Impact of hexythiazox on life table parameters of the Amblyseius swirskii (Acari: Phytoseiidae) and its prey Tetranychus urticae

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Abstract: The two-spotted spider mite Tetranychus urticae Koch (Acari: Tetranychidae) is one of the most important and destructive herbivorous mites in farm and greenhouse that has developed high levels of resistance to many acaricides. In this study, we investigated the effect of sublethal concentrations of hexythiazox at LC₁₀, LC₂₀, and LC₅₀ on the development and reproduction parameters of Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae) and its prey T. urticae. The crude data were analyzed based on age-stage, two-sex life table analysis. Hexythiazox (at LC₂₀ and LC₅₀ levels) reduced the oviposition period (9.68, 8.06 days), total lifespan (22.37, 20.88 days), and total fecundity (50.97, 46.21 eggs/female) compared to the control but did not affect those parameters of A. swirskii. The intrinsic rate of increase (r) and finite rate of increase (λ) were not significantly different at tested concentrations, but the net reproductive rate (R₀), gross reproductive rate (GRR), and mean generation time (T) reduced significantly. Our study demonstrated lower toxicity of hexythiazox on A. swirskii compared to its prey. It could be concluded that the use of selective acaricides at lower concentrations may be helpful in integrated pest management programs.

Keywords: Two-spotted spider mite, LC₅₀, life table, biological parameters, Phytoseiidae

Introduction

Species belonging to the Phytoseiidae family have good potential for use against tetranychid herbivorous mites, whiteflies, and thrips on various agricultural systems in fields and greenhouse crops (Nomikou et al., 2001; Ghazy et al., 2013; Fathipour and Maleknia, 2016). One of the most effective species is Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae) because of its ability to develop and reproduce on a wide range of food sources (Alinejad et al., 2016), including the two-spotted spider mite, Tetranychus urticae Koch (Acari: Tetranychidae), an economically important pest, on which it feeds on eggs and nymphs (El-Laitby and Fouly, 1992; Momen and El-Sawy, 1993; Zhang, 2003). Amblyseius swirskii could be considered an excellent candidate to regulate two-spotted spider mite population density under a desirable level (Asadi et al., 2019). The control of T. urticae is mainly based on the use of acaricides (Wang et al., 2014; Sarbaz et al., 2017; Havasi et al., 2018,
Impact of hexythiazox on life table parameters (Ganjisaffar et al., 2019b). However, a high rate of fecundity and a short development time leads to the rapid development of resistance to a wide variety of chemical classes of acaricides (Van Leeuwen et al., 2010; Sangak Sani et al., 2019), thereby causing difficulty in their control (Hoyt et al., 1985). Thus, this mite can develop resistance against applied acaricides, increasing production costs and reducing crop profitability. Several studies have shown that some phytoseiid mites cannot maintain T. urticae populations below the economic injury level, especially when pest mite density is high (Ibrahim and Yee, 2000; Alzoubi and Cobanoglu, 2007). Therefore, the combination of using compatible pesticides, along with biological control agents, has been widely recommended as an essential part of integrated pest management (IPM) strategies (Sáenz de Cabezón Irigaray et al., 2007) in agricultural systems. Hexythiazox is a non-systemic acaricide (Sáber et al., 2016) of the thiazolidine group (Salman and Ay, 2014) with contact and stomach action. This acaricide is not effective on adults, but the eggs laid by treated females are non-viable (Ganjisaffar and Perring, 2017). This compound is used to control many tetranychid mites, such as genera Panonychus, Tetranychus, and Eotetranychus (Sanatgar et al., 2011; Salman and Ay, 2014; Ganjisaffar and Perring, 2017).

The overall effects of acaricides or pesticides on predatory mites should be evaluated by considering the impact on the biology of both species (Alinejad et al., 2014; Havasi et al., 2019a, 2020a). A sound approach to this problem is to examine the demographic toxicology of the pesticide. Sublethal effects are determined as physiological and behavioral effects on individuals that survive the exposure to a toxic compound (Desneux et al., 2007); on the other hand, the study on the life table parameters provides accurate information relating to growth, survival, reproduction, and mortality (Bozhgani et al., 2019). Although a large body of research has focused on measuring the sublethal effects of different acaricides/pesticides on the life table parameters of phytoseiid and two-spotted spider mites (Marcie, 2007; Park et al., 2011; Ghaderi et al., 2013; Lopez et al., 2015; You et al., 2016; Havasi et al., 2020a), no study has determined the sublethal (LC$_{10}$, LC$_{20}$, and LC$_{30}$) effects of hexythiazox on the demographic parameters of T. urticae and its predator A. swirskii, based on the age-stage, two-sex life table theory. Research on the toxicological effects of hexythiazox on T. urticae and its predator (A. swirskii) will enhance the ability to design and execute mite management programs. Our results first demonstrated the lethal and sublethal effects of hexythiazox on T. urticae and improved the potential use of hexythiazox for T. urticae control for future use.

Materials and Methods

Stock colonies of T. urticae and A. swirskii

Stock colonies of Amblyseius swirskii were provided from rearing in the College of Agriculture and Natural Resources, University of Tehran (Alborz, Iran), and then reared in the laboratory on Phaseolus vulgaris L. var. Khomein (Fabaceae). Colonies were kept and fed with T. urticae. The two-spotted spider mites were set up from samples collected from infested plants in Pakdasht (South-east of Tehran, Iran) and were released on bean plants under greenhouse conditions of $25 \pm 2^\circ C$, $60 \pm 5\%$ RH, and 16:8 (L:D) h. According to McMurtary and Scriven (1965) method, the predator rearing arenas were made and stored in a growth chamber at $25 \pm 2^\circ C$ and $70 \pm 5\%$ RH and a photoperiod of 16:8 (L:D) h. Finally, bean leaves heavily infested with T. urticae were added daily to each arena as the food source.

Acaricide tested

A selective miticide, hexythiazox (Nisorun, EC 10%; SUMI AGRO, Turkey), was used in our experiments (Fontes et al., 2018). The recommended field rate for controlling the two-spotted spider mite is 10-24 oz/acre, based on the instruction mentioned in the label (Onager EW Miticide EW MITICID, 2016). The acaricide was diluted with distilled water to achieve the desired concentration.
Concentration–response bioassay
The concentration–response bioassay was carried out based on the leaf-dipping method (Helle and Overmeer, 1985; Ibrahim and Yee, 2000) (the mortality covering the range of 10%–90%). Petri-dishes were prepared based on the Alinejad et al. (2014) method. Bean leaf discs (4 cm) were submerged for 15 seconds into hexythiazox solutions. The control leaf discs were treated only with distilled water. The leaf discs were dried at room condition for about 3 hours and placed into Petri dishes (6 × 1.5 cm). Then, twenty same-aged (24-hour-old) adult mites (male and female, 10: 10) were placed on the treated leaf discs for each concentration. The fertilized adult female was placed on a leaf disc and removed after 24 h to obtain the same-age cohorts. The mites that hatched from those eggs completed their juvenile development on the same treated leaf surfaces. The bioassay was replicated four times at five concentrations (4000, 4600, 5400, 6500, and 7700 \(\text{mg}/\text{l}\) for \(A\). swirskii; 1000, 1450, 2200, 3300, 5000 \(\text{mg}/\text{l}\) for \(T\). urticae) of hexythiazox and control. The mortality of the mites was counted after 24 hours. The mites were considered dead when they did not move after stimulation. All experiments were conducted in the laboratory at \(25 \pm 2 ^\circ\text{C}\), LD 16:8 h and \(60 \pm 5\% \) (70 ± 5% for predators) RH.

Life table assay
The number of 45 \(A\). swirskii and 100 \(T\). urticae females (< 24 h) from the laboratory colony were used to evaluate the sublethal effects of hexythiazox. Bean leaf discs were treated with sublethal concentrations including \(\text{LC}_{10}, \text{LC}_{20}, \text{LC}_{30}, \text{distilled water (control)},\) and allowed to dry for three hours. Then females were placed on the leaf discs. After 24 h, the surviving females, in each treatment, were separately introduced onto the untreated bean leaf discs (4 cm diameter). After that, the only one laid egg was saved in each experimental arena after 24 h, and the mortality rates were recorded until adults. Then newly-emerged females were coupled with males (males from the stock colony were used when not enough males were available for mating with females) for mating after the adult emergence. All information relating to these males was not included in the life table analysis. Finally, the experimental units were monitored daily. The fecundity of females was recorded daily. Population parameters were calculated in both males and females, and changes were recorded until the last mite’s death. Further, in each experimental arena, 15 to 30 immature stages of \(T\). urticae were added as a food source of \(A\). swirskii. Every 48 h, the old and highly infested leaf discs were replaced with new ones.

Statistical analysis
The dose-response curve was used to estimate \(\text{LC}_{50}, \text{LC}_{10}, \text{LC}_{20}, \text{and LC}_{30}\) for both mites species using the Probit method (SPSS, version 19.0). The original data for all individuals were analyzed according to the theoretical model (Chi, 1988). All parameters, including the age-stage-specific survival rate \((s_i)\), age-specific survival rate \((l_i)\), age-specific fecundity \((m_i)\), as well as all population growth parameters the intrinsic rate of increase \((r)\), the finite rate of increase \((\lambda)\), the gross reproductive rate \((\text{GRR})\), and the net reproductive rate \((R_0)\) (Fathipour and Maleknia, 2016) were calculated according to the method of Chi and Liu (1985) and Chi (1988) using TWOSEX-MS Chart (Chi, 2019b). The mean and standard errors of the population growth parameters were estimated by the bootstrap technique (Efron and Tibshirani, 1993). Furthermore, the paired bootstrap test (100,000) test using TWO-SEX-MS Chart program was employed for the statistical differences among the means of parameters related to development, fecundity, reproductive periods as well as population growth parameters (Efron and Tibshirani, 1993; Huang and Chi, 2013; Akkopru et al., 2015).

Results
Concentration-response bioassay
The results showed that the \(\text{LC}_{50}\) of \(A\). swirskii and \(T\). urticae (for both sexes) were 5617 and 2352 \(\text{mg}/\text{l}\), respectively. No mortality was recorded in control (Table 1).
Development time, adult longevity, and total life span
The sublethal effects of the hexythiazox on developmental time, adult longevity, and total lifespan of *A. swirskii* and *T. urticae* for both sexes are shown in Tables 2 and 3, respectively. The developmental times of *A. swirskii* and its prey were not significantly different among all experimental treatments. The longevity of *T. urticae* significantly decreased in the LC30 treatment (varying from 9.74 to 10.56 days for males; 10.29 to 12.98 days for females) in comparison with the control. However, longevity did not change in *A. swirskii* males and females (Table 2). In control, the lifespan (mean number of days from egg to death) of *T. urticae* females was significantly reduced in response to increasing concentrations from LC20 to LC30. However, the lifespan of *A. swirskii* in both sexes was not affected.

Table 1 Probit analysis for the concentration-mortality response of hexythiazox on adult stages of *Tetranychus urticae* and *Amblyseius swirskii*.

<table>
<thead>
<tr>
<th>Species</th>
<th>N1</th>
<th>df</th>
<th>LC10 (mg/l)</th>
<th>LC20 (mg/l)</th>
<th>LC30 (mg/l)</th>
<th>Slope ± SE</th>
<th>P-value</th>
<th>x²</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>T. urticae</em></td>
<td>480</td>
<td>4</td>
<td>925.2</td>
<td>1274.6</td>
<td>1605.6</td>
<td>3.42 ± 0.32</td>
<td>0.38</td>
<td>6.87</td>
</tr>
<tr>
<td><em>A. swirskii</em></td>
<td>480</td>
<td>4</td>
<td>3824.7</td>
<td>4364.3</td>
<td>4799.9</td>
<td>9.28 ± 0.72</td>
<td>0.48</td>
<td>7.98</td>
</tr>
</tbody>
</table>

1 N° individuals per replicate, four replicates per concentration, six concentrations per assay.

Table 2 Effects of sublethal concentrations of hexythiazox on developmental time, longevity, and total life span (day ± SE) of *Amblyseius swirskii*.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Parameters</th>
<th>Control</th>
<th>LC10</th>
<th>LC20</th>
<th>LC30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Developmental time</td>
<td>6.16 ± 0.33a</td>
<td>6.08 ± 0.26a</td>
<td>6.21 ± 0.38a</td>
<td>6.15 ± 0.30a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longevity</td>
<td>21.55 ± 0.28a</td>
<td>21.60 ± 0.24a</td>
<td>21.54 ± 0.31a</td>
<td>21.62 ± 0.21a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total life span</td>
<td>27.73 ± 0.34a</td>
<td>27.69 ± 0.29a</td>
<td>27.74 ± 0.36a</td>
<td>27.77 ± 0.34a</td>
</tr>
<tr>
<td>Female</td>
<td>Developmental time</td>
<td>5.91 ± 0.21a</td>
<td>5.87 ± 0.19a</td>
<td>5.85 ± 0.18a</td>
<td>5.87 ± 0.20a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longevity</td>
<td>23.26 ± 0.22a</td>
<td>23.17 ± 0.24a</td>
<td>23.23 ± 0.21a</td>
<td>23.21 ± 0.17a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total life span</td>
<td>29.15 ± 0.32a</td>
<td>29.03 ± 0.32a</td>
<td>29.01 ± 0.25a</td>
<td>29.07 ± 0.23a</td>
</tr>
</tbody>
</table>

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by similar letters in the same row are not significantly different using the paired bootstrap test at 5% significance level.

Table 3 Effects of sublethal concentrations of hexythiazox on developmental time, longevity, and total life span (day ± SE) of *Tetranychus urticae*.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Parameters</th>
<th>Control</th>
<th>LC10</th>
<th>LC20</th>
<th>LC30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Developmental time</td>
<td>10.52 ± 0.11a</td>
<td>10.49 ± 0.11a</td>
<td>10.47 ± 0.12 a</td>
<td>10.43 ± 0.10a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longevity</td>
<td>10.56 ± 0.18a</td>
<td>10.62 ± 0.41a</td>
<td>10.09 ± 0.35a</td>
<td>9.74 ± 0.44b</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total life span</td>
<td>21.04 ± 0.25a</td>
<td>21.06 ± 0.45a</td>
<td>20.59 ± 0.41a</td>
<td>20.11 ± 0.49b</td>
</tr>
<tr>
<td>Female</td>
<td>Developmental time</td>
<td>10.69 ± 0.08a</td>
<td>10.72 ± 0.07a</td>
<td>10.57 ± 0.06a</td>
<td>10.55 ± 0.04a</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longevity</td>
<td>12.98 ± 0.07a</td>
<td>12.95 ± 0.09a</td>
<td>11.91 ± 0.11b</td>
<td>10.29 ± 0.13c</td>
</tr>
<tr>
<td></td>
<td>(day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total life span</td>
<td>23.69 ± 0.08a</td>
<td>23.67 ± 0.11a</td>
<td>22.37 ± 0.12b</td>
<td>20.88 ± 0.12c</td>
</tr>
</tbody>
</table>

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level.

Reproductive Periods
The highest fecundity of *A. swirskii*: 14.16; *T. urticae*: 61.19 eggs/female was observed in control (Tables 4 and 5). Conversely, higher concentration (LC30) resulted in the lowest fecundity. The females treated with LC20 and LC30 had no significant difference on adult and total pre-oviposition periods (APOP: the duration from female emergence to first oviposition; TPOP: time from egg to first oviposition) compared to the control. The maximal oviposition period of *T. urticae* was observed in control, reach a maximum of 10.89 days. This parameter significantly decreased in response to increasing concentrations from LC20 to LC30 (ranging from 10.89 to 8.06 days), but no significant effect was
observed on the oviposition period of *A. swirskii*. The mean number of eggs per *A. swirskii* female was not affected by sublethal concentrations, while it showed a declining trend for *T. urticae* exposed to LC$_{20}$ and LC$_{30}$ (Table 5).

**Population growth parameters**
The GRR and $R_0$ parameters of *A. swirskii* were significantly reduced by all treatments of hexythiazox (Table 6). However, $r$ and $\lambda$ and $T$ parameters were essentially the same. GRR, and $R_0$ of *T. urticae* at LC$_{20}$ and LC$_{30}$ were also significantly reduced (Table 7). Similarly, $r$ and $\lambda$ were not affected by any concentration of hexythiazox, but $T$ declined in both higher treatments (LC$_{20}$ and LC$_{30}$). In *A. swirskii*, likewise, *T. urticae*, the shortest $T$ was obtained for LC$_{30}$ treatment (Tables 6, 7).

**Table 4** Mean (± SE) reproductive period and total fecundity of *Amblyseius swirskii* for control and sublethal concentrations of hexythiazox.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
<th>LC$_{30}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oviposition period (day)</td>
<td>14.07 ± 0.34a</td>
<td>14.03 ± 0.29a</td>
<td>14.00 ± 0.34a</td>
<td>14.03 ± 0.34a</td>
</tr>
<tr>
<td>APOP (day)$^1$</td>
<td>3.15 ± 0.12a</td>
<td>3.13 ± 0.09a</td>
<td>3.11 ± 0.12a</td>
<td>3.03 ± 0.14a</td>
</tr>
<tr>
<td>TPOP (day)$^2$</td>
<td>9.03 ± 0.23a</td>
<td>9.00 ± 0.21a</td>
<td>8.96 ± 0.19a</td>
<td>8.95 ± 0.28a</td>
</tr>
<tr>
<td>Total fecundity (eggs/female)</td>
<td>14.16 ± 0.35a</td>
<td>14.08 ± 0.28a</td>
<td>14.03 ± 0.39a</td>
<td>14.11 ± 0.36a</td>
</tr>
</tbody>
</table>

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the each row are significantly different using the paired bootstrap test at 5% significance level.$^1$ APOP = adult pre-oviposition period (the duration from adult emergence to the first oviposition); $^2$, TPOP = total pre-oviposition period (the duration from egg to the first oviposition).

**Table 5** Mean (± SE) reproductive period and total fecundity of *Tetranychus urticae* for control and sublethal concentrations of hexythiazox.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
<th>LC$_{30}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oviposition period (day)</td>
<td>10.89 ± 0.08a</td>
<td>10.41 ± 0.09a</td>
<td>9.68 ± 0.11b</td>
<td>8.06 ± 0.13c</td>
</tr>
<tr>
<td>APOP (day)$^1$</td>
<td>1.09 ± 0.05a</td>
<td>1.11 ± 0.05a</td>
<td>1.12 ± 0.02a</td>
<td>1.12 ± 0.03a</td>
</tr>
<tr>
<td>TPOP (day)$^2$</td>
<td>11.66 ± 0.09a</td>
<td>11.71 ± 0.10a</td>
<td>11.57 ± 0.09a</td>
<td>11.55 ± 0.08a</td>
</tr>
<tr>
<td>Total fecundity (eggs/female)</td>
<td>61.19 ± 0.27a</td>
<td>58.69 ± 0.29a</td>
<td>50.97 ± 0.29b</td>
<td>46.21 ± 0.39c</td>
</tr>
</tbody>
</table>

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the each row are significantly different using the paired bootstrap test at 5% significance level.$^1$ APOP = adult pre-oviposition period (the duration from adult emergence to the first oviposition); $^2$, TPOP = total pre-oviposition period (the duration from egg to the first oviposition).

**Table 6** The effect of sublethal concentrations of hexythiazox on the life table parameters (Mean ± SE) of *Amblyseius swirskii*.

<table>
<thead>
<tr>
<th>Population growth parameters</th>
<th>Control</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
<th>LC$_{30}$</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross reproduction rate ($GRR$)</td>
<td>10.89 ± 0.95a</td>
<td>9.96 ± 1.01b</td>
<td>9.99 ± 1.02b</td>
<td>9.97 ± 1.02b</td>
<td>Eggs/female</td>
</tr>
<tr>
<td>Net reproductive rate ($R_0$)</td>
<td>9.62 ± 0.96a</td>
<td>8.51 ± 0.98b</td>
<td>8.55 ± 0.99b</td>
<td>8.48 ± 0.99b</td>
<td>Eggs/female</td>
</tr>
<tr>
<td>Intrinsic rate of increase ($r$)</td>
<td>0.1413 ± 0.007a</td>
<td>0.1303 ± 0.008a</td>
<td>0.1323 ± 0.008a</td>
<td>0.1339 ± 0.007a</td>
<td>Day$^{-1}$</td>
</tr>
<tr>
<td>Finite rate of increase ($\lambda$)</td>
<td>1.151 ± 0.008a</td>
<td>1.139 ± 0.009a</td>
<td>1.141 ± 0.004a</td>
<td>1.143 ± 0.008a</td>
<td>Day$^{-1}$</td>
</tr>
<tr>
<td>Mean generation time ($T$)</td>
<td>16.01 ± 0.29a</td>
<td>16.39 ± 0.28a</td>
<td>16.11 ± 0.24a</td>
<td>15.98 ± 0.30ab</td>
<td>Day</td>
</tr>
</tbody>
</table>

Means within each row followed by the same letters are not significantly different. The SE was estimated by using 100,000 bootstrap and compared by using the paired bootstrap test at 5% level.
**Table 7** The effect of sublethal concentrations of hexythiazox on the life table parameters (Mean ± SE) of *Tetranychus urticae.*

<table>
<thead>
<tr>
<th>Population growth parameters</th>
<th>Control</th>
<th>LC&lt;sub&gt;10&lt;/sub&gt;</th>
<th>LC&lt;sub&gt;20&lt;/sub&gt;</th>
<th>LC&lt;sub&gt;30&lt;/sub&gt;</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross reproduction rate (GRR)</td>
<td>55.08 ± 2.09a</td>
<td>54.78 ± 2.01a</td>
<td>45.89 ± 1.64b</td>
<td>42.39 ± 1.62b</td>
<td>Eggs/female</td>
</tr>
<tr>
<td>Net reproductive rate (R&lt;sub&gt;0&lt;/sub&gt;)</td>
<td>49.32 ± 2.44a</td>
<td>49.11 ± 2.45a</td>
<td>41.92 ± 2.07b</td>
<td>36.69 ± 1.86c</td>
<td>Eggs/female</td>
</tr>
<tr>
<td>Intrinsic rate of increase (r)</td>
<td>0.2391 ± 0.004a</td>
<td>0.2342 ± 0.003a</td>
<td>0.2288 ± 0.003a</td>
<td>0.2212 ± 0.003a</td>
<td>Day&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Finite rate of increase (λ)</td>
<td>1.265 ± 0.005a</td>
<td>1.260 ± 0.005a</td>
<td>1.245 ± 0.004a</td>
<td>1.236 ± 0.004a</td>
<td>Day&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean generation time (T&lt;sub&gt;G&lt;/sub&gt;)</td>
<td>16.59 ± 0.07a</td>
<td>16.54 ± 0.09a</td>
<td>16.03 ± 0.09b</td>
<td>15.58 ± 0.07c</td>
<td>Day</td>
</tr>
</tbody>
</table>

Means within a row followed by the same letters are not significantly different. The SE was estimated by using 100,000 × bootstraps and compared by using the paired bootstrap test at 5% significance level.

**Survival and fecundity curves**

The total lifetime of decreased from 26 days in the control and LC<sub>10</sub> treatment to 25 and 24 days in the LC<sub>20</sub> and LC<sub>30</sub>, respectively (Fig. 1). For *A. swirskii*, the maximal value of the total lifetime for the control was 33 days, while it was 32, 31, and 32 days for the cohort treated with LC<sub>10</sub>, LC<sub>20</sub>, and LC<sub>30</sub>, respectively (Fig. 2). The results of *l<sub>x</sub>* curves indicated decreased *T. urticae* and *A. swirskii* treated with experimental doses. The *m<sub>0</sub>* for *T. urticae* was estimated to be 5.13, 4.82, and 4.86 eggs/female/day for the mites treated with LC<sub>10</sub>, LC<sub>20</sub>, and LC<sub>30</sub> of hexythiazox, respectively, which appeared on days 17, 16, and 15 during the life span, respectively (Fig. 3). Also, the value of *m<sub>0</sub>* on *A. swirskii* were 0.68, 0.62, 0.63, and 0.65 eggs/individual/day for the mites treated with the control, LC<sub>10</sub>, LC<sub>20</sub>, and LC<sub>30</sub> observed on days 13, 18, 17, and 15 of *A. swirskii* lifespan, respectively (Fig. 4).

![Figure 1](image_url)  
**Figure 1** Age-specific survivorship (*l<sub>x</sub>* of *Tetranychus urticae* at sublethal concentrations of hexythiazox.)
Figure 2 Age-specific survivorship ($l_s$) of *Amblyseius swirskii* at sublethal concentrations of hexythiazox.

Figure 3 Age-specific fecundity ($m_x$) of *Tetranychus urticae* at sublethal concentrations of hexythiazox.
Impact of hexythiazox on life table parameters

Discussion

The increase of resistance to pesticides in phytoseiid mites is known to be associated with variations in biological characteristics (Salman and Ay, 2014). On the other hand, finding efficient biological control agents is the first step in developing biological control programs (Fathipour et al., 2020). In the current study, we investigated the efficacy of *A. swirskii* as a predator of *T. urticae* LC$_{10}$, LC$_{20}$, and LC$_{30}$ of hexythiazox using life table parameters as our measurements of survivorship quality. We found that hexythiazox had no significant effect on the development time of *T. urticae* and *A. swirskii*. The findings are in agreement with Alinejad et al. (2016) and Sanatgar et al. (2011), reporting that the development time of *A. swirskii* and *Phytoseiulus persimilis* (Athias–Henriot) did not influence by sublethal concentrations of spirotetramat and hexythiazox, respectively. Hamedi et al. (2010), Alinejad et al. (2014), and Li et al. (2017) showed that the development time of *Phytoseiulus plumifer* (Canestrini and Fanzago), *A. swirskii*, and *T. urticae* was decreased as concentrations of fenpyroximate, fenazaquin, and bifenazate increased. In the current study, hexythiazox affects adult longevity and a total lifetime in both sexes of *T. urticae* but not on *A. swirskii* (Saber et al. (2018), Sangak Sani et al. (2019), Havasi et al. (2018), and Bozhgani et al. (2018a) reported that the longevity and total lifespan of *T. urticae* significantly decreased when the cohort was exposed to the sublethal concentrations of abamectin, spiromesifen, diflufenican, and chlorfenapyr. In other studies, Sarbaz et al. (2017), Bozhgani et al. (2018b), and Havasi et al. (2019a) found that longevity and total lifespan of *N. californicus* are decreased when treated by spiromesifen, spirotetramat, and thiamethoxam.

The adverse effects of sublethal treatments of hexythiazox on ovipositional period and total
fecundity of *A. swirskii* were confirmed by Havasi et al. (2020b), who found a similar trend for the total fecundity of *N. californicus* exposed to Biorime®. In contrast, Ghasemzadeh and Qureshi (2018) and Shahbaz et al. (2019) demonstrated an adverse effect of acetamiprid on *A. swirskii* and *Amblyseius cucumeris* Oudemans. This difference might be due to the susceptibility of the phytoseiid species or the formulation type. Acetamiprid is widely used as second-generation chloro-neonicotinoids with systemic activity (Devan et al., 2015). Examination of three sublethal concentrations tested in the current study showed that the shortest oviposition period of *T. urticae* was strongly affected as concentration increased from LC$_{20}$ to LC$_{30}$. We found the lowest fecundity of *A. swirskii* on higher LC$_{30}$. Many studies have demonstrated the adverse effect of various pesticides on fecundity and oviposition period of phytoseiid predators (e.g., Li et al., 2017; Havasi et al., 2018; Bozhgani et al., 2018b, 2019; Leviticus et al., 2019).

Life table response experiments at the population level are considered a better measure of response to pesticides than individual life history characteristics (Stark and Banks, 2003); this approach discusses lethal and sublethal effects and their mixture (Stark et al. 1998; Stark and Banks, 2000). The $r$-values integrate the impact of mortality and fecundity into a single value, so it is greatly affected by the wide range of variables consisting of survival, developmental time, longevity, fecundity schedule, and sex ratio, which are affected by climatic and nutritional conditions (Khederi and Khanjani, 2014). The $r$-value and finite rate of increase did not differ for either species.

In the present study, $r$ value varied from 0.1413 to 0.1339 and 0.2391 to 0.2213 day$^{-1}$ for predatory mite and *T. urticae*, respectively. Variable growth rates of *A. swirskii* in response to fenazaquin (0.130 to 0.060 day$^{-1}$; Alinejad et al., 2014), fenpyroximate (0.13 to 0.06 day$^{-1}$; Ghasemzadeh and Qureshi, 2018), spirodiclofen on *N. californicus* (0.237 to 0.153 day$^{-1}$; Maroufpoor et al., 2016); spirodiclofen on *P. persimilis* (0.24 to 0.26 day$^{-1}$; Salman and Keskin, 2019) have been reported. However, Sanatgar et al. (2011), Maroufpoor et al. (2016), and Leviticus et al. (2019) reported that hexythiazox, spirodiclofen, and fluralaner a significant reduction in $r$ and $\lambda$ parameters on *P. persimilis*, *N. californicus*, and *T. urticae*. In the present study, $R_0$, $GRR$, and $T$ of *T. urticae* and *A. swirskii* populations changed when exposed to LC$_{20}$ and LC$_{30}$. Our findings are consistent with Ghasemzadeh and Qureshi (2018) and Sanatgar et al. (2011), showing that the parameters above significantly declined by dose dependence of thiacloprid and hexythiazox on *A. swirskii* and *P. persimilis*. Due to $l_x$ and $m_x$ curves, hexythiazox at tested concentrations reduces these parameters in *A. swirskii* and its prey *T. urticae*. Furthermore, all tested concentrations demonstrated that the chances of reaching adulthood were decreased as concentration increased. In the present study, the highest mortality rate occurred at the LC$_{20}$, and the $l_x$ of *A. swirskii* decreased from 33 days in control to 31 days in treatment. Li et al. (2017) and Havasi et al. (2018) proposed a similar trend for the curves of $l_x$ and $m_x$ of *T. urticae* treated with difludazin bifenazate, which is consistent with the findings of the present study. In another study, Shahbaz et al. (2019) noted that both $l_x$ and $m_x$ showed a declining trend for *A. swirskii* treated with acetamiprid. Sanatgar et al. (2011) found that hexythiazox had little effect on the survival of immature stages of treated *P. persimilis*, and the most influence was reported on adult mites.

Improvement of IPM programs requires understanding how pesticides affect the pests’ natural enemies (Havasi et al., 2020a). Universally, a single chemical control system against pests cannot be successful (Kaplan et al., 2012). Remarkably, exposure to LC$_{20}$ and LC$_{30}$ resulted in a detrimental effect on *T. urticae* population increase (i.e., $R_0$, $T$ and GRR, and fecundity). Findings indicated that hexythiazox does not have adverse effects on the $r$ and $\lambda$ parameters of *A. swirskii* at sublethal concentration.
In conclusion, it seems that pesticides can be considered as an economic, labor-saving, and effective tool of pest management (Damalas and Eleftherohorinos, 2011). Still, IPM programs are complex and variable, and there is more work to be conducted to understand these control strategies (Ullah, 2017). From this study, it could be concluded that hexythiazox could reduce life table parameters of *T. urticae* more than its predator, *A. swirskii*. Finally, the hexythiazox demonstrated minor harm to *A. swirskii* by its lower toxicity than its prey *T. urticae*.

Acknowledgments

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Impact of hexythiazox on life table parameters ________________________________________ J. Crop Prot.


تأثیر هگزی تیازوکس در غلظت‌های مختلف بر پارامترهای جدول زندگی

*Tetranychus urticae* (Acari: *Phytoseiidae*)

مهدی رضایی، دانشگاه تهران، کرج، ایران.

چکیده: کنار تاریخ دو گونه: تیازوکس در سه غلظت‌های مختلف را بر پارامترهای جدول زندگی

*A. swirskii* که کاهش معنی‌داری را در طول دوره تخم‌بردنی (赞誉) و

*LC30* و *LC10* و نتایج (赞誉) نشان دادند. مقادیر ترخ نهایی افزایش بیشتر (赞誉) معنی‌داری را در هر سه تیازوکس نشان دادند اما نمی‌تواند در نسل (赞誉) به

*swirskii* نسبت به *T. urticae* نشان دهد. می‌توان نتیجه گرفت که استفاده از گونه کنکان انتخابی در

*Phytoseiidae*، *LC30*، جدول زندگی، پارامترهای بیولوژیکی.