, Subtropical, and Temperate Regions. In: Campos, H., Ortiz, O. (eds) The Potato Crop. Springer, Cham. https://doi.org/10.1007/978-3-030-28683-5_8.

Kumar, S., G.K. Mahapatro, D.K. Yadav, K. Tripathi, P. Koli, P. Kaushik, K. Sharma, and S. Nebapure, 2022. Essential oils as green pesticides: An overview. The Indian Journal of Agricultural Sciences, 92(11): 1298-1305.https://doi.org/10.56093/ijas.v92i11.122746

Li, S., H. Li, Q. Zhou, F. Zhang, N. Desneux, S. Wang, and L. Shi, 2022. Essential oils from two aromatic plants repel the tobacco whitefly *Bemisia tabaci*. Journal of Pest Science, 95:971–982. https://doi.org/10.1007/s10340-021-01412-0

Marabi, R.S., S.B. Das, A.K. Bhowmick, R. Pachori, and H.L. Sharma, 2017. Seasonal population fluctuation of whitefly (*Bemisia tabaci* Gennadius) in soybean. Journal of Entomology and Zoology Studies, 5(2): 169-173.

Massoud, M.A., M.M. Adel, O.A. Zaghloul, M.I.E. Mohamed, and K.H. Abdel-Rheim, 2018. Eco-friendly nano-emulsion formulation of *Mentha piperita* against stored product pest *Sitophilus oryzae*. ACHT 6(6):1–6. https://doi.org/10.4172/2329-8863.1000404

Mohareb, A.S., M.A. Elashmawy, M.E. Nawar, A.K. Abdelrahman, F.M. Ahmed, A.E. Hassona, and M.Z. Salem, 2023. Chemical compositions and antifungal activity of *Corymbia citriodora*, *Cupressus macrocarpa*, and *Syzygium cumini* extracts: GC–MS and HPLC analysis of essential oils and phenolic compounds. Biomass Conv. Bioref. 1-30. https://doi.org/10.1007/s13399-023-05106-8

Naveen, N.C., R. Chaubey, D. Kumar, K.B. Rebijith, R. Rajagopal, B. Subrahmanyam, and S. Subramanian, 2017. Insecticide resistance status in the whitefly, Bemisia tabaci genetic groups Asia-I, Asia-II-1 and Asia-II-7 on the Indian subcontinent. Scitific Report, 7: 40634 https://doi.org/10.1038/srep40634

Pathania, M., A. Verma, M. Singh, P.K. Arora, and N. Kaur, 2020. Inuence of abiotic factors on the infestation fluctuation of whitey, *Bemisia tabaci* (Gennadius 1889) in cotton and its management strategies in North-Western India. Internathional. Journal of tropical Insect Scince 40: 969–981. https://doi.org/10.1007/s42690-020-00155-2

Perera, T.M.D.R., and N. Senanayake, 2023. Management of Whiteflies (*Bemisia tabaci*. Gennadius) Using Amblyseius swirskii Athias-Henriot (Swirski-Mite) in Chilli Crop. Tropical Agricultural Research and Extension, 26(1): 74-79. https://doi.org/10.4038/tare.v26i1.5623

Perring, T.M., P.A. Stansly, T. Liu, H.A. Smith, and S.A. Andreason, 2017. Whiteflies: Biology, Ecology, and Management. Sustainable Management of Arthropod Pests of Tomato, 73-110. https://doi.org/10.1016/B978-0-12-802441-6.00004-8

Povea, M.B., W.A. Monal, J.V. Cauich-Rodríguez, A.M. Pat, N.B. Rivero, and C.P. Covas, 2011. Interpenetrated chitosan-poly (acrylic acid-co-acrylamide) hydrogels. Synthesis, characterization and sustained protein release studies. Materials Sciences and Applications, 2(06): 509. https://doi.org/10.4236/msa.2011.26069

Rajkumar, V., C. Gunasekaran, J. Dharmaraj, P. Chinnaraj, C.A. Paul, and I. Kanithachristy, 2020. Structural characterization of chitosan nanoparticle loaded with Piper nigrum essential oil for biological efficacy against the stored grain pest control. Pesticide Biochemestry and Physiology . 166: 104566. https://doi.org/10.1016/j.pestbp.2020.104566

Reichling, J., P. Schnitzler, U. Suschke, and R. Saller, 2009. Essential oils of aromatic plants with antibacterial, antifungal, antiviral, and cytotoxic properties–an overview. Forschende Komplementärmedizin/Research in Complementary Medicine, 16(2): 79-90. https://doi.org/10.1159/000207196

Saad, K.A., M.M. Roff, and A.B. Idris, 2017. Toxic, repellent, and deterrent effects of citronella essential oil on *Bemisia tabaci* (Hemiptera: Aleyrodidae) on Chili plants. Journal of Entomological Science, 52(2): 119-130.

Sedlaříková, J., M. Janalíková, O. Rudolf, J. Pavlačková, P. Egner, P. Peer, V. Varaďová, and J. Krejčí, 2019. Chitosan/thyme oil systems as affected by stabilizing agent: Physical and antimicrobial properties. Coatings, 9(3): 165. https://doi.org/10.3390/coatings9030165

Shah, M.A., K. Malik, A. Bhatnagar, S. Katare, S. Sharma, and S.K. Chakrabarti, 2019. Effect of temperature and cropping sequence on the infestation pattern of *Bemisia tabaci* in potato. Indian Journal Agriculture Science, 89(11): 1802-1807.

Sharifian, I., S. Farahani, M. Sanchooli, and F. Sarani, 2015. Comparison between the insecticidal efficacy of a novel pellet formulation and an obsolete one, Phostoxin. Journal of Entomology and Zoology studies, 3(3):7–10. https://doi.org/10.13140/RG.2.1.4122.2240

Snedecor, G.W., and W.G. Cochran, 1967. Statistical Methods. Ames, IA.,650

Stein, S.E., 2014. NIST mass spectral search program version 2.2 and NIST/EPA/NIH Mass Spectral Library. (National Institute of Standards and Technology, US Secretary of Commerce, USA). https://www.nist.gov/system/fles/documents/srd/NIST1aVer2 2Man.pdf. Accessed June 2014

Subba, B., S. Pal, T. Mandal, and S.K. Ghosh, 2017. Population fluctuation of whitefly (*Bemisia tabaci* Genn.) infesting tomato (*Lycopersicon esculentus* L.) and their sustainable management using biopesticides. Journal of Entomology and Zoology studies, 5(3): 879-883.

Sugumar, S., D. Chandrakar, G. Kanimozhi, A. Mukherjee, and N. Chandrasekaran, 2015. Eucalyptus Oil Emulsion Loaded Biodegradable Polymeric Beads as a Bio-Larvicide Agent Against *Culex Tritaeniorhynchus*. Advanced Science, Engineering and Medicine, 7(2): 134-139. https://doi.org/10.1166/asem.2015.1660

Tak, J.H., E. Jovel, and M.B. Isman, 2017. Synergistic interactions among the major constituents of lemongrass essential oil against larvae and an ovarian cell line of the cabbage looper, *Trichoplusiani*. Journal of Pest Science, 90: 735-744. https://doi.org/10.1007/s10340-016-0827-7

Vicenço, C.B., W.P. Silvestre, G.F. Pauletti, N.M. de Barros, and J. Schwambach, 2021. *Cinnamomum camphora* var. linaloolifera essential oil on pest control: Its effect on *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae). Research, Society and Development, 10(7): e45710716216-e45710716216. http://dx.doi.org/10.33448/rsd-v10i7.16216

Wagan, T.A., H. Hua, H. Bozdoğan, and M.M. Khan, 2022. Repellency, contact toxicity, and anti-oviposition effects of three ethanol-extracted plant essential oils on *Bemisia tabaci* (Hemiptera: Aleyrodidae). Physiologia Plantarum, 174(6): e13799. https://doi.org/10.1111/ppl.13799

Wanule, D., J.V. Balkhande, P.U. Ratnakar, A.N. Kulkarni, and C.S. Bhowate, 2014. Extraction and FTIR analysis of chitosan from American cockroach. International Journal of Engineering Science and Innovative Technology (IJESIT) 3(3): 299-304.

Wu, W., M. Yang, Q. Feng, K. McGrouther, H. Wang, H. Lu, and Y. Chen, 2012. Chemical characterization of rice straw-derived biochar for soil amendment. *Biomass and bioenergy* 47: 268-276. https://doi.org/10.1016/j.biombioe.2012.09.034

Zahid, N., M. Maqbool, Y. Siddiqui, S. Manickam, and A. Ali, 2015. Regulation of inducible enzymes and suppression of anthracnose using submicron chitosan dispersions. Scientia Horticulturae, 193: 381-388. https://doi.org/10.1016/j.scienta.2015.07.014

Zarrad, K., A. Laarif, H.A. Ben, I. Chaieb, and J. Mediouni-Ben Jemâa, 2017. Anticholinesterase potential of monoterpenoids on the whitefly *Bemisia tabaci* and their kinetic studies. Journal of Agriculture and Science Technology, 19: 643-652.