Research Article

SUBLETHAL EFFECTS OF FLONICAMID ON LIFE TABLE OF *Myzus persicae* (Sulzer)

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ABSTRACT

The green peach aphid, *Myzus persicae* (Sulzer) (Aphididae: Hemiptera) is a cosmopolitan polyphagous pest of more than five hundred plant species belonging to at least forty different plant families including several economically important agricultural crops. The sublethal effect of LC_{25} concentration of flonicamid on *M. persicae* was assessed by using an age-stage two-sex life table approach for integrated management of this pest. A leaf-dip bioassay showed that flonicamid was very toxic to the adults of *M. persicae* at 48 h with the calculated LC_{25} concentration value of 0.0115 g a.i./L. The adults (parental generation) of *M. persicae* exposed to the LC_{25} concentration (sublethal dose) of flonicamid showed inhibitory effects on the life history traits across its generations such as reduction in adult longevity and fecundity of parental generation (F_0); shortening the durations of fifth instar nymphs, adult female longevity, oviposition period, total longevity and fecundity of F_1 & F_2 generations. On the other hand, stimulatory effects were observed on the duration of first, second, third, and fourth instar nymphs; and pre-adults in F_2 generation in the flonicamid-treated aphids. Consistently with the effects on individual traits, a higher mean generation time (T) and shorter intrinsic rate of increase (r), finite rate of increase (λ), and net reproductive rate (R_0) of F_2 generation were observed in the flonicamid treated aphids, although r, λ, R_0, T, and gross reproductive rate (GRR) of F_1 generation were not significantly affected. The findings revealed the exposure of parental adults of *M. persicae* to sublethal concentration of flonicamid could induce hormetic (both inhibitory and stimulatory) effects on their succeeding generations. This study is useful for assessing the overall effects of flonicamid on *M. persicae*. The hormetic effects should be considered when it used flonicamid in the integrated management of *M. persicae* in crop fields.

Key words : Flonicamid, hormetic, life table, *Myzus persicae*, sublethal.

INTRODUCTION

The use of chemical insecticides becomes a frequent means to manage aphids in crops. Frequent use of chemical insecticides to control the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) has resulted in the development of resistance to various classes of insecticides including organophosphates, carbamates, pyrethroids, and neonicotinoids (Bass *et al.*, 2014; Tang *et al.*, 2017).

The indiscriminate and repeated use of insecticides results in multifaceted effects such as immediate death of insects, development of resistance and cross-resistance in insects (Herron *et al.*, 2001; Koo *et al.*, 2014; Cui *et al.*, 2016; Chen *et al.*, 2017b) or bring changes in physiology and behavior of an insect (Rehan and Freed, 2015). Insecticidal effects on insects can generally be divided into direct lethal effects that cause mortality, and sublethal effect that causes no apparent mortality (Rehan and Freed, 2015). However, exposure of an insect to a sublethal dose of an insecticide induces biological and behavioral changes in surviving insects through changes in multiple biological traits of insects such as survivorship, longevity, and fecundity (Boina *et al.*, 2009), feeding and oviposition (Tan *et al.*, 2012; He *et al.*, 2013), and the genetic constitution of successive generations (Lee, 2000; Desneux *et al.*, 2007). Consequently, stage-specific survival rate, reproduction rate, and population parameters are also impacted (Liang *et al.*, 2018). Thus, it is essential to identify sub-lethal effects on demographic traits of arthropod pests for giving a more accurate assessment of insecticide efficiency to optimize the application (Stark and Banks, 2003). For a comprehensive understanding of the sublethal effects of an insecticide on an insect, it is necessary to consider its effect on the survival rate and fecundity throughout the whole life span.

M. persicae is a cosmopolitan polyphagous pest of more than five hundred plant species belonging to at least forty different plant families including several economically important agricultural crops (van Emden and Harrington, 2007) and greenhouse crops (Sanchez *et al.*, 2010; Mehta, 2012). The pest is characterized by its rapid development due to its high reproductive capacity. It causes direct damage to its host plants by sucking sap leading to stunting or death. Moreover, it serves as an efficient vector to transfer more than 100 plant viruses in different hosts, particularly in solanaceous vegetables (Cloyd and Sadof, 1998; Ellis *et al.*, 1998; Blackman and Eastop, 1984; van Emden *et al.*, 1969; Hughes, 1963; Blackman and Eastop, 2000).

Flonicamid, a pyridine organic compound, has been categorized as a neonicotinoid though the mode of action is different from that of other neonicotinoids (Chen *et al.*, 2014). So it has been recommended against a wide range of homopterous insect pests including *M. persicae.* However, the potential sublethal (inhibitory or stimulatory) effects of flonicamid on *M. persicae* are still feebly assessed. This paper presents the assessment of sublethal effects of the LC_{25} concentration of flonicamid on *M. persicae* using the age-stage two-sex life table approach for integrated management of this pest.

MATERIALS AND METHODS

Cabbage (*Brassica oleracea* L. var. *capitata*) is an important commercial vegetable grown in Nepal for a long time, and is one of the most preferred hosts of *M. persicae*. Thus, this crop was selected as a host plant for *M. persicae* in this study. Cabbage (Green coronet variety) seedlings were grown in Vegetable Development Centre, Khumaltar, Lalitpur under a net house to obtain a regular supply of insect free cabbage seedlings. Such seedlings were grown in a 24-well plastic tray and in a coco pit-compost nursery mixed in a 3:1 ratio in batches at 15 to 20 days intervals to maintain tender leaves for insect rearing.

The colony of *M. persicae* was established inside a nylon cage in the premises of the Central Agricultural Laboratory, Pulchowk, Lalitpur with apterous adults collected from non-pesticide contaminated cabbage fields and was periodically supplemented with nymphs collected from the same fields to maintain its genetic heterogeneity. Before starting the experiment, parent insect stock was reared for 2 to 3 generations in the laboratory in an incubator maintaining 25 ± 1 ºC temperature,

65 ± 5% relative humidity (RH), and with a photoperiod of 16: 8 (L: D) h. The experiment was set up in a two-chambered seed germinator available in the seed laboratory under Central Agriculture Laboratory maintaining temperature, humidity, and light as per the objective. All the experiments were performed in controlled conditions keeping the constant relative humidity (RH %) at 65 ± 5, temperature at 25 ± 1 ºC, and photoperiod at 16:8 hours light and dark. Flonicamid (Ulala) 50 % WG, a commercial formulation of flonicamid was used in all experiments. Serial dilutions were made using distilled water, and the desired concentration of the solution was used immediately after preparation to minimize any chemical decomposition.

Lethal toxicity bioassays (Experiment 1) were carried out by preparing five different concentrations of flonicamid 50% WG by diluting in distilled water i.e. 0.05, 0.025, 0.0125, 0.00625, and 0.003125 g a.i/L. Cabbage leaves were dipped in each insecticide solution for 30 seconds separately and were air dried by placing them upside down for 1 h. Leaves were then transferred into insect-rearing cups (0.5-liter capacity with a diameter of 10 cm base, 11.5 cm top, and 6.5 cm height). Six-day-old 10 individuals of *M. persicae* were placed in each rearing cup with the aid of a fine camel hairbrush. The insect-rearing cups were maintained in a growth chamber at 25 ± 1 ºC and 65 ± 5% RH. Four replicates were conducted for each concentration. These bioassays were repeated four times in each concentration at different dates. Insect mortality was assessed after 48 h of continuous exposure to insecticide, and the insects that cannot move or only one leg vibrates slightly (after probing gently with a soft hairbrush) were recorded as dead insects (methodology used in Liang *et al.*, 2018). Based on lethal toxicity bioassays data, LC_{25} value was calculated by using total mortality data from up to 96 h of experimentation with the help of the linear regression method after making corrections of data wherever necessary by using the following correction factor,

$$\text{Corrected mortality \% of treatment} = \frac{(\text{Mortality\% in treatment} - \text{Mortality\% in control})}{(100 - \text{Mortality\% in control})} \times 100$$

To assess the sublethal effects of flonicamid on F_0 generation Experiment 2 was set after completion of the lethal toxicity bioassay. Six days old apterous aphids were treated with LC_{25} concentration of flonicamid. After 48 h, the survived aphids were transferred individually to untreated fresh leaves in the insect-rearing cup. Adults were observed daily for recording survival and numbers of newborn nymphs which were then removed. The total number of adults used in this study were 100 in each flonicamid exposed and unexposed (control) treatment. The leaf was replaced every alternate day to maintain leaf freshness until all adult aphids in the cohort died.

To assess the sublethal effects of flonicamid on F_1 generation Experiment 3 was started one week after the setup of Experiment 2. In this experiment, the newborn nymphs that were produced within 24 h by F_0 adults were collected as F_1 generation and transferred to the rearing cup independently. In both LC_{25} flonicamid and control treatments, the F_1 generation aphids were reared on fresh untreated leaves. The total number of newborn nymphs used in this study was 65 individuals used in both flonicamid and control treatments. Daily records of the survival and development of the insect were kept. During the reproductive period of the F_1 generation, newly born aphids were counted and then removed. Fresh untreated leaf was replaced every alternate day.

To assess the sublethal effects of flonicamid on F_2 generation, Experiment 4 was started two weeks after the setup of Experiment 3. Here, the newborn nymphs that were produced within 24 h by F_1 adults were collected as F_2 generation and transferred to the rearing cup independently. In both LC_{25} flonicamid and control treatments, the F_2 generation aphids were also reared on fresh untreated leaves

as done in experiment 3. The total numbers of newborn nymphs used in this study were 60 individuals in each flonicamid and control treatment. Daily records of insect survival and development were conducted. During reproductive period of F_2 generation, newly born aphids were counted and then removed. Fresh leaf was replaced every alternate day as above.

Raw data were analyzed based on the theory of the age-stage, two-sex life table (Chi and Liu, 1985; Chi, 1988). The mean of the development periods for each development stage, longevity for all individuals and adult females, and fecundity of *M. persicae* were calculated. The total pre-reproduction period (TPRP) was calculated by including the pre-adult age in the total. The age-stage specific survival rate (s_{xj}) (where x is the age and j is the stage), the age-stage specific fecundity (f_{xj}), the age-specific survival rate (lx), the age-specific fecundity (mx) and age-stage reproductive value (vxj) were calculated from the daily records of the survival and fecundity of all individuals in the cohort. In addition, the study estimated population parameters, including the intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T) (Huang and Chi, 2012). The life expectancy (exj) was calculated according to Chi and Su (2006), while the reproductive value (vxj) was calculated according to Tuan *et al.* (2014). These all parameters were calculated using the computer program TWOSEX-MSChart (Chi, 2018; Chi and Liu, 1985). The variances and standard errors of the population parameters were estimated using the bootstrap procedure with 100,000 random resampling and the difference of population parameters between control and insecticide treatment groups and between generations within each treatment group were compared by using the paired bootstrap test based on the confidence intervals of differences implemented in TWOSEX-MS Chart (Huang and Chi, 2013 & Chi, 2018). All graphs were created using Sigma Plot 12.0 (Systat Software Inc., San Jose, CA, USA).

RESULTS AND DISCUSSION

Toxicity of Flonicamid on *M. persicae* Adults and Calculation of LC_{25} Concentration of Flonicamid to *M. persicae*

The toxicity of flonicamid to six-day-old *M. persicae* was investigated after 48 h insect exposure to insecticide. The mortality rates of *M. persicae* adults were determined after exposure of insects to different concentrations of flonicamid. No insect mortality occurred 24 h after treatment with flonicamid. However, insect mortality increased with increasing concentration of flonicamid after 48 h. The average insect mortality of the control group in all bioassays was 0.25%. A total of 960 6-day-old aphids were used in the bioassay. The different concentrations of flonicamid used to treat the *M. persicae* adults, and the total insect mortality after 48 to 96 h were used to calculate the LC_{25} concentration of flonicamid. The calculated LC_{25} concentration of flonicamid was 0.0115 g a.i./L. The LC_{25} value was used as the sub-lethal concentration for insect life table studies. The high toxicity of flonicamide has been reported for several sucking pests, including *M. persicae*, *Aphis gossypii*, *Bemisia tabaci*, *Frankliniella occidentalis,* and *Nilaparvata lugens* (Shi *et al.*, 2022).

Sublethal Effects of Flonicamid on F0 Generation of *M. persicae*

Short-term exposure of adult *M. persicae* to LC_{25} concentration of flonicamid for 48 h had a significant effect on the longevity and fecundity of the exposed individuals (F_0 generation) (Fig. 1). As compared to the control group, the adult longevity of the F_0 generation was significantly reduced from 18.9 d to 13.6 d by flonicamid treatment. The fecundity of F_0 adults was also significantly reduced from 33.01 to 14.95 offspring/female after exposure to LC_{25} dose of flonicamid.

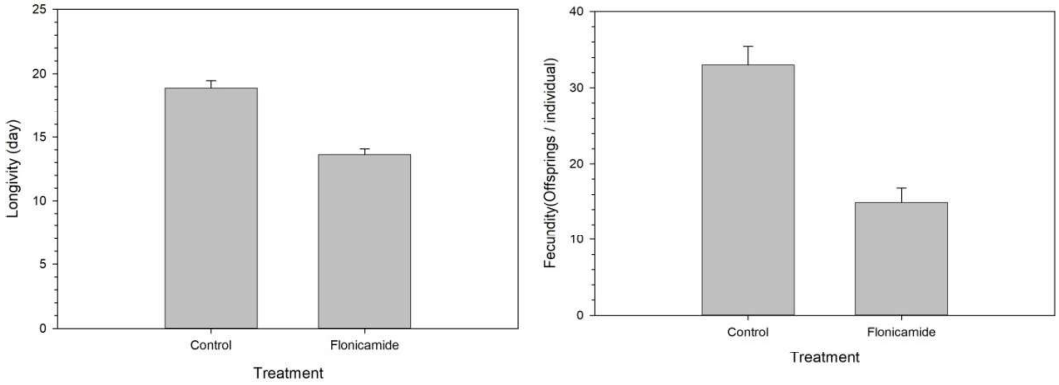

Fig. 1. The longevity and fecundity of initial parental adults (F_0 generation) of *Myzus persicae* treated with LC_{25} concentration of flonicamid for 48 h.

Effects of Flonicamid on F1 and F2 Generations of *M. persicae*

The development time, longevity, pre-reproductive period, fecundity and total pre-adult survival rate of the succeeding progenies (F_1 and F_2) were evaluated (Table 1). The duration of the fifth instar nymph (P = 0.0000), the duration of adult female (P = 0.00089), oviposition period (P = 0.0026) and fecundity (P = 0.0000) were significantly decreased in F_2 generation in comparison to F_1 generation within treatment group despite a significant increase observed in the duration of first instar nymph (P = 0.0027), second instar nymph (P = 0.0000), third instar nymph (P = 0.0489), and preadult stage (P = 0.0000). In F_2 generation, the duration of the fifth instar nymph (P = 0.0000), total longevity (P = 0.0000), the duration of adult female (P = 0.0000), oviposition period (P = 0.0000) and fecundity (P = 0.0000) were significantly decreased by flonicamid treatment in comparison to F_2 control despite significant increase found in the duration of second instar nymph (P = 0.0085), third instar nymph (P = 0.0032), fourth instar nymph (P = 0.0081) and preadult stage (P = 0.0000). These results showed the sublethal effects of flonicamide on *M. persicae* which usually happened with most insect pests after exposure to sublethal concentration of insecticides (Desneux *et al.*, 2007; Tang *et al.*, 2019). There is a reduction in fecundity and longevity of *M. persicae* across generations once the parent aphid is exposed to flonicamide which may decrease the rate of population growth, unlike exposure to sublethal concentration of imidacloprid and cyantraniliprole that would lead to a hormetic (stimulatory) response of *M. persicae* (Zeng et.al., 2016).

Effect of Flonicamid on Population Parameters of *M. persicae*

The effects of flonicamid (LC_{25}) on the population parameters of F_1 and F_2 generations of *M. persicae* were evaluated with a bootstrap technique based on the insect life tables (Table 1). Within the treatment group, the mean generation time (T) of *M. persicae* was significantly increased from F_1 to F_2 generation (P = 0.0000), and the intrinsic rate of increase (r) (P = 0.0000), finite rate of increase (λ) (P = 0.0000), the net reproductive rate (R_0) (P = 0.0000) and gross reproductive rate (GRR) (P = 0.0000) were significantly decreased. Moreover, the r, λ, R_0 and GRR were also significantly decreased in the treatment group in comparison to the control group of F_2 generation. However, there were no significant differences in the r, λ, R_0, and GRR in the treatment group in comparison to the control of F_1 generation.

Table 1. Life history and parameters of the succeeding generations after parental adults of *M. persicae* exposed to sublethal dose (LC_{25}) of flonicamid

Statistics	Stage or sex	Generation	Control		Treated	
			N	Mean ± SE [a, b]	N	Mean ± SE [a, b]
Pre-adult duration (d)	N1	F_1	59	1.32 ± 0.07aB	59	1.51 ± 0.07aB
		F_2	57	1.72 ± 0.08aA	57	1.88 ± 0.1aA
	N2	F_1	56	1.61 ± 0.07aA	53	1.49 ± 0.07aB
		F_2	57	1.68 ± 0.06bA	53	1.98 ± 0.1aA
	N3	F_1	52	1.58 ± 0.07aA	50	1.7 ± 0.09aB
		F_2	57	1.6 ± 0.08bA	52	1.94 ± 0.09aA
	N4	F_1	49	1.84 ± 0.09aA	49	1.67 ± 0.07aA
		F_2	56	1.57 ± 0.07bB	43	1.72 ± 0.08aA
	N5	F_1	9	1.22 ± 0.15aA	7	1.14 ± 0.14aA
		F_2	7	1.14 ± 0.14aA	8	1.12 ± 0.13bB
	Adult / female	F_1	49	16.88 ± 0.57aA	49	15.59 ± 0.54aA
		F_2	56	18.3 ± 0.88aA	43	11.98 ± 1.3bB
	Preadult	F_1	49	6.59 ± 0.12aA	49	6.61 ± 0.09aB
		F_2	56	6.7 ± 0.11bA	43	7.7 ± 0.12aA
	Total longevity	F_1	63	19.11 ± 1.13aB	61	18.59 ± 1.04aA
		F_2	57	24.68 ± 0.93aA	57	16.7 ± 1.22bA
Oviposition period (d)	Female	F_1	49	13.49 ± 0.51aA	49	11.82 ± 0.5bA
		F_2	56	14.32 ± 0.73aA	40	8.32 ± 1.03bB
Fecundity (offspring/female)	Female	F_1	49	41.61 ± 2.23aA	49	38.59 ± 2.24aA
		F_2	56	37.38 ± 2.25aA	40	20.05 ± 2.8bB
APRP (d)	Female	F_1	49	1.29 ± 0.08aA	49	1.08 ± 0.09aA
		F_2	56	1.27 ± 0.08aA	40	1.32 ± 0.13aA
TPRP (d)	Female	F_1	49	7.88 ± 0.14bA	49	7.69 ± 0.15aB
		F_2	56	7.96 ± 0.14aA	40	8.95 ± 0.2aA
The intrinsic rate of increase, *r*		F_1	63	0.2688 ± 0.01aA	61	0.2755 ± 0.01aA
		F_2	57	0.259138 ± 0.01aA	57	0.1778 ± 0.01bB
The finite rate of increase, λ		F_1	63	1.3084 ± 0.01aA	61	1.3172 ± 0.01aA
		F_2	57	1.295813 ± 0.01aA	57	1.1946 ± 0.01bB
The net reproductive rate, R_o		F_1	63	32.4 ± 2.8aB	61	31 ± 2.6aA
		F_2	57	36.7193 ± 2.3aA	57	14.1 ± 2.3bB
The mean generation time, *T*		F_1	63	12.9 ± 0aB	61	12.5 ± 0.2aB
		F_2	57	13.905 ± 0.2aA	57	14.9 ± 0.3bA
The gross reproductive rate, *GRR*		F_1	63	47.5 ± 2.2aA	61	43.4 ± 2.6aA
		F_2	57	52.47 ± 3.2aA	57	34.7 ± 3.3bB

1. Standard errors (SE) were estimated by using the bootstrap technique with 100,000 re-samplings.
2. Significant differences at $P<0.05$ between two different treatments and generations were compared with paired bootstrap test implemented in TWOSEX MS-Chart.

The small letter shows significant difference between control and flonicamid treatment in each generation, while the capital letter indicates the significant differences between F_1 and F_2 generations within each treatment group ($P<0.05$)

Effects of Flonicamid on Age-Stage Specific Survival Rate and Fecundity of *M. persicae*

The age-stage specific survival rate (s_{xj}) of *M. persicae* gives the probability that a newborn will survive to age x and stage j. Overlapping among the curves of the age-stage specific survival rate (s_{xj}) of *M. persicae* in F_1 and F_2 generations treated with LC_{25} dose of flonicamid in both treated and the control groups (Fig. 2) are due to the variable developmental rate among individuals.

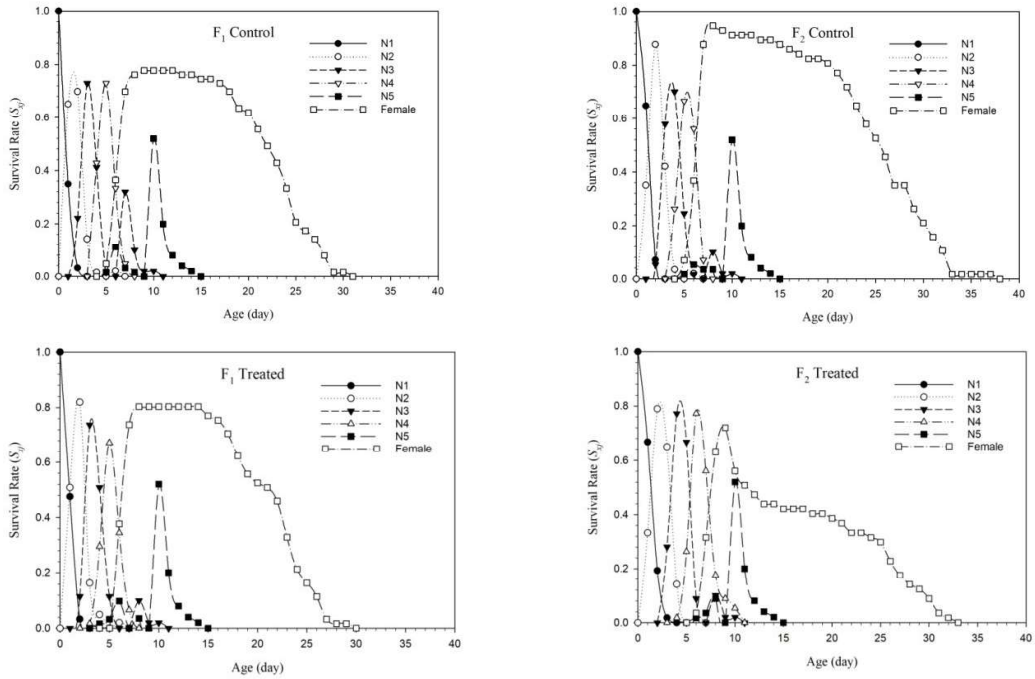

Fig. 2. Age-stage specific survival rate of *M. persicae* in F_1 and F_2 generations treated with LC_{25} dose of flonicamid.

The age-specific survival rate (lx) demonstrates a simplified overview of the survival rate without accounting for stage differentiation (Fig. 3). Interestingly, a lower l_x of F_1 generation was observed in the flonicamid treated group from day16, whereas a lower lx of F_2 generation in the flonicamid treatment was observed from day 3 day (Fig. 3).

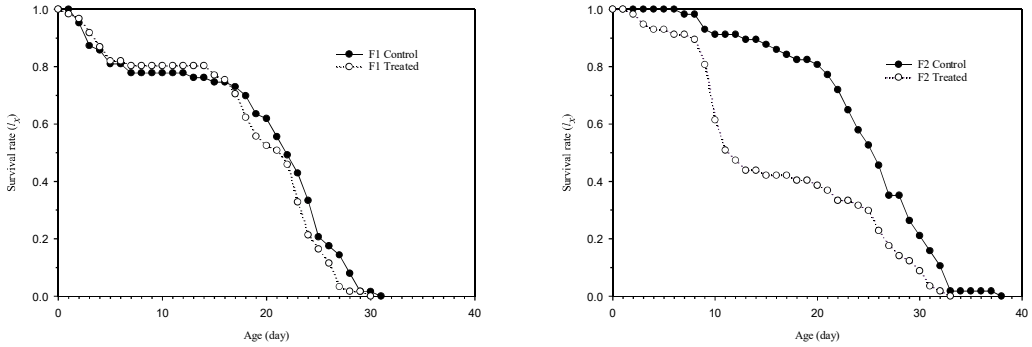

Fig. 3. Age-specific survival rate (l_x) of *M. persicae* in F_1 and F_2 generations treated with LC_{25} dose of flonicamid.

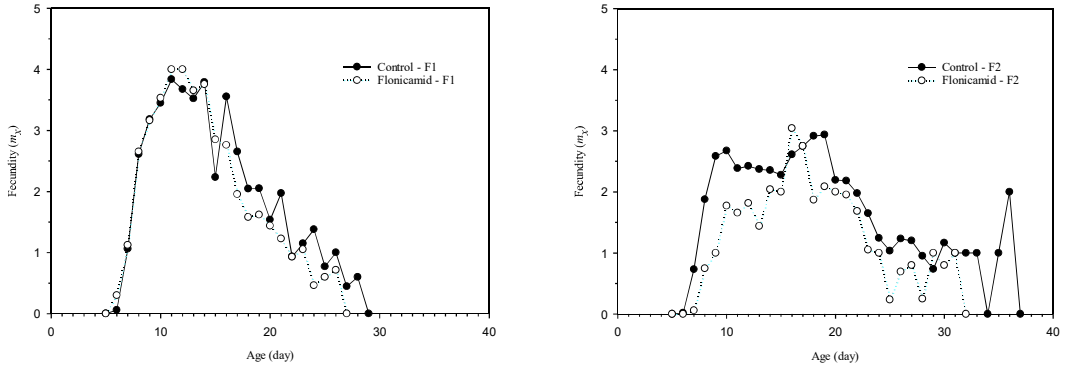

Fig. 4. Age-specific fecundity (m_x) of initial *M. persicae* exposed to LC_{25} dose of flonicamid in F_1 and F_2 generations.

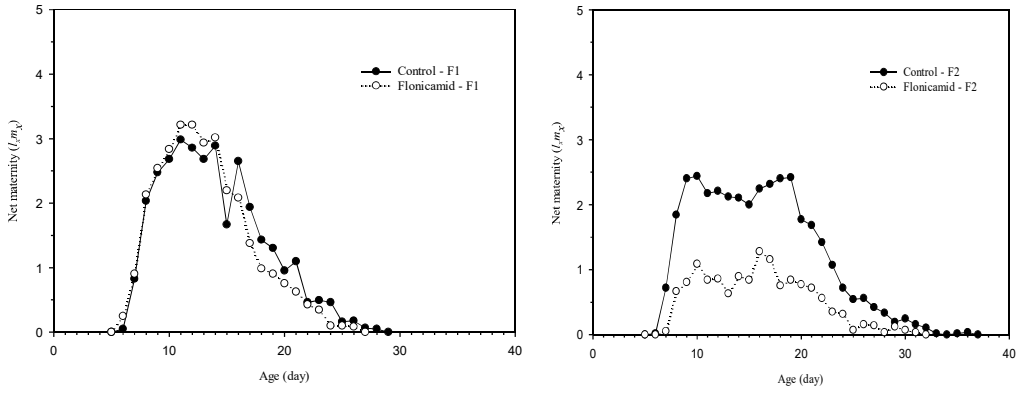

Fig. 5. Age-specific maternity ($l_x m_x$) of *M. persicae* initially exposed to LC_{25} dose of flonicamid in F_1 and F_2 generations.

The age-specific fecundity (m_x) of the flonicamid treated *M. persicae* were higher than that of the control group in F_1 generation (Fig. 4), while a similar trend of m_x of F_2 generation *M. persicae* were observed both in the treatment and the control groups (Fig. 4). The age-specific maternity (l_xm_x) (Fig. 5) showed the similar pattern as the age-specific fecundity (m_x). The highest age-specific maternity (l_xm_x) peak observed in F_1 treated group on 12th day and the lowest was in F_2 treated group on 16th day (Fig. 5). The data demonstrate that sublethal concentrations of flonicamid could suppress the growth of *M. persicae* across generations. Shi *et al.* (2022) has also reported suppression of growth of *A. gossypii* after exposure of sublethal and low lethal concentrations of flonicamid.

The age-stage-specific life expectancy (e_{xj}) is the length of time that an individual of age x and stage j is expected to survive after age x (Fig. 6). The life expectancy (e_{xj}) curves indicated that offspring (F_1 and F_2) of adult *M. persicae* with flonicamid exposure could to survive shorter than the control (Fig. 6).

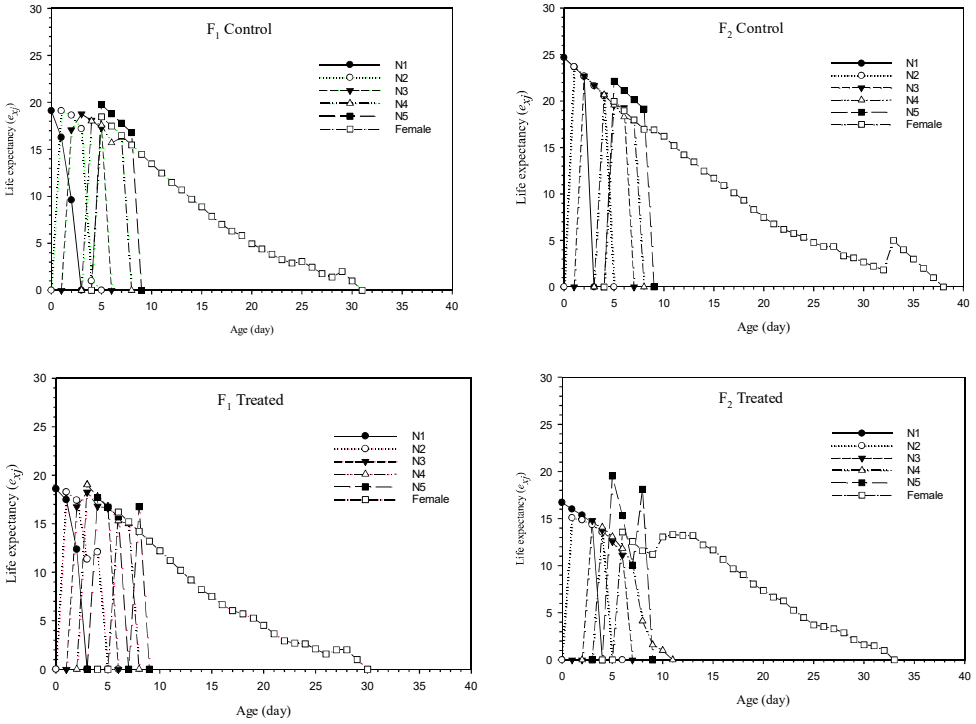

Fig. 6. Age-stage specific life expectancy (e_{xj}) of *M. persicae* initially exposed to LC_{25} dose of flonicamid in F_1 and F_2 generations.

The age-stage-specific reproductive value (v_{xj}) describes the contribution of an individual of age x and stage j to the future population as defined by Fisher (1930). A higher maximum reproductive value of each stage and a shorter preadult period of F_1 generation of *M. persicae* were observed in the treatment group than those of the control (Fig. 7), while in F_2 generation, except the 1st instar nymph, a lower v_{xj} of each stage in the treatment group was observed than that of the control (Fig. 7).

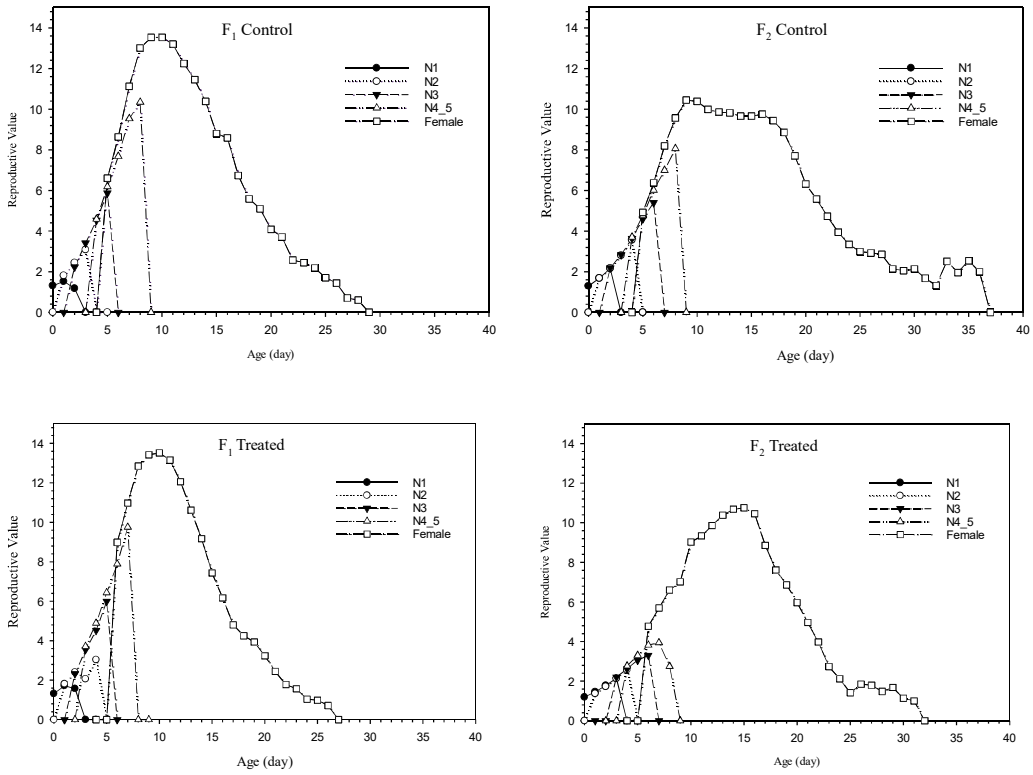

Fig. 7. Age-stage specific reproductive value (v_{xj}) of *M. persicae* initially exposed to LC_{25} dose of flonicamid in F_1 and F_2 generations.

The approach for ecotoxicological analysis based on life histories and population fitness using demography and measures of population growth rate results in more accurate assessments of the impacts of pesticides and other toxicants because measures of population growth rate combine lethal and sublethal effects (Stark and Banks, 2003).

CONCLUSIONS

The study results indicated that the application of LC_{25} concentration of flonicamid causes hormesis in *M. persicae* across three generations. The exposure of parental aphids to a sublethal dose of flonicamid resulted in a significant decrease in adult longevity, total longevity, oviposition period, fecundity, and population parameters r, λ, R_0, and GRR and increase T in F_2 generation. These results suggested that short-term exposure of *M. persicae* to the sublethal concentration of flonicamid might induce hormesis in the insect across generations. Since life table analysis integrated all these factors into population parameters, it is the most important tool for the overall evaluation of population fitness and hormesis. Nevertheless, given that the genetic variation in field populations is naturally greater than that of laboratory strains, the situation in the field may be more complex, and further investigations on the sublethal effects of this insecticide on *M. persicae* in the field are advisable.

Insecticide-induced hormesis, which may potentially occur after application, should be taken into consideration for the integrated management of *M. persicae* in the field.

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REFERENCES

Bass, C., Puinean, A. M., Zimmer, C. T., Denholm, I., Field, L. M., & Foster, S. P. (2014). The evolution of insecticide resistance in the peach potato aphid, *Myzus persicae*. *Insect Biochemestry and Molecular Biology,* 51, 41-51. 10.1016/j.ibmb.2014.05.003.

Blackman, R. L., & Eastop, V. F. (1984). *Aphids on the world's crops, an identification guide*. Wiley, New York. Google Scholar.

Blackman, R. L., & Eastop, V. F. (2000). *Aphids on the World's Crops, an Identification and Information Guide*, second ed. John Wiley & Sons Ltd, Chichester, UK.

Boina, D. R., Onagbola, E. O., Salyani, M., & Stelinski, L. L. (2009). Antifeedant and sublethal effects of imidacloprid on Asian citrus psyllid, *Diaphorina citri*. *Pest Management Science,* 65(8), 870–877. doi 10.1002/ps.1767.

Chen, M. L. Tao, McLean, J., & Lu, C. (2014). Quantitative Analysis of Neonicotinoid Insecticide Residue in Foods: Implementation for Dietary Exposures. *Journal of Agricultural Food Chemistry,* 62(26), 6082-6090. doi 10.1021/jf501397m.

Chen, X. W., Li, F., Chen, A. Q., Ma, K. S., Liang, P. Z., Liu, Y., Song, D. L., & Gao, X. W. (2017b). Both point mutations and low expression levels of the nicotinic acetylcholine receptor beta1 subunit are associated with imidacloprid resistance in an *Aphis gossypii* (Glover) population from a Bt cotton field in China. *Pesticide Biochemistry and Physiology,* 141, 1-8.

Chi, H. (1988). Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology*, 17, 26-34.

Chi, H. (2018). TWOSEX-MS Chart: *A computer program for the age-stage, two-sex life table analysis.* http://140.120.197.173/Ecology/Download/Twosex-MSChart-exe-B200000.rar. (Accessed 30 June 2018).

Chi, H., & Liu, H. (1985). Two new methods for the study of insect population ecology. *Bulletin of Insect Zoology*, Academia Sinca, 24, 225-240.

Cloyd, R. A., & Sadof, C. S. (1998). Aphids: Biology and Management. *Floriculture Indiana*, 12(2), 3-7.

Cui, L., Qi, H., Yang, D., Yuan, H., & Rui, C. (2016). Cycloxaprid: a novel cisnitromethylene neonicotinoid insecticide to control imidacloprid-resistant cotton aphid (*Aphis gossypii*). *Pesticide Biochemistry and Physiology*, 132, 96-101.

Desneux, N., Decourtye, A., & Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology,* 52, 81-106.

Ellis, P. R., Pink, D. A. C., Phelps, K., Jukes, P. L., Breeds, S. E., & Pinnegar, A. E. (1998). Evaluation of a core collection of *Brassica oleracea* accessions for resistance to *Brevicoryne brassicae*, the cabbage aphid. *Euphytica*, 103, 149-160.

He, Y. X., Zhao, J. W., Zheng, Y., Weng, Q. Y., Biondi, A., Desneux, N., & Wu, K. M. (2013). Assessment of potential sublethal effects of various insecticides on key biological traits of the tobacco whitefly, *Bemisia tabaci*. *International Journal of Biological Science*, 9, 246-255.

Herron, G. A., Powis, K., & Rophail, J. (2001). Insecticide resistance in *Aphis gossypii* Glover (Hemiptera: Aphididae), a serious threat to Australian cotton. *Australian Journal of Entomology,* 40, 85-89.

Huang, Y. B., & Chi. H. (2013). Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. *Journal of Applied Entomology,* 137, 327-339.

Hughes, R. D. (1963). Population dynamics of the cabbage aphid, *Brevicoryne brassicae* (L.). *Journal.*

Koo, H.-N., An, J.-J., Park, S.-E., Kim, J.-I., & Kim, G.-H. (2014). Regional susceptibilities to 12 insecticides of melon and cotton aphid, *Aphis gossypii* (Hemiptera: Aphididae), and a point mutation associated with imidacloprid resistance. *Crop Protection,* 55, 91-97.

Lee, C. Y. (2000). Sublethal effects of insecticide on longevity, fecundity, and behavior of insect pests: a review. *Journal of Bioscience*, 11, 107-112.

Liang, P-Z., Ma, K.-S., Chen, X.-W., Tang, C.-Y., Xia, J., Chi, H., & Gao, X.-W. (2018). Toxicity and Sublethal Effects of Fluflonicamide, a Novel Butenolide Insecticide, on the Development and Fecundity of *Aphis gossypii* (Hemiptera: Aphididae). *Journal of Economic Entomology*, XX(X), 1-7. doi: 10.1093/jee/toy381.

Mehta, P. K. (2012). Scenario of insect pest problems under a protected environment. In Mehta *et al.*, (Ed) *Pest management in high-value crops under protected environment,* (.) ICAR Short Course. Department of Entomology, CSK Himachal Pradesh KrishiVishwavidyalaya, Palampur, India. 181 pp.

Rehan, A., & Freed, S. (2015). Fitness Cost of Methoxyfenozide and the Effects of Its Sublethal Doses on Development, Reproduction, and Survival of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae). *Neotropical Entomology,* 44, 513-520.

Sanchez, J. A., Spina, M. L., Michelena, J. M., Lacasa, A., & Mendoza, A. H. D. (2010). Ecology of aphid pests of protected pepper crops and their parasitoids. *Biocontrol Science and Technology*, 21(2), 171-188.

Shi, D., Luo, C., Lv, H., Zhang, L., Desneux, N., You, H., Li, J., Ullah, F., & Ma, K. (2022). Impact of sublethal and low lethal concentrations of flonicamid on key biological traits and population growth associated genes in melon aphid, *Aphis gossypii* Glover. *Crop Protection*, https://doi.org/10.1016/j.cropro.2021.105863.

Stark, J. D., & Banks, J. E. (2003). Population-level effects of pesticides and other toxicants on arthropods. Annual Review of Entomology, 48, 505-519.

Tan, Y., Biondi, A., Desneux, N., & Gao, X. W. (2012). Assessment of physiological sublethal effects of imidacloprid on the mirid bug, *Apolygus lucorum* (Meyer-Dür). *Ecotoxicology,* 21, 1989-1997.

Tang, Q. L., Ma, K. S., Hou, Y. M., & Gao, X.W. (2017). Monitoring insecticide resistance and diagnostics of resistance mechanisms in the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) in China. *Pesticide Biochemistry and Physiology*, 143, 39-47. 10.1016/j.pestbp.2017.09.013.

Tang, Q., Ma, K., Chi, H., Hou, Y., & Gao, X. (2019). Transgenerational hormetic effects of sublethal dose of flupyradifurone on the green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae). PLoS ONE 14(1): e0208058. https:// doi.org/10.1371/*journal of pone, 0208058.*

Tuan, S. J., Lee, C. C., & Chi, H. (2014). Population and damage projection of *Spodoptera litura* (F.) on peanuts (*Arachis hypogaea* L.) under different conditions using the age-stage, two-sex life table. *Pest Management Science,* 70, 805-813.

Van Emden, H. F., & Harrington, R. (2007). Aphids as Crop Pests. *CABI North American Office*, Cambridge, Massachusetts. 699 pp.

van Emden, H. F., Eastop, V. F., Hughes, R. D., & Way, M. J. (1969). The ecology of *Myzus persicae. Annual Review of Entomology*, 14, 197-270.

Zeng, X, He, Y., Wu, J., Tang, Y., Gu, J., Ding, W., & Zhang, Y. (2016). Sublethal effects of Cyantraniliprole and Imidacloprid on feeding behavior and life table parameters of *Myzus persicae* (Hemiptera: Aphididae) *Journal of Economic Entomology*, 109(4), 1595-1602.