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Transgenerational effects of a mixture of abamectin and thiamethoxam on demographic traits of *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae)

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ABSTRACT

Phytoseiid mites are essential natural enemies in integrated pest management (IPM) programs, offering eco-friendly alternatives to chemical control strategies. *Amblyseius swirskii* (Athias-Henriot) is a commercially significant predatory mite extensively used against soft-bodied pests, including spider mites, thrips, and whiteflies. This study determined the sublethal effects of two concentrations (LC_5 and LC_8) of a mixture of abamectin and thiamethoxam on the demographic traits of *A. swirskii* progeny (F_1 generation) produced by parents (F0 generation) treated using the age-stage, two-sex life table theory at a constant environmental condition (25 ± 1°C, 75±5% RH, and a 16:8 [L:D] photoperiod). The experiments employed the age-stage, two-sex life table approach, with the two-spotted spider mite (*Tetranychus urticae* Koch) serving as prey. Female life span was significantly shorter at LC_8 (9.49 days) than at LC_5 (10.29 days), whereas male life span did not differ significantly between LC_5 (9.38 days) and LC_8 (9.27 days). Net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ) were significantly lower in both pesticide treatments than in the untreated control, whereas no significant differences were detected between LC_5 and LC_8. In contrast, the mean generation time (T) differed significantly among all treatments. These findings suggest that even low concentrations of this product can compromise key life history traits of *A. swirskii*, potentially limiting its efficacy in biological control programs. Therefore, evaluating the compatibility of acaricides with natural enemies is critical prior to their inclusion in IPM strategies.

Keywords: Abamectin, *Amblyseius swirskii*, Life table, Sublethal effects, Thiamethoxam.

Introduction

The two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is the polyphagous pest infesting a wide variety of plant species, including ornamentals, vegetables, fruit trees, cotton, and strawberries (Jeppson et al. 1975). Its broad host range, rapid population growth, and the substantial direct and indirect damage make *T. urticae* as one of the most economically

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important mites in both greenhouse and open-field agriculture (Sabouri et al. 2009; Naher et al. 2006; Xu et al. 2012). Moreover, frequent and indiscriminate use of acaricides has led to the development of resistance in many T. urticae populations, thereby complicating its management (Nicholas et al. 1999; Van Leeuwen et al. 2010; Van Leeuwen et al. 2015). Overuse of chemical pesticides also contributes to environmental pollution, loss of biodiversity, residue accumulation in crops, and disruption of beneficial natural enemies, thereby exacerbating pest outbreaks (Helle and Sabelis 1985; Dettbern et al. 2006; Sinha et al. 2012; Chatterjee et al. 2013; Lozowicka 2015). One of the key components of integrated pest management (IPM) against *T. urticae* is the use of predatory mites, notably *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae). *A. swirskii* is a generalist predator known for its high adaptability, broad prey range, including whiteflies, thrips, and spider mites, and its ability to persist on alternative food sources such as pollen and plant exudates (El-Laithy and Fouly 1992; McMurtry et al. 2013; Knapp et al. 2018; Calvo et al. 2015). Its combination of rapid development, predation efficacy, and ecological plasticity has made it widely used agent in biological control programs, especially in greenhouse crops. Its efficacy, rapid development, and adaptability make it an ideal candidate for integrated pest management programs targeting pests such as the two-spotted spider mite (*Tetranychus urticae*), particularly in enclosed environments where minimizing chemical.

Abamectin, a naturally derived compound produced by *Streptomyces avermitilis* (Bacteria: Actinomycetota: Actinomycetes: Kitasatosporales: Streptomycetaceae) is one of the most commonly used acaricides. It targets the nervous system of mites and insects, leading to paralysis and rapid mortality (Burg et al. 1979; Clark et al. 1995). Its relatively low environmental persistence and rapid degradation reduce the risk of long-term residues in crops (Wislocki et al. 1989; Lasota and Dybas 1991). Furthermore, its translaminar action enables effective uptake into plant tissues, ensuring both contact and residual control (Gould et al. 1995; Khoualdia et al. 2013). However, research indicates that abamectin may exert lethal and sublethal effects on phytoseiid predatory mites depending on exposure route (direct contact, residual contact, or ingestion of treated prey) (Nauen and Denholm, 2005; Marčić et al. 2025).Thiamethoxam, a neonicotinoid insecticide, is also commonly employed in pest management due to its systemic activity and effectiveness. Yet, studies have demonstrated that thiamethoxam can induce both lethal and sublethal effects in predatory mites (Ghasemzadeh et al. 2018). Exposure route (e.g., foliar vs. soil drench) and dose appear to strongly influence its toxicity (Pozzebon et al. 2011; Marčić et al.

2025). Such adverse effects may reduce predator survival, reproductive capacity, and predation efficiency, ultimately diminishing the contribution of beneficial mites to the success of integrated pest management (IPM) programs.

To assess the long-term and generational risk that acaricides such as abamectin and the insecticide thiamethoxam pose to predatory mites, demographic tools like life tables are indispensable (Desneux et al. 2007). Specifically, the age-stage, two-sex life table model provides a robust framework by incorporating variations in developmental timing, survival rates, and reproduction among individuals (Chi et al. 2020; Chi et al. 2023). In the present study, only the parental (F_0) generation was directly exposed to the pesticide, whereas demographic performance was evaluated in the unexposed F_1 offspring to assess transgenerational responses to parental exposure. Given the critical role of *A. swirskii* in IPM and the potential for abamectin and thiamethoxam to affect its populations, this study aimed to evaluate the low lethal concentration and transgenerational effects of this commercial formulation on the demographic traits of the unexposed F_1 progeny of treated parents. We hypothesized that parental exposure to low lethal concentration concentrations of Agriflex would adversely affect the demographic performance of the unexposed F_1 generation of *A. swirskii*, resulting in reduced survival, longevity, fecundity, and population growth parameters, with stronger effects expected at LC_8 than at LC_5. By employing the age-stage, two-sex life table approach, we sought to generate data that can contribute to safer and more sustainable integration of this commercial formulation with biological control programs.

Materials and Methods

Host Plant Cultivation

Common bean *(Phaseolus vulgaris* L. cv. Borlotti*)* was used as the host plant for rearing *T. urticae*. Seeds were soaked in moist cloth for 24 h to ensure uniform germination and subsequently sown into plastic pots (14 cm diameter × 12 cm depth) filled with a standard substrate (1:1:1 mixture of soil, sand, and peat). Fresh cowpea plants were prepared every two weeks to ensure a continuous supply of high-quality host material throughout the experiment.

Rearing of two-spotted spider mite

The two-spotted spider mite (TSSM), *T. urticae* Koch individuals were originally collected in 2024 from strawberry greenhouses at the Faculty of Agriculture, University of Kurdistan (Sanandaj, Iran). Infested leaves were placed onto healthy Common bean plants to facilitate natural

mite migration and colony establishment. Cultures were maintained in a growth chamber at 25± 1°C, 75±5% relative humidity (RH), and 16:8 h (L:D) until dense colonies were obtained.

Phytoseiid rearing

A cohort of the phytoseiid predator of *A. swirskii* used in this study originated from stock colonies supplied by Berg Sabz Engineering Company (2024). Rearing was performed in the Entomology Research Laboratory (University of Kurdistan) using cylindrical plastic containers (20 cm diameter × 18 cm height). Common bean leaves infested with various developmental stages of *T. urticae* were provided three times weekly. To minimize potential dietary or physiological carryover effects, colonies were maintained for two generations exclusively on *T. urticae*. All cultures were kept under controlled environmental conditions (25 ± 1 °C, 75 ± 5% RH, 16:8 h L:D).

Acaricide

Agriflex (Syngenta Crop Protection) contains 3.0% w/w abamectin and 13.9% w/w thiamethoxam, formulated as an 18.5% water-suspend able concentrate (Syngenta 2025). This formulation ensures optimized dispersion and penetration due to its fine particle matrix. This acaricide was selected to evaluate its low lethal concentration and transgenerational compatibility with the predatory mite *A. swirskii* within integrated pest management (IPM) frameworks.

Toxicity Bioassay

Preliminary leaf-dip bioassays were conducted to determine an appropriate concentration range producing approximately 15–85% mortality. Common bean leaf discs were dipped in five concentrations prepared by diluting Agriflex and distilled water. No surfactant or wetting agent was added to the spray solutions to simulate the standard field application conditions of the commercial formulation. Leaves were immersed for 15 s, air-dried for 3 h, and placed on moist cotton in Petri dishes. For each concentration, 20 newly emerged females of phytoseiid mite (24 hours old, unexposed) were used per replicate. Each treatment had three replicates, and the entire assay was repeated three times (Hedayati et al. 2019). Mortality of *A. swirskii* was recorded at 24, 48, and 72 hours post-exposure. Probit analysis (POLO-PC, 2016) was performed using cumulative mortality at 72 hours to directly estimate the LC_5 (21.13 µg a.i./mL) and LC_8 (33.36 µg a.i./mL) values (Table 1), which were subsequently selected for the life-table assays. These

low-lethal concentrations were selected to minimize direct mortality while allowing assessment of developmental and reproductive parameters.

Justification for selecting LC_5 and LC_8

Preliminary toxicity assays showed that females exposed to LC_{10}, LC_{20}, and LC_{30} concentrations of Agriflex exhibited extremely low survival and completely failed to oviposit. Because no F_1 eggs could be obtained at these concentrations, higher sublethal levels were unsuitable for transgenerational analysis. In contrast, LC_5 and LC_8 produced minimal mortality and allowed sufficient surviving females to lay viable eggs. Therefore, LC_5 and LC_8 were identified as the only biologically feasible low lethal concentrations for evaluating transgenerational effects in *A. swirskii*.

Use of Previously Validated Control Data (External Control)

The untreated control data used in this study were obtained from our previously published study (Rahimi et al. 2022), which was conducted under identical laboratory conditions using the same predator colony, prey species, and experimental protocol. The original raw dataset from that study was available and was reanalyzed together with the present data using the age-stage, two-sex life table program for paired bootstrap comparisons. Therefore, the statistical analyses were based on the original raw data rather than the published summary statistics.

Life history parameters at low lethal concentration

Transgenerational low lethal concentration effects of the acaricide were evaluated by using life-table parameters of cohorts (F_1 generation) generated by offspring from treated *A. swirskii* parents (F_0 generation). To obtain cohort eggs for each treatment, 60 pairs of newly emerged (24-h-old) *A. swirskii* adults were individually placed on 2 cm diameter leaf discs of cowpea, previously treated with LC_5 and LC_8 concentrations of Agriflex. The two-spotted spider mite (TSSM) at the adult stage was used as prey to sustain the predatory mites. Control cohorts were treated with distilled water. After 24 hours, surviving adults were transferred to fresh, untreated leaf discs for oviposition. This 24 h exposure period was selected to restrict pesticide exposure to the parental (F_0) generation while allowing subsequent oviposition on untreated leaf discs, thereby enabling assessment of transgenerational effects in the unexposed F_1 generation. Eggs laid were counted daily. The developmental duration, egg hatchability, and daily mortality were monitored. Seventy

eggs (F_1 generation) laid within 24 h were collected for the life table study. Eggs were maintained separately in new individual cylindrical plastic with acaricide-free clean Common bean leaves. Observations were made at 24 h intervals with a stereomicroscope (Olympus Optical Co., Ltd., Tokyo, Japan). The development time of the F_1 generation of *A. swirskii* mites from egg to adult emergence was determined under laboratory conditions at 25 ± 1 °C, 75 ± 5% RH, and a photoperiod of 16:8 h L: D. After emergence of the F_1 generation adults, females were paired with the males, and the females' reproductive parameters (preoviposition, oviposition and total preoviposition periods as well as daily and total fecundity) and longevity were observed and recorded daily. One newly emerged F_1 male from the same treatment was maintained with each female throughout the experiment. Whenever a male died, it was replaced with another newly emerged F_1 male from the same treatment to ensure continuous mating. The number of eggs laid by each female was observed and recorded under a stereomicroscope until all mites had died.

Statistical Analysis

The life history raw data of all individuals were analyzed using the age-stage, two-sex life table procedure (Chi 1988; Chi and Liu 1985). Data were collected on the life table parameters including the age-stage specific survival rate (s_{xj}) (where x = age in days and j=stage); the age stage-specific fecundity (f_x) (daily number of eggs produced per female of age x); the age-specific survival rate (l_x); the age specific fecundity (m_x); the adult pre oviposition period (APOP, the length of the preoviposition period beginning from adult emergence); and the total preovipostion period (TPOP; the length of the pre oviposition period beginning from birth). The population growth parameters, including the net reproductive rate (R_0), intrinsic rate of increase (r), finite rate of increase (λ), and mean generation time (T) were also calculated. According to Chi and Liu 1985, age-specific survival rate was calculated as:

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

where k is the number of stages. The age-specific fecundity (m_x) was calculated as:

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}} \quad (2)$$

The net reproduction rate is defined as the mean number of offspring that an individual can produce during its lifetime and was calculated as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad (3)$$

The intrinsic rate of increase was estimated from the Euler-Lotka formula sing the method of iterative bisection with the age indexed from 0 (Goodman 1982) as:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad (4)$$

The finite rate (λ) was calculated as:

$$\lambda = e^r \quad (5)$$

The mean generation time is the time length that a population needs to increase to R0-fold of its size as the population reaches the stable age-stage distribution and was calculated as:

$$T = \frac{\ln R_0}{r} \quad (6)$$

The standard errors of the developmental times, fecundity, longevity and population parameters were estimated using the bootstrap method (Efron and Tibshirani 1993; Huang and Chi 2012), with 100,000 bootstraps resamples to obtain stable estimates of standard errors. Differences among treatments were compared using the paired bootstrap test (Efron and Tibshirani 1993). Both the bootstrap procedure and the paired bootstrap test are embedded in the computer program TWOSEX-MSChart. All figures were prepared using SigmaPlot 15 software.

Results

The mean lethal concentrations (LC_5 and LC_8) of Agriflex for *A. swirskii* were first determined (Table 1), and these low lethal concentrations were used to evaluate developmental effects. The developmental durations of immature stages and adult longevity under LC_5 and LC_8, along with the untreated control, are presented in Table 2. Exposure to either low lethal concentration clearly affected the development of the predator, with stage-specific responses observed. Compared with the control, the egg, larval, and protonymphal durations were significantly shorter in both LC_5 and LC_8 treatments ($P < 0.05$), indicating that surviving F_1 individuals completed these developmental stages in a shorter time than the control. However, deutonymphal duration did not differ

significantly between LC_5 and LC_8, and both values were longer than in the untreated control. Egg-to-adult survival also showed a concentration-dependent decline following parental exposure to Agriflex. Survival from egg to adult emergence decreased from 82.9% in the control to 76.6% and 71.8% in the LC_5 and LC_8 treatments, respectively (Table 2). This reduction indicates increased immature mortality in the F_1 generation following parental pesticide exposure, suggesting that low lethal concentrations of Agriflex may negatively affect offspring viability. Female preadult development was significantly reduced at LC_8 compared with both LC_5 and the control, while male preadult duration showed no significant difference between LC_5 and LC_8 but remained longer than in the control. Adult longevity of *A. swirskii* was substantially reduced following exposure to low lethal concentrations of Agriflex. Under control conditions reported by Rahimi et al. (2022), female and male adults lived 20.03 and 13.38 days, respectively. In contrast, longevity decreased sharply to 3.37 days (LC_5) and 2.94 days (LC_8) in females, and to 2.75 days (LC_5) and 2.54 days (LC_8) in males. This represents an 83–86% reduction in female longevity and a 79–81% reduction in male longevity relative to the untreated control. The reduction was significantly greater at LC_8 than LC_5 for females ($P < 0.05$), whereas male longevity did not differ significantly between the two concentrations. A similar trend was observed for total longevity (premature + adult). Control females lived 27.35 days and males 19.12 days (Rahimi et al. 2022). These values declined dramatically under pesticide exposure, decreasing to 10.29 (LC_5) and 9.49 days (LC_8) in females and to 9.38 (LC_5) and 9.27 days (LC_8) in males. The magnitude of reduction was greater at LC_8, especially in females, consistent with their heightened sensitivity to Agriflex.

Age–stage survival curves (s_{xj}) for the LC_5 and LC_8 treatments differed markedly from the control patterns previously illustrated in Rahimi et al. (2022). Although control cohorts exhibited extended survival plateaus, both low lethal concentrations produced sharply declining curves, with pronounced stage overlap indicating variability in development among individuals. Peak survival probabilities for the larval, female, and male stages occurred earlier and at lower values under LC_8 than LC_5, reflecting reduced physiological tolerance as concentration increased (Figure 1).

Exposure of *A. swirskii* to low lethal concentrations (LC_5 and LC_8) of Agriflex markedly suppressed reproductive performance compared to the untreated control at 25 °C (Rahimi et al. 2022). Both LC_5 and LC_8 shortened the pre-oviposition and total pre-oviposition periods, reduced fecundity, and decreased oviposition duration, indicating a strong inhibitory effect of the pesticide on reproductive output. Notably, even the lower LC_5 concentration caused a substantial reduction

in egg production, highlighting the high sensitivity of *A. swirskii* to Agriflex and the potential implications for its population dynamics under pesticide exposure.

Age-specific survival and reproductive parameters of *A. swirskii* under low lethal concentrations of Agriflex (LC_5 and LC_8) reveal that survival (l_x) declined with increasing age, with a steeper decrease observed at LC_8, indicating stronger mortality. Oviposition commenced earlier at LC_8 (day 5) than at LC_5 (day 6), but both fecundity (m_x) and age-specific fecundity ($l_x m_x$) were markedly reduced compared to the control. The peak reproductive output occurred later in LC_5 than in LC_8, reflecting a concentration-dependent acceleration of reproductive timing accompanied by reduced reproductive performance. Although peak age-specific fecundity (m_x) was similar between LC_5 (2.4 eggs/day) and LC_8 (2.5 eggs/day), reproduction ceased earlier at the higher concentration, indicating a shortened reproductive window and reduced lifetime reproductive output. These results highlight the inhibitory effect of Agriflex on both survival and reproduction, with greater impacts at higher low lethal concentrations (Figure 2).

Life expectancy (e_{xj}) of *A. swirskii* was markedly affected by low lethal concentrations of Agriflex and varied across developmental stages and sexes. Compared with the control conditions at 25 °C reported by Rahimi et al. (2022), exposure to LC_5 and LC_8 substantially reduced life expectancy, particularly at the larval stage. Females consistently exhibited higher life expectancy than males, yet the difference became more pronounced under LC_8. These results indicate that low lethal concentration pesticide exposure accelerates mortality and disproportionately affects immature stages and males, contrasting with the relatively stable life expectancy observed at optimal rearing temperature (25 °C), where survival curves decline gradually with age (Rahimi et al. 2022, Fig. 3).

The age-stage-specific reproductive value (v_{xj}) of *A. swirskii* demonstrated a clear concentration-dependent pattern, peaking during early reproductive ages and declining with advancing age. Low lethal concentrations exposure to Agriflex accelerated the timing of peak reproduction, with the highest reproductive rates observed earlier at LC_8 than at LC_5. Although daily egg production per adult was similar between LC_5 (2.4 eggs/day) and LC_8 (2.5 eggs/day), reproduction ceased earlier at the higher concentration, indicating a reduced reproductive window. Compared with optimal conditions at 25 °C (Rahimi et al. 2022), where peak reproductive output occurs later and persists for a longer duration, low lethal concentration pesticide exposure both advanced and truncated

reproductive potential, highlighting a concentration-dependent suppression of population growth (Figure 4).

Low lethal concentration concentrations of Agriflex markedly affected the population growth parameters of *A. swirskii* (Table 4). Compared with the untreated control (Rahimi et al. 2022), both LC_5 and LC_8 significantly reduced the net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ) (paired bootstrap test, $P < 0.05$). However, no significant differences in these parameters were detected between LC_5 and LC_8. In contrast, the mean generation time (T) differed significantly among all treatments, decreasing from 16.41 days in the control to 9.33 and 8.60 days at LC_5 and LC_8, respectively. These findings indicate that even low lethal concentration of Agriflex can substantially reduce the reproductive potential and population growth of *A. swirskii*, which may ultimately compromise its effectiveness as a biological control agent.

Discussion

The rapid expansion of the global population has intensified the demand for sustainable food production, making effective pest management increasingly critical (Godfray et al. 2010; Savary et al. 2019). While chemical control remains widely employed (Maghsoudi et al. 2016), integrated Pest Management (IPM) approaches, which optimize pesticide use by minimizing application frequency and timing treatments for maximum efficacy, are increasingly emphasized (Cuthbertson and Murchie 2006). Successful IPM relies on understanding pesticides' direct and residual effects on non-target organisms, particularly natural enemies, and selecting compounds or predator strains that minimize negative impacts (Tommy and Robinson 2009). Detailed knowledge of ecological and biological traits of natural enemies is essential for effective biological control (De Vis et al. 2006). Although acute toxicity of many pesticides may be low, sublethal effects—especially on reproduction—can substantially suppress population growth and compromise long-term biocontrol efficacy (Holt et al. 2006; Sanatgar et al. 2011). Life table analyses provide a framework for quantifying survival, mortality, and reproductive performance across life stages, identifying vulnerable stages, and predicting population dynamics (Carey 2001; Miranda et al. 1998; Fathi et al. 2010). Demographic parameters such as the intrinsic rate of increase (r) integrate both lethal and sublethal effects, offering a comprehensive assessment of pesticide impact beyond individual toxicity tests (Hamidi et al., 2011; Marcic, 2003). Our results showed that low lethal concentration of Agriflex significantly shortened the developmental durations of *A. swirskii*, particularly during

the egg, larval, and protonymph stages. The reduction in egg duration was consistent with the findings of Shahbaz et al. (2019), although differences in prey species may account for some discrepancies (Gotoh et al. 2004). Similar reductions in larval developmental duration have also been reported by Mousavi et al. (2023). Protonymph duration was likewise significantly reduced following Agriflex exposure, whereas fenazaquin did not significantly affect this developmental stage in *A. swirskii* (Alinejad et al. 2014). The mechanisms underlying these responses were not investigated in the present study. Future studies focusing on the physiological and biochemical effects of sublethal pesticide exposure may help explain the observed changes in developmental duration. Female longevity decreased with increasing pesticide concentration, while males were less affected, consistent with general patterns of shorter male lifespan due to higher energy expenditure and lower fat reserves (Sabelis 1985) and reduced feeding behavior under pesticide exposure (Ibrahim and Yee, 2000). Pre-oviposition periods were shortened, whereas daily egg production remained stable, suggesting low lethal concentration exposure primarily affects developmental timing rather than immediate fecundity. Total oviposition duration decreased, likely reflecting combined effects on mobility, nutrition, and reproductive physiology (Hamedi et al., 2009). Fertility did not differ significantly between LC_5 and LC_8, consistent with some pesticide studies reporting variable outcomes (Ghasemzadeh et al. 2018; Shahbaz et al. 2019). Comparison with control populations at 25 °C (Rahimi et al. 2022) underscores the magnitude of these effects: under optimal conditions, developmental stages were generally longer, and survival and reproductive potential higher, highlighting that even low lethal concentrations can constrain population growth and reduce the efficacy of *A. swirskii* in biological control programs. Life expectancy and age-stage-specific reproductive value (v_{xj}) peaked during early adult female emergence and declined thereafter, whereas males exhibited no reproductive contribution (Yang and Chi 2006; Hu et al. 2010). These parameters are critical for optimizing the timing of mass releases of natural enemies (Kontodimas et al. 2007). Compared with the untreated control, both LC_5 and LC_8 significantly reduced the net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ), demonstrating that even low-lethal concentrations of Agriflex can substantially impair the population growth potential of *A. swirskii*. No significant differences in R_0, r, or λ were detected between LC_5 and LC_8, indicating that both concentrations produced comparable demographic effects. In contrast, the mean generation time (T) differed significantly among all treatments, suggesting that parental exposure influenced the timing of population

development. Similar reductions in demographic performance following pesticide exposure have also been reported for phytoseiid mites in previous studies (Alinejad et al. 2016; Shahbaz et al. 2019; Hamedi et al. 2011). Collectively, these findings demonstrate that parental exposure to low-lethal concentrations of Agriflex can adversely affect the demographic performance of the unexposed F_1 generation, highlighting the importance of integrating both lethal and low lethal concentration assessments when evaluating pesticide compatibility with biological control agents in IPM programs.

A limitation of the present study is that the untreated control was obtained from a previously generated dataset collected under identical laboratory conditions rather than being established concurrently with the treated groups. Although the original raw control data were reanalyzed together with the present data using the same analytical procedures, future studies including concurrent untreated controls would further strengthen the robustness of these findings.

Conclusions

The present study demonstrated that low lethal concentration exposure of the parental generation (F_0) to the abamectin–thiamethoxam formulation significantly affected the demographic performance of the unexposed F_1 offspring of *A. swirskii*. Compared with the untreated control (Rahimi et al. 2022), both LC_5 and LC_8 reduced developmental duration, adult longevity, life expectancy, reproductive value, and key life-table parameters, including the intrinsic rate of increase (r), finite rate of increase (λ), and net reproductive rate (R_0), indicating a marked reduction in population growth potential. These findings demonstrate that the age-stage, two-sex life table provides a sensitive approach for detecting low lethal concentration effects expressed in the unexposed F_1 offspring following parental exposure. Under the controlled laboratory conditions of this study, the results suggest that parental exposure to Agriflex may reduce the demographic performance of *A. swirskii*. Therefore, the compatibility of this commercial formulation with *A. swirskii* should be further evaluated under greenhouse and field conditions before broad recommendations are made for its integration with biological control programs in IPM. Future studies evaluating the F_2 and subsequent generations are needed to determine whether these effects persist beyond the first offspring generation and to provide a more comprehensive assessment of transgenerational pesticide effects.

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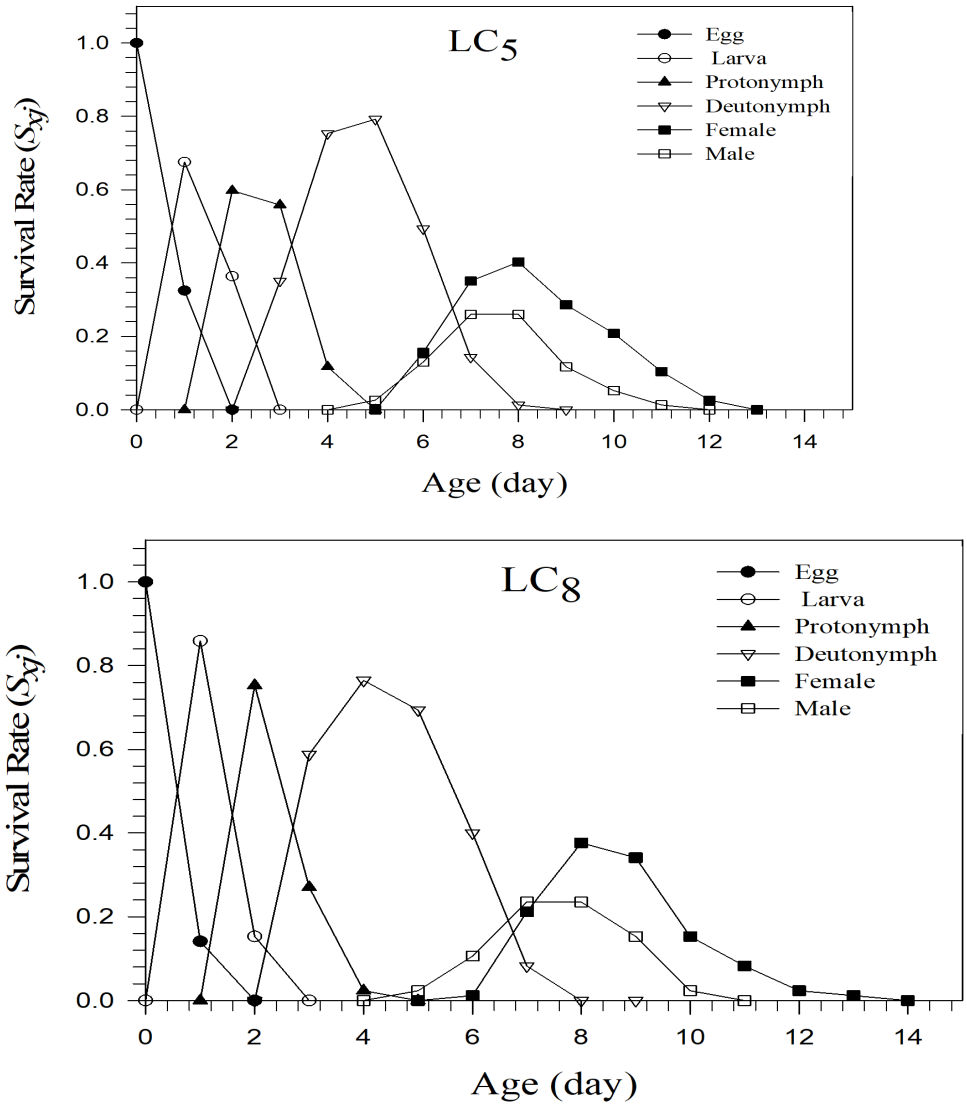


557 **Figure 1.** Age-specific survival rate (S_{xj}) of *Amblyseius swirskii* treated with Agriflex (LC_5 and
558 LC_8).
559

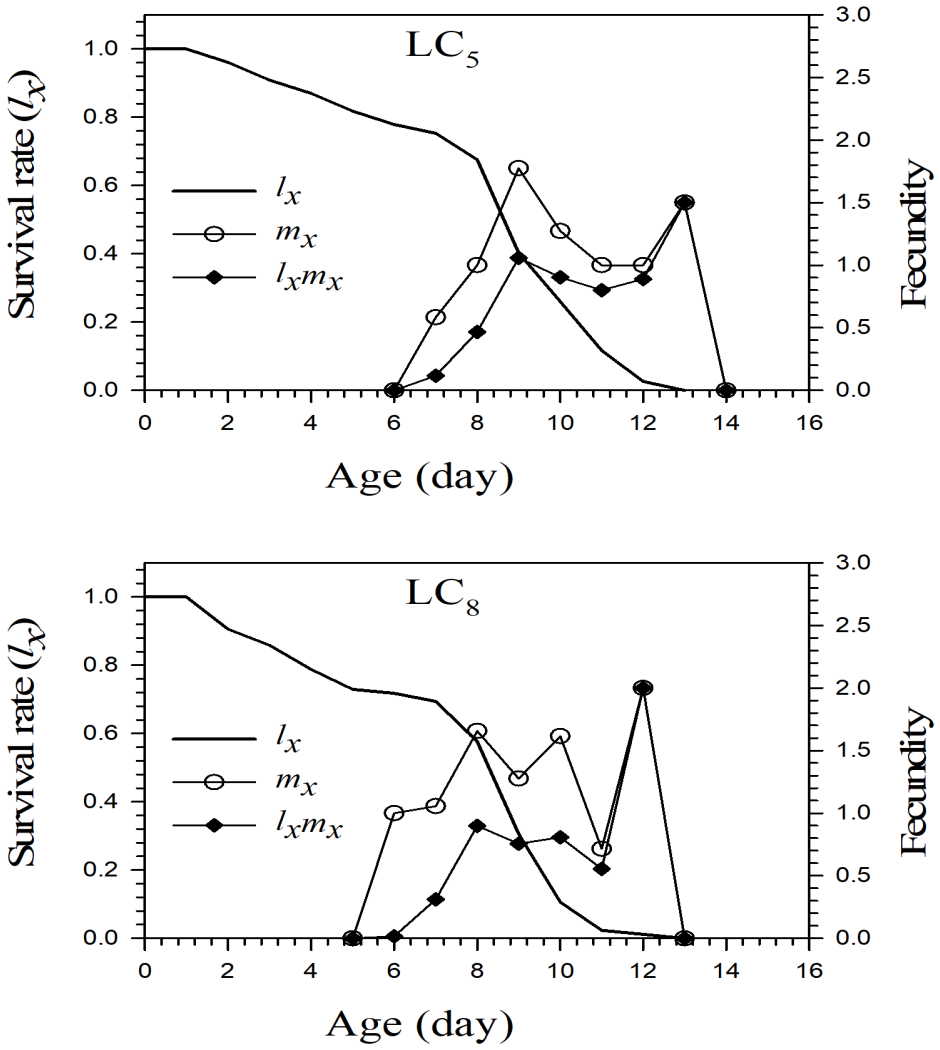
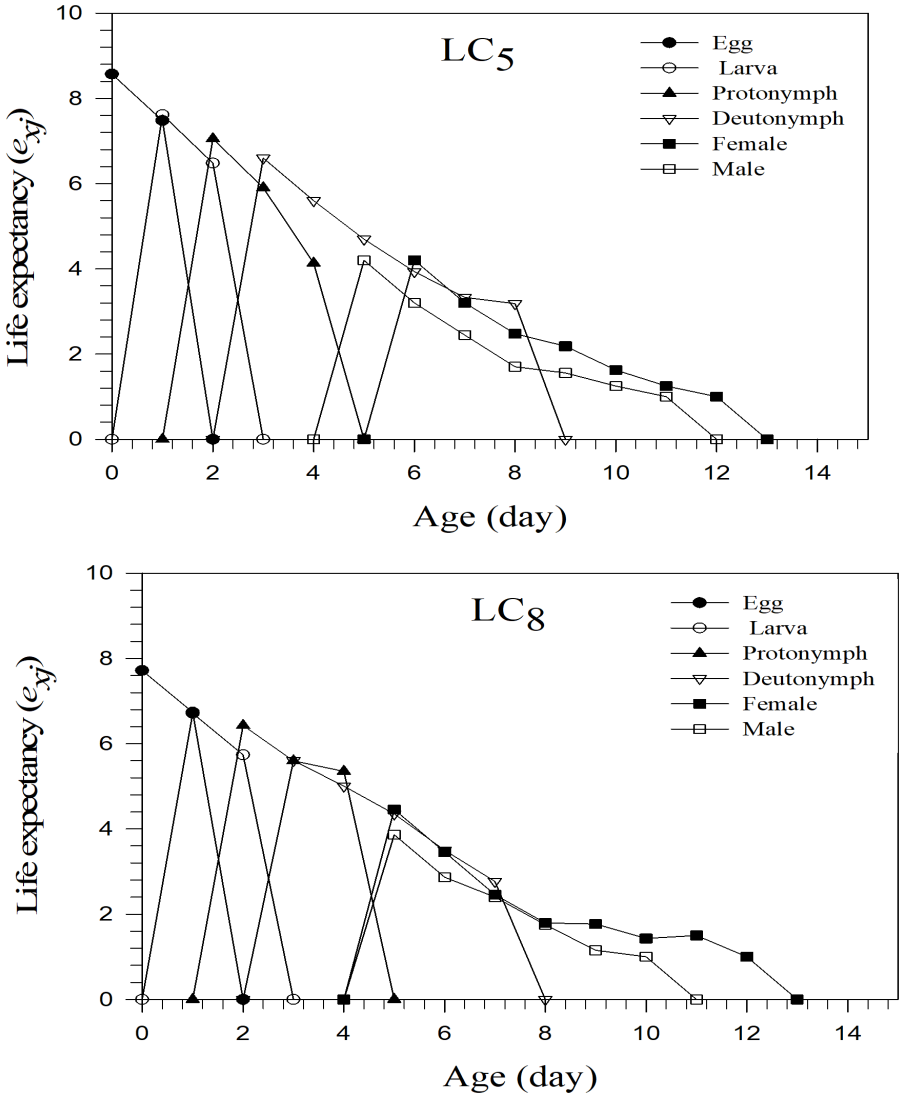
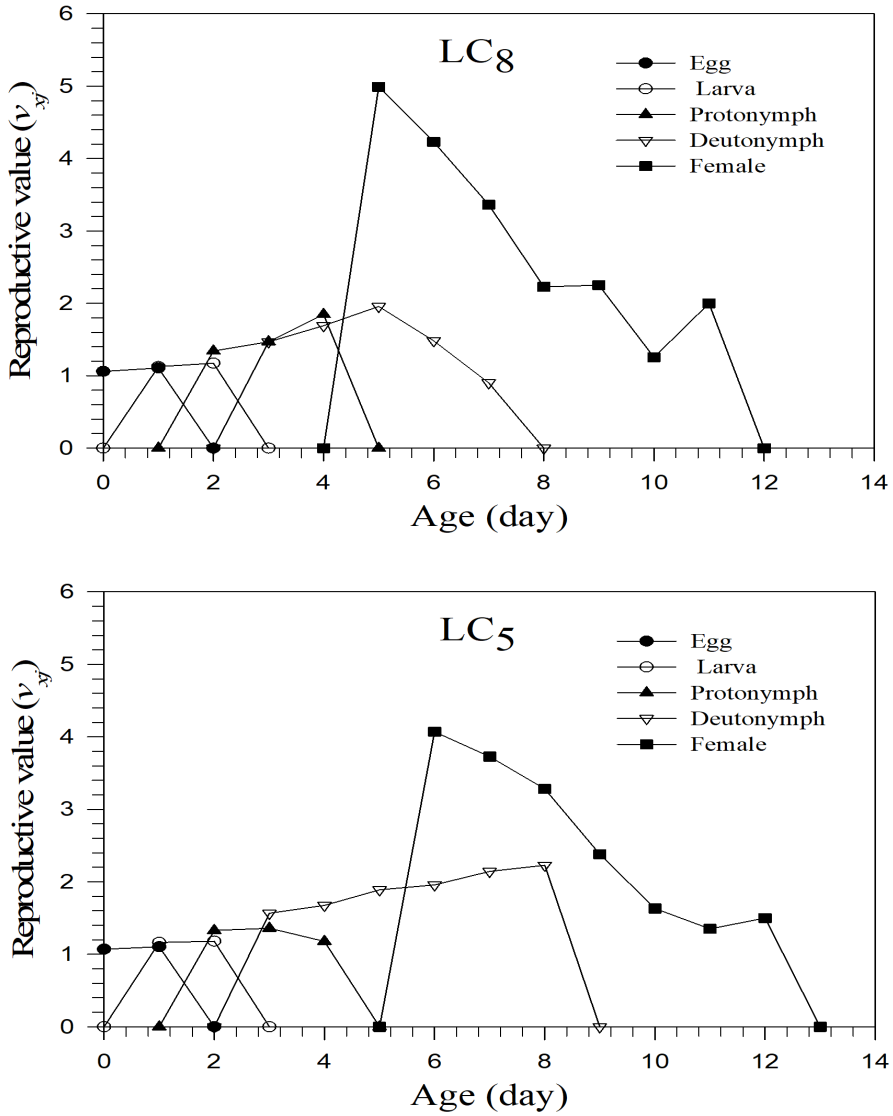


Figure 2. Age-specific Survival rate (l_x), age-specific fertility (m_x) and age-specific maternity ($l_x m_x$) of *Amblyseius swirskii* treated with Agriflex (LC_5 and LC_8).



562 **Figure 3**. Age-specific life expectancy (e_{xj}) of *Amblyseius swirskii* treated with treated with
563 Agriflex (LC_5 and LC_8).
564



565 **Figure 4.** Age-specific reproduction value (v_{xj}) of *Amblyseius swirskii* treated treated with Agriflex
566 (LC_5 and LC_8).
567

568 **Table 1.** Mean lethal concentrations (LC_5, LC_8 and LC_{50}, µg a.i./ml) of Agriflex for *Amblyseius*
569 *swirskii* Athias-Henriot.

Treatment	Slope ± SE	χ^2 (df [b])	LC_5	LC_8	LC_{50}
Agriflex	6.298±0.721	3.401(13)	21.13(9.55-35.62)	33.36(17.03-52.28)	307.80(237.95-403.77)

570

Table 2. Development time of different stages and longevity (days ±SE) of *Amblyseius swirskii* Athias-Henriot (male and female) treated with Agriflex (LC_5 and LC_8).

Stage	Treatment					
	Control (Rahimi *et al*., 2022)		LD_5		LD_8	
	n	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE
Egg	70	1.6 ± 0.06a	77	1.32 ± 0.05b	85	1.14 ± 0.04c
Larva	65	1.11 ± 0.04a	72	1.04 ± 0.02b	75	1.00 ± 0c
Protonymph	58	1.91 ± 0.04a	64	1.33 ± 0.06b	71	1.18 ± 0.05c
Deutonymph	58	2.14 ± 0.08a	59	3.17 ± 0.06b	61	3.26 ± 0.07b
Female preadult	34	7.32 ± 0.08a	35	6.91 ± 0.14b	35	6.54 ± 0.12c
Male preadult	24	5.75 ± 0.09a	24	6.62 ± 0.17b	26	6.73 ± 0.16b
Female adult longevity	34	20.03 ± 0.75a	35	3.37 ± 0.17b	35	2.94 ± 0.14c
Male adult longevity	24	13.38 ± 0.52a	24	2.75 ± 0.14b	26	2.54 ± 0.11b
Female total longevity	34	27.35 ± 0.77a	35	10.29 ± 0.24b	35	9.49± 0.20c
Male total longevity	24	19.12 ± 0.52a	24	9.38 ± 0.23b	26	9.27 ± 0.21b

n = number of individuals per stage. Means followed by the same lowercase letter within a row indicate no significant difference among treatments (paired bootstrap test, $P < 0.05$). Standard errors were estimated using the bootstrap technique with 100,000 resampling.

Control data were obtained from Rahimi et al. (2022) under identical laboratory conditions and are included for comparison.

Table 3. Adult pre-oviposition (APOP), total pre-oviposition period (TPOP), fecundity (eggs/female) and oviposition days (day) of *Amblyseius swirskii* Athias-Henriot treated with Agriflex (LC_5 and LC_8).

Parameter	Treatment					
	Control (Rahimi *et al*., 2022)		LD_5		LD_8	
	n	Mean ± SE	*n*	Mean ± SE	*n*	Mean ± SE
APOP	34	2.32 ± 0.08a	35	0.60 ± 0.08b	35	0.40 ± 0.08c
TPOP	34	9.65 ± 0.1a	35	7.51 ± 0.16b	35	6.94 ± 0.16c
Fecundity (*F*)	34	27.24 ± 0.93a	35	4.11 ± 0.23b	35	4.00 ± 0.22b
Oviposition days	34	16.15 ± 0.54a	35	2.17 ± 0.12b	35	2.03 ± 0.11b

Standard errors were estimated by using the bootstrap technique with 100,000 resampling. Means followed by the same letter in a row indicate no significant difference between cultivars (paired bootstrap test, $P < 0.05$).

Control data were obtained from Rahimi et al. (2022) under identical laboratory conditions and are included for comparison.

Table 4. Life table parameters (mean ± SE) of *Amblyseius swirskii* Athias-Henriot treated with Agriflex. R_0, net reproductive rate; r, intrinsic rate of increase; λ, finite rate of increase; T, mean generation time.

Parameter	Treatment		
	Control (Rahimi *et al*., 2022)	LD_5	LD_8
R_0 (offspring/individual)	13.22 ± 1.69a	1.870 ± 0.256b	1.647 ± 0.232b
r (day^{-1})	0.15 ± 0.008a	0.067± 0.015b	0.058 ± 0.0167b
λ (day^{-1})	1.17 ± 0.009a	1.069 ±0.015b	1.059 ± 0.0176b
T (day)	16.41 ± 0.21a	9.326 ± 0.187b	8.596 ± 0.18c

Control data were obtained from Rahimi et al. (2022) under identical laboratory conditions and are included for comparison.