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Toxicity and Sublethal Effects of Commonly Used Insecticides on South American Tomato Pinworm, *Tuta absoluta* Meyrick, 1917 (Lepidoptera: Gelechiidae)

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ABSTRACT

This study investigates the toxicity and sub-lethal effects of four insecticides, flubendiamide, emamectin benzoate+lufenuron, thiocyclam, and spinosad, on third instar larvae, eggs and pupae of *Tuta absoluta*, a major pest in tomato cultivation. The findings of this study can help inform the development of effective and sustainable pest management strategies for *Tuta absoluta* in tomato cultivation. The LC_{50} values of these insecticides was assessed through bioassays, and the results showed varying levels of toxicity depending on the insecticide and the stage of the pest. Spinosad exhibiting the highest toxicity at 7.05 mg a.i/L against third instar larvae, followed by emamectin benzoate+lufenuron (14.24 mg a.i/L), flubendiamide (37.29 mg a.i/L), and thiocyclam (65.17 mg a.i/L). Additionally, the study evaluated the sub-lethal effects of these insecticides, including their impact on demographic parameters such as net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), mean generation time (T), and doubling time (DT). The results indicated that all tested insecticides demonstrated high efficacy in controlling the larval stage of *T. absoluta*, while also exhibiting good efficacy against other growth stages, such as eggs and pupae. The larval stage was found to be the most susceptible to insecticides, while the pupal stage exhibited the lowest susceptibility to spinosad and emamectin benzoate+lufenuron. Pest eggs showed the lowest susceptibility to flubendiamide and thiocyclam. Therefore, the study suggests that spinosad and emamectin benzoate+lufenuron are highly toxic against *T. absoluta* and may be valuable in integrated pest management programs for controlling this pest.

Keywords: Tomato leaf miner, chemical insecticides, toxicology, lethal effect, pest control.

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INTRODUCTION

The South American tomato pinworm, *Tuta absoluta* Meyrick,1917 (Lepidoptera: Gelechiidae), is a significant pest in tomato cultivation worldwide including South America, Europe, Africa and the Middle East (Desneux et al, 2010; Biondi, Guedes, Wan, & Desneux, 2018; Han et al, 2019), causing substantial economic losses. The pest has been observed to have a broad temperature tolerance, with the ability to survive in Mediterranean conditions where it can produce 10-12 generations per year without diapause in greenhouse condition (Desneux et al, 2010).

T. absoluta, initially identified as *Phthorimaea absoluta* in 1917 from specimens in Peru, has emerged as a significant threat to global tomato cultivation, spreading rapidly across Afro-Eurasia (Biondi et al, 2018). This pest's impact on tomato production has been well-documented (Biondi et al, 2018; Rostami, Madadi, Abbasipour, Allahyari, & Cuthbertson,2020). In Iran, the first detection of *T. absoluta* occurred in in Urmia (November 2010) and Borazjan (January 2011), leading to its rapid proliferation and establishment as a key pest in both greenhouse and open-field tomato crops (Baniameri & Cheraghian, 2012). The pest's characteristics, including high reproductive capacity, short life cycle, and larval penetration into plant tissues, have contributed to challenges in its management (Desneux, Luna, Guillemaud, & Urbaneja,2011; Mansour & Biondi, 2021; Desneux et al, 2022). The spread and impact of *T. absoluta* underscore the urgent need for effective pest control strategies to safeguard tomato production globally.

Chemical control is a widely employed and effective strategy for managing invasive pest species (Hulme, 2009; Paini et al, 2016; Soares et al, 2019a; Han, Lavoir, Rodriguez Saona, & Desneux, 2022). Insecticides are typically administered at concentrations designed to eliminate the targeted insect pests (Wang et al, 2019; Ullah et al, 2019; Khan et al, 2021; Hafeez et al, 2022). However, various abiotic and biotic factors can lead to spatiotemporal fluctuations in these concentrations, thereby influencing the intended doses/concentrations (Desneux et al, 2005). These dynamic concentrations/doses, which may be sublethal or low lethal, can contribute to the development of resistance and potentially induce sublethal effects on the life-history traits of exposed arthropods (Guedes, Smagghe, Stark, & Desneux, 2016; Xu et al, 2022; Gul et al, 2021; Ullah et al, 2020; Shi et al, 2022).

Furthermore, the extensive use of chemical insecticides has the potential to trigger multiple adverse effects on non-target insects, the environment, and human health (Desneux, Decourtye, & Delpuech, 2007; Biondi, Desneux, Siscaro, & Zappalà, 2012; Lu, Wu, Jiang, Guo, & Desneux, 2012; Guedes et al, 2016; Soares et al, 2019b; Akhtar et al, 2021).Four insecticides: flubendiamide, emamectin benzoate+lufenuron, thiocyclam, and spinosad are commonly used to control *T. absoluta*, with various chemical groups and modes of action employed to target different stages of the pest's life cycle. Flubendiamide is a diamide insecticide that disrupts the ryanodine receptor, leading to paralysis and death in insects (Das, Mukherjee, & Roy, 2017). Emamectin benzoate+lufenuron is a combination of an avermectin and a chitin synthesis inhibitor, which affects the nervous system and growth of insects (Liu, Guo, Zhang, & Xue, 2022; Wilson & Cryan, 1997). Thiocyclam is an insect growth regulator that inhibits chitin synthesis, preventing the development of insects (Mustafa et al, 2024). Spinosad is a bacterial insecticide derived from *Saccharopolyspora spinosa* that acts as a nicotinic acetylcholine receptor agonist, causing paralysis and death in insects (Mayes, Thompson, Husband, & Miles, 2003). The bio-insecticides spinosad and emamectin benzoate demonstrate significant efficacy against a wide range of lepidopterous pests found on vegetables globally, with particular effectiveness observed against *T. absoluta* (Gacemi & Guenaoui, 2012).

In the context of agriculture, arthropods are frequently exposed to sub-lethal concentrations of pesticides due to the natural degradation of these chemicals after initial application in crops. This exposure can result in a range of sub-lethal effects on various biological parameters, including developmental rate, longevity, and fecundity (Chen, Li, Lu, Zhang, & Liu, 2016). Hence, the assessment of sub-lethal impacts of insecticides on insects holds significant importance in understanding the repercussions of pesticides on agroecosystems. These sublethal effects may affect the fertility, fecundity and other demographic parameters of the pest. The present study undertook a comprehensive evaluation of the lethal and sublethal effects of four distinct insecticides (flubendiamide, emamectin benzoate+lufenuron, thiocyclam, and spinosad) on *T. absoluta* under controlled laboratory conditions.

MATERIALS AND METHODS

Tuta absoluta rearing

The adult moths used in the study were sourced from an insectarium located in a plant protection laboratory in Borazjan, Bushehr province. These moths had been reared for five generations, starting from an originally field-collected population. For rearing, a plastic container was prepared, which opened a window in the wall of the container to create ventilation. Tomato leaves were placed inside the dish. A piece of cotton soaked in 10% diluted honey was used to feed the moths (Genç, 2017). The adults were released in the containers to oviposit for 24 hours. After 24 hours, the moths were collected with an electric aspirator and transferred to another container. The rearing containers were kept in an insectarium under the controlled climatic conditions (25±1°C; RH: 65±5%, L:D, 16:8). Adults were reared for 3 more generations and then the eggs were used for treatment (Salek-Ebrahimi & Gharekhani 2014).

Insecticides

The insecticides that used in this study were flubendiamide (Takumi®, 20% WG, Nihon Nohyaku, Japan), emamectin benzoate+lufenuron (Proclim Fit®, 50% WG, Syngenta, Switzerland), thiocyclam hydrogen oxalate (Evisect®, 50% SP, Nippon Kayaku, Japan) and spinosad (Tracer®, 24% SC, Dow Elanco, England) (Table 1).

Table 1. General information on tested insecticide formulations.

Action Ingredients (AI)/Trade name	Supplier	Mode of action[1]	Chemical group	Concentration	Formulation[2]	Dose
Flubendiamide/ Takumi®	Nihon Nohyaku	Ryanodine receptor modulators	Diamide	20%	WG	0.2 gr/L
Emamectin benzoate+lufenuron/ Proclim Fit®	Syngenta	Glutamate-gated chloride channel (GluCl) allosteric modulators Inhibitors of chitin biosynthesis affecting CHS1	Avermectins Benzoylureas	50%	WG	0.25 gr/L
Thiocyclam hydrogen oxalate/ Evisect®	Nippon Kayaku	Nicotinic acetylcholine receptor (nAChR) channel blockers	Nereistoxin analogues	50%	SP	1 gr/L
Spinosad/ Tracer®	Dow Elanco	Nicotinic acetylcholine receptor (nAChR) allosteric modulators	Spinosyns	24%	SC	0.25 ml/L

[1]Mode of action: IRAC (2021). [2]Formulation: WG: water-dispersible granules, SP: soluble powder, SC: suspension concentrate.

Bioassay of *T. absoluta*

Prior to the execution of the primary experiments, preliminary investigations were conducted to ascertain the effective concentration range of insecticides. In each concentration, three replicates were considered, with a minimum of 20 individuals at varying developmental stages per replication. The treatments were administered on third instar larvae, eggs, and pupae. The larvae were categorized based on head capsule size and body length, and 20 of them were placed in a petri dish containing the poison. The petri dishes were sealed with parafilm to prevent the evaporation of the insecticide. Pupae were submerged in the toxin concentrations for several seconds and kept in an incubator until the emergence of adult insects, which were then counted under the same climatic conditions as previously stated. The eggs were gently transferred to petri dishes using a fine brush and immersed in the poison solution for 10 seconds. After drying, the eggs were placed in the incubator to monitor the number of losses until hatching (4-7 days), and the number of hatched eggs was subsequently recorded (Goudarzvande Chegini, Abbasipour, Karimi, & Askarianzadeh, 2017; Sheikhigarjan, Rahmani, Imani, & Javadzadeh, 2015; Malek Mohammadi & Eghbalian 2018; Kabiri Raeisabad 2019). If the mortality rate in the control group was high (more than 10%), the replication was discarded. In cases where the mortality rate in the control group was low (less than 10%), the observed mortality rate was corrected using the Abbott formula (Abbott, 1925).

Measurement and evaluation of biological parameters of *T. absoluta*

A total of 100 third instar larvae of *T. absoluta* were treated with LC_{30} concentration of each insecticide utilizing the residual pesticide method (Parsaeyan, Saber & Bagheri, 2013). Following a 24-hour exposure period, the surviving larvae were separated from each treatment and kept individually in plastic containers with fresh tomato leaves in incubator until they underwent pupation. The Duration of the pupal stage was recorded. In order to evaluate the fertility, the adults were collected and kept as a pair of males and females in plastic containers with fresh tomato leaves. The number of eggs laid by each female and the hatching rate were recorded until the death of the last female. The hatched larvae were placed in a petri dish containing a piece of fresh tomato leaf, and the larval development period was recorded. The entire experimental processes were performed in a controlled insect rearing room under the same climatic conditions described previously (Esmaily, Saber, Bagheri, & Gharekhani, 2014).

Experimental design and data analysis

A completely randomized design was adopted, and the treatment means were separated using the least significant difference (LSD) test. Carry's method compiles the life table (Carey, 1993). The Probit method was used to analyze bioassay data. Statistical analysis was performed with SAS software version 9.1.3. Due to the normal distribution of the data, no transformation was applied to them.

RESULTS

Toxicity of insecticides on different *T. absoluta* life stages

The toxicity levels of four different insecticides on *T. absoluta* eggs, third instar larvae and pupae are given in Table 2. The LC_{50} values of spinosad, emamectin benzoate+lufenuron, flubendiamide and thiocyclam were recorded as 15.98, 30.16, 80.94 and 154.98 mg a.i./l on *T. absoluta* eggs, 7.05, 14.24, 37.29 and 65.17 mg a.i/l on third instar larvae and 17.19, 32.28, 55.18 and 105.66 mg a.i/l on pupa, respectively. The comparison of LC_{50} values among the tested insecticides revealed a significant difference in their toxic effects on T. absoluta due to the non-overlap in the LC_{50} values. Notably, spinosad exhibited the highest toxicity on *T. absoluta* eggs, third instar larvae and pupae, followed by emamectin benzoate+lufenuron> flubendiamide> thiocyclam.

Table 2. Toxicity of commonly used insecticides on different stages of *T. absoluta*.

Stage	Insecticides		Spinosad	Emamectin Benzoate + Lufenuron	Thiocyclam	Flubendiamide
Egg	Slope±SE		3.89±0.72	1.93±0.31	4.21±0.78	3.13±0.55
	χ2		28.93	38.91	29.1	32.07
	LC30	(95%FL)	11.72 (13.55-8.77)	16.12 (21.74 -9.44)	116.36 (134.03 – 87.64)	55.01 (65.90 –38.92)
	LC50	(95%FL)	15.98 (17.44-13.94)	30.16 (36.52 –22.58)	154.98 (168.74 –134.78)	80.94 (90.48 –68.17)
	LC90	(95%FL)	34.1 (48.80 -28.62)	139.46 (238.85-103.23)	312.26 (426.87-267.63)	208.05 (311.73-169.09)
Larvae	Slope±SE		4.84±0.75	1.98±0.30	5.11±0.79	3.84±0.57
	χ2		41.55	41.84	41.26	46.15
	LC30	(95%FL)	6.22 (6.79-5.42)	7.75 (10.10- 4.91)	51.41 (55.84-45.04)	27.23 (30.38-22.92)
	LC50	(95%FL)	7.05 (7.59-6.33)	14.24 (16.95- 11.18)	65.17 (69.65-62.82)	37.29 (40.72-33.97)
	LC90	(95%FL)	12.97 (16.03 -11.49)	63.04 (108.09 – 46.42)	116.09 (150.61 -100.52)	80.44 (110.41-67.03)
Pupa	Slope±SE		3.54±0.87	1.85±0.30	4.38±0.78	3.47±0.55
	χ2		16.71	37.41	31.6	39.01
	LC30	(95%FL)	12.22 (13/54-9/80)	12.1 (16.05 -7.33)	80.18 (90.59-63.55)	38.95 (44.95-30.35)
	LC50	(95%FL)	17.19 (20.61-15.63)	32.28 (27.94 -18.07)	105.66 (114.03-94.62)	55.18 (60.71 -48.66)
	LC90	(95%FL)	39.61 (98.40 -28.58)	114.99 (219.05 -81.08)	207.37 (282.40-177.35)	129.24 (182.61-106.90)

The dose/response curve slope indicates a higher slope of thiocyclam, implying that even a slight increase in its concentration led to further mortality in *T. absoluta* life stages. Additionally, the reaction of the South American tomato pinworm life stages to emamectin benzoate+lufenuron is more monotonic compared to other insecticides. The dose/response curve slope of spinosad, flubendiamide and thiocyclam were increased, respectively (Table 2).

Sublethal effects of insecticides on growth parameters of stable population *T. absoluta*

The sublethal effects of spinosad, emamectin benzoate+lufenuron, thiocyclam and flubendiamide on South American tomato pinworm population growth parameters were investigated. Life tables were utilized to assess these effects. Sustainable population growth parameters including reproduction rates, growth rates and growth period are presented in Table 3. All parameters, except mean generation time (T), were significantly different in treatments. The gross reproductive rate (GRR), which reflecting the total number of female offspring produced by a female over its lifetime, was high in the control (67.41 ± 4.31) and decreased in thiocyclam (58.25 ± 2.85), flubendiamide (49.24 ± 3.21), emamectin benzoate+lufenuron (41.42 ± 2.56) and spinosad (28.41 ± 3.81), respectively.

Table 3. Stable population parameters of *T. absoluta* treated with LC30 concentration of different insecticides.

Parameter	Treatment					Statistical Parameters
	control	Spinosad	Emamectin benzoate + Lufenuron	Thiocyclam	Flubendiamide	
Gross Reproduction Rate (GRR)	67.41± 4.31 a	28.41± 3.81 e	41.42±2.56 d	58.25±2.85b	49.24±3.21c	F=78,df=10 P<0.001
Net Reproductive Rate (R_0)	65.26±3.44 a	23.56± 2.80 e	34.55±3.32 d	49.42±2.72b	38.41±3.41c	F=100.98,df=10 P<0.001
Intrinsic Rate of Increase (r_m)	0.179±0.006 a	0.132± 0.005 e	0.141±0.005d	0.162±0.004b	0.154±0.003c	F=60.41,df=10 P<0.001
Finite Rate of Increase (λ)	1.195±0.009 a	1.141±0.007 e	1.151±0.006d	1.176±0.004b	1.165±0.005c	F=43.26,df=10 P<0.001
Mean Generation Time (T) (Day)	23.81± 0.27 d	23.71±0.25 d	25.11±0.37a	24.01±0.34b	23.41±0.34c	F=16.88,df=10 P<0.001
Doubling Time (DT)(Day)	3.61±0.008e	5.15±0.005a	4.81±0.004b	4.17±0.002d	4.35±0.003c	F=59.68,df=10 P<0.001

Different letters indicate the difference between the treatments in comparing the means with the LSD test. ** Significance at 1% probability level.

The net reproductive rate of the control was highest (65.26 ± 3.44), significantly different from the gross reproduction rate due to the survival parameter. The intrinsic population growth rate is the most crucial parameter for population growth type and rate, indicating positive, negative, or stable growth (Cortes, 2016). Spinosad had the most negative effect on r_m (0.132± 0.005), while the control had the highest r_m (0.179 ± 0.006), indicating a decreasing effect of insecticide treatments on r_m.

The finite rate of increase was lowest in spinosad treatment (1.141±0.007) and highest in the control (1.195 ± 0.009). The mean generation time was longest in emamectin benzoate+lufenuron (25.11±0.37), while there was no significant difference between control and spinosad treatment in generation duration.

The population of South American tomato pinworm in control doubled after 3.61 days, and the highest time to double the population was related to spinosad treatment (5.15 ± 0.005 days) (Table 3). These results suggest that insecticide treatments, particularly spinosad, negatively affect the population growth of South American tomato pinworm, increasing the doubling time and decreasing the intrinsic population growth rate.

Sublethal effects of insecticides on the biological parameters of *T. absoluta*

The results of the investigation into the impact of sublethal concentration (LC_{30}) of various studied insecticides on the duration of development and survival of *T. absoluta* immature stages are presented in Table 4.

Table 4. Mean length of immature stages (days) of *T. absoluta* treated with LC30 concentration of insecticides.

Treatment	Egg period	Larval period	Pupa period
Control	4.07±0.11 d	9.31±0.09 c	6.48±0.85 d
Spinosad	4.89±0.13 a	11.65±0.21 a	8.35±0.12 a
Emamectin benzoate + Lufenuron	4.66±0.14 ab	11.13±0.23ab	7.79±0.10 b
Thiocyclam	4.41±0.17 b	10.57±0.21 b	7.54±0.9 bc
Flubendiamide	4.26±0.16 c	10.48±0.24 b	7.34±0.74 c
Statistical Parameters	F=20.3478,df=10 P<0.001	F=73.96,df=10 P<0.001	F=4.45,df=10 P=0.02354

Different letters indicate the difference between the treatments in comparing the means with the LSD test.

The analysis of the data revealed significant differences in the length of development among treatments for all immature stages of *T. absoluta* (egg, larval, and pupal). The spinosad treatment showed the most considerable impact, with a significantly longer egg length compared to other treatments and the longest larval and pupal periods. The control group exhibited the shortest development periods for both larval and pupal stages. The results indicate that the duration of development and emergence of immature stages of *T. absoluta* significantly differed among treatments, with the longest period observed in the spinosad treatment. This information could be useful in optimizing pest management strategies for *T. absoluta*.

The reproductive, fertility, and longevity outcomes of *T. absoluta* adults following exposure to the LC_{30} concentration of various insecticides are presented in Table 5. The insecticides significantly reduced the reproductive rate of adult females, with the lowest number of eggs laid recorded in the spinosad treatment. Similarly, the fertility rate (percentage of egg hatching) was significantly lower in the spinosad treatment compared to other treatments. The highest regeneration rate was observed in the control group. Consequently, the lowest life expectancy of *T. absoluta* was recorded in the spinosad and emamectin benzoate+lufenuron treatments.

Table 5. Mean reproductive parameters of *T. absoluta* treated with LC30 different insecticides.

Treatment	Fertility	Fecundity	Female longevity
Control	130.33± 2.14 a	69.85±0.43 a	15.43±0.44 a
Thiocyclam	92.98± 2.18 b	60.85±0.54 b	11.30±0.46 b
Flubendiamide	86.74± 1.42c	51.44±0.67 c	9.55±0.39 c
Emamectin benzoate + Lufenuron	77.52± 2.14 d	46.74±0.71 d	6.88±0.28 d
Spinosad	59.65±0. 48 e	40.99±0.81 e	7.55±0.26 d
Statistical Parameters	F=842.08,df=10 P<0.001	F=1262.62,df=10 P<0.001	F=334.23,df=10 P<0.001

Different letters indicate the difference between the treatments in comparing the means with the LSD test.

DISCUSSION

The control of the South American tomato pinworm moth primarily relies on insecticides such as emamectin benzoate, spinosad, thiophenoxide, and flubendiamide (Lietti, Botto & Alzogaray, 2005). Despite the limited efficacy of chemical control, due to larval feeding behavior, chemical control may be considered as an alternative approach to manage the pest population (Cherif, Mansour Grissa-Lebdi, 2013). Research on the susceptibility of the South American tomato pinworm moth to insecticides in Iran is relatively scarce, with studies by Sheikhigarjan et al (2015), Sohrabi, Modarresi, & Hosseini (2015), Nozad-Bonab, Hejazi, Iranipour, & Arzanlou (2017), Jamshidnia, Abdoli, Farrokhi, & Sadeghi (2018), Malek Mohammadi & Eghbalian (2018), and Kabiri Raeisabad (2019) highlighting the high efficacy of insecticides in controlling this Pest. This study specifically investigated the lethal effects of four insecticides on various biological stages of the South American tomato pinworm, including eggs, larval instars, and pupae. Among the insecticides tested, spinosad exhibited the highest toxicity across all biological stages of the pest. Furthermore, emamectin benzoate+lufenuron, flubendiamide, and thiocyclam were found to be comparatively less toxic in their impact on the South American tomato pinworm moth, respectively.

The high toxicity of spinosad to South American tomato pinworm has also been reported extensively in the literature (Braham & Hajji, 2012; Nozad-Bonab et al, 2017; Kandil, Abdel-Kerim, & Moustafa, 2020; Moeini-Naghade, Sheikhigarjan, Moeini-Naghadeh, & Zamani, 2020; Moustafa, El-Hefiny, Abdel-kerim, & Kandil, 2023).

The delayed toxin effects of spinosad on the G1 progeny of *T. absoluta* have been demonstrated by Benchaâbane, Aribi, Kilani-Morakchi, & Chaabane (2016). the application of spinosad in combination with *Bacillus thuringiensis* (BT) against the South American tomato pinworm in a greenhouse resulted a significantly higher mortality rate (88.33 ± 1.43%) compared to other treatments (Jamshidnia et al, 2018). These findings align with those of Sheikhigarjan et al, (2015) who found that spinosad's toxicity and larvicidal effect on the South American tomato pinworm moth were higher than those of thiocyclam and flubendiamide.

Based on the current research, all insecticides tested exhibit high efficiency at controlling the larval stage of the South American tomato pinworm, as well as good efficacy in controlling other growth stages, such as eggs and pupae. The study found that the larval stage of the pest is the most susceptible to insecticides, while the pupal stage is the least susceptible to spinosad and emamectin benzoate+lufenuron insecticides. Additionally, the study found that pest eggs are also the least susceptible to flubendiamide and thiocyclam, a finding that is consistent with the research conducted by Sohrabi et al (2015).

Spinosad and emamectin benzoate+lufenuron exhibited the most substantial adverse effects on the biological parameters, reproductive capabilities and life table of the target pest. Conversely, thiocyclam and flubendiamide demonstrated moderate toxicity levels.

The most determinant parameter of population growth is the intrinsic rate of population increase (r_m). The decline in survival and fertility, which results in a decrease in r_m, is the most significant response of insects to sublethal doses of insecticides, leading to a reduction in pest and parasitoid populations in subsequent generations (Desneux et al, 2007). The data revealed that the lowest intrinsic rate of population growth of the pest was observed in the spinosad treatment. Furthermore, the immature period of the pest was prolonged under the influence of spinosad treatment, providing additional opportunities and time for effective pest management on the farm. Overall, the findings suggest that spinosad and emamectin benzoate+lufenuron have detrimental effects on the biological and demographic parameters of the pest, while flubendiamide and thiocyclam have less severe impacts. Therefore, it is recommended to utilize spinosad and emamectin benzoate+lufenuron for the successful control of *T. absoluta*.

The trend of survival reduction and oviposition rate in treatments are shown in Figure 1. With increasing pest age, survival and oviposition rates have decreased in all treatments. In all treatments, the survival curves were similar to the survival curve of the first type, so the mortality rate was lower at an early age and increased at later ages.

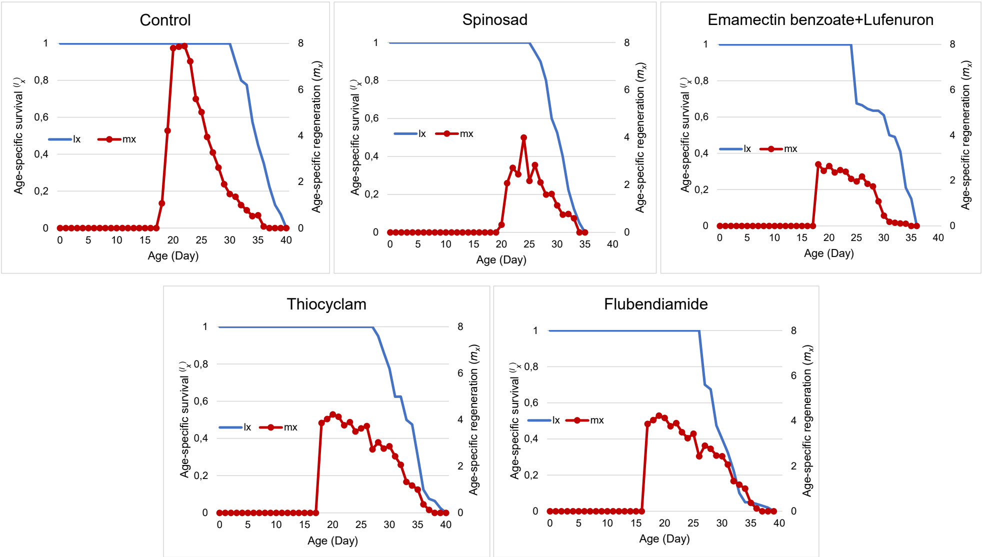

Figure 1. Age-specific survival (l_x) and age-specific regeneration (m_x) curves in *T. absoluta* unexposed (control) and exposed to LC_{30s} of spinosad, emamectin benzoate+lufenuron, thiocyclam and flubendiamide insecticides.

It should be noted, however, that the results obtained from a limited laboratory-scale experiment may not be applicable to real-world conditions. While laboratory investigations can aid in the pesticides selection for use in natural field conditions, it is imperative that future research endeavors are conducted under authentic natural conditions to enhance the generalizability and practical relevance of the findings.

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