JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(1), 274–285
https://doi.org/10.12911/22998993/143976
ISSN 2299–8993, License CC-BY 4.0

Received: 2021.10.16
Accepted: 2021.11.15
Published: 2021.12.01

Antifeedants Impact of Plant Essential Oil on Green Peach Aphid on Potato Crops

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ABSTRACT

The antifeedant activities of different essential oils (EO) were tested against green peach aphids, and their potential role in inducing plant resistance pathways on potato cultivars was studied. Measuring the two common enzyme indicators, guaiacol Peroxidase (POX) and Polyphenol oxidase (PPO), expressed post-physical or chemical injury in plants. The impact of EO on aphid feeding behaviour was monitored using Electrical Penetration Graph (EPG) recording for 8 hrs post-treatment. The effect of the EO on aphid mortality was measured in vitro. The results showed that 60% of the essential oil extracts have insecticidal activity against *M. persicae*. The results also revealed that some EO has significantly increased the PPO level and had no significant impact of the different treatments on POX and insect behaviour than the control. Mustard, Sage, Jojoba, Eucalyptus, Bitter cucumber, Camphor, and Rosemary oil have natural induction in potato. Camphor, Sage, Pomegranate, and Bitter-cucumber caused a disturbance in the settling behavior of *M. persicae* and prolonged searching for a feeding site. Mustard, Eucalyptus, and Sage resulted in delaying drop potential associated with non-persistent and semi-persistent viruses. Lavender, Eucalyptus, and Mustard caused a delay in sieve element behavior related to persistent virus transmission.

Keywords: POX, PPO, EO, induced resistant, EPG, *M. persicae*.

INTRODUCTION

Potato, *Solanum tuberosum* L., (Solanaceae) is one of the essential primary food crops worldwide. It has been attacked by many insect pests, which causes economic losses. Green peach aphid *Myzus persicae* (Sulzer) (Homoptera: Aphididae) is the most economically important insect pest on potatoes in the West Bank. It primarily causes damage by directly feeding the plant phloem and carries over 200 viral diseases (Westwood and Stevens 2010). Therefore, it is crucial to search for alternative ways to control plant insect pests and diseases and contribute to sustainable agriculture production and food security (Chandler et al. 2011; Liao et al. 2017).

EO has been used to control various plant diseases and insect pests. EO contains antioxidants, repellents and fumigants for protection against pests (Ayvaz et al. 2010; Digilio et al. 2008). SAR and ISR have induced resistance in plants that depends on the jasmonic acid and salicylic acid signalling pathways by inhibiting the insect gut's digestive enzymes (Fu and Dong 2013; Harun-Or-Rashid and Chung 2017; Pieterse et al. 2014). The electrical penetration graph EPG is used to investigate phloem and xylem feeding insects' feeding behaviors by monitoring the stylist behavior within plant tissues (Tjallingii and Esch 1993). Different feeding behaviors show varying waveforms pathways. A non-probing aphid stylist outside the plant (np) is associated with aphid settling through the mesophyll. Pathway activities (C) are associated with navigating aphid stylet. Intercellular pathway punctures potential drop (PD), with its three sub-phases it is related to intracellular punctures associated with the non-persistent virus. Phloem-feeding (E1) is associated with sieve element salivation or persistent virus inoculation. Sieve element ingestion (E2) is associated with sieve element sap removal. G is associated with xylem ingestion and drinking. F is associated with the difficulty of penetration and the feeding dealing (Halarewicz and Gabrys 2012).

The current study aimed to determine the effect of the indigenous Palestinian medicinal EO on potato plant-induced defences (POX and PPO) and monitor the changes in aphid probing, feeding, and settling behaviour to evaluate the EO impact on aphids.

MATERIAL AND METHOD

Insect colony

GPA colony was brought to the laboratory from an infected potato plant collected from PTUK / Palestine. All stages of the aphid are maintained on the young potato plants for the laboratory trials following the methodology described by (Stobbs et al. 2015). The mature aphids were kept on plants for 24 h, resulting in neonate nymphs with an age of 0–24 h that were used throughout the experiments.

Plant culture maintenance

The potato plants were propagated in a glasshouse at PTUK and maintained under standard conditions of 25 ± 5°C, 65 ± 5% relative humidity, and a photoperiod of 16h light. Plants were fertilized weekly with irrigation water containing Nitrogen: Phosphate: Potassium (NPK) (13:13:13).

Enzyme defence of host plant assessment

The POX and PPO activities were measured spectrophotometrically using (Hach Lange DR6000 UV-VIS Spectro-photometer, Germany). The "Sponta" potato cultivar was spread with EO. After 48 hr, the plant sample was frozen at –80 °C for protein extraction, 0.3 g plant homogenized with 1.25 µL of 0.1M potassium phosphate (K_3PO_4) buffer (pH 7, containing 7% (w:v) polyvinyl-pyrrolidone (PVP). Then, 100 µL of 10% solution of Triton X-100 was added with mixing vigorously around 10 seconds (sec), centrifuged for 8000 rpm for 15 min (Hettich® MIKRO 200/200 R centrifuge, Z652121 SIGMA). Determine POX activity, 10 µL of enzyme extract was added to 2 mL disposable cuvette containing 1 mL of freshly prepared 5 mM guaiacol with 0.02 mM hydrogen peroxide (H_2O_2) dissolved in 0.1M K_3PO_4 buffer pH 8 (Aman, 2015). For the PPO assay, 10 µL of enzyme extract was added to 2 mL disposable cuvette containing 500 µL of fresh prepared 10 mM catechol dissolved in 0.1M K_3PO_4 buffer pH 8. A spectrophotometer device measured the changes in absorbance at 470 nanometers (nm) for 30 sec at room temperature. Enzyme-specific activity for both enzymes was reported as Absorbance/min/mg of fresh tissue weight (Boughton et al. 2006; Furumo and Furutani, 2008).

Electrical penetration graph EPG

GPAs were starved for an hour; then, they were attached with fine gold wire with conductive silver paint and connected to the electrode; a second electrode, constructed of thicker copper wire, was placed in the experimental soil plant. EPG was located within a faraday cage covered in silver foil to minimize interference and was run at a temperature of 24 ± 3°C. A voltage source and an 8-DC EPG amplifier with a 10^9 Ω input resistance. Eight channels were used concurrently for each adult GPA on potato seedlings sprayed with EO or water as the control. Each recording lasted for eight hours. All the signals were recorded and analyzed using the STYLET$^+$ software.

Data collection and analyses method

The data were collected using the Analysis of variance (ANOVA) test using the general linear models procedure (PROC GLM). The significance level was determined by applying the Student–Newman–Keuls test at α = 0.05. On means and the standard deviation (Std) of 5 replicates with POX and PPO test and eight replicates with the EPG test. With readings at P = 0.05. All statistical analyses were performed using Statistical Analysis System (SAS) (SAS Institute 2008). Figures and diagrams were created using the sigma plot system 11.0.

RESULT

Assessment of EO treatment on enzyme activity of host plant

EO treatment impact on PPO of potato leaves

The plant treated with some of the EO exhibited an increased significant response of PPO activity. The plants treated with Lavender and Jojoba showed the highest significant impact on PPO activity (1.27 and 1.09 OD/min/mg) compared with the control (0.13 OD/min/mg) (Figure 1), followed by Coriander, Thyme, Sesame, Bitter Cucumber, Nettle, which increased the PPO level. On the other hand, Mentha, Sage, Rosemary, Pomegranate, Camphor, Mustard and Eucalyptus had a non-significant impact on the PPO activity.

EO treatment impact on POX of potato leaves

Figure 2 showed that plants treated with EO exhibited a decreased significant response of the POX activity. Plants treated with Lavender, Coriander, Rosemary, Jojoba, Thyme, Nettle, Bitter Cucumber and Sesame showed a significant reduction in the POX activity compared with the control (Figure 2). On the other hand, Camphor, Mentha, Pomegranate, Sage, Mustard and Eucalyptus had a non-significant increase in the POX activity.

Electrical penetration graph (EPG)

The first time Aphids waveforms

Table 2 illustrates the delayed behavior of GPA during the first two hours of EPG recordings. C waveform reported no significant impact on the plants treated with all EO than control. Although Pomegranate, Jojoba. Bitter Cucumber, Sage, Sesame, and Rosemary delayed the first start of the pathway behaviour compared with control but was not significantly different. Camphor, Sage, Rosemary, Jojoba, Pomegranate, Coriander, and Mentha recorded the most prolonged delay (NP) in GPA settling behavior compared with the control. In E1 and E2, there was a non-significant delay between the plants treated with EO and control. Bitter cucumber, Mustard, Eucalyptus, Camphor, and Mentha prevented GPA sieve element behavior for E1 and E2. A non-significant impact of Jojoba, Rosemary, Thyme, Mentha, Sage on delaying G waveform compared with control. However, Bitter-cucumber, Mustard, Eucalyptus, Camphor, and Lavender prevented GPA xylem

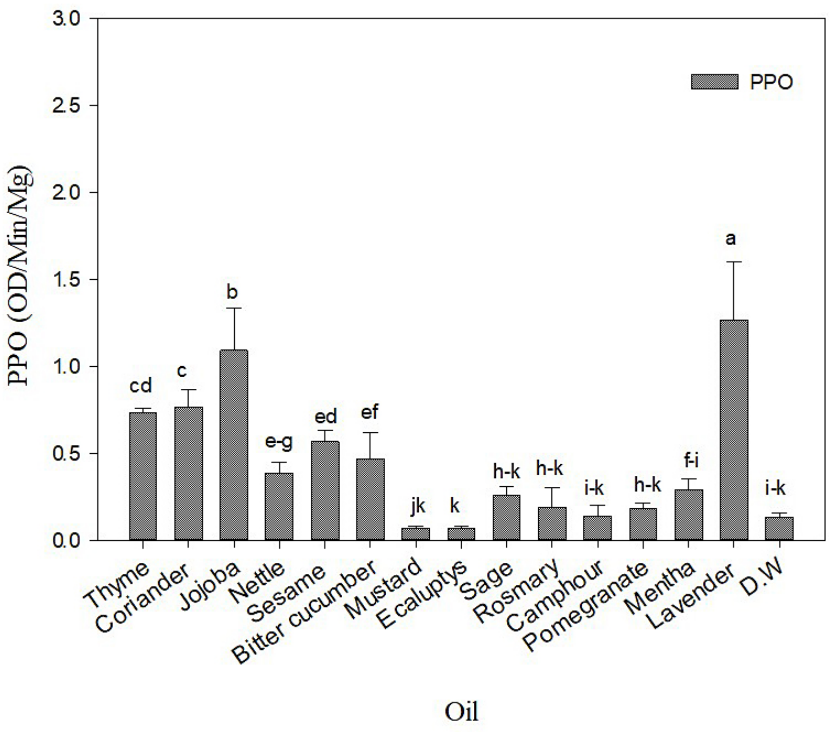

Figure 1. PPO activity measured in (OD/min/mg) in a potato plant post different EO treatments, results represented mean and Std of 5 replicates. The bar with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05)

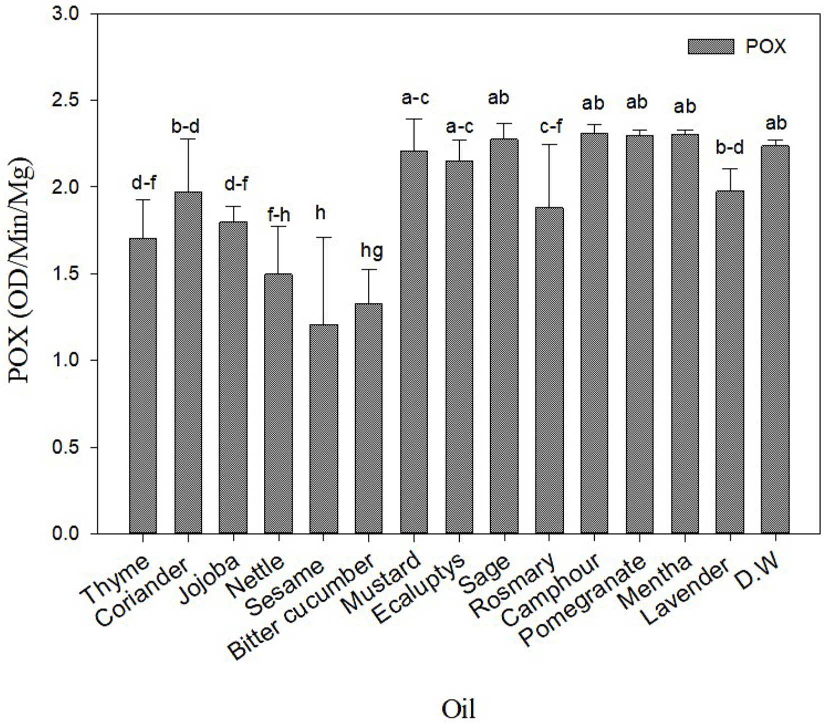

Figure 2. POX activity measured in (OD/min/mg) in a potato plant post different EO treatments, results represented mean and Std of 5 replicates. The bar with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05)

feeding behavior. The EO treatments showed a non-significant impact compared with control on GPA penetration difficulty and the feeding dealing (F). At the same time, EOs treatments have a significant effect on PD. Mustard oil recorded the highest reading compared with the control, followed by Lavender, Pomegranate, Nettle, Jojoba, Sesame, and Sage.

Table 1. List of essential oils used in the study

English name	Scientific name	Family
Thyme	*Thymus vulgaris*	Lamiaceae
Coriander	*Coriandrum sativum*	Apiaceae
Jojoba	*Simmondsia chinensis*	Simmondsiaceae
Nettle	*Urtica dioica*	Urticaceae
Sesame	*Sesamum indicum*	Pedaliaceae
Bitter-cucumber	*Colocynthis citrullus.*	Cucurbitaceae
Mustard	*Sinapis arvensis*	Brassicaceae
Eucalyptus	*Eucalyptus* globulus	Myrtaceae
Sage	*Salvia officinalis*	Lamiaceae
Rosemary	*Rosmarinus officinalis*	Lamiaceae
Camphor	*Cinnamomum camphora*	Lauraceae
Pomegranate	*Punica granatum*	*Lythraceae*
Mentha	*Mentha spicata*	Lamiaceae
Lavender	*Lavandula spica*	Lamiaceae

The second time of Aphid waveforms

Table 3 illustrates GPA second-time behavior during the first two-hour EPG recordings. Pathway waveform (C) reported a non-significant impact on the plants treated with all EO than the control. Although Sage, Bitter cucumber, Sesame, Rosemary, Mustard, Jojoba, Pomegranate, Mentha, Nettle, Lavender, Thyme, Camphor delayed the C behavior compared with control but was not significantly different. NP waveforms of Bitter-Cucumber, Mentha, Pomegranate, and Lavender recorded the most extended delay in GPA settling behavior than the control. Jojoba had the highest decreasing significant reading of 8 sec than the control; moreover, Thyme, Coriander, Nettle, Sesame, Mustard, Eucalyptus, Sage, Rosemary, and Camphor did not show any results. There was a significant delay between the plants treated with EO and control. In turn, in E1 and E2, the EO treatments had no difference compared with control. Bitter cucumber, Mustard, Eucalyptus, Rosemary, Camphor, Pomegranate, Menthe, and Lavender prevented GPA sieve element behavior for E1 and E2. G waveform recorded a non-significant increment impact of Bitter Cucumber, Nettle, Mentha, and Sage compared with control. However, Thyme, Jojoba, Mustard, Eucalyptus,

Table 2. Electrical Penetration Graph recordings the first time of GPA behavior waveform on potato seedlings post EO treatment. The results represent the mean and Std of 8 replicates during the first 2 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of 1st time of 2 h							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	103.2±43.9a*	227.4±75.5 a	2419.5±915.7 a	2446.5±894.4 a	2239.6±1878.2 a	2598.5±516.8 a	384.6±154.1b
Coriander	152.0±150.0 a	247.5±231.9 a	2024.0±0.0 a	4384.0±3602.0 a	1408.2±314.6 a	1143.5±952.4 a	308.2±220.1 b
Jojoba	203.5±255.5 a	633.3±430.3 a	–	1763.0±0.0 a	944.7±308.1 a	2736.0±0.0 a	658.6±394.7 b
Nettle	72.0±0.0 a	336.7±161.8 a	2125.0±0.0 a	–	2463.7±1010.2 a	830.0±83.4 a	925.2±948.9 b
Sesame	91.5±84.1 a	536.6±203.7 a	5606.0±0.0 a	3161.0±0.0 a	996.2±269.1 a	1021.0±186.6 a	611.2±136.4 b
Bitter-cucumber	85.4±84.6 a	579.2±293.8 a	–	–	959.6±145.1 a	649.0±0.0 a	546.0±324.0 b
Mustard	151.0±225.2 a	295.5±405.1 a	–	–	2724.8±10638.0 a	–	2830.0±1501.6 a
Eucalyptus	83.3±95.4 a	104.0±43.8 a	–	–	2410.0±2447.8 a	–	257.0±1690.0 b
Sage	393.0±0.0 a	577.5±231.4 a	3075.5±682.3 a	2562.0±0.0 a	2603.3±1352.3 a	2095.0±906.5 a	600.5±284.6 b
Rosemary	259.6±19.6 a	520.0±290.7 a	–	7200.0±0.0 a	1249.7±347.2 a	2671.0±0.0 a	536.7±288.7 b
Camphor	426.0±0.0 a	315.6±304.4 a	–	–	651.8±259.6 a	–	306.6±313.8 b
Pomegranate	188.6±192.3 a	729.3±162.0 a	3705.0±1360.4 a	–	2021.8±2383.7 a	–	1236.1±737.2 b
Mentha	111.0±78.0 a	300.6±239.1 a	–	–	1279.4±494.8 a	2096.5±712.0 a	179.0±230.6 b
Lavender	143.4±38.7 a	318.2±77.4 a	–	–	588.2±179.7 a	–	1315.0±1512.0 b
D.W	144.6±68.7 a	429.5±299.4 a	2966.5±901.5 a	7200.0±0.0 a	735.8±257.9 a	1699.4±1499.4 a	537.5±472.9 b

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Table 3. Electrical Penetration Graph recordings the second time of GPA behavior waveform on potato seedlings post EO treatment. The results represent the mean and Std of 8 replicates during the first 2 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of 2ed time of 2 h							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	0.0±0.0a*	435.8±205.6a	3496.0±0.0ba	2887.0±0.0	2438.0±1707.6a	–	477.7±240.3b
Coriander	0.0±0.0 a	271.0±260.2a	471.0±170.8b	3671.0±0.0	3140.3±2444.2a	448.7±179.6 a	90.0±0.0b
Jojoba	8.0±0.0 a	630.0±40.9 a	–	2209.0±0.0	1578.8±230.7 a	–	821.5±457.0b
Nettle	0.0±0.0 a	507.7±169.5a	1977.0±0.0ba	–	2105.7±1304.8	3100.0±0.0 a	449.6±145.7b
Sesame	0.0±0.0 a	655.0±326. a	5859.0±0.0a	7200.0±0.0	1529.0±670.1 a	908.0±0.0 a	869.0±385.6b
Bitter-cucumber	3000.5±3250.6a	660.7±250.9	–	–	1474.5±1102.5a	5290.0±0.0 a	1209.0±1280.0ba
Mustard	0.0±0.0 a	633.0±0.0 a	–	–	2997.0±1326.5a	–	2917.0±1485.8a
Eucalyptus	0.0±0.0 a	263.0±165.5a	–	–	1866.5±1290.7a	–	2917.0±1485.0a
Sage	0.0±0.0 a	690.3±174.5a	5539.5±1270.7a	6629.0±0.0	2568.8±1566.9a	1740.0±0.0 a	1471.4±1180.4ba
Rosemary	0.0±0.0 a	648.0±272.4a	–	–	2539.3±2168.4a	–	549.6±287.1b
Camphor	0.0±0.0 a	340.3±102.2a	–	–	644.2±261.0 a	1411.0±0.0 a	360.3±285.7b
Pomegranate	794.0±0.0 a	552.3±127.1a	–	–	1953.3±1048.9a	–	2002.7±846.1ba
Mentha	2490±2106 .8 a	508.2±208.6 a	–	–	1494.2±672.4 a	1995.3±395.1a	538.0±164.6b
Lavender	491.0±0.0 a	454.8±79.4 a	–	–	829.0±349.3 a	–	1323.4±1256.1ba
D.W	383.0±365.6 a	327.8±130.3a	4027.0±0.0ba	–	916.8±268.1 a	1534.7±1587.5a	589.0±468.8b

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Rosemary, Pomegranate, and Lavender prevented GPA xylem feeding behavior. EO treatments showed a non-significant impact compared with control on GPA penetration difficulty and the feeding dealing (F). Mustard, Coriander, Sage, Rosemary, Thyme, Nettle, Pomegranate, Eucalyptus, Jojoba, Sesame, Mentha, and Bitter Cucumber. EO treatments have a significant impact on PD. Mustard and Eucalyptus oils recorded the highest reading compared with the control, followed by Pomegranate, Sage, Lavender, Bitter cucumber, Sesame, and Jojoba.

The third time of Aphids waveforms

GPA third-time behavior during the first two-hour EPG recordings was shown in Table 4. C waveform reported no significant impact on the plants treated with all EOs, compared with the control. Although Eucalyptus, Sage, Jojoba, Pomegranate, Sesame, Mustard, Bitter Cucumber, Rosemary, Mentha, Lavender, Nettle, and Thyme prolong the C behaviour compared with the control, In turn, the Coriander and Camphor's readings had no significant effect compared to the controls. NP waveforms, Bitter Cucumber, Lavender, and Pomegranate, recorded the most prolonged delay in settling behavior, compared with the control. Moreover, the Thyme, Coriander, Jojoba, Nettle, Sesame, Mustard, Eucalyptus, Sage, Rosemary, Camphor, Mentha, and Lavender oil did not record any non-settling behavior for the third time, compared with the water control. E1 and E2 recorded for the third time, showed a non-significant delay between the plants treated with EO and control. In G waveform, no significant impact of Mentha, Sage, Sesame was found, compared with the control. At the same time, the rest of the EO did not record any xylem ingestion and drinking behavior for the third time during the first 2 hr recordings. F waveform, Mustard had a maximum deyled time for the third time visit compared with control followed by Bitter Cucumber, Rosemary, Sage, Pomegranate, Thyme, Coriander, Jojoba, and Eucalyptus. Lavender and Camphor and Mentha reading were lower than the control. The electrical penetration graph record showed that the EO treatments significantly impacted PD during the first two hours. Mustard oil showed the highest reading compared with the control reading, followed by Pomegranate, Sage, Lavender, Eucalyptus, Bitter cucumber, Sesame, and Jojoba.

The duration of Aphid waveforms on the first two-hour recording

The duration time spent by aphid on the C waveform reported no significant impact on the plants treated with all EO, compared with the control (Table 5). Although Thyme, Coriander, Sesame, nettle, Rosemary, Sage, and Jojoba prolong the C behavior compared with the control. NP duration time also showed no significant differences from the control. Similar results were recorded for E1 and E2 duration time. However, Bitter cucumber, Mustard, Eucalyptus, Camphor, Mentha, and Lavender, prevented GPA sieve element behavior for E1 and E2 during the first 2 hr recording. G duration time showed a non-significant impact of most of the EO, compared with the control. There was also a non-significant impact of F duration time compared with the control. The EO treatments have a non-significant effect on the duration time on PD. Lavender oil recorded the longest time compared with the control followed by Mentha, Rosemary, Camphor, Bitter Cucumber, Coriander, Mustard, Sesame, Jojoba, Pomegranate, Nettle, and Sage.

The frequency of occurrence of Aphids waveforms on the first two-hour recording

The frequency of occurrence of C waveform had a significant impact on the plants treated with all EO, compared with control (Table 6). In turn, the frequency of occurrence in NP waveforms showed no significant difference between all EO and control. E1 and E2 waveforms showed significant occurrences between different plants treated with EO and the control. In the G waveform, a non-significant impact of EO, compared with the control. The EO treatments showed a non-significant impact compared with the control on the frequency of occurrence of the F waveforms. A similar effect was recorded in the number of occurrences for PD waveforms during the first 2 hr of recordings.

Duration of Aphids waveforms on eight-hour recording

Table 7 illustrates the duration of aphid behavior during eight-hour EPG recordings. Duration of the C waveform reported no significant impact on the plants treated with all EO than control. As for the duration of NP waveforms, Nettle, Mustard, Rosemary, Mentha, and Bitter Cucumber recorded the most extended delay in GPA

Table 4. Electrical Penetration Graph (EPG) recordings the third time of GPA behaviors waveform on potato seedlings post EO treatment, the results represent the mean and Std of 8 replicates during the first 2 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of 3^{ed} time of 2 hr							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	–	512.8±246.4a*	–	–	2943.3±1724.1a	–	624.3±231.0b
Coriander	–	464.8±262.4a	7187±0	–	2745.0±1305.0a	–	556.3±200.5b
Jojoba	–	698.5±20.5 a	–	2258±0	2482.3±1048.5a	–	1051.7±540.5ba
Nettle	–	549.1±159.5a	–	–	2205.4±1405.3a	–	514.6±135.7b
Sesame	–	678.5±317.5a	6021±0	–	2006.5±939.1 a	1653.0±0.0 a	1099.5±497.3ba
Bitter-cucumber	5558.0±0.0a	605.0±19.8 a	–	–	3232.6±2431.4a	–	1274.4±1417.6ba
Mustard	–	659.0±0.0 a	–	–	3839.6±688.7 a	–	3151.0±1543.2a
Eucalyptus	–	887.0±121.6a	–	–	2124.5±1418.5a	–	1359.8±1702.5ba
Sage	–	780.5±153.0 a	–	–	3139.5±2242.0a	2211.0±0.0 a	1564.2±1256.6ba
Rosemary	–	592.5±365.6a	–	–	3150.0±3513.1a	–	575.0±391.0b
Camphor	–	384.0±87.8 a	–	–	961.8±583.7 a	–	647.0±754.7b
Pomegranate	1278.0±0.0 a	683.3±165.4 a	–	–	3105.5±1806.4 a	–	2852.3±1656.0a
Mentha	–	574.0±89.5 a	–	–	679.3±123.1 a	3384.0±0.0 a	524.0±128.0b
Lavender	1409.0±0.0 a	550.7±172.8a	–	–	1041.8±222.3 a	–	1437.2±1216.1ba
D.W	540.0±616.6a	503.0±270.7a	4679±0	–	2006.8±2121.2a	2547.5±1501.2	686.4±488.8b

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Table 5. Electrical Penetration Graph (EPG) recordings the duration of GPA behavior waveform on potato seedlings post EO treatment, the results represented the mean and Std of 8 replicates during the first 2 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of the Duration of 2 h							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	83.0±65.9a*	2667.2±316.5 a	232.0±348.3 a	42.0±30.0 a	4088.4±326.0ba	5.0±0.0 a	36.4±4.3 a
Coriander	168.3±189.4a	2260.0±975.2 a	102.0±28.0 a	1632.0±2296.7a	3712.5±2313.8b	12.0±0.0 a	75.0±97.5 a
Jojoba	147.4±77.9 a	1061.4±929.9 a	–	31.00±0.0 a	5836.8±875.8ba	–	67.6±66.2 a
Nettle	9.5±3.5 a	1429.0±1218.5a	115.7±81.0 a	–	5486.9±1272.2ba	5.7±1.5 a	49.7±46.5 a
Sesame	91.5±84.1 a	1905.2±1302.3a	306.3±457.8 a	1545.0±485.1 a	5034.7±2327.4ba	22.7±17.6a	68.3±64.2 a
Bitter-cucumber	94.8±86.0 a	477.0±639.8 a	–	–	6611.2±688.1ba	16.0±0.0 a	80.3±78.9 a
Mustard	151.0±225.3a	72.0±89.1 a	–	–	7018.5±136.3ba	–	71.4±35.6 a
Eucalyptus	83.3±95.5 a	221.0±206.5 a	–	–	7019.3±196.8a	–	33.5±17.5 a
Sage	195.0±0.0 a	1384.6±1988.3a	121.0±0.0 a	245.0±0.0 a	5557.8±2307.3a	48.0±0.0 a	47.0±32.2 a
Rosemary	166.6±128.2a	1419.3±1278.1a	–	147.0 ±0.0 a	5494.0±1362.8ba	4.0±0.0 a	97.8±87.3 a
Camphor	0.0±0.0 a	684.5±780.3 a	–	–	6316.2±1312.6ba	11.0±0.0 a	88.2±128.3a
Pomegranate	223.0±176.0	931.6±1148.8a	47.0±27.0 a	–	6040.3±908.4ba	–	50.0±33.0 a
Mentha	146.7±39.2 a	759.5±689.3 a	–	–	6088.3±707.7ba	15.0±11.6 a	162.2±80.3 a
Lavender	291.8±329.6	428.0±412.9 a	–	–	6346.5±745.4ba	–	139.0±106. a
D.W	270.9±168.2	1037.8±1241.5a	824.0±1108.7a	4855.0±0.0 a	5478.1±2350.1ba	23.2±16.0 a	37.8±30.3 a

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Table 6. Electrical Penetration Graph (EPG) recordings the frequency of GPA behavior waveform on potato seedlings post EO treatment, the results represented the mean and Std of 8 replicates during the first 2 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of the frequency of occurrence of 2 hr							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	1.0±0.0a*	68.8±29.9a	1.3±0.6a	1.3±0.6b	15.2±8.0b	1.0±0.0a	62. 5±20.5a
Coriander	1.2±0.4a	63.6±14.5ba	3.0±0.0a	2.0±0.0b	15.8±6.8b	1.0±0.0a	53.8±21.2ba
Jojoba	1.0±0.0a	31.2±26.5bac	–	8.0±0.0a	24.0±24.1b	1.0±0.0a	41.0±21.6ba
Nettle	1.0±0.0a	27.7±20.2bac	2.7±0.6a	–	27.1±30.1b	1.3±0.6a	45.7±24.9ba
Sesame	1.0±0.0a	33.6±33.6bac	1.3±1.5a	3.0±1.4b	23.1±15.0b	4.0±5.2a	35.3±16.1ba
Bitter-cucumber	1.7±1.2a	13.4±4.9bac	–	–	16.6±12.3b	2.0±0.0a	22.4±11.8b
Mustard	1.0±0.0a	4.0±24.5bac	–	–	19.7±14.4b	–	20.3±14.8b
Eucalyptus	1.0±0.0a	39.0±15.7c	–	–	17.6±12.9b	–	19.3±12.6b
Sage	1.0±0.0a	6.5±22.8bac	2.0±0.0a	2.0±0.0b	17.6±9.1b	4.7±3.2a	41.3±21.6ba
Rosemary	1.0±0.0a	25.5±23.9bac	–	1.0±0.0b	9.8±6.2b	1.0±0.0a	25.8±20.7ba
Camphor	1.0±0.0a	14.3±27.5bc	–	–	22.4±11.5b	2.0±0.0a	33.7±21.1ba
Pomegranate	1.4±0.9a	17.6±32.5bc	1.0±0.0a	–	24.3±28.4b	–	39.9±28.3bab
Mentha	1.6±0.8a	29.4±22.9bc	–	–	29.9±12.3b	2.4±1.7a	47.6±13.5ba
Lavender	2.0±2.2a	18.0±18.5bac	–	–	59.3±9.9a	–	54.8±12.6ba
D.W	2.6±2.9a	15.3±22.1bc	2.5±2.1a	1.0±0.0b	23.6±20.2b	3.0±1.4a	35.6±26.0ba

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Table 7. Electrical Penetration Graph (EPG) recordings the duration of GPA behavior waveform on potato seedlings post EO treatment, the results represented the mean and Std of 8 replicates during the first 8 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of the Duration of 8 hr							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	108.4±39.7a*	5439.3±4433.7ba	1569.7±1280.5a	2553.0±4310.2a	15759.2±9018.1ba	9.4±5.2b	490.0±210.3a
Coriander	205.0±215.4a	11065.4±4930.0a	1046.7±924.4a	9166.0±0.0a	11535.0±3488.5b	8.5±4.9b	766.0±361.6a
Jojoba	136.5±74.6a	7727.5±5713.5ba	428.5±277.9a	3036.0±0.0a	18792.7±7444.4ba	8.8±2.2b	569.0±451.2a
Nettle	6268.3±7336.4a	3566.3±1578.2ba	330.2±473.3a	10057.2±11233.8a	16723.5±7135.1ba	6.0±1.4b	348.0±156.0a
Sesame	351.7±207.9a	5287.2±4466.5ba	1133.5±692.1a	14821.0±8302.8a	18581.3±10855.8ba	37.8±9.9b	627.6±210.0a
Bitter-cucumber	2340.5±7781.3a	1829.7±1196.9ba	638.0±553.2a	5033.0±5933.9a	17993.3±7842.2ba	16.0±0.0b	314.9±185.0a
Mustard	5508.1±4472.8a	9306.8±13063.9ba	–	–	24474.6±5979.1ba	–	446.6±450.0a
Eucalyptus	120.5±99.7a	1315.3±1076.0ba	–	–	27789.7±1215.9a	–	470.3±335.5a
Sage	244.0±69.3a	8390.6±9208.9ba	2825.0±3902.4a	4573.0±5706.4a	19694.1±8617.5ba	30.0±28.8b	546.6±304.2a
Rosemary	3392.5±4605.8a	2956.8±2229.1ba	273.5±296.3a	13458.0±5676.0a	19646.0±7595.5ba	14.0±14.1b	340.8±244.0a
Camphor	824.0±562.9a	798.1±1059.1b	137.0±0.0a	–	27415.7±1290.4a	11.0±0.0b	329.9±167.7a
Pomegranate	500.8±578.5a	2592.3±3469.5ba	152.0±41.0a	13458.5±18535.0a	25098.7±3397.0ba	323.0±0.0a	484.1±357.8a
Mentha	2929.7±4873.5a	2073.0±1890.2ba	81.0±77.8a	10364.3±8941.0a	18873.6±8460.4ba	29.3±7.6b	444.3±250.2a
Lavender	676.6±1203.6a	366.3±431.4b	–	–	27103.0±1743.2a	–	727.6±271.6a
D.W	2196.4±3330.7a	3380.6±4476.0ba	2362.6±3030.8a	6891.8±7840.0a	20201.0±10273.3ba	23.2±16.0b	476.5±299.8a

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

Table 8. Electrical Penetration Graph (EPG) recordings the frequency of GPA behavior waveform on potato seedlings post EO treatment, the results represented the mean and Std of 8 replicates during the first 8 h recording. A column with different lower case letters indicated a significant difference (ANOVA PROC GLM, Student–Newman–Keuls test, P= 0.05). (NP, C, E1, E2, F, G and DP)

EPG variables of the frequency of occurrence of 8 hr							
Treated (EO)	NP	C	E1	E2	F	G	DP
	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD	Mean ± StD
Thyme	1.0±0.0a*	145.3±79.6b	9.7±8.0a	6.5±2.1b	44.7±12.9b	1.6±1.3b	136.7±60.2a
Coriander	3.4±2.2a	223.2±109.6a	7.3±5.9a	3.0±3.4b	40.2±10.9b	1.5±0.0b	195.4±88.0a
Jojoba	1.2±0.4a	102.0±83.1cb	2.0±0.0a	3.7±2.1b	70.2±89.7b	1.0±0.6b	135.5±111.5a
Nettle	2.6±1.5a	45.4±43.6cb	2.8±1.9a	3.8±1.9b	42.6±25.4b	1.3±0.5b	84.3±38.0a
Sesame	2.5±2.1a	83.7±68.7cb	5.8±4.0a	5.0±4.0b	91.3±64.1b	5.3±4.3b	133.7±45.3a
Bitter-cucumber	3.1±2.2a	45.5±28.9cb	2.5±2.4a	3.3±2.3b	46.4±40.3b	2.0±0.0b	69.6±42.0a
Mustard	1.5±0.9a	40.3±53.1cb	–	–	76.9±75.1b	–	96.0±98.6a
Eucalyptus	1.0±0.0a	17.8±18.1c	–	–	82.4±68.9b	–	99.7±73.4a
Sage	1.0±0.0a	97.9±76.2cb	4.5±2.4a	3.0±4.0b	53.0±20.0b	5.7±4.5b	115.3±61.1a
Rosemary	3.8±2.5a	56.5±44.8cb	4.5±3.5a	4.3±2.4b	41.0±39.3b	1.0±0.0b	74.7±55.7a
Camphor	1.0±0.0a	20.0±25.9c	1.0±0.0a	–	51.9±33.5b	2.0±0.0b	66.6±32.7a
Pomegranate	7.3±15.3a	27.9±21.0cb	1.3±0.0a	22.0±29.7ab	89.4±83.9b	68.0±0.0a	108.0±77.8a
Mentha	3.0±1.2a	50.4±42.5cb	1.0±0.6a	1.5±1.0b	66.4±40.1b	2.4±1.7b	108.0±52.6a
Lavender	3.0±3.9a	6.8±6.0c	–	–	191.4±54.7a	–	188.6±78.6a
D.W	7.1±11.0a	69.8±98.8cb	4.2±3.3a	1.5±1.0b	66.3±79.8b	3.0±1.4b	112.9±77.2a

* Within a column, means followed by the same letter are not significantly different (P > 0.05) using 'Duncan's multiple range test.

settling behavior compared with control. In E1 and E2 duration time, a non-significant delay was found between the plants treated with EO and the control. Mustard, Eucalyptus, and Lavender prevented GPA sieve element behavior for both E1 and E2. In G waveform, a significant impact on the total duration time of Pomegranate was found, compared with the control. However, Mustard, Eucalyptus, and Lavender prevented GPA xylem feeding behaviour. EO treatments showed a non-significant impact of the duration time, compared with the control on GPA penetration difficulty and the feeding dealing (F). The EO treatments have no significant impact on the duration time of the PD waveform.

Frequency of occurrence of Aphids waveforms on eight-hour recording

Table 8 illustrates the frequency of occurrence during the eight-hour EPG recordings. C waveform showed no significant impact of frequency of occurrence on the plants treated with most EO compared with control. However,Coriander recorded a significantly higher number of occurrences during the C behavior than the controls. NP, E1 and E2 waveforms recorded no difference between the number of occurrences to all EO compared with control. G waveform, indicated a significant impact of the number of occurrence of Pomegranate, compared with the control. Lavender treatments showed significantly higher occurrences than control on the GPA penetration difficulty and the feeding dealing (F). The EO treatments have a non-significant impact on the number of occurrences of PD.

DISCUSSION

Plant essential oils are a mixture of volatile plant secondary metabolites that interfere with herbivore physiology, metabolite, and behavior. Some EOs are toxic to insects; others may interfere with oviposition, development and reproduction (Powell 1992; Sintim et al. 201) and interfere with the insect nervous system (Shapiro 2012). EOs have many antimicrobial, insecticidal, repellant and anti-feeding activities against many insect pests and diseases (Hamouda et al. 2014; Hori 1999). Thus, essential oils are considered a nontoxic and safer alternative to chemical control without harming non-target orgasms (Kordali et al. 2007; Shapiro 2012).

The plant-induced resistance against herbivores involves chemical signals or physiological response structures draw more attention in pest control programs (Schaller 2008). The PPO and POX activity levels have been used to measure plant adaption to biotic and abiotic stress and induced response against stimuli (Thipyapong et al. 2004). The current studies showed that the PPO level increased while the POX level decreased post EO application compared with the control; similar results were reported by Bakkali et al. (2008). This could be due to phenols, alcohol and aldehydes substances that are considered antioxidants (Fattouch et al. 2010)

GPA total penetration duration time was reduced while the frequency of penetration increased by Mustard, Eucalyptus, Bitter-cucumber, Lavender Jojoba, and Mentha treatments. Increased aphid number of penetration occurrence and reduction in the penetration duration time indicate unstably and failure of the feeding process. During EPG recordings, GPA settling and feeding behavior were significantly affected by EO treatments. Bitter cucumber and Lavender recorded the most prolonged delay in settling behavior and potential delay in transferring any form of a virus. GPA pathway of a plant treated with Pomegranate, Sage, Eucalyptus and Bitter cucumber recorded the most prolonged delay in GPA settling behavior.

Previous studies reported that Pomegranate oil has a toxic and anti-feeding impact on the red flour beetle (*Tribolium castaneum*) (Hamouda et al. 2014), delayed larval and pupal development and a significant reduction in insect population (Gandhi et al. 2010). Sage is well-known to have antioxidant, antimicrobial and antiviral properties (Birmpa et al. 2018). In the meantime, Sage oil was also reported to exhibit insecticidal activities against *T. castaneum* (Khiyari et al. 2014) and *Drosophila melanogaster* and *Bactrocera oleae* (Pavlidou et al. 2004).

On the other hand, Eucalyptus repellent activities affected the reproductive and settling behavior of psyllid *Ctenarytaina eucalypti* (Brennan et al. 2001) and *Bactrocera* zonata (Ilyas et al. 2017). During PD recording associated with non-persistent and semi-persistent virus transmission, Camphor, Jojoba, Sage Bitter cucumber, and Mentha recorded the most extended delay in PD settling behavior, thus delaying any potential transfer non-persistent and or semi-persistent viruses. Sieve element salivation (E1) and sieve element sap removal (E2) records associated with persistent virus inoculation were delayed in the plants treated with Sesame, Sage, Rosemary, Coriander and Jojoba. The chemical composition of Sage, Camphor and Jojoba consist mainly of camphor, limonene, caryophyllene, eugenol, and carvacrol. In contrast, the chemical composition of Thyme is Terpinene, Carvacrol, Thymol; and for Mint are Menthol, Menthone. All these chemicals were reported to have insecticidal properties against insect pests (Hori 1999). Such as camphor, which is toxic and insect repellant (Obeng-Ofori et al. 1998), carvacrol is an Acetylcholinesterase inhibition (Anderson and Coats 2012), terpinene, carvacrol, thymol all are endocrine disruptors (Kumar et al. 2011), menthol, and menthone are neurotoxic to several insects (Pavela 2007).

Sesame oil could affect the aphid feeding behavior through secondary metabolites and allelochemicals (Sintim et al. 2012). Mustard created stylet puncture in all living cells related to virus ingestion, inoculation, and acquisition. The first-time activities showed that Sage, Jojoba, and Mustard have a good result for the most prolonged delay in aphid settling behavior and potential viral transmission. Hori (1999) reported that thyme, sage, rosemary and mint inhibited the GPA settling behavior and reduced duration of stylet penetration time and penetration frequency.

Xylem feeding (G) has the most extended delay on Jojoba, Mentha and Sage. In contrast, the difficulty of penetrating plant by aphid and the feeding delaying (F) was recorded on Mustard and Sage. It was found that Mustard and Eucalyptus created stylet puncture in all living cells that course virus ingestion, inoculation, and acquisition. Eucalyptus has a low stylet puncture of non-persistent virus and plant damage during the first two-hour, duration and frequency. At the same time, duration and frequency during the eight-hour showed that Bitter cucumber, Camphor, Nettle, and Rosemary, have a low stylet puncture of non-persistent virus and plant damage. Mint, Thyme, Lavender showed anti-feeding and repellant impact, while rosemary showed the repellant impact (Hori 1999). It was found that mineral oil could control aphids and virus transmission (Singh 1981). The plant mineral oil inhibited aphid virus inoculation and acquisition (Boquel et al. 2013; Pollard 1973; Powell 1992;), either by removing the virus particle from aphid stylet or preventing them from being inoculated to the plant.

This study investigated the role of medicinal plant oils in inducing the potato resistance systems against aphid pests to alternate aphid chemical control with insecticides. The new findings will open a wide door to EO as an environmentally friendly method against aphids. It suggested using high numbers of oil types to confirm the ability of EOs to induce plant resistance. Such EOs could interfere with the settling and feeding behavior of sap-feeding insects, such as aphids. Delaying in the first encounters to plant tissues would enhance the loss of non-persistent virus found in aphid mouthpart before being injected in healthy plant tissue. Prolonging the searching behavior and preventing aphids from reaching phloem tissues would also enhance the elimination of the semi-persistent and persistent viruses injected by viruliferous aphids.

Acknowledgements

The authors acknowledge Palestine Technical University –Kadoorie for their project funding and financial support. Special thanks go to Palsame® essential oils Company for providing essential oil samples for this study.

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