Integration of mineral oil and water-washing as an effective tool to control *Pseudaulacaspis pentagona* (Targioni-Tozzetti) (Hemiptera: Diaspididae)

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Received: 14/04/2024
Accepted: 24/12/2024
Published: 27/06/2025

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DOI: 10.2298/JAS2502173J

Abstract:

This study was aimed to evaluate the efficiency of winter control by water-washing + mineral oil compared to repeated use of insecticides in controlling *Pseudaulacaspis pentagona* (Targioni-Tozzetti) in peach orchards of the Mazandaran province. This experiment was conducted as a completely randomised design with three treatments and five replications in a peach orchard located in the Makran village, Miandorud city: (1) chlorpyrifos (Chlorpyrifos-methyl Kavosh®, 40% EC) and ethion (Ethion Kavosh®, 47% EC) at a concentration of 2 L/1000L of water, (2) water-washing + mineral oil (Volk Kavosh®, 90% EC) at a ratio of 5% (V/V), and (3) control (no spraying). The results showed that there was a significant difference between the efficiency of water-washing+mineral oil compared to the chemical insecticides in controlling *P. pentagona*. Water-washing+mineral oil spraying showed an efficacy of 80.25% and 75.71% in controlling nymphs and adults of P. pentagona, respectively, during the spring season. The efficiency of the mentioned treatment in reducing the population of nymphs and female adults during the summer season was 77.00% and 69.12%, respectively. Water-washing + mineral oil recorded 70.32% and 71.09% in controlling the populations of nymphs and adults of this pest during the autumn season. On the other hand, the efficiency of the insecticides on the nymphs and adults was 63.70% and 55.78%, 61.68% and 49.78%, 37.03% and 40.83% during spring, summer and autumn, respectively. As a result, the findings showed that winter control with a single application of water-washing + mineral oil had higher and significant efficiency than three applications of chemical insecticides.

Keywords: white peach scale; mineral oil; chemical insecticide; efficiency

INTRODUCTION

More than 25 million tons of peaches and nectarines are produced worldwide every year. Iran is the fifth largest peach and nectarine producer in the world with a production volume of approximately 864 thousand tons per year (FAO, 2022). Among the provinces that produce peaches and nectarines in Iran, the Mazandaran province has the highest production of the above products with more than 273.7 thousand tons (Anonymous, 2023). Several pests are active in stone fruit orchards, especially peaches in the region, each of which causes significant damage to this product. One of the most important pests of peach trees is white peach scale (WPS), *Pseudaulacaspis pentagona* (Targioni-Tozzetti) (Hemiptera: Diaspididae), whose habitat is mostly in tropical, temperate and humid regions (Sharifi et al., 2020).

This pest was first introduced to northern Iran (Guilan province) in 1964 along with improved mulberry cuttings from Japan. Since then, pest outbreaks have been observed on Japanese and native mulberry trees of this province (Taksokhan, 1999). The WPS has a wide host range, including fruit, forest and ornamental trees, and damages 121 genera from 54 plant families (CABI, 2022; Miller and Davidson, 2005; Toorani, 2017). This pest generally settles on the branches and trunks of stone fruits and it is also observed on fruits and leaves in high population density or severe infestation (Sharifi et al., 2020). Trees infested by this scale gradually weaken and eventually decline (Gholamian and Aghajanzadeh, 2016).The study of the biology of WPS in the west of the Mazandaran province shows that this pest has three generations per year and overwinters as fertile female adults (Gholamian et al., 2013).Currently, the WPS is a serious threat to peach and kiwi orchards. Due to the increase in the cultivated area of these crops as well as mulberry orchards to produce silkworms, the damage caused by this pest has become economically important (Ali Akbar Aghadokht et al., 2018).

The application of chemical insecticides is a common and main strategy for controlling WPS in fruit orchards (Morales-Rodriguez and McKenna, 2019). The most susceptible developmental stage of WPS and other armoured scales is the first-instar nymphs, which do not have a wax cover (Erkiliçand Uygun, 1997; Tatara, 1998; Graora, 2005), so that chemical control measures are carried out simultaneously with this developmental stage and most sprays are timed to correspond to about 50% of crawler (first-instar nymphs) emergence (Zhuang et al., 2016; Morales-Rodriguez and McKenna, 2019). Suppressing the population of WPS is difficult in the later developmental stages (second- and third-instar nymphs and female adults) due to the development of a hard and waxy cover (armour) on their body that effectively protects them from adverse conditions, especially exposure to insecticides (Graora, 2005; Bazrafshan et al., 2010; Tozlu et al., 2020). This issue has led to an increase in the times of insecticide use to control this pest in the above developmental stages. However, the application of chemical insecticides causes serious problems such as the development of pesticide resistance in pests, disruption of the natural balance, negative effects on natural enemies of the pests and beneficial insects (pollinators) and environment (Kwaiz et al., 2009). The search for alternative control methods that have less negative and destructive effects is necessary for implementing an effective pest management programme and control WPS at all developmental stages. One alternative in the management of scale insects is the application of mineral oil spray (Moretti et al., 2002; Bazrafshan et al., 2010). Spraying with mineral oils plays a significant and important role in controlling armoured scales in many crops, especially fruit trees (Morales-Rodriguez and McKenna, 2019). Zhuang et al. (2015) found that mineral oil effectively controlled the first nymphal instars of WPS on kiwifruit in China. The results on peach and nectarine trees in Iran revealed that mineral oil at a rate of 2.5% caused a high mortality in the overwintering adults of *P. pentagona* (Bazrafshan et al., 2010; Mafi Pashakolaei et al., 2015; Alizadeh et al., 2021). Gholamian et al. (2013) also indicated that winter spraying of kiwifruit trees in the Ramsar city (in northern Iran) using mineral oil at a rate of 2% caused the highest mortality rate in the overwintering generation of WPS. The results of another study showed that the use of mineral oils such as misrona oil and alboleum oil at a rate of 2.5% caused a decrease in the WPS population by more than 88% (Kwaiz et al., 2009). The high density of *P. pentagona* on peach and nectarine trees in fruit orchards of northern Iran is considered a serious threat, and in some cases, gardeners spray 3 to 5 times using chemical pesticides to control this pest. The aforementioned problems related to the harmful effects of pesticides further highlight the importance of this research to reduce pesticide use. It should be noted that due to the lack of sufficient knowledge about the management and control of WPS, many sprayings are unnecessary, ineffective and poorly timed. Accordingly, this study was aimed to investigate the effect of mineral oil application at the appropriate time on the control of *P. pentagona* in peach orchards.

MATERIAL AND METHODS

This research was carried out in a peach orchard within an area of 2250 m^2 (75×30 m) located in the Makran village (36° 41E, 53° 16N) of the Miandorud city in the Mazandaran province, Iran, at an altitude of 15 m above mean sea level, from January 6 to November 15, 2021. The peach trees were a 7-year old Crest variety (*Prunus persica* var. *persica* ‘Crest’) in 15 rows and each row contained six trees (90 trees in total). The inter-row distance and the distance between trees within a row was 5 m. This experiment was conducted as a randomised complete block design with three treatments and five replications. The experimental treatments included: (1) chlorpyrifos (Chlorpyrifos-methyl Kavosh®, 40% EC, Kavosh Kimia Kerman Co., Kerman, Iran) and ethion (EthionKavosh®, 47% EC, Kavosh Kimia Kerman Co., Kerman, Iran) at a concentration of 2 L/1000 L of water, (2) water-washing + mineral oil

(Volk Kavosh®, 90% EC, Kavosh Kimia Kerman Co., Kerman, Iran) at a ratio of 5% (V/V), and (3) control (no spraying). The orchard was divided into five blocks and each block included three rows and each row had six trees. Each row of trees in each block was randomly assigned to a treatment.

The treatments were applied to the studied trees when 70% of the WPS eggs had hatched on the tree trunk (Table 1).

Table 1. Dates of the application of the treatments during the seasons in 2021.

Treatments	Dates of application				
	January 7	January 21	May 5	July 6	August 21
WMO	Water-washing				
		Mineral oil spraying			
INCS			Chlorpyrifos		Chlorpyrifos
				Ethion	

WMO: water-washing and mineral oil treatment; INCS: insecticide treatment.

Foliar spraying with the appropriate insecticides was carried out on three dates based on the executive instructions provided by the Plant Protection Organization and the recommendations of the experts of the Ministry of Agricultural Jihad (Table 1). Foliar spraying was done uniformly by a rechargeable manual sprayer and ten litres of solution were used for each treatment. After the treatment, the name of each treatment was written on an aluminium sheet and installed on the trees of each row. It should be noted that a random sample was taken in the blocks (one tree of each row in each block) on January 6, 2021, to determine the WPS population before applying treatments. For sampling, a 10-cm^2 piece (5 × 2 cm) was separated from the bark of the trunk or tree branch, where the pest infestation was observed. Sampling was done at 14-day intervals from February 4, 2021 to mid-November, 2021. The sampling method was as follows: on the first sampling date, a tree in each row of each block was randomly selected and a sample was taken from it. Then, on the subsequent date, the next tree in the same row was sampled, so that, at the end of this study, all the trees in each row of each block (all the trees in the orchard) were sampled. The samples were placed in plastic bags and transported to the laboratory. Then, the nymphs (not separated into nymphal stages) and adults were counted under a stereomicroscope. The mobility of nymphs and adults after stimulation with a needle was a measure of their viability. After counting the number of live and dead nymphs and adults, the efficacy of the control methods was calculated using the formula of Henderson and Tilton (1955):

$$(1)\ Efficacy(\%) = \left(1 - \frac{T_a \times C_b}{T_b \times C_a}\right) \times 100_{(1)}$$

where T_a was the number of live individuals in the treatment after spraying, T_b was the number of live individuals in the treatment before spraying, C_a was the number of live individuals in the control after spraying, and C_b was the number of live individuals in the control before spraying.

Statistical analysis

The data of WPS population were statistically analysed based on a randomised complete block design using the SAS software, version 9.3 (SAS Institute, 2017) by the GLM method. The mean comparison of the treatments was also done using the Duncan's multi-range test at the probability level of 5%. In addition, the efficacy of mineral oil and insecticides was compared using an independent two-sample t-test.

RESULTS AND DISCUSSION

The effect of the control methods on the WPS population on different sampling dates

Spring

According to the results of variance analysis on the sampling dates in spring, applying the treatments had a significant effect on the control of the different developmental stages of *P. pentagona* ($p<0.01$). Since water-washing + mineral oil was the only treatment applied until April 27, therefore, a significant difference was observed between this treatment and the other treatments in the number of nymphs and adults of WPS, and the lowest population density of both developmental stages was obtained for the water-washing + mineral oil treatment. Considering that the insecticide treatment had not yet been applied, there was no significant difference between the insecticide and the control treatments (Table 2).

Table 2. Mean comparison of the nymphs and the adult population of *P. pentagona* affected by the treatments on the different sampling dates in the spring of 2021.

Developmental stage	Sampling date	Mean±SE‡			F-value
		CONT	INCS	WMO	
Nymphs	April 1	3.00±0.25a	3.20±0.18a	0.60±0.12b	31.40**
	April 13	4.20±0.23a	4.40±0.28a	0.80±0.10b	87.71**
	April 27	6.20±0.31a	5.80±0.26a	1.00±0.10b	66.11**
	May 11	10.60±0.47a	3.40±0.22b	2.40±0.15b	103.52**
	May 25	10.00±0.51a	3.60±0.26b	2.00±0.16c	70.74**
	June 10	5.00±0.38a	2.00±0.14b	1.20±0.09c	86.00**
	Spring	6.50±0.36a	3.73±0.23b	1.33±0.11c	68.78**
Adults	April 1	9.00±0.45a	9.00±0.30a	2.20±0.18b	105.09**
	April 13	13.60±0.64a	13.00±0.55a	2.20±0.15b	176.40**
	April 27	8.80±0.74a	8.20±0.65a	1.80±0.13b	123.71**
	May 11	4.20±0.34a	1.40±0.10b	1.00±0.11b	45.60**
	May 25	4.40±0.36a	2.20±0.14b	1.20±0.09c	33.50**
	June 10	6.00±0.32a	3.00±0.15b	1.80±0.10c	31.91**
	Spring	7.67±0.30a	6.13±0.28b	1.70±0.11c	35.41**

‡Different letters in each row indicate a significant difference between the treatments;**indicates that the effect of the treatments was statistically significant at a 1% probability level ($p<0.01$); CON: control treatment; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

The results of the mean comparison on May 11 showed that the highest number of live nymphs and adults counted on this date was related to the control treatment, with the averages of 10.60 and 4.20 individuals per 10 cm^2 of tree trunk bark, respectively, which was a significant difference from the averages obtained for the other treatments. On the other hand, the lowest number of live nymphs and adults counted among the treatments on May 11 was obtained for the water-washing + mineral oil treatment with the averages of 2.40 and 1.00 individuals per 10 cm^2 of tree trunk bark, respectively, which was not significantly different from the insecticide treatment (Table 2). The results of the mean comparison of the effect of the studied treatments on the number of nymphs and adults of WPS on May 25 and June 10, 2021 in Table 1 show that the highest number of live nymphs and adults was counted on these dates in the control treatment, which was significantly different from the other treatments. On the other hand, the lowest number of live nymphs and adults was counted for the water-washing + mineral oil treatment, which was significantly different from the other treatments (Table 2).

Summer

As can be seen in Table 2, the application of the studied treatments significantly affected the population of the different developmental stages of *P. pentagona* in summer ($p<0.01$). On June 25, the lowest number of live nymphs and adults counted among the treatments was obtained for the water-washing + mineral oil treatment with the averages of 1.60 and 1.20 individuals per 10 square centimetres of bark, respectively, which was significantly different from the other treatments (Table 3).

Table 3. Mean comparison of the nymphs and the adult population of *P. pentagona* affected by the treatments on the different sampling dates in the summer of 2021.

Developmental stage	Sampling date	Mean±SE‡			F-value
		CONT	INCS	WMO	
Nymphs	June 25	8.80±0.45a	4.20±0.24b	1.60±0.17c	166.17**
	July 11	12.80±0.65a	3.80±0.47b	3.20±0.44b	105.80**
	July 26	10.20±0.60a	3.80±0.32b	2.40±0.17c	216.17**
	August 10	6.20±0.44a	3.20±0.36b	1.40±0.11c	51.88**
	August 25	12.80±0.75a	4.60±0.29b	3.00±0.11c	92.13**
	September 10	8.20±0.43a	2.80±0.24b	2.20±0.16b	52.84**
	Summer	9.83±0.51a	3.73±0.34b	2.30±0.14c	64.58**
Adults	June 25	4.20±0.21a	2.40±0.20b	1.20±0.08c	12.67**
	July 11	3.40±0.32a	1.60±0.35b	1.20±0.25b	25.75**
	July 26	4.60±0.38a	2.20±0.27b	1.20±0.12c	38.17**
	August 10	5.40±0.30a	3.20±0.21b	1.40±0.12c	75.25**
	August 25	3.60±0.21a	1.80±0.13b	1.20±0.14c	33.43**
	September 10	6.80±0.31a	2.80±0.20b	2.20±0.18b	85.27**
	Summer	4.67±0.33a	2.33±0.22b	1.40±0.14c	28.51**

‡Different letters in each row indicate a significant difference between the treatments; *indicates that the effect of the treatments was statistically significant at a 1% probability level ($p<0.01$); CON: control treatment; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

According to the results, on July 11 and September 10, the lowest number of different developmental stages of WPS was counted in the water-washing + mineral oil treatment, but no significant difference was observed between this treatment and the treatment with insecticides (Table 3). The results of mean comparisons on July 26, August 10 and 25 showed that the water-washing + mineral oil treatment caused a significant decrease in the density of the population of nymphs and adults of *P. pentagona* compared to the other treatments (Table 3).

Autumn

The results of variance analysis in this season showed that applying the studied treatments had a significant effect on the control of the different developmental stages of WPS ($p<0.01$) (Table 4).

Table 4. Mean comparison of the nymphs and the adult population of *P. pentagona* affected by the treatments on the different sampling dates in the autumn of 2021.

Developmental stage	Sampling date	Mean±SE‡			F-value
		CONT	INCS	WMO	
Nymphs	September 25	5.80±0.37a	2.80±0.16b	1.40±0.19c	63.17**
	October 13	3.00±0.26a	1.80±0.16b	1.00±0.15c	21.71**
	November 1	2.80±0.23a	1.80±0.13b	0.60±0.07c	26.00**
	November 15	1.40±0.14a	1.00±0.10ab	0.60±0.06b	4.00*
	Autumn	3.25±0.22a	1.85±0.12b	0.90±0.11c	17.26**
Adults	September 25	4.00±0.25a	2.20±0.30b	1.40±0.27b	17.73**
	October 13	3.00±0.21a	2.00±0.19b	1.00±0.10c	7.50**
	November 1	5.00±0.27a	2.80±0.15b	1.00±0.11c	86.00**
	November 15	3.80±0.25a	2.40±0.13b	0.80±0.06c	28.17**
	Autumn	3.95±0.25a	2.35±0.18b	1.05±0.11c	21.66**

‡Different letters in each row indicate a significant difference between the treatments; ** and * indicate that the effect of the treatments was statistically significant at the 1% and 5% probability levels, respectively ($p<0.01$ and $p<0.05$); CON: control treatment; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

According to the mean comparison on September 25, the lowest number of WPS nymphs was obtained for the water-washing + mineral oil treatment with a significant difference compared to the other treatments, but no significant difference was observed between the water-washing + mineral oil treatment and the insecticide treatment in terms of the adult population although the lowest number of WPS adult was obtained for the water-washing + mineral oil treatment (Table 4). On October 13 and November 1, the lowest number of nymphs and adults of *P. pentagona* was obtained for the water-washing + mineral oil treatment with a significant difference compared to the other treatments.

The results of comparing the average population of nymphs on November 15 showed that no significant difference was observed between the water-washing + mineral oil treatment and the insecticide treatment due to the decrease in pest density on this date, but it should be noted that there was a significant difference between the population of nymphs in water-washing + mineral oil and control treatments. This is despite the fact that the observed difference between the control and insecticide treatments was not significant (Table 4).

Comparison of the efficacy of water-washing + mineral oil and insecticides in the control of on different sampling dates

Considering that the first date of the application of insecticides was on May 5, 2021, therefore, the trend of changes in the efficacy of water-washing + mineral oil in controlling the population of WPS nymphs from February 4 to April 27, 2021 is shown in Figure 1, and the efficiencies of water-washing + mineral oil and insecticides were compared with each other from May 11, 2021 to the end of the experiment.

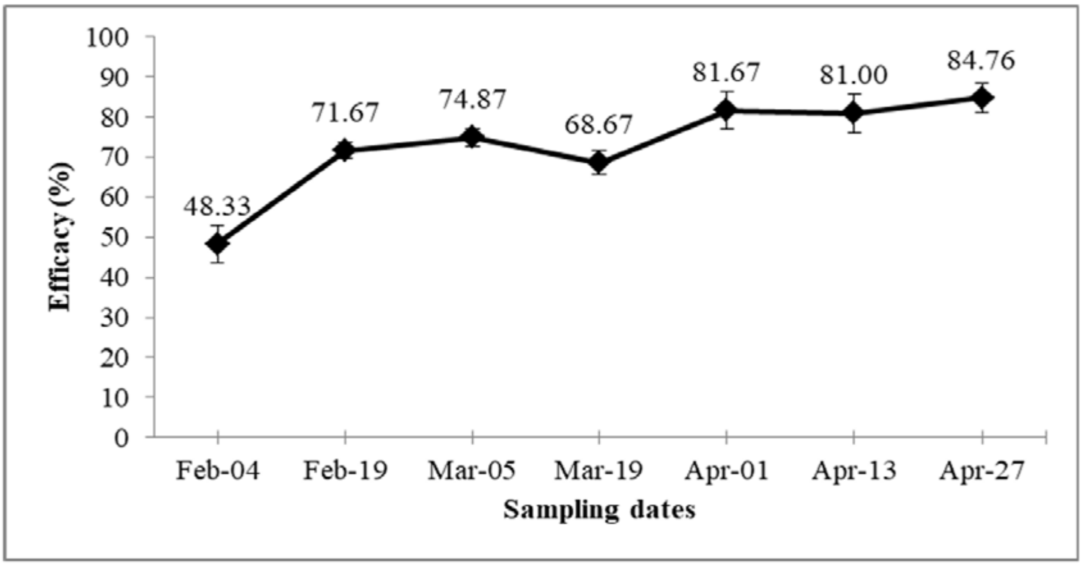

Figure 1.
The efficacy of the water-washing + mineral oil treatment in controlling the nymphs of *P. pentagona* on the different sampling dates before applying the insecticides.

As can be seen, the efficacy of this treatment increased from February 4 (48.33%) to April 27 (84.76%), 2021 (except for March 19, 2021).

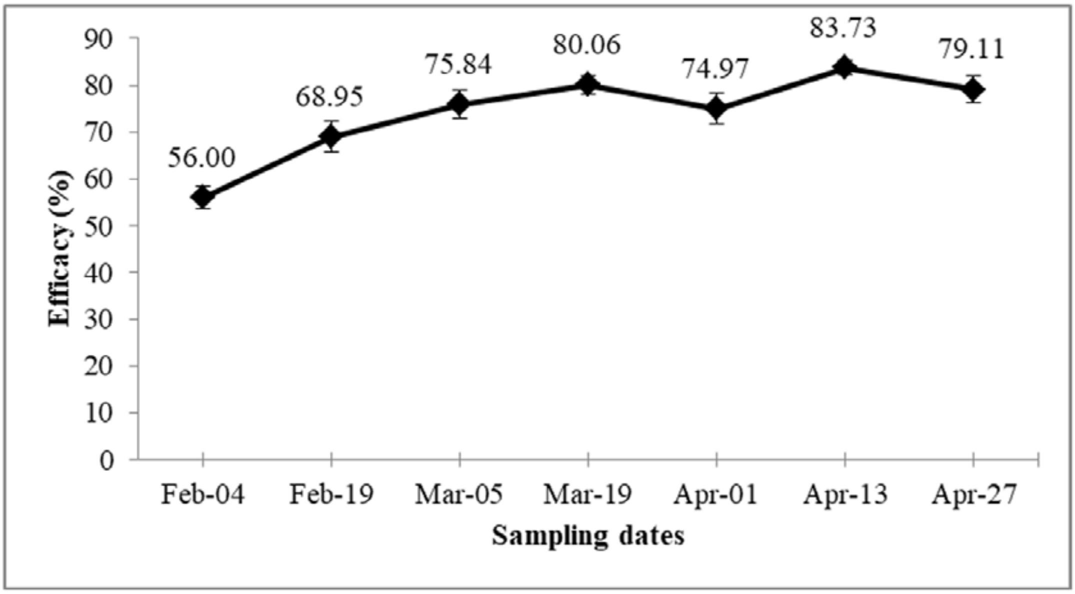

Figure 2.
The efficacy of the water-washing + mineral oil treatment in controlling the adults of *P. pentagona* on the different sampling dates before applying the insecticides.

Also, the changes in the efficiency of the water-washing + mineral oil treatment in the control of the population of WPS adults showed that the efficiency increased from February 4 to April 13, 2021 (except for April 1, 2021), so that it increased from 56.00% to 83.73%, although a slight decrease in efficiency was observed on April 27, 2021, reaching an average of 79.11% (Figure 2).

Spring

Based on the results of the t-test on May 11, 2021 (Table 5), there is a significant difference between the treatments in terms of efficiency in controlling WPS nymphs (p<0.01), but the difference between their effectiveness in controlling the adult was not significant (p>0.05).

Table 5. Mean comparison of the efficacy of the treatments in controlling nymphs and adults of *P. pentagona* on the different sampling dates in the spring of 2021.

Developmental stage	Sampling date	Mean (%)±SE‡		t-value
		INCS	WMO	
Nymphs	May 11	67.72±2.16b	77.49±2.34a	3.84**
	May 25	64.05±2.58b	80.27±2.50a	4.51**
	June 10	59.33±2.67b	76.33±2.60a	4.56**
	Spring	63.70±2.31b	80.25±3.17a	4.46**
Adults	May 11	66.33±3.33a	75.33±2.44a	1.53ns
	May 25	51.00±3.40b	73.00±3.39a	3.04*
	June 10	50.00±2.26b	68.10±3.71a	2.94*
	Spring	55.78±2.64b	75.71±3.09a	3.32*

‡Different letters in each row indicate a significant difference between the treatments; ns indicates non-significance; ** and * indicate the significance at the 1% and 5% probability levels (p<0.01 and p<0.05), respectively; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

According to the mean comparison between the treatments, the water-washing + mineral oil treatment was more effective compared to the insecticide treatment in controlling the WPS nymphs, but despite a non-significant difference between the efficacy of these two compounds on control of WPS adult, the efficiency of water-washing + mineral oil was higher than that of the insecticide (Table 5).

The results of the t-test on May 25 and June 10, 2021 indicated that there was a statistically significant difference between the treatments in terms of efficacy in controlling WPS nymphs at the 1% probability level (p<0.01), while their efficiency in controlling the adult of *P. pentagona* showed a significant difference at the 5% probability level (p<0.05). The mean comparison of the efficiency of the two treatments on these dates showed that the water-washing + mineral oil treatment was significantly more effective compared to the insecticide treatment in controlling the nymphs and the adult of this pest (Table 5). The mean comparison of the treatments during the spring season showed that the water-washing + mineral oil treatment was significantly more effective compared to the insecticide treatment in controlling the different stages of growth and emergence of *P. pentagona* (Table 5).

Summer

As can be seen in Table 6, there was a significant difference between the treatments in terms of efficiency in controlling nymphs and adults of *P. pentagona* at the 1% probability level on June 25, 2021 (p<0.01).

Table 6. Mean comparison of the efficacy of the treatments in controlling nymphs and adults of *P. pentagona* on the different sampling dates in the summer of 2021.

Developmental stage	Sampling date	Mean (%)±SE‡		t-value
		INCS	WMO	
Nymph	June 25	52.22±1.26b	81.83±2.72a	9.72**
	July 11	70.50±1.67a	74.93±2.82a	1.35ns
	July 26	67.79±2.27b	76.46±2.22a	5.35**
	August 10	49.14±3.15b	77.90±2.71a	6.92**
	August 25	64.01±2.15b	77.13±3.80a	3.31*
	September 10	66.40±3.31a	73.76±3.27a	1.84ns
	Summer	61.68±3.42b	77.00±3.30a	6.12**
Adults	June 25	44.00±2.15b	69.00±2.50a	3.86**
	July 11	53.33±2.24b	65.00±2.08a	3.57**
	July 26	52.00±2.05b	72.67±3.88a	3.33*
	August 10	40.67±2.67b	74.00±3.52a	6.35**
	August 25	50.00±2.27b	66.67±2.56a	2.39*
	September 10	58.69±2.81a	67.38±3.02a	2.11ns
	Summer	49.78±2.41b	69.12±2.55a	4.44**

‡Different letters in each row indicate a significant difference between the treatments; ns indicates non-significance; ** and * indicate the significance at the 1% and 5% probability levels ($p<0.01$ and $p<0.05$), respectively; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

The mean comparison of the efficiency of two treatments on this date showed that the water-washing + mineral oil treatment was significantly more effective compared to the insecticide treatment in controlling nymphs and adults, respectively (Table 6). Based on the results of the t-test on July 11 (Table 6), no significant difference was observed between the treatments in the control of WPS nymphs ($p>0.05$), while the treatments showed a significant difference in terms of their efficiency in controlling the WPS adult. According to the mean comparison results, the water-washing + mineral oil treatment was more effective compared to the insecticide treatment in controlling the nymphs and the adults. A non-significant difference between the two treatments in controlling nymphs may be attributed to the application of insecticides for the second time on July 6, resulting in a higher efficiency than on the previous dates and reducing the difference with the water-washing + mineral oil treatment (Table 6).

The results of the t-test on July 26, August 10 and 25, 2021 showed that there was a significant difference between the treatments in terms of efficacy in controlling nymphs and adults of *P. pentagona* ($p<0.05$). The mean comparison of the efficiency of the two treatments on these dates showed that the water-washing + mineral oil treatment was always significantly more effective compared to the insecticide treatment in controlling nymphs and adults (Table 6).

Based on the results of the t-test on September 10 (Table 6), there was no significant difference between the treatments in terms of efficiency in controlling nymphs and adults of *P. pentagona* (p<0.05). Despite a non-significant difference between the treatments, the mean comparison of the efficiency of the two treatments showed that the water-washing + mineral oil treatment was more effective than the insecticide treatment in controlling the nymphs and the adults although this difference was not statistically significant (Table 6). This non-significant difference observed between the efficiency of the treatments can be due to the application of insecticides for the third time on August 21, which reduced the difference between the efficiency of these two treatments. Based on the mean comparison of the treatments in the summer season, the efficacy of water-washing + mineral oil in controlling the nymphal and adult stages of *P. pentagona* was significantly higher than that of the treatment with insecticides (Table 6).

Autumn

The results of the t-test presented in Table 6 show that on September 25 and October 13, there was a significant difference between the treatments in terms of efficiency in controlling the WPS nymphs and the adult at the 1% and 5% probability levels, respectively ($p<0.01$ and $p<0.05$).

The mean comparison of the efficiency of the two treatments on these dates also showed that the water-washing + mineral oil treatment was significantly more effective in controlling nymphs and adults compared to the insecticide treatment (Table 7).

Table 7. Mean comparison of the efficacy of the treatments in controlling nymphs and adults of *P. pentagona* on the different sampling dates in the autumn of 2021.

Developmental stage	Sampling date	Mean (%)±SE‡		t-value
		INCS	WMO	
Nymphs	September 25	51.43±2.47b	76.29±3.11a	5.33**
	October 13	40.00±2.12b	65.00±2.08a	4.33**
	November 1	36.67±2.33b	80.00±3.16a	4.91**
	November 15	20.00±1.72b	60.00±2.71a	6.79**
	Autumn	37.03±2.26b	70.32±3.13a	4.61**
Adults	September 25	46.33±2.54b	63.67±3.12a	3.63*
	October 13	36.67±2.05b	63.33±2.65a	3.34*
	November 1	44.00±2.45b	79.67±2.33a	12.79**
	November 15	36.33±2.16b	77.67±3.74a	5.57**
	Autumn	40.83±2.33b	71.09±2.19a	5.22**

‡Different letters in each row indicate a significant difference between the treatments; ** and * indicate the significance at the 1% and 5% probability levels ($p<0.01$ and $p<0.05$), respectively; INCS: insecticide treatment; WMO: water-washing and mineral oil treatment.

The results of the t-test on November 1 and 15, 2021 also showed that there was a significant difference between the treatments in terms of efficiency in controlling nymphs and adults of *P. pentagona* at the 1% probability level ($p<0.01$). The mean comparison of the efficiency of two treatments on this date also showed that the efficiency of the water-washing + mineral oil treatment was significantly higher than that of the insecticide treatment in controlling nymphs and adults (Table 7). The mean comparison of the treatments in the summer season revealed that the efficacy of the water-washing +

mineral oil treatment was significantly higher than that of the insecticide treatment in controlling the nymphal and adult stages of *P. pentagona* (Table 7).

The trend of changes in the efficacy of water-washing + mineral oil and insecticide in the control of different developmental stages of WPS showed that the efficiency of water-washing + mineral oil in controlling nymphs decreased with a very slight slope, while the insecticide efficiency continued to decrease despite three foliar sprayings at different intervals. Comparing the efficiency of these two treatments revealed that the efficiency of water-washing + mineral oil was higher than that of insecticides on all the dates (Figure 3).

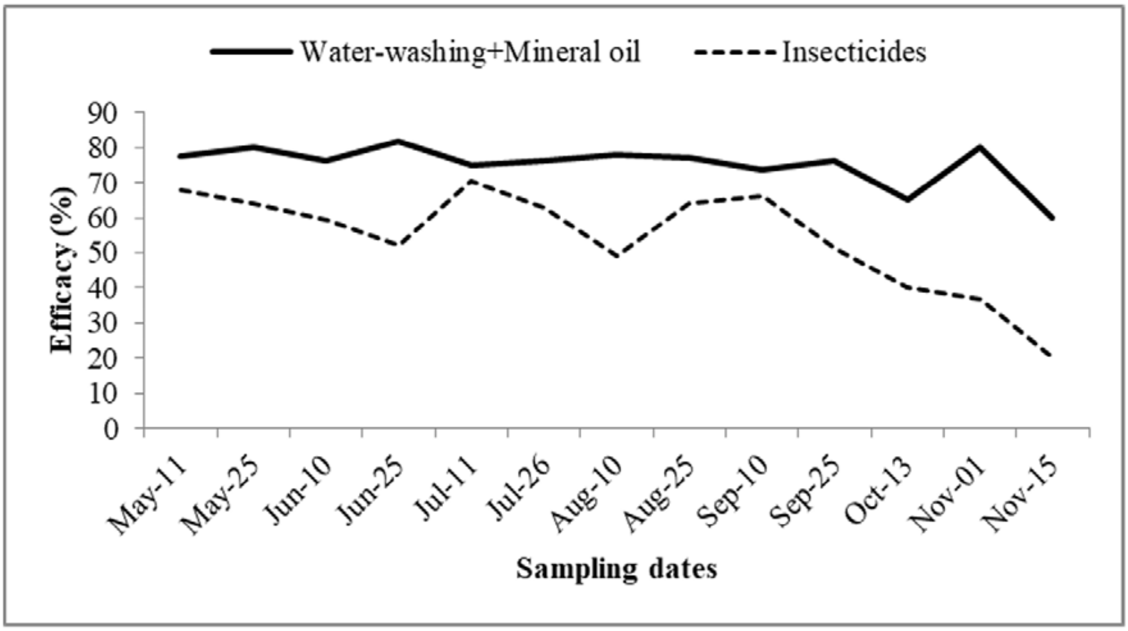

Figure 3.
The trend of changes in the efficacy of water-washing + mineral oil and insecticides in the control of WPS nymphs during the sampling dates.

The trend of changes in the effectiveness of the two compounds in relation to the control of the WPS adult was somewhat similar to that of the nymphs, although the efficacy of the water-washing + mineral oil treatment increased relatively on November 1, 2021. Comparing the efficiency of two treatments indicated that the water-washing + mineral oil treatment was more efficient than insecticides (Figure 4).

Scale insects are the most important agricultural pests on perennial plants and can cause serious damage to fruit trees. The wax coating in most species of scale insects protects them effectively from contact insecticides, so these compounds are only effective against newly hatched nymphs (Prakash and Patil, 2018). Currently, due to the special climatic conditions of the north of Iran that are favourable for the development of scale insects, chemical pesticides are used to control WPS as well as other scale insects (Sharifi et al., 2020). In recent decades, the widespread use of various chemical insecticides, which have a broad spectrum and are very stable, has plunged humanity into a crisis. One of the solutions to this problem is the use of bio-based and low-risk insecticides (Danae Toos et al., 2013). However, scale insects are often controlled using mineral oils and insecticidal soaps that dissolve the waxy coating, suffocate and finally kill them (Dreistadt et al., 2007; Soliman et al., 2007). In many cases, the results have shown that mineral oils are able to control pests at a level equivalent to that of chemical insecticides. For example, spraying boxwoods with the mineral oil controlled the Euonymus scale, *Unaspis euonymi* (Comstock) (Hemiptera: Diaspididae) as well or even better than synthetic pesticides such as pyrethroids and acephate and chlorpyrifos (both of organophosphate insecticides) (Gholamzadeh-Chitgar et al., 2018; Raupp et al., 2001).

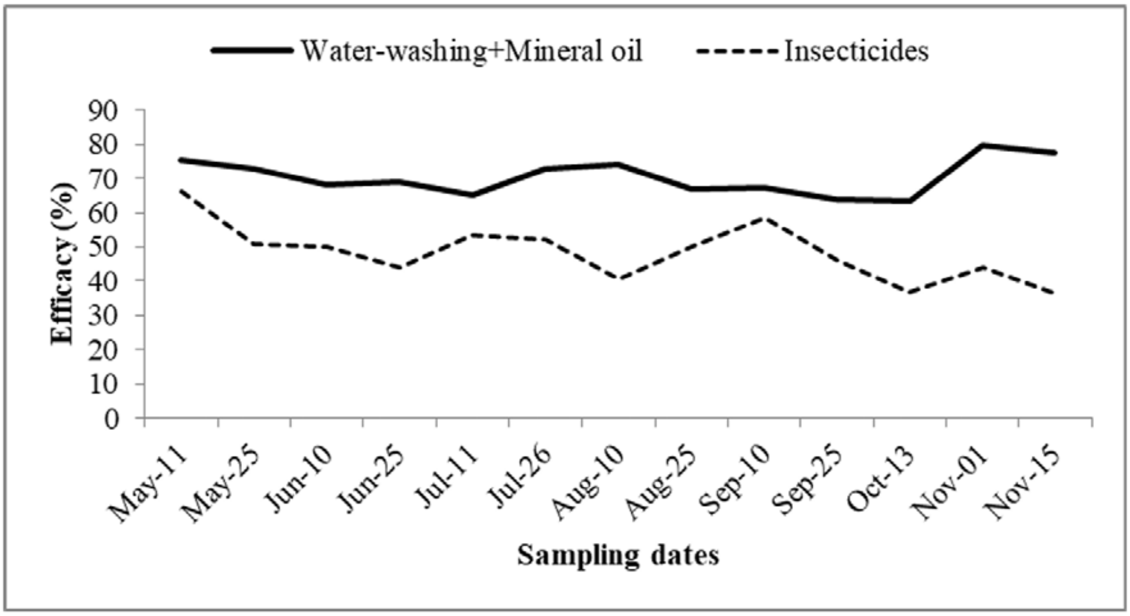

Figure 4.
The trend of changes in the efficacy of water-washing + mineral oil and insecticides in the control of WPS adults during the sampling dates.

The results of the present study show that spraying the trees once with mineral oil in winter provided better control of the population of nymphs and adults of *P. pentagona* than spraying three times with the insecticides ethion and chlorpyrifos. Considering the significant activity of this pest in peach orchards in spring and summer, we focus on the results obtained in these two seasons. The results of the current research in spring show that the use of water-washing + mineral oil in the winter control against the WPS had a significant effect on reducing the population of nymphs and adults of this pest in peach orchards, so that this treatment caused a decrease of more than 80% (average of 80.25% and range of 76.33–84.76%) in the population of nymphs and more than 75% (average of 75.71% and range of 68.10-83.73%) in the adult population. The results after the application of insecticides on May 11 also showed that foliar spraying by using the insecticides resulted in a reduction of more than 65% in the population of nymphs and adults compared to water-washing + mineral oil (reduction of more than 75%). On May 25, the reduction rate of the population of nymphs and adults caused by the insecticides was 64.05% and 51.00%, respectively, which was significantly different compared to water-washing + mineral oil (the decreases of 80.27% and 73%, respectively). The results obtained on June 10 showed that the reduction of the pest population due to the application of the insecticides (59.33% and 50.00% for nymphs and adults, respectively) was significantly lower than that caused by applying water-washing + mineral oil (76.33% and 68.10% for nymphs and adults, respectively).

Based on the results obtained in summer, the range of efficiency of water-washing + mineral oil in reducing the population of nymphs and adults was 73.76-81.83% and 65–74%, respectively, and the average was 77.01% and 69.12%, respectively, while the range of effectiveness of insecticides used on the above developmental stages was 49.14–70.50% and 40.67–58.69%, respectively, and the average was 60.84% and 49.78%, respectively. According to the six dates of sampling in summer, only on two dates, i.e., July 11 and September 10, 2021, no significant difference was observed between the efficiency of water-washing + mineral oil and insecticides in controlling nymphs and adults of *P. pentagona*, but on the other four dates, there was a significant difference between the efficiency of these treatments. It is worth noting that on all the sampling dates in this season, the efficiency of water-washing + mineral oil in controlling nymphs and adults was higher than that of insecticides. In the research conducted by Mafi Pashakolaei et al. (2015), it was revealed that the treatments of brushing the tree trunks and spraying with mineral oil were effective at a rate of 2.5% (73.61%), spraying twice with mineral oil at 2.5% intervals of one month (60.75%) and spraying once with mineral oil at a rate of 2.5% (57.63%) caused the highest mortality in overwintering adult females of *P. pentagona* within 60 days after treatment. These researchers have stated that for a successful integrated control against the mulberry scale, it is recommended to prune the branches infested by the pest at the appropriate time, brush the tree trunks along with spraying mineral oil at a rate of 2.5% in winter. In the present study, applying water-washing + mineral oil at a rate of 5% in winter had a significant efficacy in controlling the WPS population in spring, summer and even in autumn, which is consistent with the findings of the above study.

Bazrafshan et al. (2010) studied the effect of five insecticides, diazinon, azinphosmethyl, chlorpyrifos, methoxyfenozide, spinosad, and emulsifiable mineral oil on the female WPS adults by the dipping method in laboratory conditions in Iran and showed that only the mineral oil has moderate toxicity to *P. pentagona*, and that it can be used as an alternative to insecticides or along with them due to its less harmful effects on humans and the environment. The results reported by Gholamian et al. (2013) showed that spraying with chlorpyrifos + mineral oil at a rate of 1% and mineral oil spraying at a rate of 2% caused the highest mortality in the overwintering generation of *P. pentagona* on kiwifruits and oil spraying at a rate of 0.5% had the minimum control effect on this pest. The results of the present study also showed the significant effect of mineral oil spraying at a rate of 5% on the control of the WPS, so that on the sampling dates, applying mineral oil along with water-washing caused the greatest decrease in the population of nymphs and adults of *P. pentagona*.

Research conducted in Carolina's orchards showed that winter oil spraying against WPS on peach trees resulted in a 93% reduction in the pest population (Meyer and Nalepa, 1991). Smith (1969) also found that spraying overwintering WPS females twice with mineral oil at a rate of 3% at two-week intervals can destroy 100% of the pest population. The research conducted in the Qalyubia governorate of Egypt on the nymphs and adults of *P. pentagona* in field conditions showed that the mineral oils used (misrona oil 85% mayonnaise and alboleum oil 80% mayonnaise) were more effective against *P. pentagona* populations than neem extracts and fenitrothion 50%EC after five weeks of application. The mineral oils reduced the pest population by 89% (misrona oil) and 88.3% (alboleum oil), while fenitrothion and neem extracts were ranked next with 79.3% and 66.4% efficacy, respectively (Kwaiz et al., 2009).

Zhuang et al. (2015) stated that the mineral oil "EnSpray 99" showed good efficacy against the first nymphal instars of the WPS, *P. pentagona*, and its residues prevented the settlement of mobile nymphs or crawlers for approximately 12 days after oil application. The mineral oil spraying was safe and had no phytotoxicity when applied to kiwifruits to control this scale insect for the first generation of nymphs (4–18 days after fruit set). Also, the application of 1% mineral oil to the first nymphal instars of the first generation and the second generation reduced the number of fruits infested by *P. pentagona*.

The results of the studies conducted on the efficiency of mineral oils in controlling other scale insects were also positive. In the study conducted on *U. euonymi*, it was reported that spraying boxwood with mineral oil to control the first nymphal instars of *U. euonymi* by using emulsifiable oil and mayonnaise oil at rates of 0.5% and 0.7% showed efficiencies of 22.5% and 42.6%, and 30.2% and 40.6%, respectively (Gholamzadeh-Chitgar et al., 2018). The laboratory results of the study by Ghaffari Lashkenari and Damavandian (2013) regarding the response of the female adult of *Chryaomphalus dictyospermi* Morgan (Hemiptera: Diaspididae) to concentrations of 0.5%, 0.75%, 1%, 1.2%, and 1.5% showed that this scale insect can be controlled by mineral oil, and the most appropriate rate of mineral oil to control *C. dictyospermi* female adult is between 1.138% and 1.663%. Xiao et al. (2016) showed that spraying mineral oil (SuffOil-X®) three times on cycads and camellia caused a 90.36% and 100% decrease in the populations of *Aulacaspis yasumatsui* Takagi and Fioriniatheae Green (Hemiptera: Diaspididae) over 3–4 and 5 months, respectively. In Chile, Sazo et al. (2008) found that spraying mineral oil once at a rate of 1% reduced up to 73.94% and 88.10% of the population of the first generation of nymphs of the San Jose scale, *Diaspidiotus perniciosus* Comstock (Hemiptera: Diaspididae) on almond and apple trees, respectively, while two sprays with mineral oil caused a decrease of 91.49% and 80.95% in the population of nymphs on almond and apple trees, respectively. Quesada and Sadof (2017) reported that, in the field conditions, horticultural oil had 90% and 40% efficacy when applied to the first nymphal instars and adults of pine needle scale (*C. pinifoliae*) and oleander scale (*A. nerii*), respectively. These results show that mineral oil has a significant efficiency in controlling the different developmental stages of the scale insects, and the findings of the present study are in agreement with these results.

CONCLUSION

Considering the severe and widespread damage caused by *P. pentagona* in peach orchards of northern Iran, many efforts have been made to control this pest using conventional chemical pesticides, while suppressing the population of the 2nd and 3rd instar nymphs of WPS and female adults is difficult due to developing a waxy armour on their body. The results of the present study show that winter control by a single water-washing and mineral oil spraying at a rate of 5% reduced the WPS population on peach trees in the spring and then reduced the damage caused by this pest in the following seasons, i.e., summer and autumn, so that no chemical insecticides need to be used in these seasons. Since mineral oil is less dangerous for humans and safe for natural enemies of the pests, pollutes the environment much less compared to synthetic pesticides, and no pest resistance to this compound has been observed, it can be used to control this pest, minimising the use of chemical insecticides.

Acknowledgments

The authors would like to express their gratitude to the Department of Plant Protection and Central Laboratory of Sari Agricultural Sciences and Natural Resources University for providing the necessary facilities and equipment.

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Kombinacija mineralnog ulja i ispiranja vodom kao efikasan način suzbijanja *Pseudaulacaspis pentagona* (Targioni-Tozzetti) (Hemiptera: Diaspididae)

Sažetak:
Ova studija imala je za cilj da proceni efikasnost zimskog suzbijanja ispiranjem vodom u kombinaciji sa mineralnim uljem u poređenju sa ponovljenom primenom insekticida u suzbijanju *Pseudaulacaspis pentagona* (Targioni-Tozzetti) u zasadima breskve u provinciji Mazandaran. Eksperiment je sproveden po potpuno slučajnom dizajnu sa tri tretmana i pet ponavljanja u zasadu breskve koji se nalazi u selu Makran, grad Miandorud: (1) hlorpirifos (Chlorpyrifos-methyl Kavosh®, 40% EC) i etion (Ethion Kavosh®, 47% EC) u koncentraciji od 2 L/1000 L vode, (2) ispiranje vodom + mineralno ulje (Volk Kavosh®, 90% EC) u odnosu 5% (V/V), i (3) kontrola (bez prskanja). Rezultati su pokazali da postoji značajna razlika u efikasnosti između tretmana ispiranjem vodom u kombinaciji sa mineralnim uljem u poređenju sa hemijskim insekticidima u suzbijanju P. pentagona. Ispiranje vodom i prskanje mineralnim uljem pokazalo je efikasnost od 80,25% u suzbijanju nimfi odnosno 75,71% u suzbijanju odraslih jedinki *P. pentagona* tokom prolećne sezone. Efikasnost pomenutog tretmana u smanjenju populacije nimfi i odraslih ženskih jedinki tokom letnje sezone iznosila je 77,00%, odnosno 69,12%. Zabeležena je efikasnost od 70,32% u suzbijanju populacija nimfi i 71,09% u suzbijanju odraslih jedinki ovog štetnog insekta prilikom ispiranja vodom u kombinaciji sa mineralnim uljem tokom jesenje sezone. S druge strane, efikasnost insekticida na nimfe i odrasle jedinke iznosila je 63,70% i 55,78% u proleće, 61,68% i 49,78% u leto, te 37,03% i 40,83% u jesen. Kao rezultat toga, nalazi su pokazali da zimsko suzbijanje sa jednom primenom tretmana ispiranjem vodom u kombinaciji sa mineralnim uljem ima višu i značajnu efikasnost nego tri primene hemijskih insekticida.

Ključne reči: bela breskvina štitasta vaš; mineralno ulje; hemijski insekticid; efikasnost