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Effectiveness of two mineral powders on *Agonoscena pistaciae* Burckhardt and Lauterer, (Hemiptera: Psyllidae) population

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Abstract. The pistachio psylla, *Agonoscena pistaciae* Burckhardt & Lauterer (Hem.: Psyllidae), is the most important pest of pistachio orchards in Iran. It causes quantitative and qualitative reduction of the product. Different concentrations, 4 (+dimethicone) and 8 per thousand of silica, and 4 (+dimethicone), 6 (+dimethicone), and 8 per thousand of diatomaceous earth (DE) were sprayed on the whole canopy to evaluate its effectiveness on different life stages of *A. pistaciae* in the field. Sampling was carried out at 3, 8, 13-, 18-, 21-, and 28-days post-treatment. The results showed that DE8 had a decreasing effect on eggs, nymphs, and adults with a 96.4%, 80.2-93.7%, and 86.6% effectiveness. It was most effective on the eggs of *A. pistaciae*. Including dimethicone in some treatments increased the effectiveness of treatments in the density reduction of pests, but it needs further studies. Therefore, the use of DE may be an effective strategy in the integrated management of *A. pistaciae*.

Keywords: *Agonoscena pistaciae,* mineral powders, diatomaceous earth, silica, control, pistachio.

The pistachio psylla, *Agonoscena pistaciae* Burckhardt & Lauterer (Hem.: Psyllidae), is the most important and economical pest in pistachio orchards globally (Hassani et al. 2009a, b), as it significantly reduces, directly or indirectly, the quantity and quality of the pistachio nuts production. Due to its high reproductive capacity and several generations, it reproduces one or more times annually and therefore has a very large population, damaging trees and crops (Mehrnejad 2002, Shayegan et al. 2003, Mehrnejad and Copland 2006).

Management of the pistachio psylla depends primarily on chemical control (up to 6 applications); various insecticides have been used to control this pest (Mehrnejad 1993, Afshari 2000, Basirat 2003, Alizadeh et al. 2007, Sarnevesht et al. 2012, Kabiri & Amiri- Besheli 2012, Amirzade et al. 2014). However, chemical control measures can cause pest resistance, resurgence, and outbreaks of secondary pests. Moreover, broad-spectrum synthetic insecticides impair the balance between psyllids and beneficial insects, especially if used late in the season than in pre-blossom (Shayegan et al. 2003). Therefore, these harmful side effects indicate the need for alternative methods of control that do not rely on insecticides alone (Azimizadeh et al. 2012). Research programs are being conducted on other control methods, including biological control, agricultural control, etc.., but they require further research, which is time-consuming. However, non-chemical insecticides can be a proper alternative method (Glenn & Puterka 2005, Homayonfar & Zohdi 2012, Kabiri et al. 2012).

Nowadays, the application of non-chemical insecticides has increased to decrease the use of chemical insecticides. Diatomaceous earth (DE) and silica are used as non-chemical insecticides to control different pests. DE may be used as a practical alternative for some conventional pesticides on certain pests (Fauteux et al. 2005, Massey & Hartley 2009, Rouhani et al. 2019, Korunić 2013, Toledo et al. 2016, Shahbani et al. 2019), for example, against storage pest management (Korunić & Mackay 2000, Korunić 2013, Toledo et al. 2016). Therefore, the effect of two mineral powders, diatomaceous earth and silica, on *A. pistaciae* was studied for the first time in a field experiment.

Experiments were performed in a pistachio orchard east of Rafsanjan, Kerman province, Iran. Sprayings were performed on one hectare of 40-years-old "Fandoghi" pistachio trees (*Pistacia vera* L.). The trees had never been treated with systemic insecticides, and the last treatment with contact insecticides was more than a year before the present treatment.

We used the factorial experiment with a randomized complete block design, including two types of compounds with three concentrations and six samples in 2019. Treatments included three concentrations of diatomaceous earth (DE), Celite® [4 (+ 350cc Dimethicone), 6 (+ 250cc Dimethicone) and 8 per thousand], and two concentrations of silica [4 (+ 400cc Dimethicone) and 8 per thousand]. The control treatment was sprayed on the whole tree canopy. Untreated trees served as control. Sprayings were performed considering the estimated economic injury level (EJL) of *A. pistaciae*, 10 nymphs/leaf on the first of May (Hasani et al. 2009, Mehrnejad 2010). No pesticides were used during the experimental period in the orchard.

The total number of eggs, nymphs, and adults were counted on randomly collected leaves at 3, 8, 13-, 18-, 21-, and 28-days post-treatment. The trees were sampled to obtain ten leaves from each tree of each treatment (60 leaves in total). Psyllid eggs and nymphs were counted under a binocular stereomicroscope. When no sign of movement was observed, they were considered dead. The percentage of psyllid reduction was calculated as the ratio of the present psyllids on the leaves of the sample to the total psyllids in pre-treatment sampling. The adults were counted on the trees using yellow sticky traps.

The means of the number of eggs and adults per leaf and the percentage reduction of the *A. pistaciae* population were estimated and analyzed. The results on the psylla population were compared before and post-treatment. The effect of treatments was analyzed using one-way ANOVA with treatment and block as explanatory variables in SPSS20. Differences between means were tested with Tukey's test (a=1%).

The applied treatments significantly reduced the psyllid population at all stages based on the field studies. In addition, the differences between sampling dates in different post-treatment samplings were significant at all life stages of *A. pistaciae*, except for the adult stage. The interaction between sampling dates and applied insecticides was also significantly different (Table 1).

Eggs

There were significant differences in the percentage of egg reduction among different treatments at all post-treatment sampling dates (Table 2). Generally, at 13 days post-treatment, the number of eggs increased, which may be associated with the decline in the insecticidal effect of DE and silica.

The maximum significant reduction of eggs was observed in silica too late (28 days post-treatment), while in DE treatments, it was observed three days post-treatment. It seems that dimethicone has exaggerated treatment effects. Based on our result, the most effective treatment on *A. pistaciae* eggs was DE concentrations (Table 2); at 28 days post-treatment, the lowest and highest reductions in eggs number were recorded in silica 4 (+ dimethicone) and DE4 (+ dimethicone) concentrations. However, according to the interaction between treatments and sampling dates, DE8 and DE6 (+dimethicone), with about 96 and 92%, had the maximum effect on decreasing egg numbers at 13- and 3-days post-treatment.

Table 1. Analysis of variance of different treatments, sampling dates, and their interaction in different life stages of *Agonoscena pistaciae* under different treatments and sampling dates (Sd).

Life stages	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Egg	Treatment	305944.157	5	61188.831	31.466	0.000
	Sampling date	46940.269	5	9388.054	4.828	0.001
	Treatment×Sd	315132.343	25	12605.294	6.482	0.000
Nymph I	Treatment	81092.818	5	16218.564	38.215	0.000
	Sampling date	34755.394	5	6951.079	16.378	0.000
	Treatment×Sd	60631.011	25	2425.240	5.714	0.000
Nymph II	Treatment	46990.868	5	9398.174	40.838	0.000
	Sampling date	32158.820	5	6431.764	27.948	0.000
	Treatment×Sd	41148.552	25	1645.942	7.152	0.000
Nymph III	Treatment	30677.046	5	6135.409	12.419	0.000
	Sampling date	108035.713	5	21607.143	43.735	0.000
	Treatment×Sd	90910.454	25	3636.418	7.360	0.000
Nymph IV	Treatment	90883.667	5	18176.733	172.929	0.000
	Sampling date	8554.444	5	1710.889	16.277	0.000
	Treatment×Sd	7876.556	25	315.062	2.997	0.000
Nymph V	Treatment	39878.476	5	7975.695	21.685	0.000
	Sampling date	32911.010	5	6582.202	17.896	0.000
	Treatment×Sd	23278.424	25	931.137	2.532	0.001
Adult	Treatment	81856.491	5	16371.298	10.135	0.000
	Sampling date	11165.491	5	2233.098	1.382	0.241
	Treatment×Sd	14006.565	25	560.263	0.347	0.998

Nymphs I

The effect of all treatments on nymph I of psylla was significantly different on all sampling dates (Table 3). DE 4 (+dimethicone) and DE 8 were the most effective at 8- and 18-days post-treatment. The maximum significant difference between concentrations of DE was observed at 8 days post-treatment. However, it was not significant between 3- and 23-days post-treatment. Silica 8 at 8 days post-treatment was the most effective within silica concentrations, with a considerable difference in nymph I of *A. pistaciae*.

Dealing with treatments and sampling dates, DE8 with 92.5% at 18 days post-treatment and DE6 (+dimethicone) with 94.28% at 8 days post-treatment had the maximum effect on population reduction of nymph I.

Nymphs II

All treatments were significantly different on nymph II; there was also a significant difference between sampling dates, except for silica 4 (+dimethicone), which was not significantly different on six sampling dates (Table 4).

The maximum efficacy percentage for psylla nymph II decreased in 3 days post-treatment and was 65.9% for silica 4 (+dimethicone); at 8 days post-treatment was 78.6% in DE 4 (+dimethicone); at 13 days post-treatment was 98.1% in silica 4 (+ dimethicone); at 18 days post-treatment was 90.1% in DE 8; at 23 days post-treatment was 93.7% in DE 8; and at 28 days post-treatment was 83.1% in DE8.

Therefore, DE8 spraying over the whole canopy of pistachio trees effectively decreased nymph II of the pistachio psylla population. The inclusion of dimethicone in the treatments increases the efficacy of treatments. According to the sampling dates, the efficiency of the treatments was amplified after 13 days, and the significant effect of DE8 on nymph II was observed at 18-, 23-, and 28-days post-treatment (Fig. 1).

At 18 days post-treatment, DE8 with 90.08% effect and DE4 (+dimethicone) with 87.7% effect on nymph II were the most effective treatments.

Nymphs III

Among the nymphal stages of *A. pistaciae*, the effect of different treatments on nymph III was less different. However, treatment differences were significant in all sampling dates except at 3- and 18-days post-treatment. Moreover, the number of nymphs III of psylla was significantly different in all treatments except DE4 (+

Table 2. Comparison of the means (±SE) number of *Agonoscena pistaciae* eggs on pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (*p-value of one-way ANOVA between treatments and sampling dates, respectively; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$168.3^{a}_{AB}\pm39.7$	$56.3^{b}_{B}\pm33.5$	$51.3^{b}_{B}\pm37.1$	$7.0^{c}_{D}\pm2.0$	$11.6^{c}_{B}\pm6.5$	$19.3^{c}_{B}\pm8.0$	0.000
Day 8	$392.6^{a}_{A}\pm157.8$	$53.00\ ^{b}_{B}\pm11.5$	$21.3^{b}_{B}\pm7.6$	$3.3^{b}_{D}\pm1.5$	$33.0^{b}_{AB}\pm19.7$	$9.6^{b}_{B}\pm1.5$	0.000
Day 13	$64.7^{b}_{B}\pm16.8$	$34.7^{bc}_{B}\pm8.3$	$165.0^{a}_{A}\pm49.6$	$57.0^{b}_{C}\pm6.5$	$11.0^{c}_{B}\pm4.0^{*}$	$2.3^{c}_{C}\pm0.58$	0.000
Day 18	$239.6^{a}_{AB}\pm165.7$	$137.3^{b}_{A}\pm53.5$	$160.0^{b}_{A}\pm63.9$	$32.3^{bc}_{C}\pm2.1$	$8.33^{c}_{B}\pm6.5^{*}$	$11.0^{c}_{B}\pm2.6$	0.031
Day 23	$160.3^{a}_{AB}\pm35.5$	$72.0^{b}_{AB}\pm20.5$	$60.3^{b}_{B}\pm25.0$	$64.0^{b}_{B}\pm10.1$	$59.3^{b}_{A}\pm10.2$	$50.0^{b}_{A}\pm1.7$	0.000
Day 28	$32.0^{b}_{B}\pm9.8$	$14.6^{c}_{C}\pm5.7$	$49.3^{b}_{B}\pm12.6$	$80.3^{a}_{A}\pm6.6$	$27.0^{bc}_{B}\pm6.0$	$24.0^{bc}_{B}\pm9.5$	0.000
p-value	0.008	0.003	0.002	0.000	0.000	0.000	

Table 3. Comparison of the means (±SE) number of *Agonoscena pistaciae* nymph I on pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (p-value of one-way ANOVA between treatments and sampling dates; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$198.7^{a}_{A}\pm66.4$	$43.3^{b}_{A}\pm10.0$	$70.0^{b}_{B}\pm21.2$	$36.3^{b}_{B}\pm0.6$	$114.0^{ab}_{A}\pm31.1$	$85.7^{b}_{A}\pm16.6$	0.000
Day 8	$117.3^{a}_{AB}\pm9.5$	$50.0^{b}_{A}\pm14.0$	$15.3^{c}_{C}\pm5.7$	$6.7^{d}_{C}\pm2.9$	$22.3^{c}_{B}\pm7.6$	$48.3^{b}_{B}\pm2.5$	0.000
Day 13	$111.0^{a}_{AB}\pm37.3$	$22.7^{c}_{B}\pm9.9$	$100.0^{a}_{A}\pm18.7$	$56.0^{b}_{A}\pm5.2$	$27.0^{c}_{B}\pm6.2$	$21.0^{c}_{BC}\pm4.0$	0.000
Day 18	$97.3^{a}_{AB}\pm34.7$	$24.0^{b}_{B}\pm12.2$	$59.5^{a}_{B}\pm9.2$	$19.0^{b}_{C}\pm10.0$	$22.7^{b}_{B}\pm4.0$	$7.3^{c}_{C}\pm0.6$	0.000
Day 23	$92.3^{ab}_{AB}\pm63.0$	$45.3^{b}_{A}\pm11.6$	$110.0^{a}_{A}\pm13.5$	$35.0^{b}_{B}\pm17.0$	$16.3^{b}_{B}\pm2.5$	$32.7^{b}_{B}\pm6.8$	0.013
Day 28	$43.3^{a}_{B}\pm8.1$	$21.3^{b}_{B}\pm6.8$	$52.3^{a}_{BC}\pm7.4$	$53.0^{a}_{A}\pm10.1$	$42.3^{a}_{B}\pm6.7$	$29.0^{b}_{B}\pm6.0$	0.001
p-value	0.020	0.018	0.000	0.000	0.000	0.000	

Table 4. Comparison of the means (±SE) number of *Agonoscena pistaciae* nymph II on pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (p-value of one-way ANOVA between treatments and sampling times; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$128.3^{a}_{A}\pm38.2$	$43.7^{b}\pm9.6$	$101.0^{a}_{A}\pm9.9$	$43.0^{b}_{B}\pm21.2$	$89.0^{ab}_{B}\pm9.8$	$59.3^{b}_{A}\pm4.5$	0.001
Day 8	$112.0^{a}_{A}\pm28.7$	$28.3^{c}\pm15.0$	$24.7^{c}_{B}\pm10.7$	$24.0^{c}_{C}\pm14.1$	$107.5^{a}_{A}\pm0.7$	$57.5^{b}_{A}\pm13.4$	0.000
Day 13	$103.3^{a}_{AB}\pm14.4$	$22.0^{c}\pm23.4$	$105.3^{a}_{A}\pm24.6$	$101.7^{a}_{A}\pm8.5$	$40.7^{b}_{C}\pm12.2$	$47.3^{b}_{A}\pm0.6$	0.000
Day 18	$83.7^{a}_{B}\pm13.6$	$37.3^{b}\pm11.0$	$47.7^{b}_{B}\pm15.6$	$10.3^{c}_{C}\pm2.1$	$22.3^{c}_{D}\pm4.6$	$8.3^{c}_{B}\pm0.6$	0.000
Day 23	$79.3^{a}_{B}\pm14.0$	$31.0^{b}\pm14.4$	$49.3^{ab}_{B}\pm23.2$	$38.7^{b}_{B}\pm8.0$	$10.7^{c}_{D}\pm10.8^{*}$	$5.0^{c}_{B}\pm2.0$	0.000
Day 28	$49.3^{a}_{C}\pm3.5$	$30.7^{ab}\pm12.9$	$31.0^{ab}_{B}\pm12.3$	$36.7^{a}_{B}\pm4.6$	$58.0^{a}_{C}\pm26.1$	$8.3^{b}_{B}\pm3.8$	0.010
p-value	0.012	0.605	0.001	0.000	0.000	0.000	

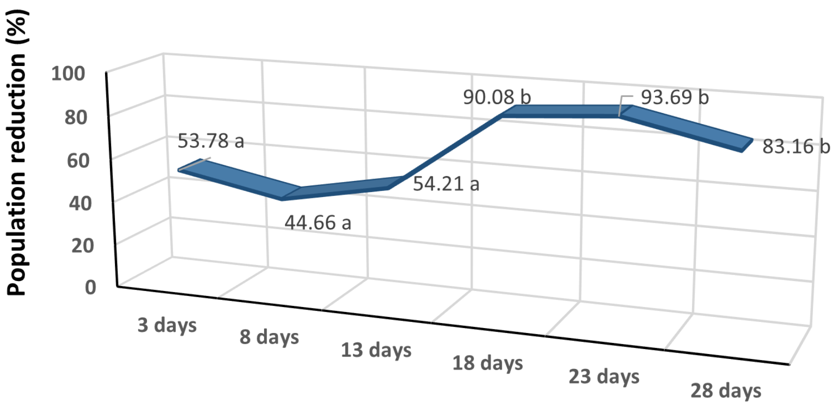

Figure 1. Effect (%) of DE8 on the reduction of pistachio psylla nymph II population at different sampling dates

dimethicone). Among the treatments, DE8 was the most effective at 23 days post-treatment with about 83.78% efficiency in the reduction of nymph III.

Nymphs IV

Only two treatments, DE6 (+ dimethicone) and DE8 differed significantly in the post-treatment sampling dates. At the same time, all treated treatments were significantly different on all sampling dates (Table 6). DE8 was the most effective treatment for nymph IV, and its effect was high, 28 days post-treatment, with a 90.58% effect (Figure 2). DE6 (+ dimethicone) was in second place after DE8, with 86.97% efficiency after 28 days.

Nymphs V

There were significant differences in nymph V density among treatments at 8, 13-, 18-, 23-, and 28-days post-treatment (Table 1). Except for silica 4 (+ dimethicone) and DE4 (+ dimethicone), all treatments had a significant effect on the reduction of the nymph V psylla (Table 7). At the same time, DE6 (+ dimethicone) was the most effective treatment for nymph V reduction at 18-, 23- and 28-days post-treatment with 49.00%, 68.85% and 81.66% efficiency; after this DE8 followed, at 18-, 23- and 28-days post-treatment with 60.34%, 61.83% and 80.24% effectiveness.

Adults

The decline of the psyllid population shows a significant difference between the treated trees and the control at 3- and 8-days post-treatment (F=10.135, df=5). The psyllid reduction on the treated trees with silica 8 was significantly higher than the control, with a 75.57% effect at 3 days post-treatment (Table 8). The treatment DE8 with 86.6% was significantly effective 8 days post-treatment. The highest reduction was observed after 23 days in DE6 (+ dimethicone), without significant differences between DE and silica treatments. The results show that DE was useful in reducing adult *A. pistaciae*, and better results are obtained after 13 days post-treatment.

Table 5. Comparison of the means (±SE) number of *Agonoscena pistaciae* nymph III on treated pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (p-value of one-way ANOVA between treatments and sampling dates; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$11.7_{C}\pm9.9^{*}$	$28.7_{C}\pm6.1$	$47.3_{B}\pm7.2$	36.7 ± 19.1	$32.0_{C}\pm15.1$	$46.0_{B}\pm20.0$	0.080
Day 8	$52.3^{b}_{A}\pm12.7$	$91.0^{b}_{A}\pm14.9$	$105.0^{ab}_{A}\pm34.7$	$51.7^{b}\pm23.7$	$127.0^{a}_{A}\pm17.3$	$138.3^{a}_{A}\pm3.1$	0.001
Day 13	$68.7^{b}_{A}\pm5.0$	$54.3^{b}_{B}\pm12.5$	$46.3^{b}_{B}\pm6.4$	$51.3^{b}\pm17.7$	$179.3^{a}_{A}\pm29.5$	$217.7^{a}_{A}\pm83.6$	0.000
Day 18	$32.3_{B}\pm8.1$	$30.7_{C}\pm8.4$	$16.0_{C}\pm1.7$	32.0 ± 16.4	$69.0_{B}\pm57.6$	$24.7_{C}\pm2.1$	0.234
Day 23	$45.0^{a}_{A}\pm20.9$	$24.0^{b}_{C}\pm10.1$	$36.7^{a}_{B}\pm14.8$	$48.7^{a}\pm2.5$	$14.0^{b}_{C}\pm8.5$	$7.3^{c}_{C}\pm0.6$	0.005
Day 28	$10.3^{b}_{C}\pm8.5$	$41.3^{a}_{BC}\pm22.0$	$20.3^{b}_{B}\pm11.5$	$34.0^{ab}\pm1.0$	$56.7^{a}_{B}\pm20.6$	$18.0^{b}_{C}\pm8.7$	0.016
p-value	0.000	0.000	0.000	0.464	0.000	0.000	

Table 6. Comparison of the means (±SE) number of *Agonoscena pistaciae* nymph IV on pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (P & P*: p-value of one-way ANOVA between treatments and sampling dates; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$138.7^{a}_{A}\pm11.8$	$49.0^{c}\pm6.6$	$43.0^{c}\pm4.4$	$84.0^{b}\pm12.5$	$38.0^{c}_{A}\pm9.5$	$20.3^{d}_{A}\pm7.2$	0.000
Day 8	$104.0^{a}_{A}\pm21.6$	$55.3^{b}\pm13.8$	$24.3^{b}\pm2.3$	$89.3^{ab}\pm5.5$	$21.3^{b}_{B}\pm4.2$	$18.0^{b}_{A}\pm8.0$	0.000
Day 13	$93.3^{a}_{B}\pm6.4$	$55.3^{b}\pm8.0$	$43.7^{b}\pm6.4$	$84.0^{a}\pm11.1$	$25.7^{c}_{B}\pm6.8$	$13.3^{c}_{B}\pm4.0$	0.000
Day 18	$83.0^{a}_{B}\pm6.1$	$52.7^{b}\pm7.0$	$40.7^{b}\pm13.6$	$85.7^{a}\pm12.1$	$21.3^{c}_{B}\pm3.2$	$15.0^{c}_{AB}\pm2.0$	0.000
Day 23	$70.7^{a}_{B}\pm14.0$	$48.7^{ab}\pm8.5$	$25.3^{b}\pm9.5$	$65.0^{a}\pm18.4$	$17.0^{b}_{B}\pm6.2$	$12.7^{c}_{B}\pm2.5$	0.000
Day 28	$63.7^{a}_{C}\pm12.1$	$41.7^{b}\pm8.6$	$17.7^{c}\pm7.2$	$72.3^{a}\pm15.2$	$8.3^{d}_{C}\pm2.1$	$6.0^{d}_{B}\pm1.7$	0.000
p-value	0.000	0.499	0.081	0.252	0.001	0.043	

The present study showed that DE had a maximum effect in 28 days post-treatments at the high dose (8 per thousand). Generally, DE showed significant differences on all sampling dates. DE8 had adverse effects on pistachio psyllid within the treatments by all life stages when sprayed on pistachio under field conditions. It was evaluated as the most effective treatment with 80-96% effectiveness in different stages of the life span of *A. pistaciae*. On the other hand, its effectiveness was delayed with increasing nymphal stage. Therefore, it was effective on nymph I at 18 days post-treatment while on nymph V at 28 days post-treatment (Table 9). Based on the field studies, kaolin application reduced the population of psylla nymphs more than acetamiprid in all spraying stages in pistachio trees. High concentrations (≥ 5%) of kaolin particle film were evaluated as most effective in reducing common pistachio psyllid oviposition (Farazmand et al. 2014).

DE 6 (+ dimethicone) was the second treatment evaluated as effective on *A. pistaciae*. The inclusion of dimethicone in the treatments seems to increase the effectiveness of the mineral powders but requires special testing, focusing on comparison treatments with and without dimethicone.

Therefore, three to four times DE spraying (6-8 per thousand) with intervals of 4–5-weeks on the canopy of pistachio trees can successfully reduce psylla nymphs. Moreover, our findings showed these products are potentially promising methods that can be used in sustainable agricultural approaches against the pistachio psyllid but should be tested for their effects on the biological control agents.

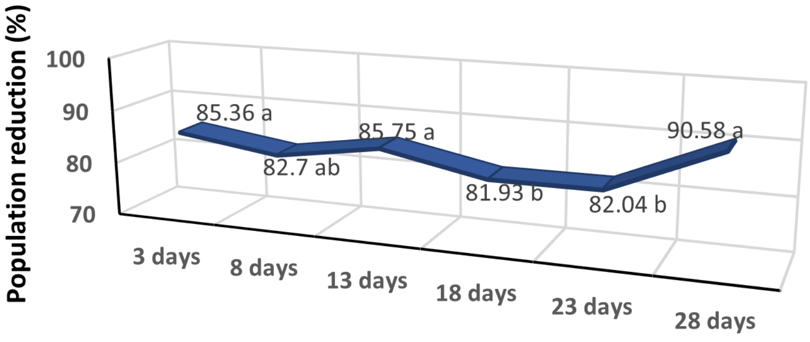

Figure 2. Effect (%) of DE8 on the reduction of pistachio psylla nymph IV population at different sampling dates.

Table 7. Comparison of the means (±SE) number of *Agonoscena pistaciae* nymph V on pistachio trees treated with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (P & P*: p-value of one-way ANOVA between treatments and sampling dates; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%); A, B, C, …: Means with similar letters in each column are not significantly different using Tukey's test (*a*=1%))

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$81.3_{AB}\pm4.2$	$42.0_{B}\pm11.8$	55.7±12.2	38.0±13.7	$32.0_{A}\pm9.8$	$27.7_{A}\pm12.1$	0.060
Day 8	$123.3^{a}_{A}\pm3.5$	$107.3^{a}_{A}\pm23.7$	$98.0^{a}\pm6.4$	$60.7^{ab}\pm23.7$	$29.7^{b}_{A}\pm6.0$	$26.3^{b}_{A}\pm8.5$	0.013
Day 13	$127.7^{a}_{A}\pm4.0$	$63.0^{b}_{B}\pm13.7$	$63.3^{b}\pm14.4$	$45.7^{b}\pm10.7$	$20.7^{c}_{A}\pm3.2$	$23.7^{c}_{A}\pm2.1$	0.000
Day 18	$35.3^{b}_{B}\pm10.3$	$30.3^{b}_{B}\pm5.5$	$31.7^{b}\pm15.1$	$63.0^{a}\pm22.6$	$18.0^{c}_{AB}\pm8.5$	$14.0^{c}_{B}\pm5.0$	0.012
Day 23	$42.7^{a}_{B}\pm8.7$	$32.0^{a}_{B}\pm16.6$	$23.3^{ab}\pm7.2$	$38.7^{a}\pm12.1$	$13.3^{b}_{B}\pm8.7$	$16.3^{b}_{B}\pm7.6$	0.028
Day 28	$42.0^{a}_{B}\pm4.4$	$33.7^{a}_{B}\pm10.7$	$31.7^{a}\pm11.1$	$30.7^{a}\pm11.9$	$7.7^{b}_{B}\pm2.9$	$8.3^{b}_{B}\pm2.1$	0.001
p-value	0.003	0.000	0.060	0.177	0.009	0.037	

Table 8. Comparison of the means (±SE) of the number of *Agonoscena pistaciae* adults on pistachio t treated trees with different concentrations of silica and DE on six sampling dates post-treatment in 2019. (p-value of one-way ANOVA between treatments; a, b, c, …: Means with similar letters in each row are not significantly different using Tukey's test (*a*=1%)).

Sampling dates	Control	Silica 4 (+Dim.)	Silica 8	DE 4 (+Dim.)	DE 6 (+Dim.)	DE 8	p-value
Day 3	$118.7^{a}\pm18.8$	$90.3^{a}\pm3.5$	$29.0^{c}\pm12.8$	$64.3^{b}\pm2.6$	$38.3^{c}\pm7.6$	$38.3^{c}\pm16.1$	0.000
Day 8	$106.7^{a}\pm11.5$	$41.3^{b}\pm2.8$	$33.3^{b}\pm1.8$	$50.7^{b}\pm5.1$	$21.0^{b}\pm8.7$	$14.3^{c}\pm14.0$	0.000
Day 13	66.3±20.0	74.0±9.17	23.3±2.4	42.7±5.5	25.0±5.0	16.0±5.3	0.403
Day 18	116.7±16.09	49.0±16.7	41.3±2.8	53.3±1.9	16.0±27.7	5.3±1.2	0.470
Day 23	82.3±10.20	54.0±20.8	54.0±20.8	30.0±5.0	1.0±1.0	5.3±1.5	0.237
Day 28	89.7±7.23	23.7±2.87	27.3±5.5	25.3±8.1	6.0±8.7	7.7±3.8	0.072

Table 9. Effectiveness of DE8 on population reduction (%) of *Agonoscena pistaciae*, in different stages of life span at different sampling dates.

Life stages	Population reduction (%)	Post-treatment sampling dates (day)
Egg	96.4	13
Nymph I	92.5	18
Nymph II	93.7	23
Nymph III	83.8	23
Nymph IV	90.6	28
Nymph V	80.2	28
Adult	86.6	8

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