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Common oils and insecticidal control and their resistance to *Aleuroclava jasmini* (Hem.: Aleyrodidae) on paper mulberry in Iran

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ABSTRACT

Aleuroclava jasmini (Hemiptera: Aleyrodidae) is a major insect pest of paper mulberry (*Broussonetia papyrifera*) in Iran, negatively affecting its production. Considering the importance of oils in the integrated management programs of such pests, the present study examined the possibility of whitefly control on paper mulberry plant to assess mortality rate (MR), synergistic rate (SR), resistance rate (RR), and lethal concentration for 50% of the population (LC_{50}) of oils and common insecticide in populations from four areas of Tehran, Iran (one susceptible and three non-susceptible). The best chemical treatments against *A. jasmini* adults and nymphs in paper mulberry plants were neem oil (1 ml L^{-1}) mixed with deltamethrin (0.5 ml L^{-1}) or with buprofezin (1 ml L^{-1}). The neem, akylarylpolyglyglycol ether and volk oils mixed with deltamethrin or buprofezin also had synergistic effects on adults and nymphs of *A. jasmini,* respectively, in Azadi, Shahrake Gharb, and Vanak areas (non-susceptible populations), but with higher concentrations ($>$ LC_{50}) and lower SR than in Garm Dareh area (susceptible population). We observed that *A. jasmini* adults showed the greatest resistance to deltamethrin in Vanak area and nymphs of this pest to buprofezin in Shahrake Gharb area.

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1. Introduction

Paper mulberry *Broussonetia papyrifera* (L.) Vent., belonging to the Moraceae family, is common in public green spaces of Tehran city, Iran. Since the late 2010s, paper mulberry production has been threatened by a major insect pest, *Aleuroclava jasmini* (Takahashi) (Homoptera: Aleyrodidae) (Bagheri et al. 2012; Javadi Khederi et al. 2019). This pest infests the undersides of leaves where the feeding of adults and nymphs excrete honeydew, which leads the growth of sooty mold fungi, and this affects the process of the plant physiology. In addition, they remove a large amount of leaf phloem sap, causing chlorosis on infested leaves, decreases respiration and photosynthesis of infested paper mulberry plants, resulting in decreased fruit yield and reduced fruit quality through reduction of glucose and citric acid (Rasekh 2010; Bagheri et al. 2012; Javadi Khederi et al. 2019). Sometimes, infestation with *A. jasmini* induced a downgrading of mulberry crops up to 90% (Rasekh 2010; Bagheri et al. 2012). It has now become common in Tehran and spread to all main paper mulberry growing regions where it causes significant problems of the respiratory system for citizen (Javadi Khederi et al. 2019).

Biological control has been successful for a range of whitefly species (van Lenteren et al. 1996; van Den Berg et al. 2000; Liotta et al. 2003; Goolsby et al. 2005) and classical bio-control has been identified as a long-term control strategy for whiteflies. However, effective insecticidal control combined with cultural practices, i.e. pruning for an open canopy, is currently the only control options available (Hosseininia et al. 2017). As in many other agricultural areas in the world, control of this pest in Iran has been heavily dependent on repeated applications of chemical insecticides (Javadi Khederi et al. 2019). However, chemicals applications have not been fully effective because of the presence of waxy shelters excreted by the whiteflies which resist against chemicals penetration and prevent contact with the whitefly's immobile nymphal and pupal stages (James 2003). Moreover, the high reproductive potential of this pest along with short life cycle on the one hand, and frequent use of synthetic

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pesticides on the other hand, result in rapid resistance to pesticides in the whitefly population (Khalaf et al. 2010). Extensive reliance on chemical insecticides for different whitefly species control has resulted in their resistance to almost all major classes of conventional insecticides and insect growth regulators throughout the world (Wardlow et al. 1972, 1975, 1976; Zou and Zheng 1988; Omer et al. 1992; Palumbo et al. 2001; Horowitz et al. 2007). As a result, the efficacy of the pesticides has reduced and the cost of chemical control continues to increase. In addition, environmental pollution and food contamination disrupted natural biological control systems, and the resurgence of this insect pest by pesticides is another scenario which needs serious concern and attention (Horowitz et al. 2007).

Thus, it is important to search the innovative methods for control of this pest, with the lowest risks and compatibility with the environment such as oils application. Essential and mineral oils have been widely investigated because they are deemed as a potential alternative to replace synthetic pesticides and because they have become more convenient to use (Hosseininia et al. 2017; Javadi Khederi et al. 2019). Therefore, the present study was an attempt to examine the possibility of whitefly control on paper mulberry plant to assess mortality rate (MR), synergistic rate (SR), resistance rate (RR) and lethal concentration for 50% of the population (LC_{50}) of oils and common insecticides on different whitefly populations.

2. Material and methods

2.1. Plant and insects

Paper mulberry seedlings obtained from National Ornamental Plant Institute (Mahallt, Iran) and they were cropped in 2.6-L pots filled with a mixture of sand: peat moss (1.3:1 by volume) in a greenhouse located at the experimental site of National Ornamental Plant Institute. Plants used in the experiments were at the three to five leaves stage. At the time of planting, 5 g of Osmocote® fertilizer (14 N–14P–14K) was applied to each pot. Plants were watered every 2 d. During the experiment, in the greenhouse, the temperature ranged from 16.6 ± 3.5 °C to 32.4 ± 4.1 °C, and the mean relative air humidity was 70.6 ± 15.5%.

Aleuroclava jasmini nymph-infested leaves were collected from paper mulberry plants cropped in different locations in Tehran in 2016 (including Vanak 35° 46′ 42.7″ N, 51° 24′ 37.8″ E 1,525 m asl, Azadi 35° 41′ 59.3″ N, 51° 20′ 16.4″ E 1,183 m asl, Shahrake Gharb 35° 45′ 21.4″ N, 51° 21′ 43.8″ E 1,441 m asl and Garm Dareh 35° 45′ 28.4″ N, 51° 4′ 1.06″ E 1,287 m asl) (Figure 1). For rearing, the leaves bearing nymphs and puparia were brought to the laboratory and were placed with paper mulberry plants in insect rearing cages at 24 ± 1 °C under a 16:8 h L: D period. The paper mulberry plants were raised free of insects under greenhouse conditions. Whitefly adults that had emerged from the field-collected leaves and settled on the paper mulberry plants were used in the bioassays.

2.2. Field experiment

2.2.1. Experimental plots

One-year-old seedlings were planted (in May 2016) in a commercial paper mulberry field on four-row beds. The assay was arranged in a randomized complete block design with 20 treatments, 3 blocks and 3 replicates. Insecticides and their rates (as shown in Table 1) were selected from the data presented by Hosseininia et al. (2017) for *Trialeurodes vaporariorum* Westwood (Hemiptera: Aleyrodidae). All the solutions which were already tested were diluted in distilled water. Plot size was 3-m long × 1.3-m wide with a 1-m buffering area between the plots. There were about 10 plants in each plot which was infested via approximately 4000 *A. jasmini* puparia collected from Garm Dareh, Alborz, Iran. This population did not receive any pesticide compound for a long time (susceptible population). After 14 days from the infestation with puparia, the number of living whiteflies (both nymphs and adults) on each selected plant was assessed. The plots were then separated by plastic, and compounds were distributed with an electrostatic atomizer backpack sprayer (1 L/plant).

2.2.2. Whitefly sampling

The sampling procedure of *A. jasmini* adults and immatures was started 1 week after applying all the insecticides. A total of 10 older middle leaves were randomly excised from the plants in each plot. These leaves were placed into carton zip-lock bags and transported in a cooler to the laboratory for counting the immature ones through a stereo dissecting microscope. From the same plant, 10 leaves – the youngest and fully-expanded – were selected for counting the adults. Adult whiteflies, collected with an engine-powered vacuum (Bi et al. 2001), were transferred to the laboratory and the adults were counted under a microscope. The number of live whiteflies (nymphs and adults) on each plant was assessed before spraying.

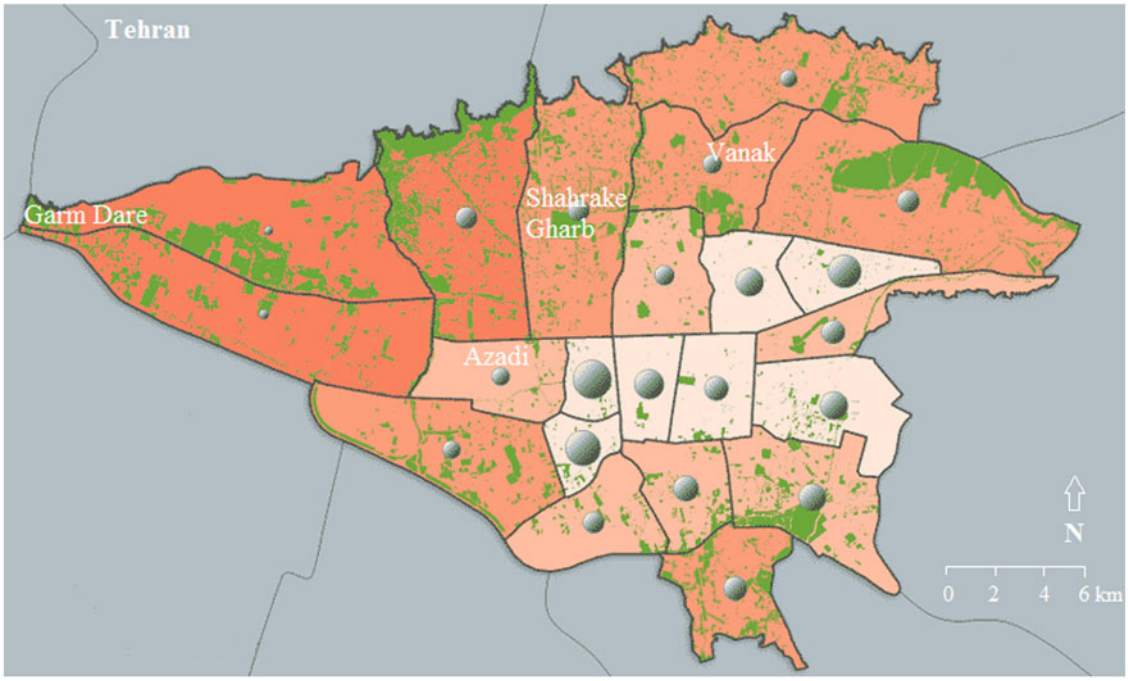

Figure 1. The map shows the locations of different areas of Tehran, Iran that the populations were collected. The map was created by using the R statistical program version 2.15.2.3.

Table 1. Insecticides tested in the field experiments.

Treatments *N.*	Active ingredient	Brand name	Concentration (ml L^{-1})
T1	Volk oil	Volk®	0.5
T2	Volk oil		1.0
T3	Volk oil + deltamethrin		0.5 + 0.5
T4	Super oil	Oral®	0.5
T5	Super oil + deltamethrin		0.5 + 0.5
T6	Akylarylpolyglyglycol ether	Citowett®	0.25
T7	Akylarylpolyglyglycol ether		0.5
T8	Akylarylpolyglyglycol ether + deltamethrin		0.25 + 0.5
T9	Akylarylpolyglyglycol ether + deltamethrin		0.5 + 0.5
T10	Neem oil	NeemAzal-T/S®	0.25
T11	Neem oil		0.5
T12	Neem oil		1.0
T13	Neem oil + deltamethrin		0.25 + 0.5
T14	Neem oil + deltamethrin		0.5 + 0.5
T15	Neem oil + deltamethrin		1.0 + 0.5
T16	Deltamethrin	Decis®	0.5
T17	Buprofezin	Applaud®	1.0
T18	Pyridaben	Sanmite®	0.5
T19	Spiromesifen	Oberon®	0.5
T20	Control, water		

2.3. Nymph and adult bioassay

Paper mulberry plants (40 cm high, 3 to 5 nodes) grown in the greenhouse were used. Leaf-dip bioassay protocols suggested by Cahill et al. (1996) and Nauen and Konanz (2005) with slight modifications were adopted. For immature bioassay whiteflies, a total of 40 *A. jasmini* female adults were confined in a clip cage (2 cm diameter, 1 cm high) on the lower side of fully-expanded leaves. Leaves were selected to allow easy attachment of clip cages and to count nymphal instars. After 24 hours from oviposition, females were removed. Then, the infested plants were kept under controlled condition (22–25 °C and 70–75% RH) for eggs hatching and nymph development.

When the second instar of nymph was predominant (10–12 days old), the first and third instars of nymph were removed with a camel's hair brush and 30 nymphs of the 30 second instar were counted. The infested leaves were dipped for 10 s in 5 serial aqueous dilutions of the tested compounds (Table 2). Five replicates were performed for each dilution and insecticide treatment. The treated leaves were placed on polyethylene cup (45-mm diameter, 95 mm high) and covered with a wire sieve (45-mm diameter). Plants were maintained 1 h at room temperature to allow leaves to be air-dried and transferred to the greenhouse. The mortality was recorded 10–12 day after the treatment when adults started emerging from the pupae. If the nymphs were clear or yellow as well as they looked

Table 2. Five serial dilutions of different compounds (ppm) for nymphs (N_2) and adults of *A. jasmine* leaf-dip bioassay.

Nymphs (N_2)						
Neem oil	Akylarylpolyglyglycol ether	Volk oil	Buprofezin	Neem + buprofezin	Akylarylpolyglyglycol ether + buprofezin	Volk + buprofezin
251	59	251	251	107	100	175
468	1174	501	468	214	200	341
871	513	1000	871	427	398	682
1622	1514	1995	1622	851	794	1383
3000	4460	4000	3000	1710	1580	1750
Adults						
Neem oil	Akylarylpolyglyglycol ether	Volk oil	Deltamethrin	Neem + deltamethrin	Akylarylpolyglyglycol ether + deltamethrin	Volk + deltamethrin
251	98	251	251	174	96	180
468	407	501	468	345	191	351
871	1698	1000	871	962	380	703
1622	7080	1995	1622	1380	795	1381
3000	29360	4000	3000	2740	1500	2760

moist and turgid, they were regarded as alive. The applied concentrations were selected according to Robertson and Preisler (1992) bioassay. Commercial formulations of neem oil 99% (NeemAzal-T/S®), akylarylpolyglyglycol ether 100% (Citowett®), volk oil 90% (Volk®), buprofezin 40% (Applaud®), neem + buprofezin, akylarylpolyglyglycol ether + buprofezin and volk oil + buprofezin were tested. For *A. jasmini* adult bioassay, non-infested leaves and recently fully-expanded leaves were dipped (10 s) in 5 serial dilutions of the tested solutions prepared with deionized water (Table 2).

After the leaves' surfaces were dried, each treated leaf was placed on the polyethylene cup and covered with a wire sieve. Then, a total of 30 adults (2–4 days old) were aspirated into a pipette tip and gently released into the cup over the wire sieve (Cahill et al. 1996; Nauen and konanz 2005). Each treatment was replicated five times. Adult mortality was assessed 24 h after initial exposure. If appendages of the insects did not move when prodded with a fine camel's hair brush, they were considered dead.

Adulthood bioassays were conducted with NeemAzal-T/S®, Citowett®, Volk®), Decis® (deltamethrin 2.5%), neem + deltamethrin, akylarylpolyglyglycol ether + deltamethrin, and volk oil + deltamethrin.

2.4. Statistical analysis

For analysis of variance, data were log-transformed using the formula log (y + 1). LSD test in a one-way randomized complete block design of ANOVA by means of SAS (2004) was run on the data collected from field experiment. A standard probit analysis (SPSS 2004) was used to estimate the slopes and the LC_{50} for nymph and adult bioassay in the laboratory and each population of *A. jasmini* tested. Synergistic rate (SR) was calculated according to $SR = (LC_{50}A + LC_{50}B)/LC_{50}$ (A + B). The effects were considered antagonistic ($SR < 0.7$), additive ($0.7 < SR > 1.8$) and synergistic ($SR > 1.8$). Resistance rate (RR) was estimated as RR = [(LC_{50} each population)/(LC_{50} base population)], and classified as RR = 1.0 which indicates no significant difference from the susceptible population, and RR > 1 which shows higher resistance to insecticide (Robertson et al. 2007; Naveen et al. 2017). The data for creating the base map of Tehran Province, Iran was obtained from the Global Administrative Areas (GADM) database (Version 2.9, http://www.gadm.org/). The map was created by using the R statistical program version 2.15.2.3 (R Core Team 2012).

3. Results

When the 9 substances (oils, insecticides, and water) were assayed in different concentrations and combinations (20 treatments), significant differences were observed in toxicity to *A. jasmini* adults and nymphs in field experiments on the susceptible population of *A. jasmini* collected from Garm Dareh area (Table 3). The highest rate of adults mortality (≈80%) was recorded in the treatments T8, T9, T13,

Table 3. Percentage of the mortality rate of different treatments on adults and nymphs (N_2-N_4) of *A. jasmini* collected from Garm Dareh area and used in field experiments.[a,b]

Treatments *N.*	Adult	Nymphs (N_2-N_4)
T1	42.17 ± 1.17^{hi}	55.04 ± 1.51^{i}
T2	47.07 ± 1.79^{gh}	58.05 ± 0.62^{hi}
T3	66.24 ± 0.90^{de}	60.30 ± 1.42^{ghi}
T4	46.28 ± 1.25^{ghi}	68.09 ± 1.43^{ef}
T5	73.28 ± 2.64^{cd}	70.28 ± 1.40^{def}
T6	36.29 ± 0.92^{i}	57.31 ± 0.86^{i}
T7	45.14 ± 3.01^{ghi}	71.14 ± 1.16^{cde}
T8	81.08 ± 1.50^{abc}	67.18 ± 1.74^{efg}
T9	84.31 ± 2.58^{a}	73.27 ± 1.39^{cde}
T10	43.24 ± 1.37^{ghi}	60.30 ± 1.74^{ghi}
T11	52.21 ± 0.77^{fg}	60.23 ± 1.18^{fgh}
T12	58.25 ± 1.95^{ef}	68.21 ± 1.34^{ef}
T13	78.00 ± 2.08^{abc}	75.18 ± 1.00^{cd}
T14	79.24 ± 2.13^{abc}	78.02 ± 1.02^{bc}
T15	84.04 ± 1.19^{ab}	83.26 ± 0.90^{ab}
T16	74.15 ± 1.86^{bcd}	70.04 ± 1.19^{def}
T17	75.05 ± 2.54^{abcd}	85.17 ± 1.17^{a}
T18	75.21 ± 1.61^{abcd}	77.23 ± 1.39^{bc}
T19	59.23 ± 2.51^{ef}	73.22 ± 1.61^{cde}
T20	7.30 ± 1.23^{j}	9.04 ± 0.98^{j}

[a]Values represent the means of untransformed data (9 replicates) ± standard error.
[b]Means with same letters within each column do not vary significantly ($P < 0.05$, LSD test).

T14, T15, T17 and T18, whereas the other treatments induced adult mortality ranging from 42.17 to 75.21% ($F_{19,\ 38} = 32.12$; $P = 0.0001$; c.v. = 7.33). In case of nymph treatments, T15 and T17 were the most efficient ($F_{19,\ 38} = 30.25$; $p = 0.0001$; c.v. = 8.09). Mortality in water-treated controls (T20) was below 7.30 and 9.04 for adults and nymphs, respectively.

Mixed of deltamethrin with oils (neem, akylarylpolyglyglycol ether and volk) showed LC_{50} on *A. jasmini* adults of 192.28 ppm (SR = 6.39), 154.70 ppm (SR = 8.39), and 289.32 ppm (SR = 5.99), respectively, while buprofezin mixed with the same oils were 121.28 ppm (SR = 6.70), 107.12 ppm (SR = 6.46), and 286.53 ppm (SR = 4.96) on *A. jasmini* nymphs (N_2-N4) from Garm Dareh area (susceptible population), respectively (Table 4). LC_{50}, SR, and RR data on *A. jasmini* adults and nymphs collected from Azadi, Shahrake Gharb and Vanak areas (non-susceptible populations) are shown in Table 5. Responses varied according to tested substances and collection areas. In Azadi area, deltamethrin mixed with oils (neem, akylarylpolyglyglycol ether and volk) showed LC_{50} on *A. jasmini* adults as 523.36, 383.70 and 764.26 ppm, respectively. In addition, SR of neem, akylarylpolyglyglycol ether and volk oils for adult mortality were observed as 3.13, 4.50 and 2.67, respectively. On the other hand, the results indicated no RR for these three oils (≈1.04), while it was very low for deltamethrin (2.05). The buprofezin mixed with akylarylpolyglyglycol ether showed the highest SR (6.71), and SR was recorded as 4.79 and 3.11 for neem and volk oils, respectively on *A. jasmini* nymphs. LC_{50} of buprofezin mixed with neem, akylarylpolyglyglycol ether and volk oils were recorded as 224.48, 189.39 and 543.43 ppm on nymphs, respectively, for the *A. jasmini* population collected in Azadi area. However, we noted no RR for these oils (≈ 1.02) and buprofezin (1.63) for nymphs of this pest. Mixed of deltamethrin with neem, akylarylpolyglyglycol ether and volk oils showed LC_{50} and SR on *A. jasmini* adults as 420.80 ppm (SR = 3.80), 293.07 ppm (SR = 6.68), and 629.81 ppm (SR = 3.23), respectively. But buprofezin mixed with the same oils were 902.77 ppm (SR = 3.08), 709.03 ppm (SR = 4.29), and 1453.73 ppm (SR = 2.38) on *A. jasmini* nymphs from Shahrake Gharb area, respectively.

On the other hand, we observed no RR for neem, akylarylpolyglyglycol ether, and volk oils on adults (≈1.20) and nymphs (≈1.09), and very low RR for deltamethrin (2.05) and buprofezin (6.38) on adults and nymphs collected in this area. In Vanak area, deltamethrin mixed with oils (neem, akylarylpolyglyglycol ether or volk) showed LC_{50} on *A. jasmini* adults as 1844.01, 892.97 and 2112.30 ppm, respectively. Also, the SR effect of neem, akylarylpolyglyglycol ether and volk oils on deltamethrin for adult mortality were estimated as 2.20, 4.75 and 2.13, respectively. No RR was observed for these three oils (≈1.21) while it was low for deltamethrin (8.83). The buprofezin mixed with akylarylpolyglyglycol ether showed the highest SR (5.27). In addition, SR was recorded as 3.19 and 2.74 for neem and volk oils, respectively on *A. jasmini* nymphs. LC_{50} of buprofezin mixed with neem, akylarylpolyglyglycol ether or volk oils were recorded as 339.20, 270.92 and 696.51 ppm on nymphs, respectively in the Vanak area. However, no RR was observed for these oils (≈1.17) and buprofezin (1.80) for nymphs of this whitefly (Table 5).

4. Discussion

Since the late 2010s, *A. jasmini* is considered a major insect pest in paper mulberry in Iran, affecting its production, up to 90%, due to sooty mold problems in the backyard and commercial mulberry. We observed a positive effect of oils on some insecticides, but low resistance of *A. jasmini* populations.

The best chemical treatments to *A. jasmini* adults and nymphs in paper mulberry seedlings were neem oils (1 ml L^{-1}) mixed with deltamethrin (0.5 ml L^{-1})

Table 4. Lethal concentration (ppm) that kill 50% of the population (LC_{50}) and synergistic rate (SR) of different compounds on *A. jasmini* adult and nymph (N_2) collected from Garm Dareh area (base population, susceptible population).

	Adult		Nymph (N_2)	
Compounds	LC_{50}	SR[a]	LC_{50}	SR
Neem oil	886.57	–	452.23	–
Akylarylpolyglyglycol ether	961.70	–	652.08	–
Volk oil	1396.14	–	1059.41	–
Buprofezin	Non tested	–	370.08	–
Deltamethrin	336.05	–	Non tested	–
Neem + deltamethrin	192.28	6.36	Non tested	–
Akylarylpolyglyglycol ether + deltamethrin	154.70	8.39	Non tested	–
Volk + deltamethrin	289.32	5.99	Non tested	–
Neem + buprofezin	Non tested	–	121.28	6.70
Akylarylpolyglyglycol ether + buprofezin	Non tested	–	107.12	6.46
Volk + buprofezin	Non tested	–	286.53	4.96

[a]SR < 0.7 Antagonistic, SR = 0.7–1.8 Additive, SR > 1.8 Synergistic.

Table 5. Lethal concentration (ppm) that kill 50% of the population (LC_{50}), synergistic rate (SR) and resistance rate (RR) of different compounds on *A. jasmini* adult and nymph (N_2) collected from Azadi, Shahrake Gharb, and Vanak areas.

	Adult			Nymph (N_2)		
Compounds	LC_{50}	SR[a]	RR[b]	LC_{50}	SR	RR
Azadi area						
Neem oil	949.95	–	1.07	483.65	–	1.07
Akylarylpolyglyglycol ether	1036.89	–	1.08	680.01	–	0.96
Volk oil	1350.03	–	0.97	1099.19	–	1.04
Buprofezin	Non tested	–	–	591.19	–	1.63
Deltamethrin	690.16	–	2.05	Non tested	–	–
Neem + deltamethrin	523.36	3.13	–	Non tested	–	–
Akylarylpolyglyglycol ether + deltamethrin	383.70	4.50	–	Non tested	–	–
Volk + deltamethrin	764.26	2.67	–	Non tested	–	–
Neem + buprofezin	Non tested	–	–	224.48	4.79	–
Akylarylpolyglyglycol ether + buprofezin	Non tested	–	–	189.39	6.71	–
Volk + buprofezin	Non tested	–	–	543.43	3.11	–
Shahrake Gharb area						
Neem oil	1019.83	–	1.15	478.70	–	1.06
Akylarylpolyglyglycol ether	1377.73	–	1.43	733.80	–	1.12
Volk oil	1455.85	–	1.04	1158.33	–	1.09
Buprofezin	Non tested	–	–	2306.65	–	6.38
Deltamethrin	579.48		1.72	Non tested	–	–
Neem + deltamethrin	420.80	3.80	–	Non tested	–	–
Akylarylpolyglyglycol ether + deltamethrin	293.07	6.68	–	Non tested	–	–
Volk + deltamethrin	629.81	3.23	–	Non tested	–	–
Neem + buprofezin	Non tested	–	–	902.77	3.08	–
Akylarylpolyglyglycol ether + buprofezin	Non tested	–	–	709.03	4.29	–
Volk + buprofezin	Non tested	–	–	1453.73	2.38	–
Vanak area						
Neem oil	1085.35	–	1.22	519.15	–	1.14
Akylarylpolyglyglycol ether	1273.25	–	1.32	775.13	–	1.19
Volk oil	1535.55	–	1.10	1257.36	–	1.19
Buprofezin	Non tested	–	–	651.49	–	1.8
Deltamethrin	2967.79	–	8.83	Non tested	–	–
Neem + deltamethrin	1844.01	2.20	–	Non tested	–	–
Akylarylpolyglyglycol ether + deltamethrin	892.97	4.75	–	Non tested	–	–
Volk + deltamethrin	2112.30	2.13	–	Non tested	–	–
Neem + buprofezin	Non tested	–	–	339.20	3.19	–
Akylarylpolyglyglycol ether + buprofezin	Non tested	–	–	270.92	5.27	–
Volk + buprofezin	Non tested	–	–	696.51	2.74	–

[a]SR < 0.7 Antagonistic, SR = 0.7–1.8 Additive, SR >1.8 Synergistic.
[b]RR = 1.0 indicates no significant difference from the susceptible population, and RR > 1 = higher resistance to insecticide.

or with buprofezin (1 ml L^{-1}), respectively in Garm Dareh (MR > 80%) and other three areas of Iran (non-susceptible population). The neem oil, tested against *Bemisia tabaci* (Gennadius) biotype B nymph on *Phaseolus vulgaris* L., was less effective than synthetic insecticides, but represents the best alternative when considering its fast degradation in the environment, low human toxicity, and probability of selecting resistant individuals due to the presence of different compounds with insecticide properties (Pinheiro et al. 2009). In addition, Javadi Khederi et al. (2019) reported that fewer adult females alighting on neem oil, *Azadirachta indica* A. Juss (Meliaceae) treated paper mulberry plants in comparison to the control. Also, they observed that exposing *A. jasmini* adult to neem oil significantly reduced the number of laid eggs. They believed that repellent effects are the main cause for this reduction. The neem-based insecticides, which have azadirachtin as their major component, may be a suitable alternative for pest management in sericulture. When neem-based insecticides enter the body of the larva, the activity of ecdysone is suppressed, the larva fails to moult, and consequently remain in the larval stage until death time (Singh et al. 2005). However, neem products must be ingested to be effective and may not kill the pest instantaneously, but incapacitate in a number of ways (Singh et al. 2005). The whitefly nymph will die only in pupal stage or its adult will be 100% malformed and sterile when Azadirachtin is in sub-concentration (Singh et al. 2005).

The deltamethrin (neurotoxic compound), with or without synergists, has been used to control the whitefly of various species such as *B. tabaci* in some crops (i.e. cotton) (Horowitz et al. 2011).

Synergized pyrethroids are efficacious primarily through contact activity, thus proper spray coverage and deposition on leaf surfaces are of high importance. These insecticides reduce oviposition via adult mortality and the establishment of nymph populations on leaves (Palumbo et al. 2001). The pirimiphos-methl plus deltamethrin (1:10 mixture) showed a higher synergistic effect in the control of *B. tabaci* in Egypt (Diab 2012). On the other hand, buprofezin – insect growth regulator (chitin synthesis inhibitor) – has been used successfully in the control of whitefly nymphs, principally in cotton crops

in North America and Israel (Palumbo et al. 2001). This compound acts specifically on immature developmental stages resulting in nymphal mortality (e.g. 2nd instar nymphs) during ecdysis. The buprofezin has different modes of action of the deltamethrin, desirable biological and environmental profiles, and it is considered as an important component in IPM programs for controlling whiteflies in several crops (Horowitz et al. 2011).

Mixed of neem, akylarylpolyglyglycol ether and volk oils with deltamethrin or buprofezin also had synergistic effects on adults and nymphs of *A. jasmini*, respectively, in Azadi, Shahrake Gharb, and Vanak areas (non-susceptible populations), but with higher concentrations ($> LC_{50}$) and lower SR than in Garm Dareh area (susceptible population). From among these three oils, akylarylpolyglyglycol ether mixed with the organosynthetic insecticides showed the most reduction in ppm ($< LC_{50}$) and the highest SR, whereas volk had the worst performance. The LC_{50} values of akylarylpolyglyglycol ether for *T. vaporariorum* adult, egg and nymph stages were estimated to be 2.58, 1.31 and 0.25 ml L^{-1}, respectively, showing a better result than pirimicarb alone for those developmental stages (0.08, 2.55, and 0.98 g/l, respectively) (Naveh et al. 2010). The LC_{50} of pirimicarb and citowett, for *Myzus persicae* Sulzer (Hemiptera: Aphididae) adults, were 0.04 g/l and 0.14 ml L^{-1}, respectively, and the mixture of this compounds (both with Lc_{25} values) resulted in the mortality rate of 68.92% in this aphid adults, and 65.18, 65.55 and 66.85% on adults, eggs, and nymphs of *T. vaporariorum*, respectively (Naveh et al. 2010). The application of the mixture of citowett oil (0.339 ml L^{-1}) and pirimicarb (0.372 g L^{-1}) could be recommended for simultaneous control of *T. vaporariorum* and *M. persicae* because this oil has a cheap price, compatibility with the environment, and synergistic effect with pirimicarb (greater than pirimicarb alone in LC_{50}) (Naveh et al. 2010). The citowett oil showed LC_{50} of 1554.00, 884.79 and 684.70 ppm and pyriproxyfen of 1086.00, 45.04 and 11.47 ppm whilein mixture (both Lc_{25}), they showed 52.36, 62.32 and 69.19% mortality rate to adult, egg, and immature stages of *B. tabaci*, respectively, demonstrating that citowett oil is able to enhance efficiency of pyriproxyfen (Ashtari et al. 2012). Natural products (e.g. *A. indica* and mineral oils) have antifeedant, insecticidal, and repellent effects, and neem may also act as growth regulators and fertility suppressors of whiteflies (Acosta et al. 2006; Cavalcante et al. 2006).

Aleuroclava jasmini adults and nymphs showed the greatest resistance to deltamethrin (Vanak area) and buprofezin (Shahrake Gharb area), but they were both classified as low resistant. High resistance (RR $\approx$ 74) to deltamethrin has been reported in the *B. tabaci* populations in some areas in India (Naveen et al. 2017). The intensive use of these compounds in some production systems has reduced the susceptibility of *B. tabaci*. Insecticide resistance management strategies based on the structured and restricted use of these new modes of action and coupled with the use of cultural and biological pest management tactics provide the best model for combating insecticide resistance in *B. tabaci* (Palumbo et al. 2001; Horowitz et al. 2011). Resistance to buprofezin (in field condition) has developed at a much slower rate because its use is restricted to a single treatment per season (e.g. Israel and the United States) (Palumbo et al. 2001). *Bemisia tabaci* populations resistance to neonicotinoids which has been used for more than 10 years exhibited fluctuations in China open fields, but a continual increase in protected areas and resistance variance reflects the change in intensity of insecticide utilization (Yao et al. 2017). Pyrethroid and organophosphate resistances have been declined due to using new insecticides and were not detected for abamectin from 2005 to 2014. This powerfulness against *B. tabaci* shows that application reduction contributes to some extent to the decline in resistance and indicates the importance of rational rotation in insecticide resistance management (Yao et al. 2017). Aside from the lethal effect, the sublethal concentration of imidacloprid and bifenthrin impairs the *B. tabaci* feeding, and this antifeedant property would give these insecticides potential to control this pest indirectly, increasing their toxicity persistence in the treated crops (He et al. 2013). The neem can be a good alternative in the insecticide rotation due to its fast degradation, low human toxicity and probability of selecting resistant individuals, despite its slower effect on *B. tabaci* nymphs than the synthetic agrochemicals (Singh et al. 2005; Pinheiro et al. 2009).

To avoid selecting whiteflies individual resistance to insecticides and to maintain their populations under control or with as little chemical intervention as possible, it is necessary to implement integrated pest management (IPM). IPM has several tactics and they are important when they are used together. Chemical control with selective insecticides, rotation of insecticide mechanisms actions, biological control, crop plant resistance and physical/mechanical methods are some examples of tactics inside of the IPM (Horowitz et al. 2011).

In conclusion, the best chemical treatments against *A. jasmini* in paper mulberry plants were neem oil mixed with deltamethrin (for adults) and with buprofezin (for nymphs). The oils mixed with deltamethrin or buprofezin showed synergistic

effects on adults and nymphs of *A. jasmini* control, respectively, reducing LC_{50}, while akylarylpolyglyglycol ether indicated the higher SR mixed with the studied organosynthetic insecticides. In Vanak area, *A. jasmini* adults showed the greatest resistance to deltamethrin, and in Shahrake Gharb area, the nymphs of this pest to buprofezin. Therefore, the oils can find a place in integrated pest management programs of this pest, especially where the emphasis is placed on food and environmental safety and on replacing the more dangerous and toxic pesticides. Hence, it may lead to new and more effective strategies to prevent and control of *A. jasmini* whitefly in paper mulberry green space of Tehran, Iran. Although the single leaf greenhouse bioassays provided valuable life stage tolerance information, it was an artificial environment and therefore the information has limited application. The effects of insecticides should be evaluated in experiments that replicate natural conditions as closely as possible for a true evaluation of efficacy, and trials should be carried out over an extended period to monitor their full effects and residual activity.

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