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Susceptibility of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) to Different Insecticides under Water Hardness Condition and Additives

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ABSTRACT

Water hardness can negatively affect the efficiency of pesticides. This study aimed to determine the effect of water hardness and adjuvants added to spray solution on the efficiency of insecticides. Three insecticides, namely, malathion, acetamiprid, and spiromesifen, were mixed in well water samples at 1,869, 645, and 265 mg L^{-1} hardness, standard, and deionized water, and applied against the second instar nymph of *Bemisia tabaci* using leaf dip method. In another experiment, Zero-7 at 150 ppm and Arkan at 180 ppm as additives were added to water with 1869 and 645 mg L^{-1} hardness, separately. LC_{50} values showed that the toxicity of malathion, acetamiprid, and spiromesifen was 40, 157, and 84 times less in hard water (1,869 mg L^{-1} hardness) than deionized water. The efficacy of malathion, acetamiprid, and spiromesifen was 13, 65, and 39 times less when they were diluted in water with 645 mg L^{-1} hardness than deionized water. Malathion provided 37.28 and 18.59% greater toxicity when applied in hard water containing Zero-7 and Arkan than water without the adjuvants. The efficacy of acetamiprid was, respectively, 16.93 and 18.68% greater when it was applied in hard water containing Zero-7 and Arkan compared to water without the additives. Zero-7 and Arkan in hard water enhanced the efficacy of spiromesifen by 10.26 and 13.68% compared to water without adjuvants. Generally, the toxicity of the insecticides on *B. tabaci* was considerably reduced at the highest levels of water hardness. In contrast, adjuvants overcame the antagonistic effects of cations in hard water.

Keywords: Acetamiprid, Adjuvants, Efficacy, Hard water, Malathion, Spiromesifen.

INTRODUCTION

Most spray solutions are made up of 99% water (Altland, 2010). The most significant parameters affecting water quality are hardness, pH, electrical conductivity, and turbidity (Odero, 2011; Roskamp *et al.*, 2013). Water is usually considered hard when it contains more than 500 mg L^{-1} Ca^{2+} and/or Mg^{2+} (Pratt *et al.*, 2003). Several researchers have reported that the pesticide activity decreases by increasing water hardness (Nalewaja and Matysiak, 1991; Thelen *et al.*, 1995). The researchers reported that the toxicity of propargite, spirodiclofen, and hexythiazox on *Brevipalpus phoenicis* decreased when they were diluted in water containing 438 mg L^{-1} $CaCO_3$ than in water with 342 mg L^{-1} hardness (Pereira *et al.*, 2011). Other researchers concluded that the velvetleaf (*Abutilon theophrasti*) control was enhanced from 37 to 65% by glyphosate and 16 to 33% by glufosinate in deionized water compared to tap water containing 427 mg L^{-1} $CaCO_3$ (Pratt *et al.*, 2003). The performance of glyphosate decreased when it was diluted in water with 1,799 mg L^{-1} hardness than distilled water with 353 mg L^{-1} hardness (Soltani *et al.*, 2011).

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It has been shown that adding adjuvants such as Ammonium Sulfate (AMS) can solve the hard water cation antagonism problem and increases pesticide efficiency (Pratt *et al*., 2003; Soltani *et al*., 2011). Researchers reported that the velvetleaf biomass was reduced by up to 93% when glyphosate was applied with AMS, and by 77% when it was applied without AMS (Mahoney *et al*., 2014). Other researchers reported that glyphosate and glufosinate caused a decreased velvetleaf control rate of 53 to 37% and 33 to 16%, respectively, when applied in tap water containing 427 mg L^{-1} $CaCO_3$ than in deionized water. In contrast, adding adjuvants increases weed control by up to 60% (Pratt *et al*., 2003). In another study, the mesotrione efficacy was reduced on giant ragweed (*Ambrosia trifida*), horseweed (*Erigeron canadensis*), and Palmer amaranth (*Amaranthus palmeri*) by 28, 18, and 18%, respectively, when water hardness increased from 0 to 1,000 mg L^{-1} $CaCO_3$. The addition of AMS enhanced the mesotrione efficiency by 9, 6, and 9%, on the three weed species, respectively (Devkota *et al*., 2016). In a study, it was found that 2, 4-D effectiveness was reduced on dandelion (*Taraxacum officinale*) and broadleaf Plantain (*Plantago major*) when used in water containing 594 mg L^{-1} $CaCl_2$ and 633 mg L^{-1} $MgSO_4$, respectively (Patton *et al*., 2016).

The cotton whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is one of the principal pests in tropical and subtropical areas around the world. It is also a key pest in the greenhouse that causes yield losses in economically critical crops (McKenzie *et al*., 2014; Yuxian *et al*., 2011). The control of the injurious population of *B. tabaci* is generally reliant on the use of insecticides (Sequeira and Naranjo, 2008; Wilson *et al*., 2018), although insecticides sometimes do not have the necessary effectiveness (Kachilli, 2005). Pesticide performance is influenced by many variable parameters such as pesticide selection, pesticide concentration, mixing compounds, pesticide resistance, and weather conditions at the time of spraying. However, a major factor that is often not considered is the effect of water quality on pesticide activity (Fishel and Ferrell, 2010).

Climate changes and frequent droughts have affected the ground water level in the southern areas of Iran, resulting in changes in some water quality properties such as hardness, pH, and electrical conductivity (Basirat *et al*., 2007; Heidari *et al*., 2019). There is little information about the effect of water hardness and adjuvants on the efficacy of insecticides on *B. tabaci* in the laboratory condition.

Considering the above-mentioned explanations, the present study was carried out with the objectives to determine whether water hardness influences the toxicity of pesticides and to determine whether the addition of adjuvants to water could decrease the antagonistic effect of hard water cations.

MATERIALS AND METHODS

This study was carried out at South Kerman Agricultural and Natural Resources Research and Education Center, Iran, in 2019-2020.

Water Hardness Study

Water samples were collected from 11 greenhouse cultivation areas in Kerman Province (30° 24' 35.21'' N, 56° 54' 55.7'' E), Iran, and transferred to the Soil Science Laboratory of the Agriculture and Natural Resources College, University of Tehran, to determine their physicochemical properties. Then, three water samples at different hardness levels were selected from 11 samples along standard and deionized water to use for the bioassay. Sampling was performed in July and October 2019 (Table 1).

Standard water was prepared using the CIPAC method (Handbook F, MT 18.1, P: 59) (CIPAC, 2016). In this procedure, 403

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Table 1. Physicochemical properties of well water samples used for bioassay. [a]

Water	pH		EC (µs cm^{-1})		TDS (mg L^{-1})		Ca (mg L^{-1})		Mg (mg L^{-1})		TH (mg $CaCO_3$ L^{-1})	
	1	2	1	2	1	2	1	2	1	2	1	2
w_1	7	7.5	7330	7060	5200	4589	310	320	248	260	1794.84	1869.2
w_2	7.6	7.7	2990	2900	1950	1885	95	79	110	109	689.97	645.97
w_3	7.6	7.8	997	960	650	624	71	75	23	19	271.95	265.48

[a] 1 and 2: First (9/7/2019) and second (9/10/2019) sampling; pH: Acidity; EC: Electrical Conductivity; TDS*:* Total Dissolved Solids, TH: Total Hardness.

mg $CaCl_2$ $2H_2O$ and 139 mg $MgCl_2$ $6H_2O$ were added into a beaker containing 980 mL of deionized water, stirred, and adjusted to a final volume of 1000 mL. This water sample at 342 mg L^{-1} hardness is considered as standard by the FAO and CIPAC and is often used as standard grade D **(**CIPAC, 2016).

To evaluate the influence of water hardness on the efficacy of insecticides, a concentration–response bioassay was carried out in the laboratory condition. Cucumber plant variety Emperator from Seminis Company was used for the bioassay. The plants were grown in plastic pots containing a 3:2 mixture of coco peat and perlite enriched with the NPK fertilizer (20:20:20).

Adults of *B. tabaci* (B biotype) were collected from the cucumber greenhouses of Southern Kerman. A blower-vac was used to collect adult whiteflies into a lace bag placed in the entrance of the vacuum port. The collected insects were transferred into cages (50×40×70 cm) each containing two potted cucumber plants. The cages were located in a growth chamber set at 25±1°C, 65±5% RH and LD 16:8 hours. Whitefly was reared up to six generations on cucumber to establish a laboratory colony without contact with insecticide. For synchronization, the cucumber plants were artificially infected based on the IRAC method (NO: 016) to obtain cohorts in the second instar nymph stage. Fifty male and female whiteflies were transferred into a rearing cage (40×35×60 cm) containing a potted cucumber plant using an aspirator. Adults were kept in cages for 24 h to lay eggs, and then removed. Nine days after removing the insects, the synchronous 2nd instar nymphs were used for the bioassay (IRAC, 2009).

The commercial formulation of insecticides, spiromesifen (SC 24%, Bayer Company, Germany), malathion (EC 57%, Samiran Company, Iran) and acetamiprid (SP 20%, Gyah Company, Iran) were used for experiments.

The insecticides were diluted with the target water samples at 1,869, 645, 265 mg L^{-1} hardness levels, standard, and deionized water. The diluted insecticide solution contained 0.02% triton X-100 as a non-ionic wetting agent. A preliminary assay for each insecticide was carried out to achieve the mortality range of 25-75%. Then, the final five concentrations were calculated by logarithmic relations and used to determine LC_{50} values (Robertson and Priesler, 1992). Each treatment was performed with three replicates, and the bioassay was repeated twice. In each experimental unit, 15 to 20 insects were used, with an average of 100 insects per concentration.

The leaf dip method was used for the bioassay test (Nauen *et al*., 2008; Cuthbertson *et al*., 2009; Yuxian *et al*., 2011). Leaf discs containing 2nd instar nymph were cut to fit 40 mm diameter Petri dishes and were immersed for 10 s into the serial dilution of the insecticide concentrations. Then, they were allowed to dry in air and kept in petri dishes embedded with a thin layer of 1.5% agar gel.

The control leaf discs were dipped in deionized water containing 0.02% triton X-100. The treated Petri dishes were incubated in a growth chamber at 25±1°C, 65±5% RH and LD 16:8 hours. The mortality of the insects was assessed 24, 72, and 96 hours

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after treatment with malathion, acetamiprid and spiromesifen, respectively, using a stereo microscope (Nauen *et al*., 2008). Nymphs were considered dead if their bodies were brown and dry (Cuthbertson *et al*., 2009).

Statistical Analysis

The probit analysis of the bioassay data was carried out using Polo-Plus software (LeOra Software Company, 2007). The lethal dose ratio was used for statistical differences between the LC_{50} values and considered significant if confidence intervals (95% CLs) did not include the value one (Robertson and Priesler, 1992).

Adjuvant Study

As adjuvants, Zero-7 (Z-7) (Sabz Typh Products, Iran) and Arkan (Ar) (Nutrica Organic Agriculture Company, Iran) were provided from the market and added to water samples at 1,869 and 645 mg L^{-1} hardness and at the rate of 150 and 180 ppm, respectively. The insecticide was added in the last stage (McMullan, 2000). The concentration of the adjuvants was determined based on initial experiments. The LC_{50} value calculated from the initial experiment was used for each pesticide. The leaf dip method was applied for the bioassay test, as described earlier (Nauen *et al*., 2008; Cuthbertson *et al*., 2009). The number of dead nymphs was recorded 24, 72, and 96 hours after treatment with malathion, acetamiprid, and spiromesifen, respectively. Adjusted mortality percentage was calculated using Abbott's formula (Abbott, 1925).

Statistical Analysis

The experiment was performed using a Completely Randomized Design (CRD). The mortality data were analyzed using PROC GLM procedure in SAS 9.2 (SAS Institute) appropriate for the factorial arrangement of the treatments. Tukey comparison test at P< 0.05 was used for analysis. Slicing analysis was also performed, if the interaction between the factors was significant.

RESULTS AND DISCUSSION

Water Hardness Study

Analysis of the bioassay data showed that the efficiency of the insecticides on the 2nd instar nymphs of *B. tabaci* was influenced by water hardness. The LC_{50} values of acetamiprid, malathion, and spiromesifen were calculated as 68.57, 64.02, and 39.79 ppm, respectively, in water with 1,869 mg L^{-1} hardness. The insecticides provided the highest toxicity in deionized water. The malathion efficacy increased by 40.8, 13.22, and 8.06-fold when it was applied in deionized water than in well water at 1869, 645, and 265 mg L^{-1} hardness, respectively. Malathion was 12.24-, 3.96-, and 2.42-fold more toxic to *B. tabaci* in standard water than in water at 1,869, 645, and 265 mg L^{-1} hardness.

The acetamiprid efficacy was 157.3, 65.1, and 43.3 times higher in deionized water than in well water at, respectively, 1,869, 645, and 265 mg L^{-1} hardness. Acetamiprid was 23.2, 9.6, and 6.4 times more toxic when applied in standard water than in well water at, respectively, 1,869, 645, and 265 mg L^{-1} hardness (Table 2).

The spiromesifen performance was 84.9, 39.8, and 18.6 times better in the solution prepared from deionized water than well water at, respectively, 1,869, 645, and 265 mg L^{-1} hardness. The spiromesifen toxicity was reduced by 10.4-, 4.9-, and 2.3-fold when applied in well water at, respectively, 1,869, 645, and 265 mg L^{-1} hardness compared to standard water. The performance of spiromesifen and malathion was better than acetamiprid in the solution prepared with water at 265 and 645 mg L^{-1}

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Table 2. LC_{50} values of insecticides in different water samples on 2nd instar nymph of *B. tabaci*

Insecticide	Water[a]	LC_{50} (ppm)	(95%CL)	Slope (±SE)	χ^2 (df)	Heterogeneity factor
Malathion	w_1	64.02	(12.74-95.82)	1.57(±0.51)	1.64(13)	0.13
	w_2	20.74	(1.22-35.7)	1.31(±0.47)	1.83(13)	0.14
	w_3	12.65	(2.7-20.53)	1.53(±0.43)	1.99 (13)	0.16
	sw	5.23	(0.66-9.76)	1.39(±0.39)	3.17(13)	0.25
	di	1.57	(0.1-3.75)	0.93(±0.25)	2.55(13)	0.19
Acetamiprid	w_1	68.57	(10.65-98.43)	2.43(±0.85)	1.33(13)	0.1
	w_2	28.36	(5.6-39.59)	2.02(±0.7)	1.66(13)	0.13
	w_3	18.88	(6.4-26)	2.2(±0.64)	1.52(13)	0.12
	sw	2.96	(0.33-5.3)	1.66(±0.51)	1.13(13)	0.087
	di	0.44	(0.01-1.2)	0.92(±0.27)	2.1(13)	0.16
Spiromesifen	w_1	39.79	(11.77-52.05)	3.52(±0.98)	1.15(13)	0.089
	w_2	18.66	(4.5-25.31)	3.28(±0.87)	1.88(13)	0.14
	w_3	8.72	(1.31-13.1)	2.33(±0.78)	1.07(13)	0.082
	sw	3.82	(0.8-6.26)	1.75(±0.48)	3.32(13)	0.26
	di	0.47	(0.01-1.34)	0.88(±0.26)	2.1(13)	0.16

[a] w_1, w_2, w_3: Well water with hardness 1869, 645, 265 mg L^{-1} respectively; sw: Standard water, di: Deionized water.

hardness (Figure 1). The lethal dose ratio was used to determine a significant difference between the LC_{50} values. There was a significant difference in the performances of the insecticides when they were applied in water at 1,869 mg L^{-1} hardness compared to the other solution. The lethal dose ratio showed that there was no difference in the toxicity of insecticides in 645 mg L^{-1} hardness water compared to 265 mg L^{-1} hardness (Table 3).

The efficacy of malathion and spiromesifen was not significantly different in the solutions prepared from water at 265 mg L^{-1} hardness compared to standard water. However, compared to standard water, the LC_{50} ratio of acetamiprid in water with 265 mg L^{-1} hardness was different (Figure 2).

The basis of hard water antagonism was described for glyphosate. Nuclear magnetic resonance spectrometry was used to evaluate the effect of carrier solutions on glyphosate activity based on ^{14}C-glyphosate absorption. Several researchers proposed that Ca^{2+} coordinated to carboxyl, phosphonate, or unpaired amine electron groups of glyphosate molecules and formed a trident structure (Madsen *et al*., 1978; Motekaitis and Martell, 1985; Thelen *et al*., 1995). Subramaniam and Hoggard (1988) described the formation of a tetradentate ligand by the coordination of Ca^{2+} through amine nitrogen, carboxylate oxygen, and two phosphonate oxygens. The dissociated glyphosate molecule can act as a chelating agent, forming stable herbicide–metal complexes with cations present in hard water .These complexes decrease pesticide absorption and translocation and result in reduced efficiency (Pratt *et al*, 2003; Patton *et al*, 2016).

Dyguda-Kazimierowicz *et al*. (2014) explained hydroxide ion reacted with malathion in water by hydrolysis process and bound to the central phosphorus, then lost its proton. According to the theory of

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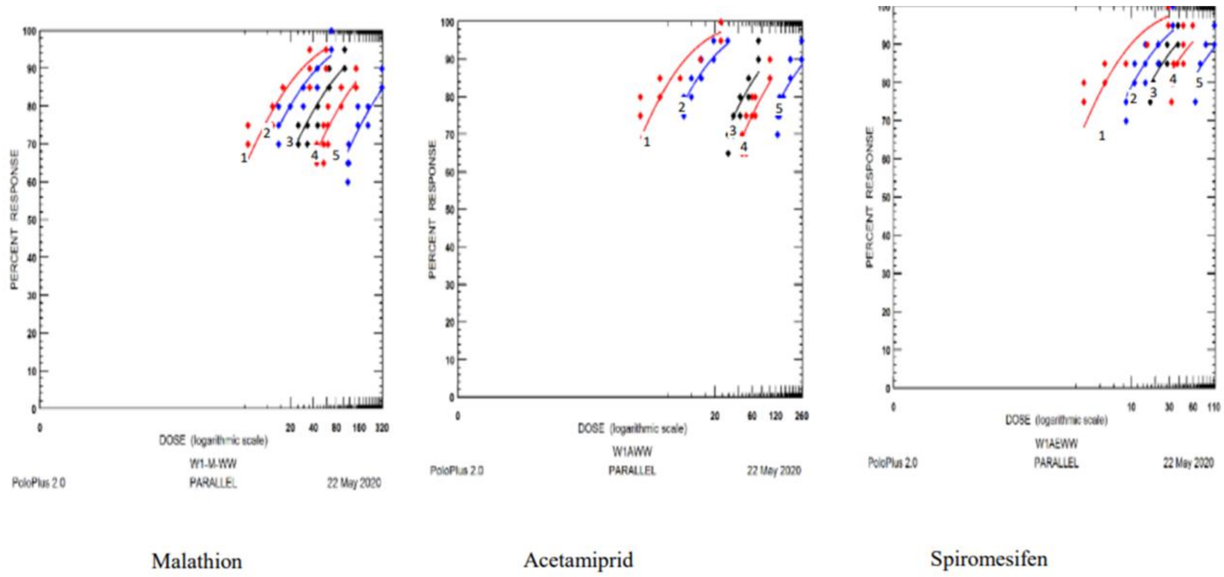

Figure 1. Dose-Response lines of experimental insecticides in water samples.

Table 3. Lethal dose ratio (LC_{50}) of insecticides in water samples.

	Malathion				Acetamiprid			Spiromesifen		
Water ratio[a]	Ratio*	Limits 0.95	Sig	Ratio*	Limits 0.95	Sig	Ratio*	Limits 0.95	Sig
w_1/w_2	3.08	(1.02-9.35)	*	2.42	(1.1-5.48)	*	2.13	(1.09-4.16)	*
w_1/w_3	5.06	(1.91-13.43)	*	3.63	(1.66-7.93)	*	4.56	(2.05-10.17)	*
w_1/sw	12.24	(3.85-38.85)	*	23.2	(7.7-69.93)	*	10.42	(4.35-25)	*
w_1/di	40.8	(9.37-177.62)	*	157.34	(28.8-259.63)	*	84.92	(15.42-167.57)	*
w_2/w_3	1.64	(0.51-5.27)	ns	1.5	(0.72-3.14)	ns	2.14	(0.93-4.94)	ns
w_2/sw	3.96	(1.06-14.86)	*	9.6	(3.3-28.05)	*	4.89	(1.97-12.12)	*
w_2/di	13.22	(2.66-65.77)	*	65.1	(12.15-148.57)	*	39.84	(7.11-123.13)	*
w_3/sw	2.42	(0.72-8.13)	ns	6.4	(2.25-18.17)	*	2.3	(0.83-6.26)	ns
w_3/di	8.06	(1.77-36.74)	*	43.33	(8.23-98.1)	*	18.61	(3.14-71/18)	*
sw/di	3.33	(0.65-17.14)	ns	6.8	(1.1-42.47)	*	8.15	(1.33-49.88)	*

[a] w_1, w_2, w_3: Well water with hardness 1,869, 645, 265 mg L^{-1} respectively; sw: Standard water, di: Deionized water.

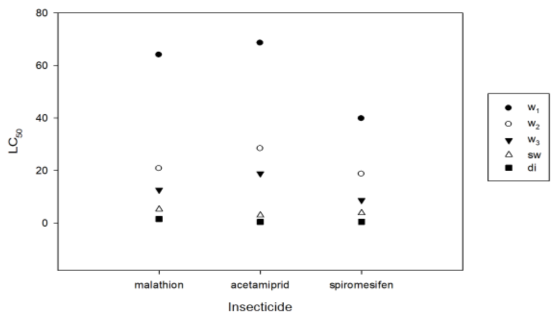

Figure 2. LC_{50} values of insecticides in water samples.

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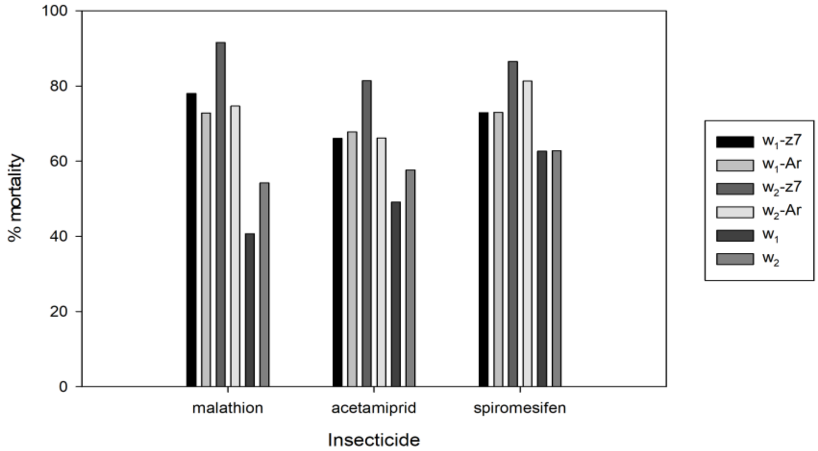

Figure 3. Mortality percentage of 2nd instar nymph of *B. tabaci* in insecticide solution with/without additive. w_1, w_2: Water with 1869 and 645 mg L^{-1} hardness; z7: Zero-7, Ar: Arkan.

Thelen *et al*. (1995), Ca^{2+}can bind to negatively charged oxygen.

Huan *et al*. (2016) and Todey *et al*. (2018) reported that acetamiprid reacted with hydroxide ions or water molecules in an aqueous medium, and that oxygen from the hydroxide group bound to the central carbon of the acetamiprid and, afterward, lost its proton. Based on Thelen *et al*. (1995), Ca^{2+} can coordinate to negatively charged oxygen and formed pesticide-cation salt, resulting in efficacy reduction.

The ester group in spiromesifen molecules can hydrolyze in an aqueous medium and forms enol metabolite, which is further metabolized by the hydroxylation of methyl groups or the cyclopentyl ring (Babczinski and Arthur, 2005). The dissipated molecule possesses an oxygen atom with negative charge (Doherty, 2018; SPEX Certipreb, 2017) that can bind to Ca^{2+} present in the spray solution according to Madsen *et al*. (1978) and Thelen *et al*. (1995).

Adjuvants Study

There was significant interaction ($\alpha < 0.05$) between the experimental factors, therefore, slicing analysis was also performed (Table 5). Regardless of water hardness, addition of the adjuvants to the spray solution enhanced the performance of the pesticides on *B. tabaci*. The three insecticides provided the highest toxicity on whitefly nymph in 645 mg L^{-1} hardness water containing Zero-7 (Z-7). The performance of the insecticides was not influenced by adjuvant type, when they were applied in water at 1,869 mg L^{-1} hardness. Because the mortality percentage of *B. tabaci* by insecticide in hard water containing Z-7 or Ar was not different.

The toxicity of malathion was significantly different with acetamiprid when they were applied in both the water samples containing Z-7 (Table 4). The efficacy was not meaningfully different between malathion and spiromesifen after adding Z-7 to water with 1,869 mg L^{-1} hardness. Toxicity was not different between the three insecticides in water with 1,869 mg L^{-1} hardness with Ar (Table 4). In contrast, there was significant difference in the efficacy of the insecticides when they were applied in water at 645 mg L^{-1} hardness containing Ar (Figure 3).

In water with 1,869 mg L^{-1} hardness containing Z-7 and Ar, Malathion efficacy was, respectively, 37.28 and 32.1% greater than water without the adjuvants. Compared to water without the additives, Malathion provided 37.36 and 20.43% greater toxicity in water with 645 mg L^{-1} hardness containing, respectively, Z-7 and Ar. However, Malathion performance was better in water with 1,869

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Table 4. Mortality percentage of 2nd instar nymph of *B. tabaci* in insecticide solutions with/without adjuvants.[a]

Treatment[b]	Malathion (Mean±SE)	Acetamiprid (Mean±SE)	Spiromesifen (Mean±SE)
w_1	40.70±0.2 d	49.12±0.05 d	62.63±0.09 c
w_1+Z-7	77.98±0.73 b	66.05±0.53 b	72.89±0.9 b
w_1+Ar	72.80±0.68 b	67.80±0.67 b	72.98±0.43 b
w_2	54.21±0.37 c	57.63±1.02 c	62.80±0.12 c
w_2+Z-7	91.57±0.25 a	81.40±0.88 a	86.49±0.94 a
w_2+Ar	74.64±0.91 b	66.14±0.49 b	81.31±0.68 a

[a] Means followed by the same letter within a column are not significantly different according to Fisher's protected Tukey at P< 0.05. [b] w_1, w_2: Well water with 1869 and 645 mg L^{-1} hardness; Z-7: Zero-7, Ar: Arkan.

Table 5. Analysis of slicing based on significant test of LSmeans values.[a]

Treatment		A	S		S
w_1+ Z-7		0.0003**	0.09ns		0.02*
w_1+ Ar	M	0.051ns	0.95ns	A	0.045*
w_1		0.007**	< 0.0001**		< 0.0001**
w_2+ Z-7		0.001**	0.09ns		0.09ns
w_2+ Ar	M	0.007**	0.03*	A	< 0.0001**
w_2		0.25ns	< 0.0001**		0.001**

[a] w_1, w_2: Well water with 1869 and 645 mg L^{-1} hardness; Z-7: Zero-7; Ar: Arkan; M, A, S: Malathion, Acetamiprid, Spiromesifen. **Significant at the 1% level (P< 0.01), *Significant at the 5% level (P <0.05).

mg L^{-1} hardness and both adjuvants than water with 645 mg L^{-1} hardness. The addition of Z-7 had a greater impact on the quality of both water samples in the solution prepared from malathion.

The acetamiprid toxicity was 16.93 and 18.68% greater in water with 1,869 mg L^{-1} hardness containing, respectively, Z-7 and Ar than water without the additives. Acetamiprid provided 23.77 and 8.51% more mortality in water with 645 mg L^{-1} hardness and, respectively, Z-7 and Ar compared to water without the adjuvants.

The spiromesifen efficacy increased by 10.26 and 10.35% in water with 1,869 mg L^{-1} hardness and, respectively, Z-7 and Ar than in water without the additives. The spiromesifen efficiency was also improved by 23.69 and 18.51% in water with 645 mg L^{-1} hardness containing Z-7 and Ar than in water without the additives. There was no significant difference in the toxicity of the spiromesifen when it was applied in water at 1,869 mg L^{-1} hardness containing Z-7 or Ar. In water with 645 mg L^{-1} hardness, the spiromesifen efficiency was better in the presence of Z-7 than Ar.

Zero-7 (Z-7) consists of Sulfate ion (SO_4^-) and urea, also known as Carbamide (Co $(NH_2)_2$). It has also been shown that SO_4^- can bind to Ca^{2+} and form $CaSO_4$, which precipitates and prevents the formation of Ca^{2+}-salt of the pesticide. Likewise, NH_4^+ of urea moiety easily form absorbed pesticide-NH_4 salt, resulting in the reduced antagonistic effect of cations in hard water (Pratt *et al*., 2003; Soltani *et al*., 2011).

Arcan (Ar) is composed mainly of Nitrate (NO_3^-) and ammonium (NH_4^+) ions. Nitrate can conjugate to cations in hard water, especially Ca^{2+} and Mg^{2+}, and form Ca $(NO_3)_2$. Thus, it allows NH_4^+ to form pesticides-NH_4^+ salt that is readily absorbed by the cuticle of plant or insect integument **(**Bunting ***et al*.,** 2004**).**

Various studies have reported the role of SO_4^- or NO_3^- and NH_4^+ in enhancing the performance of pesticides. The control of velvetleaf by glufosinate was better in water with 1799 mg L^{-1} hardness with AMS than

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without AMS (Soltani *et al*., 2011). In other study, AMS overcame the antagonistic effect of cations in tap water with 427 mg L^{-1} $CaCO_3$ and deionized water containing 500 mg L^{-1} $CaCO_3$ on glyphosate and glufosinate in velvetleaf control (Pratt *et al*., 2003). Bunting *et al*. (2004) reported that adding 28% Urea Ammonium Nitrate (UAN) to the solution of foramsulfuron plus COC (Crop Oil) or NIS (as Nonionic Surfactant) enhanced foxtail (*Setaria faberi*) control to 90 and 85% compared to the 20% control without UAN. Moreover, the maximum absorption of foramsulfuron in cup grass (*Eriochloa villosa*) was 84% with MSO plus UAN. Dodds *et al*. (2007) reported that absorption of bispyribac increased 4- to 5-fold when 32% UAN was added to the solution of herbicide compared to the solution without UAN. Nosrati *et al*. (2011) concluded that glyphosate applied in water containing calcium (0.1 M) provided the least control of licorice (*Glycyrrhiza glabra*) compared to distilled water. The addition of diammonium sulfate and urea ammonium nitrate improved the quality of water samples containing 0.1 M calcium and 0.1 M magnesium, respectively.

CONCLUSIONS

It was revealed that water hardness affected the efficacy of the insecticides. The efficiency of insecticides was reduced in water with hardness more than 1,000 mg L^{-1}. The highest toxicity of pesticides on the 2^{nd} nymph of *B. tabaci* was observed in an aqueous solution without ions. Moreover, the additives improved the quality of water and increased the performance of the insecticides. Zero-7 was more effective than Arkan.

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حساسیت سفیدبالک پنبه *Bemisia. tabaci* (Gennadius) (Hemiptera : Aleyrodidae) به حشره‌کش‌های مختلف در شرایط سختی آب و مواد افزودنی

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چکیده

سختی آب می‌تواند تاثیر منفی بر کارایی آفت‌کش‌ها بگذارد. این مطالعه با هدف بررسی اثر سختی آب و مواد افزودنی بر کارایی حشره‌کش‌ها انجام گردید. سه حشره‌کش مالاتیون، استامی‌پرید و اسپیرومسیفن در نمونه‌های آب چاه با سختی ۱۸۶۹، ۶۴۵ و ۲۶۵ پی‌پی‌ام، آب استاندارد و دیونیزه ترکیب شده و روی پوره سن دوم سفیدبالک پنبه *Bemisia. tabaci* با استفاده از روش غوطه وری برگ استفاده شد. در آزمایش دیگر، مواد افزودنی Zero-7 و آرکان به ترتیب با غلظت ۱۵۰ و ۱۸۰ پی‌پی‌ام به آب با سختی ۱۸۶۹ و ۶۴۵ پی‌پی‌ام افزوده شد. غلظت کشنده ۵۰ درصد نشان داد سمیت مالاتیون، استامی‌پرید و اسپیرومسیفن در آب سخت (۱۸۶۹پی‌پی‌ام) به ترتیب ٤٠، ۱۵۷ و ٨٤ بار کمتر از آب دیونیزه بود. کارایی مالاتیون، استامی‌پرید و اسپیرومسیفن رقیق شده در آب با سختی ۶۴۵ پی‌پی‌ام، به ترتیب ۱۳، ۶۵ و ۳۹ بار کمتر از آب دیونیزه بود. مالاتیون در آب سخت محتوی Zero-7 و آرکان به ترتیب ۲۸.۳۷ و ۱۸/۵۹ درصد سمیت بیشتری در مقایسه با آب بدون افزودنی نشان داد. کارایی استامی‌پرید در آب سخت محتوی Zero-7 و آرکان به ترتیب ١٦/٩٣ و ١٨/٦٨ درصد بیشتر از آب بدون افزودنی بود. عملکرد اسپیرومسیفن در محلول آب سخت با اضافه کردن Zero-7 و آرکان ١٠/٢٦ و ١٣/٦٨ درصد در مقایسه با آب بدون افزودنی بهبود یافت. بطور کلی، سمیت حشره‌کش‌ها در آب سخت روی سفید بالک پنبه بطور قابل ملاحظه‌ای کاهش یافت، افزودنی‌ها بر اثرات آنتاگونیسمی کاتیون‌های آب سخت غلبه کردند.

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