Sublethal effects of Oberon Speed® on Phytoseiulus persimilis and Amblyseius swirskii (Acari: Phytoseiidae) and potential compatibility for integrated management of two-spotted spider mite

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Abstract

The two-spotted spider mite, Tetranychus urticae Koch (TSSM), is an important cosmopolitan pest of horticultural crops that is often managed in greenhouses with a combination of acaricides and augmentation of predatory mites. Here we examined the transgenerational effects of low concentrations of a widely-used acaricide, Oberon Speed® (a combination of spiromesifen and abamactin), on the life history of TSSM and two of its predators, Phytoseiulus persimilis Athias-Henriot and Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae). The concentrations employed corresponded to the LC10, LC20 and LC30 values calculated for TSSM protonymphs 48 h post-exposure in a topical bioassay, which yielded an LC50 value of 207.2 ppm. Parental exposure of TSSM to all three sublethal concentrations increased the total developmental time of progeny; both the LC20 and LC30 treatments reduced adult longevity and number of oviposition days, but only the LC30 treatment increased the preoviposition period. Similarly, both the LC20 and LC30 treatments significantly reduced life table parameters (r, R0, λ, and GRR), and increased generation time (T) and population doubling time (DT). Although maternal exposure to the acaricide had various impacts on progeny life history, the life table parameters of A. swirskii were largely unaffected in comparison to those of P. persimilis, suggesting the former species would be more compatible for integration with Oberon Speed® for control of TSSM in greenhouse vegetable production.

Introduction

The two spotted spider mite (TSSM), Tetranychus urticae Koch (Acari: Tetranychidae) is one of the most polyphagous and economically important pests of agricultural and horticultural crops in the world (Khanamani et al., 2012; Sarbaz et al., 2017; Havasi et al., 2020), attacking more than 1,100 plant species (Asadi et al., 2019), and thriving under a wide range of environmental conditions (Çobanoğlu and Kandiltaş, 2019). Mites feed from individual plant cells, causing loss of chlorophyll and reduced photosynthetic productivity (Havasi et al., 2022), loss of plant vigor, leaf drop, and even plant death (Geroh and Tehri 2015; Susurluk and Gürkan 2020; Shang et al. 2022). Chemical acaricides have long played a vital role in suppressing this pest (Li et al., 2017), but the evolution of resistance traits in TSSM, environmental hazards, and adverse effects on non-target organisms (Leviticus et al., 2020; Kheradmand et al., 2022; Havasi et al., 2022) provide powerful incentives to develop alternative control methods.

Predatory mites in the family Phytoseiidae have been used for biological control of spider mites with various degrees of success in different agroecosystems (Abad-Moyano et al., 2009). The predatory mite, Phytoseiulus persimilis Athias-Henriot (Acari: Phytoseiidae) feeds on all spider mite life stages and has rapid development and reproduction (Moghadasi et al., 2016). Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae) is another effective predator of TSSM (Nguyen et al. 2015), one that also feeds on whiteflies, making its application particularly useful in situations where control of both pests is required (Asadi et al., 2019).
Oberon Speed® is a combination of spiromesifen (IRAC group 23) and abamectin (IRAC group 6) with good efficacy against TSSM (Noorbakhsh, 2022). Abamectin has an inhibitory effect on the mite nervous system and is effective and is against active TSSM life stages, exhibiting toxicity via both contact and ingestion, whereas spiromesifen is an inhibitor of lipid biosynthesis with contact activity against eggs and nymphs (Ardeshir et al., 2019). On their own, predatory mite augmentation programs can fail to provide adequate control of TSSM populations over the full cycle of crop production, necessitating the eventual application of an acaricide. Therefore, the use of an integrated of acaricides and phytoseiid mites is suggested as the most effective management solution for this pest. Indeed, successful biological control of TSSM can be achieved through adaptation of predators to current pesticides used in targeted agricultural systems (Sarbaz et al., 2017). The overall effects of acaricides or pesticides on predatory mites should be evaluated by considering the impact on the biology of both species. 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 (Havasi et al., 2021).

Considering that chemical and biological methods are very important in controlling T. urticae in the present research, in order to prevent the development of resistance and minimize dangerous damage on the natural enemy, the sublethal effects of Oberon speed® on the TSSM and the predators P. persimilis and A. swirskii were investigated in laboratory conditions.

Materials and methods

Plants

Seeds of cucumber (Cucumis sativus L., cv. ‘Nagin’) were planted in plastic pots (15 cm diam x 9 cm ht) filled by coco peat and perlite (1:1) in a greenhouse at the Faculty of Agriculture, Urmia University. Seeds were germinated, and plants grown, under climate-controlled conditions of 25 ± 3 °C, 65 ± 5 % RH, and a 16:8 h (L:D) photoperiod. All plants used in experiments were at the 4-5 leaf growth stage.

Spider mites

A colony of TSSM was established from material collected from cucumber plants in a greenhouse in Urmia, West Azerbaijan, Iran, and maintained in screen cages (90 x 90 x 150 cm) under the same physical conditions as the plants. Infested plants (10 pots per cage) were periodically replaced with healthy ones as they began to show symptoms of heavy mite damage.

Predatory mites

Colonies of P. persimilis and A. swirskii were established from material obtained from Hegmatane Company, Hamedan, Iran. Rearing arenas were constructed from 15 × 20 cm rectangles of clear plastic sheeting resting on water-soaked foam in plastic containers (25 × 25 × 40 cm). Strips of tissue paper saturated with water were laid along the edges of each plastic sheet to prevent escapes (McMurtry and
Scriven 1965). The predatory mites were provisioned daily with a mixture of immature life stages of TSSM from the greenhouse colony. Both colonies were maintained in a climate-controlled chamber set to 25 ± 2 °C, 65 ± 5% RH, and a 16:8 (L:D) photoperiod (= standard experimental conditions).

TSSM toxicity assay

The acaricide Oberon Speed® SC 240 (Bayer Cropscience, Monheim am Rhein, Germany), containing the active ingredients abamectin @ 11.4 g/L and spiromesifen @ 228.6 g/L (hereafter, ‘the miticide’), was used in all experiments of the study. Contact toxicity bioassays were conducted on protonymphs of TSSM, as immature life stages are the recommended target of the insecticide, and their control is critical to preventing reproduction of the pest. In order to determine the LC$_{80}$ and LC$_{20}$ values of Oberon Speed®, a series of preliminary tests were performed with concentrations of 20, 30, 40, 50 and 60 ppm of the active ingredients (at a ratio of 0.05 : 1, abamectin : spiromesifen), which corresponded to 83.30, 124.97, 166.64, 208.31 and 249.98 ppm of the commercial formulation, with distilled water used as a control. Cucumber leaf discs (6 cm diam) were punched from leaves of Cucumis sativus L., cv. 'Nagin', and each was manually infested with 20 TSSM protonymph (< 24 h old). Leaf discs with mites were then sprayed in a Potter spray tower Burkard Scientic, Uxbridge, UK), delivering a volume of 0.7 ml at a pressure of 3.9 kPa/mm$^2$. Each treated leaf disc (n = 4 per treatment) was then placed in a Petri dish (9 cm diam) on a tray and transferred to a climate-controlled chamber set to 25 ± 3 °C, 65 ± 5% RH, and a 16:8 h (L:D) photoperiod (= standard experimental conditions). Protonymph mortality was recorded 24h later and were calculated from Probit analysis was conducted using SPSS software (SPSS, 2013) to obtain slope, SE, and confidence limits. Concentrations corresponding to LC$_{10}$, LC$_{20}$ and LC$_{30}$ were determined and these concentrations were used in subsequent experiments.

Exposure of TSSM protonymphs to sublethal concentrations

Three concentrations of Oberon Speed®, corresponding to the LC$_{10}$, LC$_{20}$, and LC$_{30}$ values determined above, were selected to assay their sublethal effects on TSSM (n = 50 mites per treatment), with distilled water used as a control. Protonymphs (< 12 h post-molt) were removed from the laboratory colony and transferred to freshly cut cucumber leaf discs (6 cm diam, 10 mites per disc) and then sprayed with the appropriate concentration in the spray tower (as above). After 24 h on a laboratory bench, in a growth chamber, each surviving protonymph was transferred to a fresh cucumber leaf disc (one per disc) in a Petri dish (prepared as above) and reared under the standard experimental conditions. Leaf discs were replaced daily and the lifetime fecundity of each mite was recorded daily until its death. About 100 eggs were collected from the oviposition of ca. 50 females in each treatment and their development was observed and recorded daily in order to observe any parental effects on the F1 generation. Following adult molts, each female was paired with a male, each pair isolated in a Petri dish, and daily oviposition counted under a dissecting microscope until the female died. A few mites absconded from the rearing arena to die in the wet foam, and these were excluded from analysis. Leaf disc were kept moist and replaced as necessary, usually every third or fourth day.
Maternal exposure of *P. persimilis* and *A. swirskii* to sublethal concentrations

Pairs of mites of both predatory species (n = 30 per treatment, < 24 h post-molt) were exposed to leaf residues of Oberon speed® corresponding to the LC$_{10}$, LC$_{20}$ and LC$_{30}$, concentrations determined for TSSM (above), with distilled water used as a control. Leaf discs (6 cm diam) were each infested with 20 TSSM protonymphs, assigned to one of the four treatments (n = 30 discs per treatment), and treated in the spray tower (as above). A pair of predatory mites was then transferred to each leaf disc, which was then placed in a Petri dish (9 cm diam) in a growth chamber under the standard experimental conditions. After 72 h, a series eggs (n = 50 per treatment, <12 h old) were selected at random and each was placed on a fresh (untreated) leaf disc in a clean Petri dish where their eclosion and development was monitored daily. Following molts to adult, mite pairs were established on fresh leaf discs, one per disc, and each was provisioned with ca. 20 immature stages of TSSM, refreshed daily. Oviposition was monitored daily until the female died.

Data analysis

Data from the concentration response bioassay were subjected to probit analysis (SPSS ver. 22), after correcting for control mortality using Abbott's formula (Abbott 1925). The demographic parameters of all mite species were analyzed with the age-stage-specific two-sex life table using TWO-SEX MSChart (Chi, 2022). Standard errors of all population parameters were calculated using the bootstrap technique with 100,000 replicates and treatments were compared using the paired bootstrap test of TWOSEX–MSChart (Chi and Yang 2003) with 95% confidence intervals.

Results

Toxicity of Oberon Speed® to TSSM

Probit analysis revealed that Oberon Speed® had an LC$_{50}$ of 207.17 ppm for the TSSM (95% CL = 181.46 – 252.58) at 48h post-exposure, with LC$_{10}$, LC$_{20}$, and LC$_{30}$ values estimated to be 97.71 (66.66 – 118.34), 126.47 (98.84 – 146.01), and 152.32 (128.51 – 173.59) ppm, respectively.

Parental exposure to sublethal concentrations

Exposure of TSSM in the protonymph stage to all sublethal concentrations of the miticide delayed the development of progeny, the delay becoming more pronounced as the concentration increased from LC$_{10}$ to LC$_{30}$ (Table 1). Adult longevity (both male and female) was also reduced significantly by parental exposure to the LC$_{20}$ and LC$_{30}$ concentrations, and females in these treatments laid eggs on fewer days. Parental exposure to increasing sublethal concentrations also progressively reduced the value of life table parameters measured for progeny, increasing both generation time and population doubling time (Table 2). The age-specific survival rate ($l_x$), age-specific fecundity ($m_x$) and age-stage-specific fecundity ($f_{xj}$) of TSSM were all negatively affected (Fig. 2), and survival was reduced in LC$_{30}$ treatment.
Maternal exposure of *P. persimilis* to sublethal concentrations

Maternal exposure to the LC$_{30}$ concentration significantly delayed development of *P. persimilis* compared to controls, whereas exposure to lower concentrations did not (Table 3). The LC$_{30}$ concentration also reduced the longevity of males and female progeny, and the number of days on which female progeny laid eggs; maternal effects on the preoviposition period were inconsistent across concentrations, but the LC$_{20}$ treatment significantly increased this period. Only the LC$_{30}$ treatment significantly reduced the intrinsic rate of increase ($r$), the finite rate of increase ($\lambda$) and the gross reproductive rate ($GRR$) relative to controls, and increased the generation time ($T$) and population doubling time ($DT$) (Table 4). The LC$_{30}$ treatment was also the only one to decrease female lifespan (Fig. 3) and reduce fecundity (Fig. 4).

Maternal exposure of *A. swirskii* to sublethal concentrations

No maternal treatment with any sublethal concentration of Oberon Speed® significantly affected the overall development time of *A. swirskii* compared to controls, and although various treatments slightly affected the duration of some immature stages, these impacts were mostly compensated by opposite effects on other stages (Table 5). The LC$_{10}$ treatment increased the preoviposition period of female offspring, whereas the LC$_{20}$ treatment reduced the longevity of female offspring and LC$_{30}$ treatment reduced the longevity of both male and female offspring; all three treatments reduced the number of days on which female offspring laid eggs. However, these impacts were not sufficient to significantly affect *A. swirskii* life table parameters, save for generation time ($T$), which was slightly increased by the LC$_{20}$ treatment (Table 6).

Discussion

The integration of chemical and biological control is often critical to the success of an integrated pest management (IPM) program for arthropod pests (El-Wakeil et al. 2006; Volkmar et al. 2008). Therefore, it is very important to find a pesticide that is effective on pests and less dangerous for natural enemies (Torres and Bueno, 2018). Detailed knowledge of the effects of different pesticides on the natural enemies will help to determine the timing of sprays, thus avoiding the most susceptible stages (El-Wakeil et al., 2013). Pesticides commonly used in commercial greenhouse management were evaluated for compatibility with two biological control agents: a leafminer parasitoid, Diglyphus isaea (Walker), and a predatory mite, Neoseiulus californicus (McGregor). The results showed that potentially compatible miticides (bifenazate, hexythiazox, spiromesifen, acequinocyl, etoxazole, and clofentezine) identified in laboratory trials were also evaluated in a greenhouse study and found to be compatible with leafminer biocontrol (Abraham et al., 2013). The studies conducted on the sublethal effects of pesticides showed that the negative and nonlethal effects of pesticides on pests and natural enemies can provide practical information for the formation of effective pest control strategies (Irigaray et al., 2007; Havasi et al., 2022; Mohammadi et al., 2022; Mokhtari et al., 2022). In this regard, in the study of Alinejad et al. (2015), on the effect of sublethal concentration of phenazine, Martinez-Villar et al. (2005), on sublethal concentration of azadirachtin, Wang et al. (2014) and Marcic (2007) on sublethal concentration of bifenthrin and
spirodiclofen observed a decrease in fertility. Similarly, Shen et al. (2021) on sublethal concentration broflanilide, Havasi et al. (2018, 2021 and 2022), on sublethal concentrations of difloidazin, Hexythiazox and Biomite, Shatrian Mohammadi et al. (2022) on sublethal concentration of Proteus, Leviticus et al. (2020) on fluralaner, similar results (decrease during the oviposition period and fertility rate in adult females) were obtained. Also, in the present research, the egg-laying period and the total life span by sublethal concentrations of oberon speed® showed a significant decrease compared to the control in TSSM. The growth parameters of TSSM population were also affected by the sublethal concentrations of oberon speed®, and with the increase of the sublethal concentration, the value of GRR, \( R_0 \) and \( r \) parameters decreased. In the investigation of the sublethal concentration effects of spiromesifen on TSSM by Rajaee et al. (2022), sublethal effects of diuvidazin on life table parameters of TSSM by Havasi et al. (2018) and sublethal effects of spirodiclofen, abamectin and pyridaben by Saber et al. (2018), similar to the present study, the population growth parameters of TSSM decreased. Also, in the review of Marcic et al. (2009) and Rajaee et al. (2022) on the sublethal effects of spiromesifen on TSSM observed a significant decrease in population growth parameters. In the study of sublethal effects of spinetoram on TSSM by Wang et al. (2016), reducing the time of growth and development from egg to adult and increasing fertility, as well as increasing the intrinsic rate of the population, increasing the net reproduction rate and reducing the average time of one generation, reducing the duration of eggs and larvae, which is significantly different from the present results were observed. This difference can be attributed to the type of acaricide used and laboratory conditions.

Havasi et al. (2021) in a study on the effect of sublethal concentrations of hexathiazox on TSSM showed that the intrinsic rate of population increase \( (r) \) and the finite rate of population increase \( (\lambda) \) were not significantly different in the tested concentrations, but the net rate of reproduction \( (R_0) \), the gross rate reproduction (GRR) and mean reproductive time \( (T) \) were significantly reduced.

Also, Havasi et al. (2022) showed that when the adult stage of on TSSM were treated with biomite, the intrinsic rate of population increase \( (r) \) and the finite rate of population increase \( (\lambda) \) in different treatments did not decrease significantly compared to the control, which is different from the results of this research that differences in acaricide mode of action may be an important contributory factor in these differences.

In the present research, the results showed that sublethal concentrations of oberon speed® decrease fertility in TSSM, which is consistent with the results of Marcic (2007), Sangak Sani et al. (2019), Marcic et al. (2010), Askari Serizdi et al. (2013), Martinez-Villar et al. (2014), Phukan et al. (2017).

Demographic approaches give a better understanding of the side effects of pesticides on beneficial organisms (Rahmani and Bandani, 2013). The sublethal effects of acaricides on predatory mites have been done in order to use them in integrated pest management (Ibrahim and Yee, 2000; Hamedi et al., 2010; Hamedi et al. 2011; Alinejad et al. 2016; Mollaloo et al., 2017; Abdel-Rahman and Ahmed, 2018; Shahbaz et al. 2019; Ahmed et al. 2021).
Sanatgar et al. (2011), and Alinejad et al. (2016) which reported the use of sublethal concentration of hexythiazox and spiromesifen had no significant effect on P. persimilis and A. swirskii, respectively. However, a significant reduction occurred in the $r$ and $\lambda$ values of A. swirskii and N. californicus when they were treated with fenazaquin (Alinejad et al. 2014) and Spirodiclofen (Maroufpoor et al. 2016), respectively.

Residual effects of etoxazole, spiromesifen, fenpyroximate, bifenazate, and acequinocyl on life parameters of Galendromus occidentalis (Nesbitt) under laboratory conditions were studied. Fenpyroximate reduced adult female longevity to <24 h, and no eggs were laid. Longevity of spiromesifen and acequinocyl-treated adult females was reduced to 4 days, with observed reductions in fecundity and fertility. Etoxazole and bifenazate did not reduce adult female longevity, but progeny were not produced (Irigaray and Zalom, 2006.).

The results achieved in this study showed that oberon speed® at sublethal concentrations have potential to adversely effect on P. persimilis in compare A. swirskii predator. Thus more care should be taken when this insecticide with P. persimilis and A. swirskii is used in IPM programs.

**Conclusion**

In conclusion, our investigation was the first step to explore the sublethal effect of oberon speed® on *T. urticae* and its two predators, *P. persimilis* and *A. swirskii* with respect to both sexes based on two-sex theory. The sublethal concentration (LC$_{30}$) effects of oberon speed® on the TSSM were more successful and on two predators have side effect. The sublethal concentration showed a significant difference in the parameters of population growth and the length of the life cycles of TSSM, and with the increase of the sublethal concentration, the fecundity rate, the length of the spawning period, the life span of both males and females decreased, and the length of the immature period increased. In the comparison between the two predators, the *P. persimilis* is more sensitive than the *A. swirskii* predator, and in the *P. persimilis*, the length of the immature period increases, the length of the mature period of the male and female decreases, and the length of the spawning period decreases, as well as its population growth parameters ($GRR, R_0, r$) had a significant decrease in the sublethal concentration of LC$_{30}$ compared to the control, while in the *A. swirskii*, no significant difference was observed between the population growth parameters, only the length of the female period showed a decrease compared to the control.

Considering the adverse effects of the sublethal concentration for the simultaneous use and management of TSSM, the release time interval of the predator mite should be considered in the biological control of TSSM in order to be more successful. Of course, considering that this is a laboratory result, it must be evaluated and confirmed in greenhouse or farm conditions in order to be recommended.

**References**


61. SPSS, 2013. SPSS Statistics for Windows, Ver. 22.0. IBM Corp., Armonk, NY, USA.


Tables

Table 1. Mean (± SE) duration (no. days) of *Tetranychus urticae* life stages and lifetime fecundity (no. eggs / female) following parental exposure to sublethal concentrations of Oberon Speed®. Means were separated with paired bootstrap test (*P* < 0.05) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.

<table>
<thead>
<tr>
<th>Life stage / Treatment</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>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>3.39 ± 0.05 b</td>
<td>3.35 ± 0.07 b</td>
<td>3.42 ± 0.07 b</td>
<td>3.75 ± 0.08 a</td>
</tr>
<tr>
<td>Larva</td>
<td>1.67 ± 0.05 b</td>
<td>1.75 ± 0.05 b</td>
<td>1.91 ± 0.05 a</td>
<td>1.93 ± 0.06 a</td>
</tr>
<tr>
<td>Protonymph</td>
<td>1.48 ± 0.06 c</td>
<td>1.55 ± 0.06 c</td>
<td>1.81 ± 0.06 b</td>
<td>2.26 ± 0.06 a</td>
</tr>
<tr>
<td>Deutonymph</td>
<td>1.40 ± 0.05 b</td>
<td>1.53 ± 0.06 b</td>
<td>1.86 ± 0.04 a</td>
<td>1.97 ± 0.05 a</td>
</tr>
<tr>
<td>Total develop. time</td>
<td>7.95 ± 0.11 c</td>
<td>8.20 ± 0.11 b</td>
<td>9.04 ± 0.12 b</td>
<td>10.00 ± 0.15 a</td>
</tr>
<tr>
<td>Preoviposition period</td>
<td>2.47 ± 0.09 b</td>
<td>2.46 ± 0.10 b</td>
<td>2.53 ± 0.09 b</td>
<td>3.00 ± 0.08 a</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>22.26 ± 0.16 a</td>
<td>22.06 ± 0.18 a</td>
<td>20.92 ± 0.15 b</td>
<td>19.86 ± 0.17 c</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>15.29 ± 0.16 a</td>
<td>14.88 ± 0.18 a</td>
<td>14.17 ± 0.16 b</td>
<td>14.05 ± 0.18 b</td>
</tr>
<tr>
<td>Oviposition days</td>
<td>14.29 ± 0.19 a</td>
<td>14.24 ± 0.20 a</td>
<td>13.43 ± 0.19 b</td>
<td>13.05 ± 0.20 b</td>
</tr>
<tr>
<td>Fecundity (no. eggs)</td>
<td>38.84 ± 0.75 a</td>
<td>38.22 ± 0.8 a</td>
<td>35.04 ± 0.73 b</td>
<td>25.84 ± 0.87 c</td>
</tr>
</tbody>
</table>

Table 2. Mean (± SE) life table parameters for *Tetranychus urticae* following exposure of protonymphs to sublethal concentrations of Oberon Speed®. Means were separated with paired bootstrap test (*P* < 0.05) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.
<table>
<thead>
<tr>
<th>Parameter / Treatment</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>
</tr>
</thead>
<tbody>
<tr>
<td>( r )</td>
<td>0.20 ± 0.01 a</td>
<td>0.19 ± 0.01 ab</td>
<td>0.17 ± 0.01 b</td>
<td>0.14 ± 0.01 c</td>
</tr>
<tr>
<td>( R_0 )</td>
<td>27.36 ± 1.96 a</td>
<td>22.22 ± 2.08 ab</td>
<td>19.96 ± 1.91 b</td>
<td>13.86 ± 1.49 c</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>1.22 ± 0.01 a</td>
<td>1.21 ± 0.01 ab</td>
<td>1.19 ± 0.01 b</td>
<td>1.15 ± 0.01 c</td>
</tr>
<tr>
<td>( GRR )</td>
<td>30.22 ± 1.76 a</td>
<td>27.07 ± 2.00 ab</td>
<td>25.12 ± 1.84 b</td>
<td>19.20 ± 1.44 c</td>
</tr>
<tr>
<td>( T )</td>
<td>16.32 ± 0.17 c</td>
<td>16.45 ± 0.17 c</td>
<td>17.22 ± 0.18 b</td>
<td>19.03 ± 0.24 a</td>
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<tr>
<td>( DT )</td>
<td>3.42 ± 8.84 c</td>
<td>3.68 ± 0.13 bc</td>
<td>3.99 ± 0.15 b</td>
<td>5.02 ± 0.23 a</td>
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</table>

**Table 3.** Mean (± SE) duration (no. days) of *Phytoseiulus persimilis* life stages and lifetime fecundity (no. eggs / female) following maternal exposure to sublethal concentrations of Oberon Speed®. Means were separated with paired bootstrap test (\(P<0.05\)) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.

<table>
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<th>Life stage / Treatment</th>
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<tr>
<td>Larva</td>
<td>1.48 ± 0.08 b</td>
<td>1.51 ± 0.09 b</td>
<td>1.55 ± 0.09 b</td>
<td>1.82 ± 0.07 a</td>
</tr>
<tr>
<td>Protonymph</td>
<td>1.35 ± 0.07 b</td>
<td>1.49 ± 0.08 b</td>
<td>1.36 ± 0.08 b</td>
<td>1.86 ± 0.06 a</td>
</tr>
<tr>
<td>Deutonymph</td>
<td>1.24 ± 0.07 b</td>
<td>1.18 ± 0.06 b</td>
<td>1.34 ± 0.09 b</td>
<td>1.86 ± 0.08 a</td>
</tr>
<tr>
<td>Total develop. time</td>
<td>6.29 ± 0.19 b</td>
<td>6.26 ± 0.19 b</td>
<td>6.37 ± 0.18 b</td>
<td>7.81 ± 0.17 a</td>
</tr>
<tr>
<td>Preoviposition period</td>
<td>1.97 ± 0.16 b</td>
<td>2.08 ± 0.19 ab</td>
<td>2.46 ± 0.17 a</td>
<td>2.00 ± 0.16 ab</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>20.70 ± 0.22 a</td>
<td>21.00 ± 0.24 a</td>
<td>21.12 ± 0.25 a</td>
<td>8.08 ± 0.21 b</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>14.67 ± 0.19 a</td>
<td>14.67 ± 0.42 a</td>
<td>14.67 ± 0.19 a</td>
<td>13.91 ± 0.21 b</td>
</tr>
<tr>
<td>Oviposition days</td>
<td>15.87 ± 0.31 a</td>
<td>16.04 ± 0.31 a</td>
<td>15.88 ± 0.33 a</td>
<td>14.31 ± 0.28 b</td>
</tr>
<tr>
<td>Fecundity (no. eggs)</td>
<td>29.97 ± 0.88 a</td>
<td>30.31 ± 0.92 a</td>
<td>30.23 ± 0.89 a</td>
<td>24.81 ± 1.18 b</td>
</tr>
</tbody>
</table>

**Table 4.** Mean (± SE) life table parameters for *Phytoseiulus persimilis* following maternal exposure to sublethal concentrations of Oberon Speed®. Means were separated with a paired bootstrap test (\(P<0.05\)) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.
Table 5. Mean (± SE) duration (no. days) of *Amblyseius swirskii* life stages and lifetime fecundity (no. eggs / female) following maternal exposure to sublethal concentrations of Oberon Speed®. Means were separated with paired bootstrap test ($P < 0.05$) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.

<table>
<thead>
<tr>
<th>Life stage / Treatment</th>
<th>Control</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
<th>LC$_{30}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>2.23 ± 0.08 a</td>
<td>1.68 ± 0.07 b</td>
<td>2.12 ± 0.08 a</td>
<td>2.02 ± 0.07 a</td>
</tr>
<tr>
<td>Larva</td>
<td>1.52 ± 0.08 a</td>
<td>1.26 ± 0.06 b</td>
<td>1.69 ± 0.08 a</td>
<td>1.54 ± 0.08 a</td>
</tr>
<tr>
<td>Protonymph</td>
<td>1.48 ± 0.08 b</td>
<td>1.70 ± 0.10 ab</td>
<td>1.52 ± 0.08 b</td>
<td>1.78 ± 0.07 a</td>
</tr>
<tr>
<td>Deutonymph</td>
<td>1.21 ± 0.06 b</td>
<td>1.55 ± 0.08 a</td>
<td>1.46 ± 0.09 a</td>
<td>1.66 ± 0.08 a</td>
</tr>
<tr>
<td>Total develop. time</td>
<td>6.43 ± 0.17 a</td>
<td>6.12 ± 0.12 a</td>
<td>6.74 ± 0.13 a</td>
<td>6.97 ± 0.16 a</td>
</tr>
<tr>
<td>Preoviposition period</td>
<td>2.03 ± 0.18 b</td>
<td>2.61 ± 0.14 a</td>
<td>2.44 ± 0.16 ab</td>
<td>2.04 ± 0.17 b</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>21.00 ± 0.15 a</td>
<td>20.64 ± 0.19 a</td>
<td>19.52 ± 0.17 b</td>
<td>18.58 ± 0.22 c</td>
</tr>
<tr>
<td>Longevity ( )</td>
<td>14.57 ± 0.17 a</td>
<td>14.33 ± 0.17 ab</td>
<td>14.64 ± 0.17 a</td>
<td>14.00 ± 0.19 b</td>
</tr>
<tr>
<td>Oviposition days</td>
<td>16.07 ± 0.26 a</td>
<td>14.30 ± 0.35 b</td>
<td>15.04 ± 0.30 b</td>
<td>14.50 ± 0.25 b</td>
</tr>
<tr>
<td>Fecundity (no. eggs)</td>
<td>26.04 ± 0.53 a</td>
<td>23.33 ± 0.61 b</td>
<td>25.68 ± 0.59 a</td>
<td>22.75 ± 0.46 b</td>
</tr>
</tbody>
</table>

Table 6. Mean (± SE) life table parameters for *Amblyseius swirskii* following maternal exposure to sublethal concentrations of Oberon Speed®. Means were separated with a paired bootstrap test ($P < 0.05$) and standard errors by bootstrap with 100,000 samples. Values bearing different letters were significantly different among treatments.
<table>
<thead>
<tr>
<th>Parameter / Treatment</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>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.19 ± 0.01 a</td>
<td>0.19 ± 0.01 a</td>
<td>0.17 ± 0.01 a</td>
<td>0.16 ± 0.01 a</td>
</tr>
<tr>
<td>R&lt;sub&gt;0&lt;/sub&gt;</td>
<td>16.20 ± 1.90 a</td>
<td>16.04 ± 1.62 a</td>
<td>14.27 ± 1.94 a</td>
<td>12.70 ± 1.74 a</td>
</tr>
<tr>
<td>λ</td>
<td>1.21 ± 0.01 a</td>
<td>1.20 ± 0.01 a</td>
<td>1.18 ± 0.01 a</td>
<td>1.18 ± 0.01 a</td>
</tr>
<tr>
<td>GRR</td>
<td>20.54 ± 1.65 a</td>
<td>19.33 ± 1.33 a</td>
<td>19.86 ± 1.75 a</td>
<td>17.86 ± 1.48 a</td>
</tr>
<tr>
<td>T</td>
<td>14.81 ± 0.36 b</td>
<td>14.89 ± 0.21 b</td>
<td>15.72 ± 0.26 a</td>
<td>15.48 ± 0.30 ab</td>
</tr>
<tr>
<td>DT</td>
<td>3.68 ± 0.21 a</td>
<td>3.72 ± 0.16 a</td>
<td>4.10 ± 0.25 a</td>
<td>4.22 ± 0.28 a</td>
</tr>
</tbody>
</table>

**Figures**

**Figure 1**
Age-stage-specific survival rates ($S_{xj}$) of TSSM protonymphs exposed to various sublethal concentrations of Oberon Speed®.

Figure 2

Age-specific survival rate ($l_x$), age-specific fecundity ($m_x$) and age-stage-specific fecundity ($f_{xj}$) of TSSM after exposure to various sublethal concentrations of Oberon Speed® as protonymphs.
Figure 3

Age-stage-specific survival rate ($S_{xj}$) of *Phytoseiulus persimilis* after exposure to various sublethal concentrations of Oberon Speed®.
Figure 4

Age-specific survival rate ($l_x$), age-specific fecundity ($m_x$) and age-stage-specific fecundity ($f_{xij}$) of *Phytoseiulus persimilis* after exposure to various sublethal concentrations of Oberon Speed®.