Research Article

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# Effects of spirodiclofen on life history traits and population growth of a spider mite predator *Oligota flavicornis* (Coleoptera: Staphyllinidae) based on the age-stage two-sex life table theory

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## Abstract

**BACKGROUND: Knowledge of the compatibility between spirodiclofen and the predator *Oligota flavicornis* is an important aspect for the management of spider mites.**

**RESULTS: We used the age-stage, two-sex life table to assess the effects of spirodiclofen on the life history traits and population growth of *O. flavicornis*. At the maximum recommended concentration (60 mg a.i. $L^{-1}$) and also at twice the maximum recommended dosage (120 mg a.i. $L^{-1}$), the preadult stages of *O. flavicornis* were significantly lengthened, while the adult longevity and fecundity decreased significantly. The finite rate ($\lambda$), intrinsic rate of increase ($r$), and net reproduction rate ($R_0$) decreased, while the mean generation time ($T$) was longer after both the 60 and 120 mg a.i. $L^{-1}$ treatments than it was in the control and 30 mg a.i. $L^{-1}$ treatments. Life expectancy and reproductive value were higher in the control and 30 mg a.i. $L^{-1}$ treatment than in the 60 and 120 mg a.i. $L^{-1}$ treatments; the two higher concentrations were detrimental to the development of *O. flavicornis*.**

**CONCLUSION: A proper combination of the *O. flavicornis* and spirodiclofen to control the spider mite, while avoiding the side effect of spirodiclofen, could be achieved based on the knowledge of life tables.**


**Keywords:** spirodiclofen; *Oligota flavicornis*; development; reproduction; life table

## 1 INTRODUCTION

Spider mites, belonging to Tetranychidae, are undoubtedly the most important phytophagous mites worldwide, and more than 1200 species are known to be pests, damaging over 300 plant species.[1] Dozens of acaricides have been used in pest management; currently, among all acaricides, spirodiclofen is the most used acaricide all over the world.[2] Spirodiclofen, a tetronic acid derivative with acaricidal action, is effective against many phytophagous mite species and all developmental stages of mites, including eggs, and has a pronounced residual effect.[3,4] It has been used for controlling *Panonychus citri*,[5] *Raoiella indica*,[6] *Tetranychus urticae* and *Tarsonemus pallidus*,[7–9] *P. ulmi* and *Aculus schlechtendali*.[10,11] However, the use of pesticides can hamper the effectiveness of natural enemies,[6,12,13] interfere with their physiology, behavior, and population growth,[14] alter the balance between natural enemies and their prey, lead to ecological backlashes,[15,16] and disrupt the ecosystem services they provide.[14] Therefore, the conservation and augmentation of natural enemy insects in a pest management system mainly based on pesticides are important strategies to reduce the side effects of acaricides, while improving the efficiency of natural enemies.

The arboreal rove beetle, *Oligota flavicornis* (Boisduval & Lacordaire) (Coleoptera: Staphylinidae), feeds on all stages of tetranychid mites, and is a dominant natural enemy insect in citrus orchards in southeast China.[17–19] Large numbers of spider mites are sucked out by *O. flavicornis*, and the empty corpses remain. Seasonal fluctuation,[18] predation rate,[20] temperature-dependent development,[21] mass rearing, and augmented release[22,23] of *O.*

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*flavicornis* have been reported. However, the compatibility of *O. flavicornis* with pesticides is unknown. Limited data availability makes it difficult to provide support for natural enemy protection and field application of pesticides.

Recent studies have also shown that several predatory mites could be highly compatible with spirodiclofen[8,24,25]; however, the adverse consequences that arthropod natural enemies are negatively affected by sublethal spirodiclofen concentrations in different ways, such as physiological events,[26] mortality,[6,10,13] longevity and reproduction,[27,28] parasitism rate and emergence rate[16] and life-table parameters[29,30] have also been reported. However, it is not understood comprehensively how spirodiclofen affects the development, survival, fecundity, and population growth of *O. flavicornis*, which is the primary consideration for the compatibility of natural enemy insects with pesticides.

For an overall and comprehensive understanding of the effect of spirodiclofen on *O. flavicornis*, it is necessary to consider its effects on the development, survival, and reproduction of all individuals of both sexes, and it is also important to understand its effect on the stage differentiation, because individuals at different stages often respond differently to pesticides. Moreover, the effects on life history traits should be expressed at the population level, considering that population growth rate is recognized as an ecologically more relevant endpoint.[31,32] However, traditional female age-specific life tables[33–35] ignore the male population and stage differentiation, they are incapable of providing correct information on the side-effects of spirodiclofen on *O. flavicornis* or other natural enemies. The age-stage, two-sex life table can, however, consider life-history data for both sexes and variable developmental rates among individuals; therefore, it can properly describe the developmental duration, survival and reproduction, stage differentiation and population growth.[36,37] In this study, data regarding the life histories of *O. flavicornis* fed on *T. cinnabarinus* at different multiple recommended concentrations of spirodiclofen were collected and analyzed based on the age-stage two-sex life table theory.

## 2 MATERIALS AND METHODS

### 2.1 Spider mites and insect cultures

Colonies of *T. cinnabarinus* and *O. flavicornis* were established from specimens originally collected in Fuzhou city, China (25°56′N, 119°15′E). Mulberry trees were grown as the host plants for the rearing of the spider mite (*T. cinnabarinus*) in a glasshouse and *O. flavicornis* were reared on *T. cinnabarinus* for more than 4 years following the method of Lin *et al.*[21] Clean mulberry leaves were first placed on water-soaked sponges, and then, a few spider mites were transferred onto the leaves with a fine bush. After one week, an infested leaf piece was transferred into a glass jar (1 L), and four pairs of adult *O. flavicornis* were released into the jar. The jar was covered with a lid with holes, which was covered with nylon gauze for ventilation. Fresh leaves with spider mites were supplied twice a week, and leaves with staphylinid eggs were collected and used to maintain the colony. Prey and predator breeding and experiments were conducted in an environmental chamber at 25 ± 1 °C, 75 ± 5% RH, and a 16 L:8 D h photoperiod.

### 2.2 Chemical tested

The commercial formulation Envidor® (240 g/L spirodiclofen suspension concentrate, Bayer Crop Science, Germany), was used in this study. The maximum recommended concentration (obtained from the commercial products label) was 4000 times dilution with distilled water; equaling 60 mg a.i. $L^{-1}$. Four different concentrations of spirodiclofen were used in the study, namely, 0 (control), 30, 60, and 120 mg a.i. $L^{-1}$. Because most farmers use the maximum concentration recommended by the producer, we use 60 and 120 mg a.i. $L^{-1}$ to detected possible effect of higher doses.

### 2.3 Life table study

A leaf disk (3 cm in diameter) was cut from mulberry leaves, and 60 adults of *T. cinnabarinus* females were gently transferred onto the disk with a fine brush. After 24 h, these adult females were removed from the disk (approximately 400 eggs of *T. cinnabarinus*). Then, the disks were dipped in the spirodiclofen solutions (0, 30, 60, and 120 mg a.i. $L^{-1}$) for 5 s, correspondingly, and allowed to air-dry for 1 h. Each leaf disk was placed abaxial side facing upward on a wet filter paper in a plastic Petri dish (3.5 cm in diameter) with holes for ventilation. Fifty *O. flavicornis* eggs (laid within 24 h) were randomly collected from the stock population, and placed individually on a leaf disk. The leaf disks with *T. cinnabarinus* eggs and dipped in spirodiclofen solution were replaced every day. The presence of an exuvium on the leaf disk was used as evidence of successful molting. Rice husks were placed under the leaf disk, so that *O. flavicornis* could spin a cocoon. The prepupal stage of *O. flavicornis* was confirmed when the cocoon was formed. Emerged adults from the same concentration treatment were paired, and placed in a glass oviposition jar (9 cm in height, 6.5 cm in diameter) with a plastic cover. There were holes with nylon gauze on the plastic cover for ventilation. The mulberry leaves (7 cm × 7 cm) with all *T. cinnabarinus* stages and treated using the pesticide dipping method were provided daily to *O. flavicornis*. Superfluous individuals of one sex were paired with adults of the opposite sex from the mass-reared *O. flavicornis* colony; however, the complementary individual was excluded from demographic analysis. The survival and fecundity of the staphylinid beetles were recorded daily until the death of all individuals.

### 2.4 Life table analysis

All raw data for the *O. flavicornis* individuals were analyzed according to the age-stage, two-sex life table[36,37] using the computer program TWOSEX-MSChart.[38] Age-stage specific survival rate ($s_{xj}$) described the probability that a newly laid egg would survive to age $x$ and stage $j$, ($x$ is age in days and $j$ is the stage), age-specific survival rate ($l_x$), age-stage specific fecundity ($f_{xj}$), age-specific fecundity ($m_x$), intrinsic rate of increase ($r$), net reproductive rate ($R_0$), finite rate of increase ($\lambda$), and mean generation time ($T$) were calculated according to Chi and Liu[36] and Chi.[37] To take both sexes into consideration, $l_x$ and $m_x$ were calculated as follows:

$$l_x = \sum_{j=1}^{k} s_{xj}$$

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

where $k$ is the number of stages. Net reproductive rate is defined as the mean number of offspring a predator can produce during



  

**Table 1.** Effects of spirodiclofen on developmental duration (days) of immature stages, adult preoviposition period (APOP), total oviposition period (TPOP), adult longevity, total longevity, oviposition days ($O_d$), and fecundity ($F$) of *Oligota flavicornis* fed on *Tetranychus cinnabarinus*. Values are means ± SE

| Stage/Parameter | *n* | Control | *n* | 30 mg a.i. $L^{-1}$ | *n* | 60 mg a.i. $L^{-1}$ | *n* | 120 mg a.i. $L^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Egg | 49 | 2.85 ± 0.07*a* | 49 | 2.88 ± 0.06*a* | 49 | 2.88 ± 0.08*a* | 47 | 2.85 ± 0.07*a* |
| L1 | 47 | 1.13 ± 0.05*a* | 47 | 1.15 ± 0.05*a* | 43 | 1.74 ± 0.07*b* | 33 | 1.70 ± 0.08*b* |
| L2 | 46 | 1.11 ± 0.05*a* | 45 | 1.09 ± 0.04*a* | 40 | 1.15 ± 0.06*a* | 30 | 1.17 ± 0.07*a* |
| L3 | 43 | 2.07 ± 0.04*a* | 42 | 2.07 ± 0.04*a* | 38 | 2.18 ± 0.06*a* | 27 | 2.22 ± 0.10*a* |
| Prepupa | 40 | 1.65 ± 0.08*a* | 40 | 1.68 ± 0.07*ab* | 34 | 1.91 ± 0.11*b* | 24 | 2.17 ± 0.08*b* |
| Pupa | 39 | 4.72 ± 0.08*a* | 38 | 4.76 ± 0.08*a* | 29 | 6.03 ± 0.12*b* | 23 | 5.83 ± 0.12*b* |
| Preadult | 39 | 13.54 ± 0.11*a* | 38 | 13.65 ± 9.44*a* | 29 | 15.72 ± 0.24*b* | 23 | 15.74 ± 0.16*b* |
| Preadult survival rate ($s_a$) | 50 | 0.780 ± 0.059*a* | 50 | 0.760 ± 0.060*a* | 50 | 0.580 ± 0.070*b* | 50 | 0.460 ± 0.070*b* |
| APOP (d) | 20 | 2.25 ± 0.19*a* | 20 | 2.40 ± 0.11*a* | 15 | 2.13 ± 0.19*a* | 13 | 2.46 ± 0.14*a* |
| TPOP (d) | 20 | 15.70 ± 0.24*a* | 20 | 16.05 ± 0.22*a* | 15 | 17.73 ± 0.48*b* | 13 | 18.23 ± 0.25*b* |
| Female adult Longevity (d) | 20 | 42.39 ± 2.48*b* | 20 | 43.30 ± 2.13*b* | 15 | 33.93 ± 3.53*a* | 13 | 35.38 ± 2.54*a* |
| Male adult Longevity (d) | 19 | 45.06 ± 3.24*b* | 18 | 46.52 ± 3.10*b* | 14 | 24.71 ± 3.53*a* | 10 | 28.01 ± 2.90*a* |
| Female total longevity (d) | 20 | 55.85 ± 2.50*a* | 20 | 56.95 ± 2.14*a* | 15 | 49.52 ± 3.49*a* | 13 | 51.15 ± 2.54*a* |
| Male total longevity (d) | 19 | 58.69 ± 3.30*b* | 18 | 60.13 ± 3.15*b* | 14 | 40.56 ± 3.61*a* | 10 | 43.71 ± 2.94*a* |
| Oviposition days ($O_d$) (d) | 20 | 32.79 ± 1.61*b* | 20 | 33.40 ± 1.46*b* | 15 | 21.07 ± 1.99*a* | 13 | 23.31 ± 1.65*a* |
| Fecundity ($F$) (eggs/female) | 20 | 173.67 ± 10.44*b* | 20 | 169.93 ± 9.70*b* | 15 | 111.89 ± 12.91*a* | 13 | 107.09 ± 11.48*a* |

The standard errors were estimated by using bootstrap technique with 100 000 resampling. The same letter within a row indicates no significant difference between treatments based on a paired bootstrap test at the 5% significance level.

its life-span. It was calculated as follows:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The intrinsic rate of increase was calculated using the iterative bisection method from the Euler-Lotka equation:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

with the age indexed from day 0.[39] The finite rate of increase was calculated as follows:

$$\lambda = e^r$$

Mean generation time is defined as the length of time a population requires to increase to $R_0$–fold of its size when the population reaches a stable age-stage distribution, and it was calculated as follows:

$$T = \frac{\ln R_0}{r}$$

Age-stage life expectancy ($e_{xj}$)[40] is the time for which an individual of age $x$ and stage $j$ is expected to live after age $x$ and it was calculated as follows:

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s'_{iy}$$

where $s'_{iy}$ is the probability that an individual of age $x$ and stage $j$ will survive to age $i$ and stage $y$, and was calculated by assuming $s'_{xj} = 1$.[40] Age-stage reproductive value ($v_{xj}$) is defined as the contribution of an individual of age $x$ and stage $j$ to the future population,[41] and it was calculated as follows[42]:

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{k} s'_{iy} f_{iy}$$

The standard errors of all life history traits and population parameters were calculated using the bootstrap method with 100,000 resampling. The differences in development time, adult longevity, adult preoviposition period (APOP) (*i.e.*, the duration from adult emergence to the first oviposition), total preoviposition period (TPOP) (*i.e.*, the duration from birth to the first oviposition), fecundity, oviposition days, and population parameters among treatments were analyzed using a paired bootstrap test at the 5% significance level. All graphs were created using the Origin 9.1 software.

### 2.5 Population projection

Survival rate and fecundity data were used to project the population growth of *O. flavicornis*[36,43] using the TIMING-MSChart program.[44]

## 3 RESULTS

### 3.1 Life history traits

The mean developmental durations of *O. flavicornis* reared on *T. cinnabarinus* treated with different spirodiclofen concentrations are provided in Table 1. The durations of the egg and the 2nd and 3rd instar larvae were not significantly different among the four treatments. The developmental durations of 1st instar, pupa and preadult was significantly longer at 60 and 120 mg a.i. $L^{-1}$ than at 30 mg a.i. $L^{-1}$ and control ($P < 0.05$); however, there were no significant differences between the two higher concentration treatments. The prepupal durations were significantly longer at 60 and 120 mg a.i. $L^{-1}$ than the control ($P < 0.05$), yet not different from that at 30 mg a.i. $L^{-1}$. The preadult survival rate ($s_a$) in the control and 30 mg a.i. $L^{-1}$ treatments were significantly higher than that in 60 and 120 mg a.i. $L^{-1}$ (Table 1).

The APOP of three spirodiclofen treatments were not significantly different from that of the control; however, the TPOP were significantly longer at 60 and 120 mg a.i. $L^{-1}$ than at 30 mg a.i. $L^{-1}$ and control ($P < 0.05$). Thus, the age of first reproduction is extended for more than 2 days in treatments with 60 and



  

120 mg/L, as a consequence of extended developmental duration of L1, prepupa and pupa. Female and male adult longevities at 60 and 120 mg a.i. $L^{-1}$ were significantly shorter than those at 30 mg a.i. $L^{-1}$ and control, and there was no significant difference between the latter two treatments ($P < 0.05$). However, the female total longevity (from egg to adult death) of three spirodiclofen treatments was not significantly different from the control, and the male total longevity at 30 mg a.i. $L^{-1}$ and control were significantly longer than those of the two higher concentration treatments (Table 1). The oviposition days ($O_d$) in the control and 20 mg a.i. $L^{-1}$ treatments were significantly greater than those in 60 and 120 mg a.i. $L^{-1}$.

### 3.2 Life table and population parameters

The overlaps observed in age-stage specific survival rate ($s_{xj}$) clearly showed the variable developmental rate among individuals (Fig. 1). The age-specific survival rate ($l_x$), age-stage specific fecundity ($f_{xj}$), and age-specific fecundity ($m_x$) of *O. flavicornis* reared on *T. cinnabarinus* at different spirodiclofen concentrations are shown in Figure 2. The curve of $l_x$ was a summation of the survival curves at different stages at age $x$. The highest peaks of $m_x$ occurred on day 18 with 4.1 offspring in the control, day 18 with 4.9 offspring at 30 mg a.i. $L^{-1}$, day 20 with 3.6 offspring at 60 mg a.i. $L^{-1}$, and day 20 with 3.7 offspring at 120 mg a.i. $L^{-1}$. The age-specific maternity ($l_x m_x$) curves showed more, higher peaks at 30 mg a.i. $L^{-1}$ and control, and always more than 2 offspring from days 17–36 at 30 mg a.i. $L^{-1}$, and from days 17–35 at control, yet never more than 2 offspring for the two higher concentration treatments (Fig. 2).

The $e_{01}$ (life expectancy at age zero) is the mean longevity of a population, and the mean longevities of *O. flavicornis* were longer at 30 mg a.i. $L^{-1}$ (46.42 days) and control (46.44 days) than at 60 mg a.i. $L^{-1}$ (30.26 days) and 120 mg a.i. $L^{-1}$ (25.58 days) (Table 1 and Fig. 3). The reproductive values ($v_{xj}$) at age zero were 1.182, 1.183, 1.140 and 1.132 $day^{-1}$ in the 0, 30, 60, and 120 mg a.i. $L^{-1}$ treatments, respectively, which are also the finite rate of increase ($\lambda$) in the respective concentration treatments (Table 2). The $v_{xj}$ value of *O. flavicornis* adults in the different concentration treatments reached the peak values of 41.8 (day 18), 44.7 (day 17), 38.8 (day 20), 41.3 (day 19) in the 0, 30, 60, and 120 mg a.i. $L^{-1}$ treatment, respectively (Fig. 3).

The finite rate of increase ($\lambda$), intrinsic rate of increase ($r$), net reproductive rate ($R_0$) and mean generation time ($T$) are listed in Table 2. There were no significant differences in any parameter between the control and 30 mg a.i. $L^{-1}$ treatments. However, the values of $\lambda$, $r$ and $R_0$ in the 60 and 120 mg a.i. $L^{-1}$ treatments were significantly lower than those in control and 30 mg a.i. $L^{-1}$ treatments. The values of $T$ in the 60 and 120 mg a.i. $L^{-1}$ treatments were not significantly different from that in the control.

### 3.3 Population projection of *O. flavicornis*

The population projections of *O. flavicornis* at different spirodiclofen concentrations with an initial population of 10 eggs are shown in Figure 4. According to the simulation, after 60 days, the population size of *O. flavicornis* would reach approximately 72 218, 76 906, 6851 and 3865 at 0, 30, 60 and 120 mg a.i. $L^{-1}$, respectively. The total population size in logarithmic scale at different spirodiclofen concentration indicated faster population growth rate for the control and 30 mg a.i. $L^{-1}$ (Fig. 5). The curves of total population size approached linearity, and slope was the finite rate (Fig. 5). The proportion of egg decreased at the two 60 (36.27%) and 120 mg a.i. $L^{-1}$ (37.71%) (45.43% at control and 48.45% at 30 mg a.i. $L^{-1}$), and the proportion of pupal (including prepupa) increased at the two 60 (23.70%) and 120 mg a.i. $L^{-1}$ (22.83%) (12.13% at control and 10.17% at 30 mg a.i. $L^{-1}$).

## 4 DISCUSSION

Although survival/mortality estimate has been the main subject in most toxicological studies, there is an increasing awareness of more subtle damage that warrants closer attention.[31] Sublethal effects should be studied and quantified to provide a more accurate assessment of the potential impacts of a pesticide on a natural enemy.[45] Actually, to obtain complete understanding of pesticides on a population, life tables give the most comprehensive analysis. In this study, our results revealed the side-effects of spirodiclofen on the development, longevity, fertility and demographic parameters of *O. flavicornis*. We observed that the preadult durations of *O. flavicornis* in the treatments at 60 and 120 mg a.i. $L^{-1}$ were longer than those in the 30 mg a.i. $L^{-1}$ and control treatments. Our results suggested that the common field practice of spirodiclofen might slow down the developmental rate of the predatory beetle, and reduce its population size. Although no other studies have examined the effects of spirodiclofen on the life history characteristics of *Oligota* staphylinids, our results agreed with certain reports on other predatory natural enemies; sublethal spirodiclofen concentration may not affect the population parameters of *Amblyseius swirskii*,[25] the longevity and fecundity of *Scolothrips longicornis*.[28] And the recommended concentration of spirodiclofen (120 mg a.i. $L^{-1}$) did not affect the population parameters of *Orius niger*.[29] However, the $LC_{90}$ concentration (457 mg a.i. $L^{-1}$) had adverse effects on *Neoseiulus californicus*.[30] Apparently, the tolerance of predatory natural enemies to spirodiclofen varies significantly among species.

The preoviposition period is the time length required for the maturation of the ovaries. Although there were no significant differences in the APOP of *O. flavicornis* among treatments, the values of TPOP at 60 and 120 mg a.i. $L^{-1}$ were significantly longer than those in the treatments at 0 and 30 mg a.i. $L^{-1}$. Because APOP is calculated from the emergence of adults, it ignores the duration of the pupal stage. However, the ovarian development and oogenesis actually begins much earlier than adult emergence.[46] Lewontin[47] showed the importance of the first reproductive age on population parameters. The extended TPOP may be a major factor in the reduction of $r$ in this study (Table 1, Table 2). Together with age-stage fecundity, the age of first reproduction strongly influences the magnitude of $r$. Therefore, TPOP is a better statistic for the description of total developmental duration on fecundity and population parameters. The significant differences in oviposition days ($O_d$) showed that *O. flavicornis* produced eggs more frequent in the control and 20 mg a.i. $L^{-1}$ treatments than those in 60 and 120 mg a.i. $L^{-1}$.

Adult longevity of *O. flavicornis* were significantly shortened at 60 and 120 mg a.i. $L^{-1}$; however, the shortening of the male longevity was greater, only half that of the female, although it did not reach a significant level at $P = 0.05$ (adult longevity: 60 mg a.i. $L^{-1}$ $P = 0.0653$, 120 mg a.i. $L^{-1}$ $P = 0.0552$; total longevity: 60 mg a.i. $L^{-1}$ $P = 0.0749$, 120 mg a.i. $L^{-1}$ $P = 0.0544$) between the two sexes (Table 1). Because *O. flavicornis* is a multiple mating insect, shorter male longevity may reduce female lifetime offspring production, because of reducing mating time.[48] Similar results were observed in our study; for example, the fecundity curve of *O. flavicornis* exposed to spirodiclofen had lower and fewer reproduction peaks. Another possible reason



  

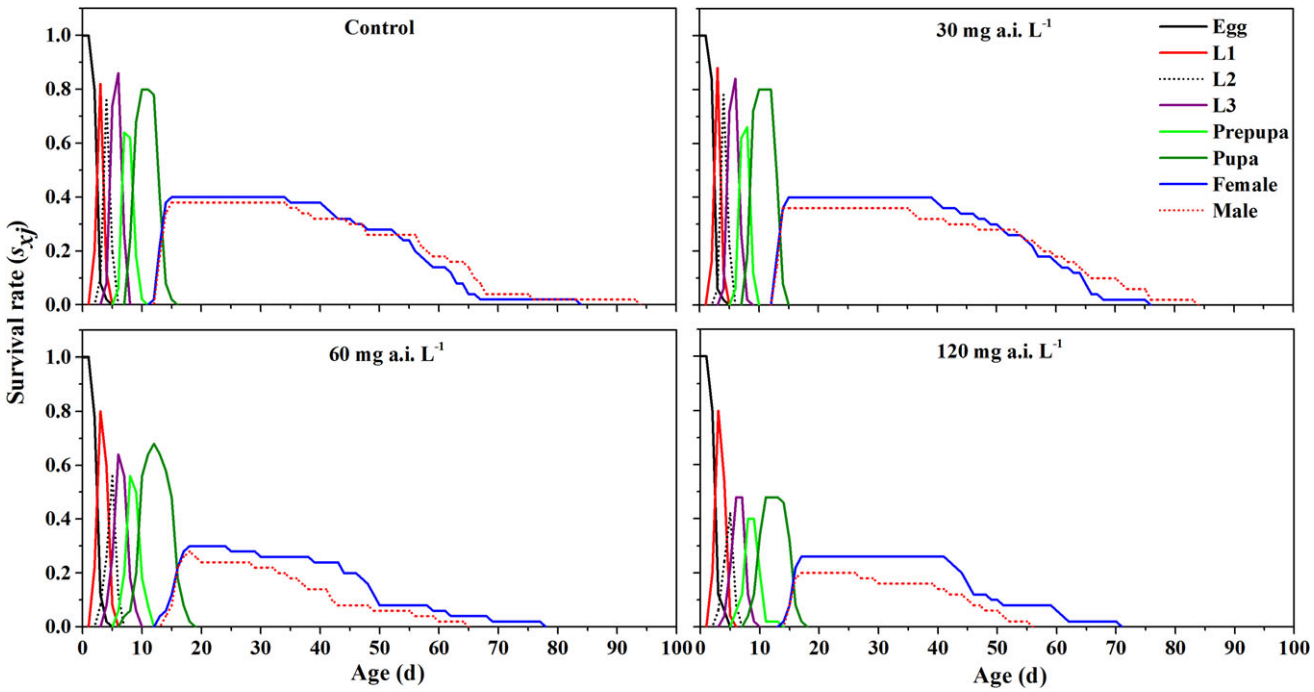


**Figure 1.** Age-stage specific survival rates ($s_{xj}$) of *Oligota flavicornis* reared on *Tetranychus cinnabarinus* treated with different concentration of spirodiclofen (0, 30, 60, 120 mg a.i. $L^{-1}$).

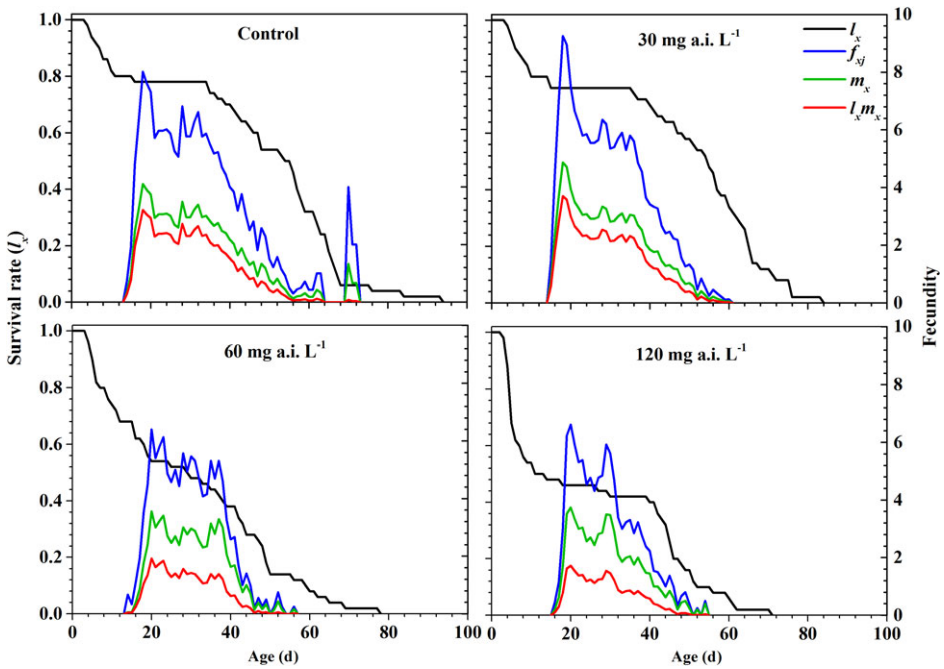


**Figure 2.** Age-specific survival rates ($l_x$), age-specific fecundity ($m_x$), age-stage specific fecundity ($f_{xj}$) and net maternity ($l_x m_x$) of *Oligota flavicornis* reared on *Tetranychus cinnabarinus* treated with different concentration of spirodiclofen (0, 30, 60, 120 mg a.i. $L^{-1}$).

for the reduction was that acetyl-CoA carboxylase inhibition by spirodiclofen could contribute to interference with the lipogeneic pathways, and lipids have been observed to be essential nutrients for the development and reproduction of insects.[49] Accordingly, it is inferred that that similar interference in pathway could have occurring in *O. flavicornis*.

Although the control of phytophagous mites with acaricides is still the major strategy to avoid losses in crop production, these compounds can also negatively affect certain life history traits, such as survival, fertility, life span, and fecundity of beneficial arthropod natural enemies.[32] To estimate the effect of acaricides on natural enemies, the life table approach is a more satisfactory tool, because it includes the development, stage differentiation, and reproduction.[31] The life table technology, especially the theory of age-stage, two-sex life table, is widely used.[50,51] Nevertheless, demographics have not been extensively used to evaluate the



  

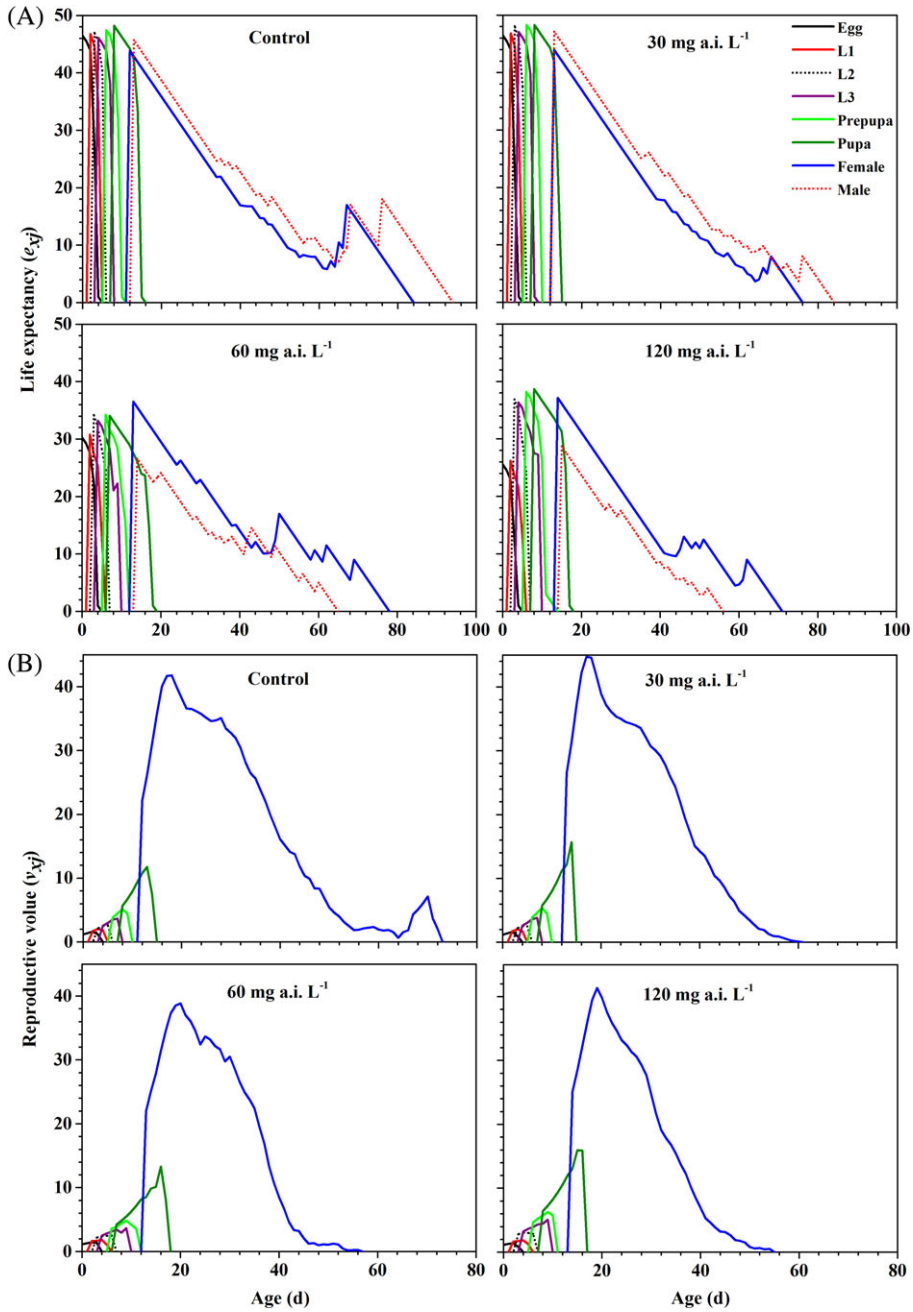


**Figure 3.** Age-stage specific life expectancy ($e_{xj}$) (A) and age-stage specific reproductive value ($v_{xj}$) (B) of *Oligota flavicornis* reared on *Tetranychus cinnabarinus* treated with different concentration of spirodiclofen (0, 30, 60, 120 mg a.i. $L^{-1}$).

**Table 2.** Effects of spirodiclofen on population parameters of *Oligota flavicornis* fed on *Tetranychus cinnabarinus*

| Parameter | Control | 30 mg a.i. $L^{-1}$ | 60 mg a.i. $L^{-1}$ | 120 mg a.i. $L^{-1}$ |
|---|---|---|---|---|
| $\lambda$ ($day^{-1}$) | 1.182 ± 0.011b | 1.183 ± 0.010b | 1.140 ± 0.012a | 1.132 ± 0.012a |
| $r$ ($day^{-1}$) | 0.167 ± 0.009b | 0.169 ± 0.009b | 0.131 ± 0.010a | 0.124 ± 0.011a |
| $R_0$ (offspring) | 69.47 ± 12.72b | 68.01 ± 12.38b | 33.57 ± 8.18a | 27.85 ± 7.25a |
| $T$ (d) | 25.32 ± 0.53ab | 25.04 ± 0.38a | 26.65 ± 0.64b | 26.63 ± 0.42b |

$\lambda$, finite rate of increase; $r$, intrinsic rate of increase; $R_0$, net reproductive rate; $T$, mean generation time. The standard errors of the parameters were estimated by using bootstrap technique with 100 000 resampling. The same letter within a row indicates no significant difference between treatments based on a paired bootstrap test at the 5% significance level.



  

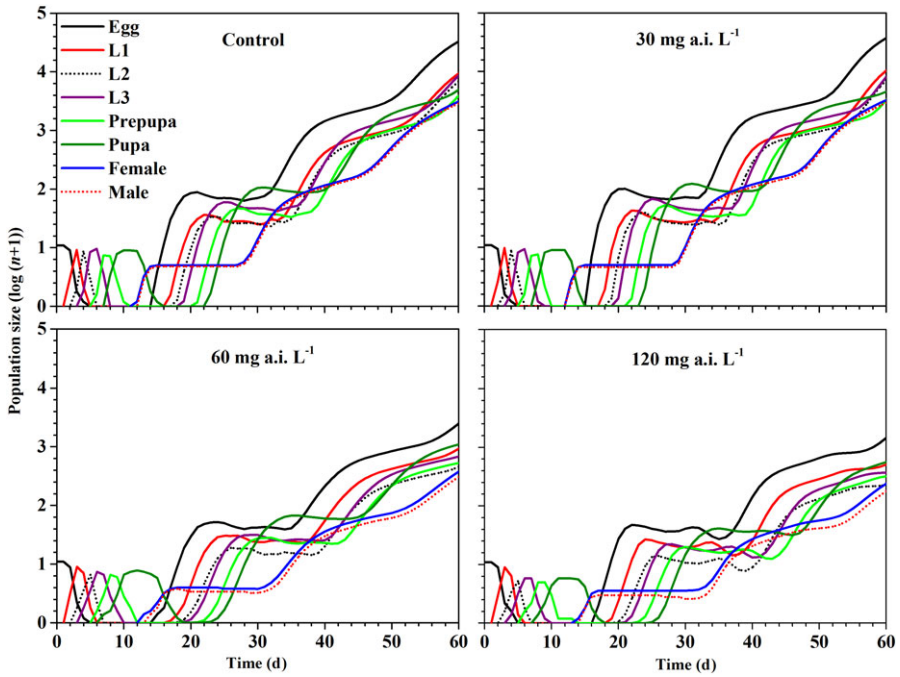


**Figure 4.** The population growth projection for *Oligota flavicornis* reared on *Tetranychus cinnabarinus* treated with different concentration of spirodiclofen (0, 30, 60, 120 mg a.i. $L^{-1}$).

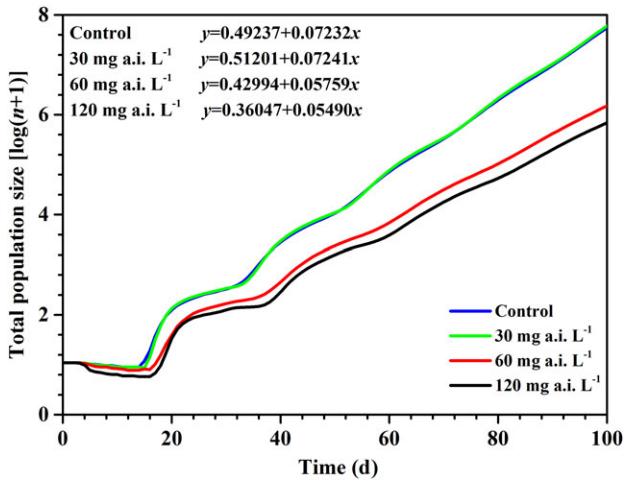


**Figure 5.** Comparison of population projections for *Oligota flavicornis* reared on *Tetranychus cinnabarinus* treated with different concentration of spirodiclofen (0, 30, 60, 120 mg a.i. $L^{-1}$). The regression equations describe the linear population growth of each treatment cohort from day 60 onwards as the population approached the stable age-stage distribution.

effects of spirodiclofen on *Oligota* staphylinids. Reports showed that spirodiclofen affected the life table parameters of *N. californicus*, *O. niger*, and *S. longicornis*,[28–30] but there was no significant effect on *A. swirskii*.[25]

Unlike other parameters, spirodiclofen at 60 and 120 mg a.i. $L^{-1}$ did not significantly prolong the mean generation time (*T*) of *O. flavicornis*, and the *O. flavicornis* population could reach a stable age-stage distribution after approximately 60 days, whether it was at 0, 30, 60 or 120 mg a.i. $L^{-1}$ (Fig. 5). However, the population size at 60 mg a.i. $L^{-1}$ was only approximately one-tenth of that at the control and 30 mg a.i. $L^{-1}$ (Fig. 4). Therefore, spirodiclofen at 30 mg a.i. $L^{-1}$ did not affect the population growth of *O. flavicornis*. However, spirodiclofen at <30 mg a.i. $L^{-1}$ could significantly affect the life-table parameters (12 mg a.i. $L^{-1}$) of *T. urticae*,[9] a favorite prey of *O. flavicornis*. Therefore, spirodiclofen concentrations that suppress spider mites population may not significantly affect *O. flavicornis*.

Although our results showed that the population growth of *O. flavicornis* was affected by spirodiclofen at 60 and 120 mg a.i. $L^{-1}$, it provided an extreme case of laboratory exposure to spirodiclofen in that *O. flavicornis* was in daily contact with spirodiclofen treated leaves and prey. However, spirodiclofen is not applied in the field at such a frequency, and the residue and dissipation of spirodiclofen are affected by temperature fluctuation, sunlight, water and biology of the field; the half-life of spirodicolfen was approximately a week.[52] Therefore, the probability that *O. flavicornis* was affected by high dose spirodiclofen was low. Meanwhile, spirodiclofen at 60 mg a.i. $L^{-1}$ can achieve approximately 80% control efficacy against pest mites under field conditions.[8,11,53] Moreover, our results showed that spirodiclofen at 30 mg a.i. $L^{-1}$ did not affect the fitness of *O. flavicornis*. Conclusively, increasing resistance of pest mites, which may lead to decline in control efficacy against pest mites,[54,55] the use of spirodiclofen at 30 or 60 mg a.i. $L^{-1}$ to control phytophagous mites while preserving *O. flavicornis* field population is a possible strategy, if the application of spirodiclofen and *O. flavicornis* is scheduled carefully to avoid or reduce the adverse effects of spirodiclofen.

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