Sublethal effects of difl oxid azin on demographic parameters of the predatory mite, Neoseiulus californicus (Acari: Phytoseiidae)

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\textbf{ABSTRACT}

The present study first evaluated the sublethal effects of difl oxid azin (Flumite\textsuperscript{c}) with three concentrations (LC5, LC10, and LC20) on life table parameters of Neoseiulus californicus (McGregor) (Acari: Phytoseiidae), as an effective predator of Tetranychus urticae (Koch) (Acari: Tetranychidae). Experimental results indicated that exposure to the sublethal concentrations of difl oxid azin, has no significant effect on the development time of the treated mite offspring. Difl oxid azin treatments gradually reduced the longevity and total life span of both sexes. The highest fecundity was observed in the control treatment (35.31 offspring/female), while the lowest was related to the LC20 concentration. However, the effects of different treatments on intrinsic (r), as well as finite rate of increase (λ) of this predator were insignificant. The r value, ranged from 0.2112 to 0.1989 day\textsuperscript{−1} for the mites treated with distilled water and the LC20 concentration, respectively. Furthermore, λ was not affected by enhancing the concentration, as the values were 1.2401 and 1.2205 day\textsuperscript{−1} for the mites treated with control and LC20, respectively. Those treated with LC20 had a significantly reduced R0, compared to those treated with control only. Thereby, the sublethal effects of difl oxid azin in combination with N. californicus were emphasized for designing management programs of T. urticae.

\textbf{Introduction}

The two-spotted spider mite Tetranychus urticae Koch (Acari: Tetranychidae) is regarded as one of the most destructive and cosmopolitan agricultural and horticultural crop pests with an extensive host range including tomato, cotton, eggplant, bean, raspberry, soybean, and ornamental trees (Van de Vrie et al. 1972; Jeppson et al. 1975; Van Leeuwen et al. 2010; Sedaratian et al. 2011; Khamanani et al. 2013). The mite is known to penetrate inside the leaf cell with whip shape chelicerae, disrupting plant growth by removing the cell contents (Krantz 1978). Chemical control is considered as the primary strategy for IPM programs due to its rapidity, cost-effectiveness, and ease of use (Zhao 2000; Akyazi et al. 2018). However, T. urticae can develop its resistance to pesticides very rapidly (Van Leeuwen et al. 2010) due to the short life cycle and high reproductive potential (Saito et al. 1983; Nauen et al. 2001).

Predatory mites in the family Phytoseiidae are considered as economically important predators and an effective alternative for biological control agents in agricultural systems (Hoy et al. 1983; Khamanani et al. 2015; Fathipour and Malekinia 2016). Among the predatory mites, Neoseiulus californicus McGregor (Acari: Phytoseiidae) is an effective species which can control the mites in different ecosystems such as fields and greenhouses (Castagnoli and Simoni 1999). In addition, the predator can adapt itself to the changes in prey population and tolerate some insecticides (Fraulo and Liburd 2007). Undoubtedly, using this predator cannot maintain the population of spider mites under the economic injury level alone (Alzoubi and Cobanoglu 2017). Therefore, the combination of using compatible insecticides, along with biological control agents has been widely recommended as an important part of IPM strategies (Elzen 2001).

Based on applied biological control of mites, the use of pesticides can unsatisfactorily affect the performance of biological control agents since phytoseiid mites are generally more susceptible to pesticides than phytophagous mites (Croft 1990). Therefore, in order to conserve these mites, using sublethal concentrations is regarded as one of the most important candidates (Stark et al. 1995). The studies conducted on sublethal effects revealed that the negative and non-lethal impacts of insecticides on pests can provide practical information for forming effective pest control strategies (Wang et al. 2009). The life-table technique has been used as an appropriate method for assessing population dynamics in the studies related to several target and non-target insects (Biondi et al. 2013; Cira et al. 2017; Nawaz et al. 2017).

Among all of the existing components, difl oxid azin is considered as a selective acaricide with synthetic origin, which belongs to a group of tetrazine and can affect a wide range of mites. It is regarded as a pesticide with contact and trans-laminar activity, and is commercially available with a common name of Flumite\textsuperscript{c} (SC 20%). In order to evaluate the sublethal effects of difl oxid azin to N. californicus, its effect on the survival, developmental rate, and fecundity throughout the whole lifespan should be considered. Thus, the present study aimed to address the potential of sublethal concentrations of difl oxid azin on developmental and reproductive fitness of the predatory mite N. californicus in order to obtain an augmentation plan in combination with one of the effective natural enemies of T. urticae.

\textbf{Materials and methods}

\textbf{Biological material}

In order to conduct the experiments, the stock population of two-spotted spider mites were obtained from infested greenhouses in Pakdasht (an East-southern part of Tehran, Iran) and were...
released on the kidney bean plants under greenhouse conditions at 25 ± 2°C, 60 ± 5% RH and a photoperiod of 16:8 (LD) h. The initial population of N. californicus was provided from Giah Bazr Alvand Company (Tehran, Iran), and was reared in the laboratory on kidney bean plants (Phaseolus vulgaris L.) infested with T. urticae. The predator rearing arenas were constructed according to McMurtry and Scriven (1965) and maintained in a growth chamber with a temperature and humidity of 25 ± 2°C and 65 ± 5% RH, along with a photoperiod of 16:8 (LD) hours. Finally, bean leaves heavily infested with T. urticae were added daily to each arena as the food source.

Pesticides
In order to conduct the experiments, diflubenzuron, IUPAC name 3-(2-chlorophenyl)-6-(2,6-difluorophenyl)-1,2,4,5-tetrazine, commercial formulation Flumite* (SC 20%) by 200 g/l Flufenzin was used.

Concentration-response bioassay
A modified leaf dip method (Helle and Overmeer 1985) was used to evaluate the response of N. californicus adults to different concentrations of diflubenzuron including 1000, 1200, 1350, 1500 and 1700 ppm (covering a range of 10–90% mortality). Then, the freshly-cut bean leaf discs (4 cm diameter) were dipped for 15 s into the diflubenzuron solutions and air-dried for about 3 h at room temperature. In addition, the control leaf discs were dipped in distilled water only and each leaf disc was transferred into the experimental arena, which was completely similar to the rearing arena but in a smaller size.

In the next procedure, 20 adult predatory mites (males and females) were placed on the treated leaf discs for each of the six concentrations by using a fine soft pointed brush. Four replicates were available per concentration. Mite mortality was assessed after 24-h exposure. Further, the sublethal concentrations including LC50, LC100 and LC20 were determined by using a probit procedure (IBM SPSS ver 19.0) for the subsequent experiments. Accordingly, four replicates per concentration and six concentrations per assay were evaluated. The experiments were conducted under laboratory conditions at 25 ± 2°C, 65 ± 5% RH and a photoperiod of 16:8 (LD) hours.

The effects of sublethal concentrations of diflubenzuron
In order to evaluate the sublethal effects of diflubenzuron on N. californicus, bean leaf discs were treated with sublethal doses including: LC50, LC100 and LC20. Distilled water was used as the control. All bean leaf discs were allowed to dry for 3 h before use in the experiment. Then, 45 predatory mites with a 24-h age were transferred onto the treated and untreated leaf discs. After 24 h, surviving females were separately introduced onto the untreated bean leaf discs (3 cm in diameter) and allowed to lay eggs. Only one laid egg was saved in each experimental arena after 24 h. The newly-emerged females were coupled with males for mating after adult emergence. Then, each predatory mite was provided with 4–6 immature stages of spider mite and maize pollen ad libitum in each experimental arena daily. Finally, the experimental units were monitored daily, the fecundity of females (45 replicates at each treatment) was daily recorded, and population parameters were calculated in both male and females until the death of the last sample.

Statistical analysis
The raw data of life table parameters were analysed according to the theory of age stage, two-sex life table (Chi and Liu 1985; Chi 1988) by using the computer program of TWOSEX-Ms Chart (Chi 2018). All population growth parameters including net and gross reproductive rate (R0 and GRR, respectively), intrinsic and finite rate of increase (r and λ, respectively), and mean generation time (T) (Fathipour and Maleknia 2016), and standard errors were calculated by using the bootstrap method with 100,000 replicates (Huang and Chi 2012; Akköprü et al. 2015).

Differences among life table parameters were compared by using paired bootstrap method based on the confidence interval of difference (Akca et al. 2015). Also, differences between various stages were compared with the Tukey–Kramer procedure was carried out using SAS (SAS Institute 2002).

Results
Bioassay of diflubenzuron on N. californicus
The regression equation of concentration-mortality was \( Y = -1.36 + 2.91X \) ([Y = mortality (probit), \( X = \) concentration (\( \mu \)g/ml)]. As shown in Table 1. The estimated LC50 for the predatory mite was 1348 \( \mu \)g a.i./ml, while no mortality was recorded for the control. In addition, the values of LC50, LC100 and LC20 were 948, 1024 and 1126 \( \mu \)g a.i./ml, respectively.

Development time, longevity, and total lifespan
Table 2 presents the effects of different concentrations of diflubenzuron on female and male development time of N. californicus. Based on the results, no significant effect was observed between males and females after the exposure of N. californicus to sublethal concentrations of the insecticides in the duration of egg (Male: F = 0.10, df = 3,114, P = 0.95; Female: F = 0.28, df = 3,114, P = 0.84), larva (Male: F = 0.01, df = 3,114, P = 0.99; Female: F = 0.18, df = 3,114, P = 0.9), protonymph (Male: F = 0.53, df = 3,114, P = 0.66; Female: F = 0.4, df = 3,114, P = 0.75), and deutonymph (Male: F = 0.52, df = 3,114, P = 0.64; Female: F = 0.09, df = 3,114, P = 0.96) between different concentrations, compared to those in the control treatment. However, as shown in Table 2, the duration of different immature stages, adult longevity, along with total lifespan for both sexes were significantly conditioned by different concentrations (longevity: F = 66.85, df = 3,36, P < 0.0001 for males vs. F = 1183.4, df = 3,114, P < 0.0001 for females; lifespan: F = 32.2, df = 3,36, P < 0.0001 for males vs. F = 524.6, df = 3,114, P < 0.0001 for female). It is worth noting that the sublethal concentrations (LC50, LC100 and LC20) resulted in reducing the longevity and total lifespan of both males and females significantly, compared to the amount in the control treatment. The longest and lowest female adult longevity, as well as the total lifespan, were observed on control and LC20 treatment, respectively (Table 2).

Reproduction
Table 3 displays the reproductive periods and total fecundity of offspring in the treated females. As shown, no significant effect

| Table 1. Probit analysis for the concentration–mortality response of diflubenzuron on adult females and males of Neoseiulus californicus. |
|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| LC50 *                | LC100 *         | LC20 *          | LC50 *          | P-value | Slope ± SE | X² | N° | df |
| 948 (869–1008)        | 1024 (954–1078) | 1126 (1068–1171)| 1348 (1308–1389)| 0.98    | 2.78 ± 0.34| 0.15 | 480 | 4  |

*20 individuals per replicate, four replicates per concentration, six concentrations per assay

* LC values are shown as \( \mu \)g a.i./ml with 95% confidence level.
was observed on the adult pre-oviposition period (APOP) ($F_{3,114} = 20.79, df = 3,114; P < 0.05$) or the total pre-oviposition period (TPOP) ($F_{3,114} = 1167.2, P < 0.0001$) decreased significantly by increasing the concentration of difludazin. In addition, the oviposition day and period varied from 11.89 to 21.86 ($F_{20} = 1167.2, P < 0.0001$) days in the LC$_{20}$ and control treatments, respectively. Further, as shown in Table 3, the sublethal concentrations of difludazin resulted in significantly reduced total fecundity of the predatory mite ($F_{3,114} = 272.7, df = 3,114; P < 0.0001$). Furthermore, the highest fecundity was observed in the control treatment (35.31 offspring/female) while the lowest was related to the LC$_{20}$ concentration (19.29 offspring/female).

**Population growth parameters**

The estimated values of life table parameters for *N. californicus* are shown in Table 4. Based on the results, the gross reproductive rate (GRR) varied from 27.18 to 14.63 in the offspring/individual. The lowest values of GRR as well as $R_0$ (12.27 offspring/individual) (net reproductive rate) parameters were obtained for the mites exposed to the LC$_{20}$ treatment. In addition, the values of the intrinsic rate of increase ($r$) and finite rate of increase ($\lambda$) among different difludazin concentrations were insignificant. As shown, the mean generation time was the longest on LC$_{20}$ and the control, followed by LC$_{10}$ and LC$_{20}$ treatments.

**Survival and fecundity**

Figure 2 compares age-specific survivorship ($l_x$), age-stage fecundity of female ($f_{ij}$), and age-specific fecundity ($m_x$) of *N. californicus* at different experimental concentrations of difludazin. As illustrated in Figure 2, the maximum value of $l_x$ when the mites were exposed to LC$_{10}$, LC$_{10}$, and LC$_{20}$ concentration of difludazin, as well as the distilled water is 33, 28, 24, and 35 days, respectively. In addition, the highest daily oviposition rate is 1.61, 1.67 and 1.26 eggs for LC$_{10}$, LC$_{10}$, and LC$_{20}$ concentration, respectively, which occurred at the age of 25, 21, and 13 days, respectively. The value of daily oviposition was recorded at 1.42 eggs for the control treatment, which occurred at the age of 24 days. Figure 1 displays the age-stage-specific survival rate ($s_x$) representing the probability that an egg can survive to age $x$ and develop to stage $j$ for different treatments. An obvious overlap was observed in the curves at different developmental periods among the individuals (Figure 1(a–d)).

**Discussion**

In general, a single chemical control method against pests cannot be successful, especially when the pesticides are not selected to

### Table 2. Mean (±SE) female and male development time (days) of *Neoseiulus californicus* for control and different concentrations of difludazin.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CK</th>
<th>LC$_3$</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egg (day)</td>
<td>1.18 ± 0.12$^a$</td>
<td>1.20 ± 0.13$^a$</td>
<td>1.11 ± 0.11$^a$</td>
<td>1.20 ± 0.13$^a$</td>
</tr>
<tr>
<td>Larva (day)</td>
<td>1.09 ± 0.09$^a$</td>
<td>1.10 ± 0.10</td>
<td>1.10 ± 0.11</td>
<td>1.11 ± 0.10$^a$</td>
</tr>
<tr>
<td>Protonymph (day)</td>
<td>1.17 ± 0.12$^a$</td>
<td>1.19 ± 0.13</td>
<td>1.30 ± 0.17</td>
<td>1.40 ± 0.16$^a$</td>
</tr>
<tr>
<td>Deutonymph (day)</td>
<td>1.27 ± 0.14$^a$</td>
<td>1.20 ± 0.13</td>
<td>1.42 ± 0.18</td>
<td>1.40 ± 0.16$^a$</td>
</tr>
<tr>
<td>Adult longevity (day)</td>
<td>20.27 ± 0.45$^a$</td>
<td>19.4 ± 0.34</td>
<td>15.9 ± 0.39</td>
<td>13.4 ± 0.37</td>
</tr>
<tr>
<td>Total lifespan (day)</td>
<td>25.00 ± 0.49$^a$</td>
<td>24.1 ± 0.43</td>
<td>20.89 ± 0.70</td>
<td>18.5 ± 0.52</td>
</tr>
</tbody>
</table>

Means within a row followed by the same letter are not significantly different (Tukey–Kramer P < 0.05). CK is the water control.

### Table 3. Mean (±SE) reproductive period and total fecundity of offspring from females of *Neoseiulus californicus* for control and different concentrations of difludazin.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CK</th>
<th>LC$_3$</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oviposition day</td>
<td>21.86 ± 0.08$^a$</td>
<td>20.1 ± 0.15$^a$</td>
<td>16.23 ± 0.11$^a$</td>
<td>11.89 ± 0.16$^a$</td>
</tr>
<tr>
<td>Oviposition period</td>
<td>22.0 ± 0.07 $^a$</td>
<td>20.5 ± 0.11 $b$</td>
<td>16.29 ± 0.11 $c$</td>
<td>12.10 ± 0.14 $d$</td>
</tr>
<tr>
<td>*APO (day)</td>
<td>2.28 ± 0.08$^a$</td>
<td>2.37 ± 0.09$^a$</td>
<td>2.32 ± 0.09$^a$</td>
<td>2.12 ± 0.08$^a$</td>
</tr>
<tr>
<td>*TP (day)</td>
<td>7.10 ± 0.17$^a$</td>
<td>7.20 ± 0.17$^a$</td>
<td>7.32 ± 0.13$^a$</td>
<td>7.29 ± 0.14$^a$</td>
</tr>
<tr>
<td>Fecundity (offspring/female)</td>
<td>35.31 ± 0.37$^a$</td>
<td>33.77 ± 0.53$^a$</td>
<td>27.52 ± 0.45$^a$</td>
<td>19.29 ± 0.35$^a$</td>
</tr>
</tbody>
</table>

Means followed by the same letter in the same row are not significantly different (Tukey–Kramer P ≤ 0.05). CK is the water control.

$^a$ APOP = adult pre-oviposition period (the duration from adult emergence to the first oviposition); $^b$ TPOP = total pre-oviposition period (the duration from egg to the first oviposition).

### Table 4. Life table parameters (mean ± SE) of *Neoseiulus californicus* for control and different concentrations of difludazin.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CK</th>
<th>LC$_3$</th>
<th>LC$_{10}$</th>
<th>LC$_{20}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r$ (day$^{-1}$)</td>
<td>0.2112 ± 0.01$^a$</td>
<td>0.2122 ± 0.01$^a$</td>
<td>0.2127 ± 0.01$^a$</td>
<td>0.1989 ± 0.01$^a$</td>
</tr>
<tr>
<td>$\lambda$ (day$^{-1}$)</td>
<td>1.2401 ± 0.01$^a$</td>
<td>1.2811 ± 0.01$^a$</td>
<td>1.2471 ± 0.01$^a$</td>
<td>1.2205 ± 0.01$^a$</td>
</tr>
<tr>
<td>$R_0$ (offspring/individual)</td>
<td>22.74 ± 2.52$^a$</td>
<td>22.22 ± 2.39$^a$</td>
<td>18.81 ± 1.9$^a$</td>
<td>12.27 ± 1.41$^a$</td>
</tr>
<tr>
<td>GRR (offspring/individual)</td>
<td>27.18 ± 2.16$^a$</td>
<td>26.73 ± 2.01$^a$</td>
<td>22.12 ± 1.61$^a$</td>
<td>14.63 ± 1.32$^a$</td>
</tr>
<tr>
<td>$T$ (day)</td>
<td>14.74 ± 0.25$^a$</td>
<td>14.51 ± 0.23$^a$</td>
<td>13.80 ± 0.18$^a$</td>
<td>12.58 ± 0.16$^a$</td>
</tr>
</tbody>
</table>

The SE was estimated using 100,000 bootstraps. The means followed by the same letter are not significantly different using paired bootstraps test at the 5% significance level. CK is the water control.
play less significant effects on natural enemies and the environment, as well as a narrow spectrum of effects on specific pest species (Kaplan et al. 2012). Phytoseiid mites are regarded as useful biocontrol agents against different small insects and mites such as TSSM, whiteflies, and thrips action as generalist predators (Messelink et al. 2008, 2010). It is worth noting that the disruption of biological control may occur when there is a harmful effect for the predatory mites than the pests (Schmidt-Jeffris and Beers 2018).

The identification of sublethal effects is necessary for giving a more detailed assessment on insecticide utility to optimize the usage (Stark and Banks 2003). So far, a large number of studies have been conducted on sublethal effects of different insecticides on biological parameters and life stages of different predatory mites (Cloyed et al. 2006; Duchovskienė and Survilienė 2009; Hamedi et al. 2010, 2011; Park et al. 2011; Kaplan et al. 2012; Maroufpoor et al. 2016; Mollaloo et al. 2017). However, to the best of our knowledge, the demographic approach was first used in the present study to evaluate the sublethal concentrations of diflubenzuron effects on development and demographic parameters of *N. californicus*. Based on the published data, this acaricide can have a significantly negative effect on longevity, fecundity, and life table parameters of *T. urticae* (Havasi et al. 2018).

Regarding the data in the present study, the use of sublethal concentrations of diflubenzuron failed to influence the development time of both sexes of *N. californicus* considerably. The findings are consistent with those in another study which found no significant difference in the duration of immature stages of *Phytoseius plumifer* (Canestrini and Fanzago) treated with sublethal concentrations of fenpyroximate (Hamedi et al. 2010). However, the results were inconsistent with the findings of Alinajad et al. (2014) with respect to the sublethal concentrations of fenazaquin on *Amblyseius swirskii* (Athias-Henriot). This inconsistency may be related to the fact that fenazaquin disrupts the electron transport chain (Dekeyser 2005) whereas diflubenzuron, is considered a selective reproduction inhibitor which prevents egg production by females (Pap et al. 1994).

Further, the sublethal effects of different concentrations of this acaricide led to reduction in the longevity and the total lifespan of *N. californicus* significantly. Similar results were reported for *P. plumifer* treated with abamectin (Hamedi et al. 2011), *G. occidentalis* (Nesbitt) affected by spiromesifen and acequinocyl (Irigaray and Zalom 2006), and *A. swirskii* treated with fenazaquin (Alinajad et al. 2014). However, Ibrahim and Yee (2000) observed no effect on the longevity and total lifespan among *Neoseiulus longispinosus* (Evans) abamectin-treated mites.

Pre-ovipositional periods, especially the total pre-oviposition period (TPOP), play an important role in the intrinsic rate of increase (Khanamani et al. 2017). Based on the results of data analysis, diflubenzuron treatment failed to influence pre-oviposition periods and decreased the oviposition period and oviposition day with increasing concentrations. The oviposition period is considered to be the duration of time from the beginning to the end of oviposition (Chen et al. 2018). The decreasing trend in oviposition day was in agreement with other studies that focused on the sublethal effects of spiridiclofen and pyridaben on *N. californicus* and *N. womersley*, respectively (Park et al. 2011; Maroufpoor et al. 2016). Contrarily, Alinajad et al. (2016) demonstrated that spiridioclofen residue does not have any significant effect on the oviposition day of *A. swirskii*. A possible explanation for this difference may be related to acaricide mode of action, different predatory species, and experimental concentrations (Nauen and Schnorbach 2005). The results of the present study introduced the sublethal concentrations of diflubenzuron, leading to significantly low fecundity for predatory mites (at LC$_{10}$ and LC$_{20}$ concentrations) when compared with those in the control. However, the result was inconsistent with that of Alinajad et al. (2016).

The significant role of demographic toxicology in evaluating the response to toxicants has been highlighted in different studies. In the current study, population parameters such as net reproductive rate ($R_0$), gross reproductive rate (GRR), and mean generation time (T) in the treated (LC$_{20}$) population were significantly lower than those in the control.
There is a general consensus that $r$ is regarded as the best measure for evaluating the total effects of a pesticide, due to its reproductive potential (Moscardini et al. 2013) and survivorship. In addition, the use of the intrinsic rate of increase ($r$) as an ecologically meaningful bioassay parameter for toxicology studies has been emphasized (Allan and Daniels 1982). The exposure of $N. californicus$ to difludazin leading to the $r$ and $\lambda$ parameters failed to have any significant effect in different treatments in such a way that the highest values for $r$ and $\lambda$ parameters were recorded for LC$_{10}$ and LC$_{20}$ concentrations, respectively. In fact, these growth rates exceeded the values reported for $A. swirskii$ exposure to spiromesifen at LC$_{20}$ ($r=0.131$ day$^{-1}$) and LC$_{10}$ ($\lambda=1.138$ day$^{-1}$) treatments (Alinejad et al. 2016). In addition, $N. californicus$ had the lowest $r$-value (0.17 day$^{-1}$) on LC$_{15}$ and then on LC$_{10}$ concentration of spiromesifen (Mollaloo et al. 2017). However, Hamedi et al. (2010) and Alinejad et al. (2014) reported that the $r$ values of treated predatory mites ($P. plumifer$, and $A. swirskii$, respectively) had a declining significance by increasing the concentration of insecticides. This discrepancy may be based on the differences in the host species of studies or the concentration of the insecticides. Regarding the curves of survival and age-specific fecundity, an increase in the concentration of this acaricide has a downward trend in $l_x$ and $m_x$ values. In line with the results of the present study, the same trend was reported for the survival probability of $P. persimilis$, when the mites were treated with bifenthrin and dimethoate (Alzoubi and Çobanoğlu 2010). The parameters such as $s_{ij}$ changed after treating individuals with difludazin. For example, an increase in difludazin concentrations led to an increase in mortality. Thus, comparative numbers alive ($s_{ij}$) were reduced by the LC$_{10}$ treatment followed by a considerable decrease in LC$_{20}$ treatment among males and females. The results were in agreement with those of Mollaloo et al. (2017), which emphasized a considerable decrease in the survival probability when $N. californicus$ were treated with spiromesifen, compared with the control treatment. In order to

Figure 2. Age-specific survivorship ($l_x$), age-stage fecundity of female ($f_{xj}$), and age-specific fecundity ($m_x$) of Neoseiulus californicus for control and different concentrations of difludazin: Control (a), LC$_{5}$ (b), LC$_{10}$ (c), LC$_{20}$ (d).
assess the natural enemies for biological control, a set of criteria rather than single-best-traits of a natural enemy should be considered (Waage 1989).

In general, the low concentrations of the pesticide may be used in combination with *N. californicus* in an IPM program of *T. urticae* (Roush 1982; Dent 2000) in order to reduce the development of resistance and adjust the predator/prey ratio. However, accurate analysis of both lethal and sublethal effects of insecticides on natural enemies should be evaluated before their integration into pest management programs (Rashidi and Ganbalani 2018). The observations during the experiments can help us to better understand the total effects of Flumite on different life stages of *N. californicus*. Based on the results, difludazin could suppress various life table attributes of the predator such as survival, fecundity, *R₀*, GRR and *T*, while the effect of difludazin failed to change the intrinsic rate of increase (*r*) and finite rate of increase (*λ*) at sublethal concentration considerably. Consequently, based on the present observations, the use of difludazin may be disruptive where this predatory mite is effective as a biological control agent. Thus, more experiments should be conducted at large spatial and temporal levels in field and semi-field conditions.

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Disclosure statement
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