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Article

Demographic analysis of progeny fitness and timing of resurgence of *Laodelphax striatellus* after insecticides exposure

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With 6 figures and 2 tables

Abstract: The resurgence of *Laodelphax striatellus* (Fallén) (Hemiptera: Delphacidae) associated with repeated applications of certain insecticides has been observed over the past several years. To comprehensively assess the effect an insecticide has on the offspring fitness and resurgence of a pest, accurately determining the survival, development, and fecundity of the population being investigated is a necessity. Because life tables include these, and other parameters of a population, they are a crucial tool for accomplishing this goal. In the present study, we evaluated the effects of three insecticides, cyantraniliprole, imidacloprid, and dinotefuran on progeny fitness and resurgence risk of *L. striatellus* by using the age-stage, two-sex life table. Experimental results show that the net reproductive rate (R_0) and fecundity (F) of the F1 progeny of *L. striatellus* treated with cyantraniliprole (R_0 = 131.68 and F=381.03) and imidacloprid (R_0 = 115.74 and F = 417.20) were significantly higher than that of the *L. striatellus* treated with dinotefuran (R_0 = 64.11 and F = 249.0) and untreated population (R_0 = 77.97 and F = 246.54). No significant difference was found in the intrinsic rate of increase (r) and finite rate of increase (λ) among treatments, except for the difference between cyantraniliprole and dinotefuran. Population projection showed that the offspring population of *L. striatellus* would increase faster after being treated with cyantraniliprole than the control population. These findings demonstrate that applications of cyantraniliprole to control *L. striatellus* may increase the fitness of their progeny, leading to a likely resurgence of this pest.

Keywords: Life table; fitness; population projection; cyantraniliprole; imidacloprid; dinotefuran

1 Introduction

The planthopper *Laodelphax striatellus* (Fallén) (Hemiptera: Delphacidae), is an economically important pest of rice that is widely distributed in the temperate zone (Zheng et al. 2017). This insect causes crop losses by phloem-feeding and/or as a vector of numerous rice viruses including rice stripe virus which can reduce rice yield by 30–50% (Otuka et al. 2012; Sun et al. 2015). Because of *L. striatellus* is capable of mass migration, it is difficult to manage *L. striatellus* in rice plantings (Otuka et al. 2012; Otuka 2013).

As a major crop pest, the field dynamics of *L. striatellus* populations are affected not only by environmental factors such as temperature, rainfall, and other physical variables, but also by the pest management strategies applied. Among all pest management strategies, chemical insecticides control is the main method for controlling the *L. striatellus* (e.g., Sanada-Morimura et al. 2011). The continued application of chemical insecticides as the favored method for controlling *L. striatellus*, has resulted in widespread insecticide resistance in this pest (Sanada-Morimura et al. 2011), as well as being responsible for reductions in the populations of natural enemies (Desneux et al. 2007). Furthermore, several previous studies have demonstrated that the application of some insecticides at sublethal doses can result in resurgence of the pest insect population (Desneux. 2007), for example Imidacloprid-induced hormesis in males of the neotropical stink bug resulted higher female fecundity (Haddi et al. 2016).

Pest resurgence is an important phenomenon that can result from numerous mechanisms and causes (Hardin et al. 1995; Dutcher 2007). Pest resurgence may due to collapse of natural enemy function caused by pesticide application (Liu et al. 2010; Zhang et al. 2015) or pesticide-induced

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hormesis (Qu et al. 2017; Wang et al. 2017; Tuelher et al. 2017). However, quantitative criteria and methods to evaluate the risk of pest resurgence have not yet been developed. In order to properly evaluate and quantify a pest resurgence, it is necessary to accurately predict when the pest population will regain its economic threshold after treatment. Huang et al. (2013) suggested an economic threshold for the rice planthopper, *Nilaparvata lugens* (Stål), as 4.56 injury equivalents per hill before rice reaches its milk stage.

Under field conditions, insecticides degraded gradually result in the exposure of insect pests to sublethal concentrations of insecticides for extended periods of time (Desneux et al. 2005). Insecticide associated resurgence in *L. striatellus* has been documented for a number of years. For example, applications of the fungicide carbendazim and the insecticide chlorpyrifos at lethal doses has been shown to ultimately increase the population size of *L. striatellus* in rice and wheat fields (Shen et al. 2007; Xu et al. 2008). Research on the effects of insecticides on *L. striatellus* populations will be invaluable in evaluating the role that particular insecticides play in sustainable management programs involving the planthopper.

Guo et al. (2016) demonstrated that cyantraniliprole, imidacloprid, and dinotefuran were highly effective against *L. striatellus*. Cyantraniliprole belongs to the anthranilic diamides class of insecticides (Selby et al. 2013). Imidacloprid is a chlorinated nicotinic insecticide which has commonly been used in China for control of several rice planthopper species, including *N. lugens, Sogatella furcifera* (Horváth), and *L. striatellus*; however, resistant populations of these species have recently been observed (Liu et al. 2015). Dinotefuran is a neonicotinoid compound with excellent pesticidal properties and offers excellent control of a wide variety of pests in many crops (Takeo et al. 2005).

In the past, the effects a particular insecticide had on an insect population were usually evaluated based on only a few of its biological parameters such as its fecundity and/or survival rate (Zhang et al. 2014; Wu et al. 2018). For a comprehensive and thorough assessment of the overall effect of an insecticide on an insect pest, life table is the most important and useful tool (Chi 1988, Liang et al. 2019). However, the amount of time and labor associated with constructing life tables has limited their use in insecticide research in the past (Zhang et al. 2018). Moreover, the traditional female age-specific life tables (Lotka 1907; Lewis 1942; Leslie 1945; Birch 1948; Carey 1993) ignore the male populations and stage differentiation. The application of female age-specific life table usually resulted in errors (Huang & Chi 2012). In contrast, the age-stage, two-sex life table takes both sexes and stage differentiation into consideration, and it has been widely adopted in researches in last few decades. Furthermore, the age-stage, two-sex life table with simplified recording method not only saves time and labor, but also avoid daily disturbance of the adults and has no significant impact on key population parameters (Zheng et al. 2016).

To comprehensively assess the effect of the three insecticides, cyantraniliprole, imidacloprid, and dinotefuran on *L. striatellus* and its resurgence, the fitness levels of the planthopper progeny, with and without insecticide treatment, were evaluated and compared using the age-stage, two-sex life table with the simplified recording method. We also assessed the risk of pest resurgence by using population projection method. The findings of the present research will be helpful to understand the effects that application of these insecticides have on the fitness of *L. striatellus* progeny. They will also provide a reference for using life tables in studying pest resurgence.

2 Materials and methods

2.1 Insects and host plants

Laodelphax striatellus individuals were originally collected in Jimo, Shandong Province, China during July 2015, and were cultured on 5 cm high rice seedlings (*Oryza sativa* L. cultivar SD13) in glass beakers (14 cm diam., 19 cm high) in a controlled climate room. The beakers were covered with cheese cloth for moisture control. All seedlings were grown in plastic pots containing nutrient soil (organic matter >35%; pH = 5.5~6.5) (Huixin Flower Soil Improvement Agent Factory, Qingdao City, Shandong Province, China) in a controlled climate room. The controlled climate room kept at 27 ± 1 °C, 60 ± 5% RH, and a 16: 8 h (L: D) photoperiod. The seedlings were replaced every 10–15 days.

2.2 Life table experiments

We used the rice seeding dipping method (Wang et al. 2008) to test the responses of *L. striatellus* to different insecticides. The insecticides used in this research were cyantraniliprole 100 g L^{-1} OD (Benevia® 10OD, FMC Corporation, Shanghai, China), imidacloprid 70 mg L^{-1} WDG (Zhejiang Hisun Chemical Co., Ltd, Zhejiang, China), and dinotefuran 200 g kg^{-1} SG (Mitsui Chemicals Agro, Inc.). Aqueous solutions of the recommended concentrations (cyantraniliprole 100 mg L^{-1}, imidacloprid 70 mg L^{-1}, and dinotefuran 200 mg L^{-1}) were prepared with distilled water containing 0.05% Triton X-100, and the distilled water containing only 0.05% Triton X-100 was used as the control. Rice seedlings with 1–2 leaves (approximately 5 cm in length) were immersed in the insecticide solutions for 30 s, air-dried, and inserted into individual glass tubes (2 cm diam., 18 cm high) containing 1 ml of distilled water. Ten pairs of adults were selected randomly from the mass-rearing population and then put into each of the glass tubes. We used a piece of cotton-wool to cover the tubes containing seedlings, and added water to the tube as needed. A total of six tubes were prepared for each treatment. After 48 h, the surviving adults were transferred to glass tubes (4 females and 1 male) containing three untreated seedlings. After 24h, the living adults were removed. Beginning at the fifth day (the day prior to the hatching of egg), all seedlings were inspected on a daily basis for newly hatched nymphs. Each of the newly hatched 1st instar nymph was then transferred into a fresh glass tube containing a new seedling, and observed daily for survival. After no nymphs emerged for a 72 h period, the seedlings were dissected using a stereomicroscope (Nikon SMZ 745T) and the number of unviable eggs was counted. The total numbers of eggs (N) used for the life table study were 136, 155, 101 and 117 for the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, respectively. The emergent nymphs were observed every 24 h and their survival recorded. When adults emerged, they were sexed and paired. Each pair adults were placed in a clean glass tube containing three new rice seedlings and allowed to mate and oviposit. If there were surplus individuals of one sex, they were paired with young adults of the opposite sex recruited from the mass-reared colony for mating. Because the recruited adults were added solely for mating purpose, they were excluded from analysis. Adult survival was recorded daily. To record egg production while avoiding frequently disturbing the insects, all pairs of *L. striatellus* were only moved every five days to fresh glass tubes containing rice seedlings. This continued until all individuals had died. The three seedlings were removed from each of the rearing tubes after the 5-day period and dissected under a stereomicroscope, as described above, to determine the mean daily fecundity. If a male died before the female, a new male added for mating purposes, but only the longevity and fecundity of the female was recorded. If the female died before the male, we added a female but only recorded the longevity of the male.

2.3 Life table analysis

The age-stage specific survival rate (s_{xj}), fecundity (f_{xj}), age-specific survival rate (l_x), age-specific fecundity (mx) were calculated with reference to Chi & Liu (1985), Chi (1988). The age-stage life expectancy (exj) was calculated with reference to Chi & Su (2006) while the age-stage reproductive value (v_{xj}) was calculated with reference to Tuan et al. (2014a, b).

In this paper, we calculated the mean fecundity (F) as:

$$F = \frac{\sum_{i=1}^{N_f} E_i}{N_f} \tag{1}$$

where N_f is the total number of female adults and E_i is the total number of eggs produced by the ith female adult. Because not all female adults produced eggs, we also calculated the mean fecundity of reproductive females (F_r) by using only the females that actually produced eggs. The value of F_r is calculated as:

$$F_r = \frac{\sum_{i=1}^{N_{fr}} E_i}{N_{fr}} \tag{2}$$

where N_{fr} is the total number of reproductive female adults. The oviposition days (O_d) and number of eggs per oviposition day (E_d) were calculated according to Cheng et al. (2018).

The standard errors for all population parameters were evaluated including r, λ, R_0, T, adult longevity, fecundity, oviposition days, and total preoviposition period of the female from birth (TPOP) by the bootstrap procedure with 100,000 resampling. The paired bootstrap test was used to detect the differences between treatments based on the confidence interval of differences (Efron & Tibshirani 1993; Huang & Chi 2012; Polat-Akköprü et al. 2015).

2.4 Population projection and resurgence risk

By using the life tables obtained in this research, we projected the population growth and its uncertainty to elucidate the predicted population size, its variability, and the resurgence risk of *L. striatellus* according to Chi (1990) and Huang et al. (2018) using the TIMING-MSChart program (Chi 2018a). To estimate the uncertainty of population growth, we initially sorted the results of the 100,000 bootstrap sampling of the net reproductive rate (R_0) obtained in the previous section to find the 2.5th and 97.5th percentiles of the sorted bootstrap samples. Afterwards, the life tables of the 2.5th and 97.5th percentiles of bootstrap R_0 were utilized to project the uncertainty of population growth of *L. striatellus*. The TIMING-MSChart program is also available at http://140.120.197.173/ecology/prod02.htm. The projected population size was then used to assess the timing and extent of the resurgent pest population.

3 Results

3.1 Development duration, mortality, and longevity of *Laodelphax striatellus*

There were noticeable differences in the development duration, mortality, and longevity among the three insecticide treatments (Table 1). The longest egg duration and highest egg mortality were observed in the *L. striatellus* group treated with imidacloprid, while the longest nymphal duration and greatest nymphal mortality occurred in individuals treated with dinotefuran. In the cyantraniliprole treatment, 96 individuals completed development into the adult stage out of the 136 eggs (N) used at the beginning of the research. The total preadult survival rate (s_a) of 71% in the cyantraniliprole treatment has no significant difference from that of the control treatment; but was substantially higher than it was in the dinotefuran (48%) and imidacloprid (59%) treatments (Table 1). In general, the lifespan of male adults was longer than it was in the females, except in the dinotefuran treatment. The total lifespans of all individuals in the cyantraniliprole and imidacloprid treatments were significantly longer than they were in the dinotefuran and control treatments.

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Table 1. Mean (± SE) of developmental time, stage mortality, longevity, preadult survival rate (s_a), and total preoviposition period (TPOP) of the *L. striatellus* treated with different pesticides. Data followed by the same lower-case letter in the same row or the same capital letter in the same column were not significantly different based on a paired bootstrap test at the 5% significance level.

Statistics	*n*	Cyantraniliprole	*n*	Imidacloprid	*n*	Dinotefuran	*n*	Control
Egg mortality	136	0.1029 ± 0.03b	155	0.1935 ± 0.03a	101	0.1683 ± 0.04ab	117	0.1538 ± 0.03ab
Egg duration	122	7.54 ± 0.07b	125	8.66 ± 0.09a	84	7.29 ± 0.05c	99	7.67 ± 0.10b
Nymph mortality	122	0.1912 ± 0.03b	125	0.2194 ± 0.03b	84	0.3564 ± 0.05a	99	0.1966 ± 0.04b
Nymph duration	96	14.43 ± 0.22ab	91	14.01 ± 0.30b	48	14.94 ± 0.31a	76	13.99 ± 0.20b
Preadult duration (d)	96	22.05 ± 0.25ab	91	22.59 ± 0.34a	48	22.23 ± 0.32ab	76	21.66 ± 0.24b
Preadult survival rate (s_a)	136	0.71 ± 0.04a	155	0.59 ± 0.04bc	101	0.48 ± 0.05c	117	0.65 ± 0.04ab
Female adult longevity (d)	47	20.34 ± 1.67abB	43	22.02 ± 1.39aB	26	19.27 ± 1.60abA	37	17.62 ± 1.17bB
Male adult longevity (d)	49	26.47 ± 1.50abA	48	30.71 ± 1.75aA	22	22.64 ± 2.35bA	39	24.95 ± 1.89bA
Total longevity (d)	136	35.80 ± 1.54a	155	34.00 ± 1.64a	101	28.23 ± 1.61b	117	31.89 ± 1.62b
TPOP (d)	47	22.39 ± 0.35ab	43	23.12 ± 0.46a	26	23.32 ± 0.42a	37	21.97 ± 0.33b

Table 2. Mean (± SE) of the oviposition days (O_d), eggs per oviposition day (E_d), fecundity (F), proportion of female adult in cohort (N_f/N), intrinsic rate of increase (r), finite rate (λ), net reproductive rate (R_0), and mean generation time (T) of the *L. striatellus* treated with three pesticides and control. Standard errors were estimated using 100,000 bootstrap resampling. A paired bootstrap test was used to detect differences between treatments. Data followed by the same lower-case letter in the same row were not significantly different.

Parameters	Cyantraniliprole	Imidacloprid	Dinotefuran	Control
N_f/N (proportion of female adults)	0.3456 ± 0.0408a	0.2774 ± 0.0360a	0.2574 ± 0.0435a	0.3162 ± 0.0431a
N_{fr}/N_f (proportion of reproductive female)	0.936 ± 0.036a	0.954 ± 0.033a	0.962 ± 0.038a	0.919 ± 0.045a
F (eggs per female)	381.0 ± 41.3a	417.2 ± 37.7a	249.0 ± 33.4b	246.5 ± 27.2b
F_r (eggs per reproductive female)	407.0 ± 41.0a	437.6 ± 36.2a	259.0 ± 32.5b	268.3 ± 26.2b
O_d (d)	21.34 ± 0.53ab	22.27 ± 1.33a	19.28 ± 1.53ab	18.50 ± 1.00b
E_d (eggs per oviposition day)	19.07 ± 0.31ab	19.65 ± 0.32a	13.43 ± 0.37c	14.50 ± 0.31d
r (d^{-1})	0. 1562 ± 0.0055a	0.1432 ± 0.0053ab	0.1303 ± 0.0072b	0. 1446 ± 0.0060ab
λ (d^{-1})	1.1690 ± 0.0064a	1.1539 ± 0.0061ab	1.1391 ± 0.0081b	1.1556 ± 0.0069ab
R_0 (offspring/individual)	131.68 ± 21.04a	115.74 ± 18.22ab	64.11 ± 13.74c	77.97 ± 13.63bc
T (d)	31.25 ± 0.56bc	33.19 ± 0.48a	31.93 ± 0.71ab	30.13 ± 0.35c

The total numbers of emerged female adults (N_f) were 47, 43, 26 and 37 in the cyantraniliprole, imidacloprid, dinotefuran, and control treatment, respectively. The proportion of female adults in the cohorts (N_f/N) ranged from 0.2574 to 0.3456, with no significant differences among the treatments (Table 2). The proportion of reproductive females (N_{fr}/N_f) ranged from 0.919 to 0.962, again with no significant differences among treatments. However, the mean fecundity per female (F) in the cyantraniliprole and in the imidacloprid treatments was higher than it was in both the dinotefuran and control treatments ($P < 0.05$) (Table 2). When only reproductive females were used to calculate the mean fecundity, the mean fecundity value per reproductive female (F_r) was higher than in the F females; similarly, the F_r values in the cyantraniliprole and imidacloprid treatments were higher than those in the dinotefuran and control treatments.

The change of survival rate and stage differentiation of *L. striatellus* in the different treatments can be observed in the age-stage survival rate (s_{xj}). In all treatments, adults of both sexes emerged at age 19 or 20 d (Fig. 1). Because of the variable developmental durations occurring among individuals, stage overlaps are evident. The values for f_{xj}, m_x, and l_xm_x of the planthoppers are shown in Fig. 2. The first reproductive age was 19, 20, 21 and 19 d for the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, respectively. The first peak value of net maternity (l_xm_x) was 7.06, 6.00, 3.89 and 5.41 eggs which occurred at age 28, 32, 31, and 29 d for the cyantraniliprole, imidacloprid, dinotefuran, and control treatments respectively.

3.2 Population parameters of *Laodelphax striatellus*

No significant differences were observed in the value of r between the *L. striatellus* progeny treated with cyantraniliprole (0.1562 d^{-1}), imidacloprid (r = 0.1432 d^{-1}) and the control (r = 0.1446d^{-1}), but the r value of the cyantraniliprole

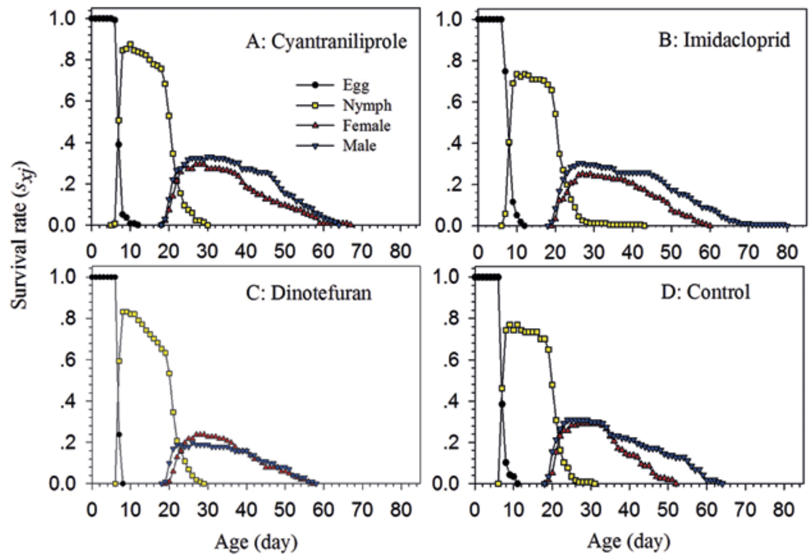

Fig. 1. Age-stage specific survival rate (s_{xj}) of the *L. striatellus* exposed to different pesticides. **A:** Cyantraniliprole. **B:** Imidacloprid. **C:** Dinotefuran. **D:** Control.

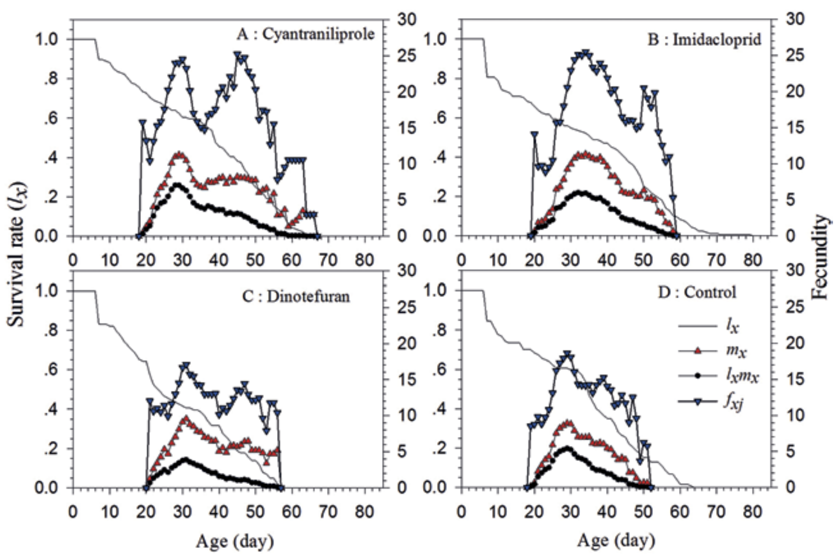

Fig. 2. Age-specific survival rate (l_x), female age-specific fecundity (f_{xj}), age-specific fecundity of the total population (m_x), and age-specific maternity (l_xm_x) of the *L. striatellus* exposed to different pesticides. **A:** Cyantraniliprole. **B:** Imidacloprid. **C:** Dinotefuran. **D:** Control.

treatment was significantly higher than the dinotefuran treatment (r = 0.1303d^{-1}) (Table 2). Comparison of the λ of the different treatments showed similar results. No significant difference was either observed in R_0 between the cyantraniliprole (R_0 = 131.68 offspring/individual) and imidacloprid treatment (R_0 = 115.74 eggs/individual). The R_0 value in the cyantraniliprole treatment was significantly higher than it was in both the dinotefuran-treated cohort (R_0 = 64.11 offspring) and the control group (R_0 = 77.97 offspring) (P < 0.05). Although there was no significant difference between T of the planthoppers treated with imidacloprid and dinotefuran (33.19 and 31.93 d, respectively), the T value of imidacloprid-treated individuals was significantly longer than in the cyantraniliprole-treated insects (T = 31.25 d) and the control group (T = 30.13 d).

The life expectancies of *L. striatellus* at age zero (e_{01}) were 35.80, 34.00, 28.23, and 31.89 d in the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, respectively (Fig. 3). The values were exactly the mean total longevity of all individuals used in this research (Table 1). At age zero, v_{01} were the same as the finite rates, i.e., 1.1690, 1.1539, 1.1391 and 1.1556 d^{-1} for the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, respectively (Fig. 4 and Table 2). The v_{xj} values increased dramatically to 94.17, 99.89, 77.75, and 77.93 d^{-1} after the female adults emerged at age 19, 20, 20, and 19 d in the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, respectively.

3.3 Population projection of *Laodelphax striatellus* treated with different insecticides

Fig. 5 shows the number of individuals of different stages simulated from initial populations of 10 eggs/100 hills. The stage curves indicate the trends and emergence times of the different stages. Our projection demonstrated that the

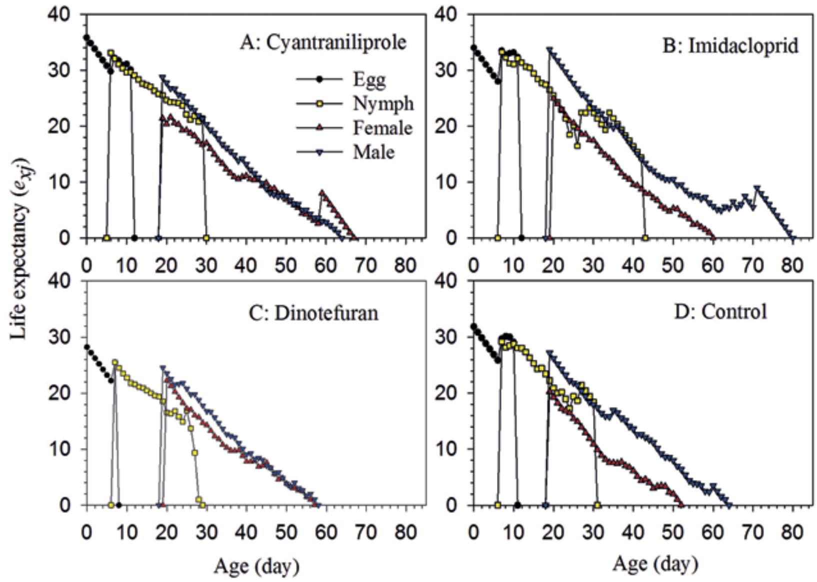

Fig. 3. Age-stage specific life expectancy (e_{xj}) of the *L. striatellus* exposed to different pesticides. **A:** Cyantraniliprole. **B:** Imidacloprid. **C:** Dinotefuran. **D:** Control.

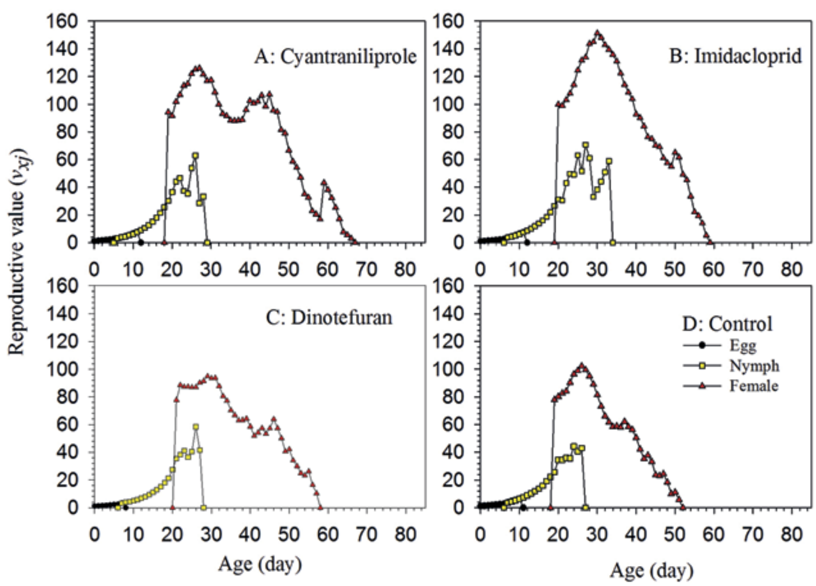

Fig. 4. Reproductive value (v_{xj}) of the *L. striatellus* exposed to different pesticides. **A:** Cyantraniliprole. **B:** Imidacloprid. **C:** Dinotefuran. **D:** Control.

L. striatellus cohort treated with cyantraniliprole would produce the largest population – after 60 days the total population size would reach 36,027 individuals, including 27,357 eggs, 8,153 nymphs, 237 female and 280 male adults. The slowest population growth occurred in the dinotefuran treatment with 8,272 total individuals including 6,567 eggs, 1,519 nymphs, 98 female and 89 male adults.

Because both nymph and adult stages are destructive to rice plants, we used the total number of the two stages to represent the effective pest population size (Fig. 6). Huang et al. (2013) calculated an economic threshold of 4.56 injury equivalents per hill for *N. lugens* before rice reaches its milk stage. In their report, they used only individuals older than 3rd instar nymphs to calculate the economic threshold. In this research, we included all nymphs and adults, and arbitrarily used 10 individuals (all instars and adults) per hill as the economic threshold. With an initial population of 10 eggs/100 hills, the effective pest population reached the economic threshold (1,000 individuals/100 hills) after 48 d in the life table of the 0.975 percentile of the cyantraniliprole-treated cohort, while in the projection using the original life table the economic threshold was attained on day 52.

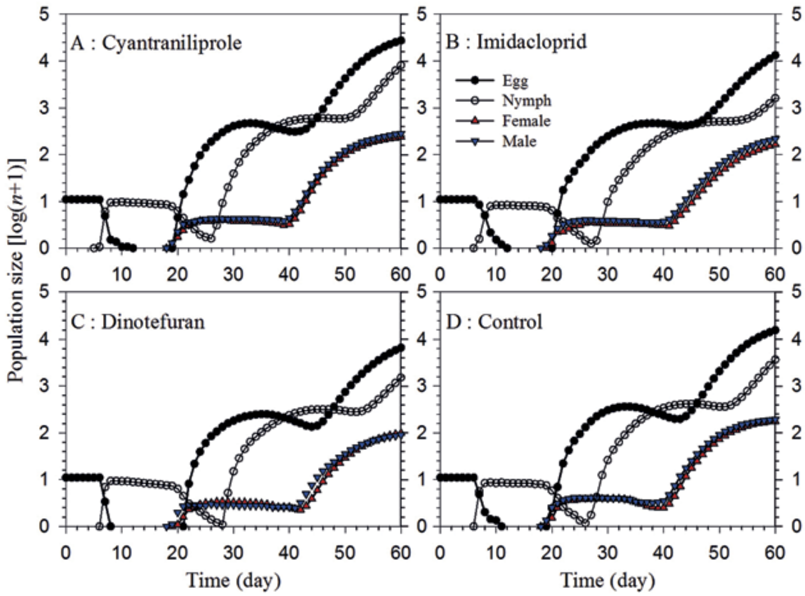

Fig. 5. Population projection of the *L. striatellus* exposed to three pesticides and control. An initial population of 10 eggs/100 hills was used in each projection.

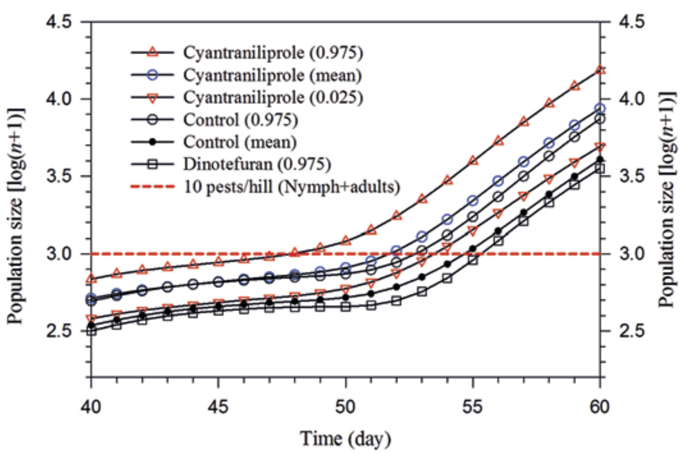

Fig. 6. Total number of nymphs and adults of the *L. striatellus* projected by using life tables of 0.975, mean, and 0.025 percentiles of cyantraniliprole-treatment, 0.975 and mean of control treatment, and 0.975 percentile of Dinotefuran. An initial population of 10 eggs/100 hills was used in each projection and the economic threshold is 1,000 individuals/100 hills.

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4 Discussion

In the rice field, the *L. striatellus* and other insects were controlled by a variety of insecticides (Lin et al., 2013), which often result in the resurgence of the pests owing to the stimulation of fecundity by insecticides (Wang et al., 2010). This scenario has been reported in *L. striatellus*, in rice fields by Shen et al. (2007) and Xu et al. (2008). Use of the age-stage, two-sex life table method in this study graphically demonstrated the progeny fitness of *L. striatellus* after insecticides treatment. Among them, the average oviposition of progeny of *L. striatellus* treated with cyantraniliprole and imidacloprid significantly increased, which indicates that cyantraniliprole and imidacloprid can promote the reproduction of *L. striatellus*. This is similar to studies reporting that chlorpyrifos, triazophos and cypermethrin can increase the fertility of *L. striatellus* (Xu et al. 2008). Castellanos et al. (2019) reported, the adaptive costs were elevated for *Euschistus heros* individuals by imidacloprid, resulting in a population growth rate approximating one sixth (0.163) of that recorded for imidacloprid-susceptible strain. The results of this research have demonstrated that the effects of insecticide treatment on the developmental duration, survival, longevity, and fecundity vary depending on the treatment, and that it is inappropriate to assess the effect an insecticide treatment may have on a population's resurgence by using just one of the above parameters. In the present research, no significant differences were observed in the intrinsic rate of increase and finite rate of *L. striatellus* among the cyantraniliprole, imidacloprid, dinotefuran, and control treatments, except between cyantraniliprole and dinotefuran. Because the intrinsic rate of increase and finite rate are estimated based on the assumption of stable age-stage distribution as time approaches infinity, it is inappropriate to arrive at conclusions by using these derived parameters (Huang and Chi 2012). However, by using the developmental rate, survival rate and fecundity, population growth can be projected without assuming that the population settles down to a stable age-stage distribution (Huang & Chi 2012). A population projection based on an age-stage, two-sex life table can reveal the change of stage structure during population growth and provide valuable information on the timing and growth of various stages of the population (e.g., nymphs, adults). Projections demonstrated that faster population growth occurred in *L. striatellus* in the cyantraniliprole treatment compared to the control group (Fig. 5). In addition, the effective pest population treated with cyantraniliprole reached the economic threshold (1,000 individuals/100 hills) earlier than the control (Fig. 6).

Currently, the mechanism responsible for the effects that cyantraniliprole have on the progeny of *L. striatellus* remains unknown. Previous studies found that the expression of the vitellogenin gene in brown planthoppers was significantly up-regulated after insecticide treatment, while juvenile hormone esterase gene was significantly down-regulated, and that protein mass in fat body and the ovaries increased significantly (Ge et al. 2010a, b). Some researchers also found that the protein content in the male accessory glands (MAGs) of brown planthoppers treated with triazophos was significantly higher than that in untreated males, and was transmitted to females during mating to stimulate female reproduction (Wang et al. 2010; Ge et al. 2016). The increase in fecundity of *L. striatellus* may also be related to hormone levels and associated proteins – a distinct possibility that should be further explored.

Hormesis in insects exposed to sublethal concentrations of insecticides has been documented for several taxa and compounds (Tan et al. 2012; Qu et al. 2015; Xiao et al. 2015). Exposure to sublethal concentrations of imidacloprid stimulated the reproduction on *Myzus persicae* (Cutler et al. 2009; Rix et al. 2016) and *A. glycines* (Qu et al. 2015). In this research, we used life tables and computer projection to demonstrate that application of cyantraniliprole can increase the growth potential of *L. striatellus* progeny, thereby risking the possibility of resurgence. This fact should be taken into account in planning effective pest management program.

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