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Research Article

Survey of insecticide for control of striped rice stem borer, *Chilo suppressalis*, under field conditions: Efficiency based on a new equation

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Abstract: Increasing insect resistance to the high toxicity of organophosphates and other conventional insecticides highlights the importance of developing and identifying alternative chemicals to successfully manage insect pests, including the striped rice stem borer (SRSB) *Chilo suppressalis* (Walker). SRSB is one of the most serious pests in paddy fields worldwide, especially in northern Iran. The present study was conducted to determine the efficiency of six insecticides viz., diazinon 10 G (Bazodin) 15 kg/ha; fipronil 0.2 G (Regent) 20 kg/ha; chlorantraniliprole 0.4 G (Ferterra) 12.5 kg/ha; thiamethoxam 25 WG (Actara) 0.2 kg/ha; flubendiamide 20 WG (Takumi) 0.9 kg/ha; dinotefuran 20 SG (Starkle) 0.75 kg/ha against SRSB. The experiments were carried out in randomized complete block design with three replications in experimental paddy fields of Rice Research Institute of Iran, Guilan province, 2018 and 2019. Chlorantraniliprole had the lowest dead heart and whitehead percent and the greatest efficiency against SRSB, followed by flubendiamide and dinotefuran. Our results suggested that chlorantraniliprole, flubendiamide, and dinotefuran can replace diazinon and fipronil in paddy fields. Furthermore, a new equation has been proposed for the calculation efficiency of insecticides based on the SRSB damage percent.

Keywords: chlorantraniliprole, flubendiamide, dinotefuran, *Chilo suppressalis*

Introduction

Rice, *Oryza sativa* L. (Poales: Poaceae), is one of the principal staple grain crops worldwide and daily food for over half of the world's population (Mohanty, 2013; Wing *et al*., 2018). Rice is grown in 17 provinces and has a total area of 528,000 ha in Iran (Jalaeian *et al*., 2017; Jalaeian *et al*., 2018). The striped rice stem borer (SRSB), *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae), is considered the most economically prominent and widespread pest in most rice-growing regions around the world, including northern Iran. The pest leads to substantial yield losses and devastates rice fields (Mingjing *et al*., 2003; Zibaee *et al*., 2009; Jalaeian *et al*., 2017; Xu *et al*., 2019). The larva is the damaging life stage of the pest, as it bores into the rice stem and feeds. Feeding damage results in a foliar symptom known as 'dead heart' (dead central leaf) and whitehead at

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the vegetative and reproductive stages, respectively (Pathak, 1968; Rubia *et al*., 1996; Jiang and Cheng, 2003; Lu *et al*., 2015; Lu *et al*., 2017). Dead heart and whitehead prevent sufficient panicle production; one percent dead heart, whitehead, or combination of both symptoms in a field may result in 2.5, 4.0, or 6.4 percent yield loss, respectively (Dale, 1994; Rubia *et al*., 1996; Jiang and Cheng, 2003; Muralidharan and Pasalu, 2006). Currently, chemical control is considered the most effective method of controlling SRSB (Xu *et al*., 2019). However, accurate models to estimate insecticide efficiency according to the extent of SRSB damage have not yet been developed. The most common efficacy equations depend on two factors: first, population homogeneity, and second, survival or mortality rate (%) (Abbott, 1925; Henderson and Tilton, 1955; Püntener, 1981). The most recent studies have used dead heart and whitehead percent to measure insecticidal efficiency against SRSB (Chanu, 2013; Sarao and Kaur, 2014; Seni and Naik, 2017; Singh *et al*., 2017). Therefore, it should be mentioned that the efficiency of insecticides is an essential factor in managing SRSB in paddy fields.

Diazinon and fipronil are primarily used for managing SRSB in paddy fields (Zibaee *et al*., 2008; Yao *et al*., 2017). However, several studies have revealed that diazinon is associated with environmental risks as it negatively impacts several soil microorganisms and non-target insects (Ghassempour *et al*., 2002; Zibaee *et al*., 2008). In addition, excessive use of chemical pesticides in rice fields has led to the evolution of resistance to various conventional insecticides, including organophosphates (Lee *et al*., 1994; Polaszek, 1998; He *et al*., 2008; Gao *et al*., 2013. Furthermore, resistance to diazinon has been observed in four SRSB populations in northern Iran (Zibaee *et al*., 2009). Similarly, fipronil resistance has been reported in some fields within the last ten years, and it is now banned in China because of its toxic effects on shellfish and bees, as well as its persistence in water and soil (Tingle *et al*., 2003; Cao *et al*., 2004; Jiang *et al*., 2005). Therefore, identifying adequate insecticide replacements against SRSB in rice is now critical.

Recently, chlorantraniliprole (Anthranilic diamide) and flubendiamide (Phthalic acid diamide), a novel group of insecticides (Group 28-ryanodine receptor) according to Insecticide Resistance Action Committee (IRAC) mode of action classification, have been extensively applied to control of SRSB. The diamides selectively bind to the ryanodine receptors (RyR), causing an unregulated release of calcium from muscles, leading to feeding cessation, lethargy, paralysis, and eventually death (Cordova *et al*., 2006; Lahm *et al*., 2007; Whalon *et al*., 2008; Sial *et al*., 2011; Yao *et al*., 2017). Chlorantraniliprole has low insecticidal toxicity to beneficial arthropods and mammalian health. Thus it can be used as a replacement for conventional insecticides to control SRSB and as a component in Integrated Pest Management (IPM) protocols (Lahm *et al*., 2005; Lahm *et al*., 2007; Lahm *et al*., 2009; Troczka *et al*., 2012). Previous studies have reported that flubendiamide has a low ecotoxicological profile on non-target arthropods (Larson *et al*., 2012) and is a selective insecticide for the control of lepidopteran pests (Kato *et al*., 2009; Wu *et al*., 2013). Dinotefuran has been used extensively for controlling important agricultural insect pests (Elbert *et al*., 1998) and is known to be harmless against important predators (i.e., natural enemies in rice fields (Ghosh *et al*., 2014). This study was carried out to determine the efficiency of some novel insecticides against SRSB and to develop precise application methods for calculating pesticide efficiency according to the observed levels of damage.

Materials and Methods

Insecticides

A total of six insecticide formulations, listed in Table 1, were used in field experiments. These insecticides represented five classes, including an anthranilic diamide (Chlorantraniliprole, Dupont), a phthalic acid diamide (Flubendiamide, Nihon Nohyaku), a phenylpyrazole (Fipronil, Sadat Mahan Chemical), an organophosphate (Diazinon, Sadat Mahan Chemical), and neonicotinoids (Dinotefuran, Mitsui Chemicals, and Thiamethoxam, Syngenta).

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Table 1 Information of treatments in controlling *Chilo suppressalis* in the experimental rice field.

Treatment	Pesticides	Trade name	Formulation	LD_{50} (mg/kg)	Manufacturer	Dosage used (kg/ha)
T1	Diazinon	Basodin	G 10%	1250	Sadat Mahan chemical	15.00
T2	Fipronil	Regent	G 0.2%	92	Sadat Mahan chemical	20.00
T3	Chlorantraniliprole	Ferterra	G 0.4%	> 5000	Dupont	12.50
T4	Thiamethoxam	Actara	WG 25%	1563	Syngenta	0.20
T5	Flubendiamide	Takumi	WG 20%	> 2000	Nihon Nohyaku	0.90
T6	Dinotefuran	Starkel	SG 20%	2804	Mitsui chemicals	0.75
T7	Control	_	_		_	_

Field experiments

The field experiments were conducted in randomized complete block design in Rice Research Institute of Iran (RRII), Guilan province, during the spring and summer seasons of 2018 and 2019. The experiments had seven treatments and three replications (21 plots). The plot size was 5×4 $m^{2,}$ and the experimental layout consisted of three rows of seven plots. Each row showed a block. Seven treatments were appropriated randomly to seven plots of each block, and the distance between treatments within each block was 1 m. The seed (Hashemi is planted as a common cultivar in northern Iran) was sown in April 2018 and 2019 and then transplanted in the field in May 2018 and 2019. The agronomic practices were conducted as usual during the crop growth period. The recommended doses of insecticides were weighted on balance. The treatments were T1, diazinon 10 G 15 kg/ha; T2, fipronil 0.2 G 20 kg/ha; T3, chlorantraniliprole 0.4 G 12.5 kg/ha; T4, Thiamethoxam 25 WG 0.2 kg/ha; T5, flubendiamide 20 WG 0.9 kg/ha; T6, dinotefuran 20 SG 0.75 kg/ha; T7, untreated control. The treatments were applied 38 and 57 days after transplanting (DAT). The first and second applications were carried out when SRSB damages exceeded 2% DH and 1% WH, respectively. Observations on the incidence of dead hearts and whiteheads were taken on absolute sampling hills per plot from each replication. Then the percentage of dead hearts and the whitehead was worked out according to the following equation (Oñate, 1965):

$$DH\% \text{ or } WH\% = \frac{No.\ of\ affected\ hills}{No.\ of\ hills\ in\ the\ plot} \times \frac{No.\ of\ DH\ or\ WH}{No.\ of\ tillers\ in\ the\ affected\ hills} \times 100$$

However, we developed a new equation for the calculation of pesticides efficiency according to whitehead and dead heart percent, denoted by E:

$$Efficiency\%\ (E) = \left(1 - \frac{DC_b \times DT_{ch}}{DT_b \times DC_{ch}}\right) \times 100$$

C = Control *T* = Treatment

DC_b = Damage % in C before spraying

DC_a = Damage % in C after spraying

DT_b = Damage % in T before spraying

DT_a = Damage % in T after spr

$DC_{ch} = DC_a - DC_b$ $DT_{ch} = DT_a - DT_b$

Statistical analysis

The data recorded from field experiments were analyzed using the analysis of variance (ANOVA) for randomized complete block design (RCBD) by SPSS. The data counts were transformed by Log10, and the percent data was converted to Arcsin root square transformation. The normality test was done with Shapiro-Wilk, and the homogeneity of variance was tested by Levene’s test. Also, differences in insecticide efficiency according to time were analyzed by repeated-measure analysis. Besides, the efficiency of insecticides over two years was statistically analyzed using SAS software and Turkey’s test in a combined analysis of RCBD.

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Results

The results regarding the effect of insecticides against striped stem rice borer damages during 2018 and 2019 in the vegetative stage are summarized in Table 2. The results indicated that at six days after the first application (DAFA) in 2018, symptoms of dead heart varied between 0.11% on chlorantraniliprole to 1.47% on Thiamethoxam as against 2.64% in the untreated control ($F = 132.98$; df = 6,12; $P < 0.001$). In addition, 6 DAFA in 2019, the SRSB infestation was recorded as dead heart varied from 0.15% chlorantraniliprole to 1.49% on fipronil, wherein infestation was 2.88% in control ($F = 258.88$; df = 6,12; $P < 0.001$).

Table 2 Dead heart % and the effect of insecticides in controlling *Chilo suppressalis* before and after the first application in 2018 and 2019.

Pesticides	Dead heart (%)					
	2018			2019		
	1 DBFA	6 DAFA	12 DAFA	1 DBFA	6 DAFA	12 DAFA
Diazinon 10 G	2.22 ± 0.05	1.37 ± 0.05 b	1.24 ± 0.11 b	2.42 ± 0.11	1.43 ± 0.04 b	1.16 ± 0.05 b
Fipronil 0.2 G	2.59 ± 0.46	1.43 ± 0.04 b	1.18 ± 0.05 b	2.35 ± 0.26	1.49 ± 0.03 b	1.19 ± 0.06 b
Chlorantraniliprole 0.4 G	2.21 ± 0.06	0.11 ± 0.03 d	0.05 ± 0.02 d	2.29 ± 0.07	0.15 ± 0.01 d	0.12 ± 0.01 c
Thiamethoxam 25 WG	2.67 ± 0.11	1.47 ± 0.15 b	0.81 ± 0.13 b	2.51 ± 0.10	1.45 ± 0.10 b	1.17 ± 0.04 b
Flubendiamide 20 WG	2.23 ± 0.08	0.18 ± 0.04 cd	0.10 ± 0.03 cd	2.42 ± 0.08	0.14 ± 0.04 d	0.12 ± 0.04 c
Dinotefuran 20 SG	2.81 ± 0.19	0.34 ± 0.06 c	0.24 ± 0.08 c	2.41 ± 0.15	0.33 ± 0.01 c	0.19 ± 0.01 c
Control	2.13 ± 0.08	2.64 ± 0.11 a	3.17 ± 0.09 a	2.52 ± 0.09	2.88 ± 0.13 a	3.12 ± 0.05 a
Total mean	2.41	1.08	0.97	2.42	1.12	1.01
F	2.02	132.98	109.56	0.39	258.88	420.42
df	6,12	6,12	6,12	6,12	6,12	6,12
P-value	0.131	< 0.001	< 0.001	0.870	< 0.001	< 0.001

Means followed by the same letters are not significantly different (Tukey's test, $P \leq 0.05$).
DBFA = Days Before First Application.
DAFA = Days After First Application.

At 12 DAFT in 2018 and 2019, there was a significant difference in treatments ($F = 109.56$; df = 6,12; $P < 0.001$, $F = 420.42$; df = 6,12; $P < 0.001$). According to the results, the dead heart percentage ranged between 0.05 to 1.24% and 0.12 to 1.19 in treated plots, respectively. While the damage was evaluated to be 3.17 and 3.12% in the control plot at 12 DAFT in 2018 and 2019, respectively.

Damage symptoms of the whitehead (%) during spring and summer 2018 and 2019 were presented in Table 3. As revealed from Table 3, at 6 days after second application (DASA) in 2018 and 2019, whitehead percentage significantly varied from 0.08% to 1.90% and 0.10% to 2.02%, respectively ($F = 169.05$; df = 6,12; $P < 0.001$, $F = 164.61$; df = 6,12; $P < 0.001$). It was evaluated that the plots treated with chlorantraniliprole and flubendiamide had the lowest percentage of the whitehead during the rice reproductive stage. A similar trend was observed at 12 DASA in 2018 ($F = 228.38$; df = 6,12; $P < 0.001$), wherein the percentage of the whitehead was lowest for chlorantraniliprole, followed by flubendiamide. Furthermore, at 12 DASA in 2019, the lowest percentage of the whitehead was evaluated at chlorantraniliprole followed by flubendiamide and dinotefuran ($F = 59.79$; df = 6,12; $P < 0.001$). It should be noted that the highest percentage of the whitehead (2.23 and 2.86%) was recorded for control treatment at 12 DASA in 2018 and 2019, respectively. The efficiency of insecticides for the control of SRSB damages during 2018 and 2019 was shown in Tables 4 and 5, respectively. Based on the results, the two insecticides with relatively

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higher efficiencies in the rice reproductive stage were chlorantraniliprole and flubendiamide. The results showed that chlorantraniliprole, followed by flubendiamide and dinotefuran, had higher efficiency in controlling the dead heart.

The differences between pesticide efficiency according to repeated measures analysis are highlighted in Table 6. According to the results, chlorantraniliprole, as well as flubendiamide, had the highest efficiency. Moreover, dinotefuran had intermediate efficiency in the control of SRSB.

According to the results of a combined analysis of RCBD over two years, the efficiency of insecticides in controlling dead hearts had a significant difference (F = 97; df = 1,27; P < 0.001). However, there was no significant difference between insecticides in controlling whitehead (F = 0.02; df = 1,27; P = 0.883).

Table 3 Whitehead % and the effect of insecticides in controlling *Chilo suppressalis* before and after second application in 2018 and 2019.

Pesticides	Whitehead (%)					
	2018			2019		
	1 DBSA	6 DASA	12 DASA	1 DBSA	6 DASA	12 DASA
Diazinon 10 G	1.22 ± 0.03 bc	0.93 ± 0.07 b	0.76 ± 0.09 b	1.29 ± 0.07 b	1.03 ± 0.06 b	0.88 ± 0.03 b
Fipronil 0.2 G	1.26 ± 0.07 abc	0.98 ± 0.08 b	0.72 ± 0.04 b	1.34 ± 0.05 b	0.93 ± 0.08 b	0.85 ± 0.04 b
Chlorantraniliprole 0.4 G	1.02 ± 0.02 c	0.08 ± 0.01 d	0.03 ± 0.00 d	1.23 ± 0.05 b	0.10 ± 0.00 d	0.08 ± 0.01 c
Thiamethoxam 25 WG	1.06 ± 0.06 bc	0.97 ± 0.02 b	0.93 ± 0.04 b	1.15 ± 0.11 b	0.88 ± 0.06 b	0.79 ± 0.02 b
Flubendiamide 20 WG	1.28 ± 0.02 ab	0.18 ± 0.04 cd	0.05 ± 0.02 d	1.38 ± 0.17 b	0.14 ± 0.02 d	0.11 ± 0.01 c
Dinotefuran 20 SG	1.05 ± 0.02 bc	0.27 ± 0.03 c	0.17 ± 0.02 c	1.19 ± 0.04 b	0.29 ± 0.04 c	0.17 ± 0.04 c
Control	1.50 ± 0.11 a	1.90 ± 0.02 a	2.23 ± 0.09 a	1.81 ± 0.04 a	2.02 ± 0.10 a	2.86 ± 0.50 a
Total mean	1.20	0.76	0.70	1.34	0.77	0.82
F	9.73	169.05	228.38	6.24	164.61	59.79
df	6,12	6,12	6,12	6,12	6,12	6,12
P-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means followed by the same letters are not significantly different (Tukey's test, P ≤ 0.05).
DBSA = Days Before Second Application
DASA = Days After Second Application

Table 4 The efficiency of insecticides for *Chilo suppressalis* control after first and second application based on dead heart and whitehead in 2018.

Pesticides	Dead heart decrease (%)		Whitehead decrease (%)	
	6 DAFT	12 DAFT	6 DAST	12 DAST
Diazinon 10 G	50.44 ± 0.61 b	62.39 ± 3.10 c	39.68 ± 6.02 c	57.58 ± 6.16 c
Fipronil 0.2 G	52.83 ± 7.91 b	68.16 ± 3.79 bc	39.27 ± 3.78 c	61.87 ± 0.60 c
Chlorantraniliprole 0.4 G	95.90 ± 0.89 a	98.52 ± 0.52 a	93.97 ± 0.82 a	98.32 ± 0.13 a
Thiamethoxam 25 WG	55.09 ± 5.61 b	79.60 ± 3.50 b	27.37 ± 2.50 c	40.62 ± 2.38 d
Flubendiamide 20 WG	93.43 ± 1.61 a	96.97 ± 1.03 a	88.99 ± 2.38 ab	97.51 ± 0.86 a
Dinotefuran 20 SG	90.29 ± 1.12 a	94.31 ± 1.48 a	79.94 ± 2.17 b	88.90 ± 1.60 b
F	39.12	45.56	73.74	99.25
df	5,10	5,10	5,10	5,10
P-value	< 0.001	< 0.001	< 0.001	< 0.001

Means followed by the same letters are not significantly different (Tukey's test, P ≤ 0.05).
DAFA = Days After First Application.
DASA = Days After Second Application.

Table 5 The efficiency of insecticides for *Chilo suppressalis* control after first and second application based on D.H and W.H percent in 2019.

Pesticides	Dead heart control (%)		Whitehead control (%)	
	6 DAFT	12 DAFT	6 DAST	12 DAST
Diazinon 10 G	47.67 ± 3.83 b	60.92 ± 1.76 b	28.19 ± 2.81 c	56.45 ± 2.16 c
Fipronil 0.2 G	43.10 ± 5.65 b	58.37 ± 2.54 b	37.56 ± 4.28 c	59.78 ± 1.53 c
Chlorantraniliprole 0.4 G	94.27 ± 0.57 a	95.83 ± 0.40a	92.47 ± 0.33 a	95.81 ± 0.10 a
Thiamethoxam 25 WG	49.14 ± 3.87 b	62.11 ± 2.34 b	31.87 ± 2.53 c	56.63 ± 2.52 c
Flubendiamide 20 WG	94.66 ± 1.74 a	96.02 ± 1.44 a	90.90 ± 0.29 a	94.84 ± 0.13 ab
Dinotefuran 20 SG	87.97 ± 0.49 a	93.49 ± 0.66 a	77.75 ± 4.00 b	90.73 ± 2.40 b
F	70.35	123.56	116.26	130.40
df	5,10	5,10	5,10	5,10
P-value	< 0.001	< 0.001	< 0.001	< 0.001

Means followed by the same letters are not significantly different (Tukey's test, P ≤ 0.05).
DAFA = Days After First Application.
DASA = Days After Second Application.

Table 6 Efficiency of insecticides on *Chilo suppressalis* by repeated-measures analysis of variance in 2018 and 2019.

Pesticides	Efficiency (%)	
	2018	2019
Diazinon 10 G	52.52 ± 3.24 c	48.31 ± 3.96 c
Fipronil 0.2 G	55.53 ± 3.86 c	49.70 ± 3.32 c
Chlorantraniliprole 0.4 G	96.68 ± 0.63 a	94.60 ± 0.45 a
Thiamethoxam 25 WG	50.67 ± 6.05 c	49.94 ± 3.65 c
Flubendiamide 20 WG	94.22 ± 1.23 a	94.10 ± 0.76 a
Dinotefuran 20 SG	88.36 ± 1.73 b	87.49 ± 2.06 b
Total mean	73.00	70.69
F (time, time × treatment)	55.43, 4.55	66.71, 3.21
df (time, time × treatment)	3,15	3,15
P-value	< 0.001	< 0.001

Means followed by the same letters are not significantly different (Tukey's test, P ≤ 0.05).

Discussion

Chilo suppressalis is one of the most important rice pests, and significant losses occur annually from its outbreak globally. In this study, an equation for pesticide efficiency is proposed. It should be noted that counting larvae in intensive infestation would be difficult, and SRSB incidence in a paddy field is commonly evaluated by percentages of its typical damages, dead heart, and whitehead (Oñate, 1965). Classical equations such as Abbott (Abbott, 1925) and Henderson-Tilton (Henderson and Tilton, 1955) are used when the population or infestation is uniform and non-uniform, respectively. Also, both equations calculate efficacy based on the number of live populations. We use the current equation because 1) It determines efficiency by simple mathematical functions, 2) Evaluating the efficiency based on damages in rice fields, and 3) Considering the damage percent in treatments and control before and after spraying. To calculate the efficiency of pesticides, it is sufficient to calculate the percentage of dead hearts or whiteheads before and after spraying. This formula prevents overestimating or underestimating in calculations.

There are two reasons that the chemical control of this pest becomes difficult: 1) increased remarkable resistance to various conventional insecticides and also, and 2) larvae bore into the rice stem and feed inside (Zibaee *et al*., 2009; He *et al*., 2012; Su *et al*., 2014; Lu *et al*., 2017). Besides, the efficient control of SRSB mainly relies on the use of insecticides, and also, resistance to conventional insecticides is a severe issue for pest outbreaks (Zhu *et al*., 1987; Li *et al*., 2001; Zibaee *et al*., 2009; Hu *et al*., 2010; Su *et al*., 2014; Li *et al*., 2015). For instance, Abamectin efficiency has been reduced because of long-term improper use in rice fields (Yao *et al*., 2017). Furthermore, considerable resistance to chlorpyrifos and triazophos has been reported in SRSB (Yao *et al*., 2017). The present study evaluated the efficiency of different insecticides according to the new equation against SRSB.

Our results show that the novel anthranilic diamide insecticide chlorantraniliprole 0.4 G with an effective efficiency, followed by flubendiamide 20 WG and dinotefuran 20 SG provided the highest level of control among treatments. The insecticides mentioned above significantly reduced SRSB damages and could be an appropriate substitute for control of the resistant population of SRSB. The current results were similar to other research. Zhang *et al*. (2009) indicated that the efficiency of chlorantraniliprole for controlling SRSB was more than 90% even 36 days after application. In addition, Suri and Brar (2013) revealed the efficacy of chlorantraniliprole 0.4 G against yellow stem borer and demonstrated the effectiveness of this insecticide in managing rice stem borer. Sarao and Kaur (2014) declared that the novel insecticide chlorantraniliprole 0.4 G effectively controlled stem borer damage. Moreover, Rahaman and Stout (2019) reported that chlorantraniliprole 0.4 G had better efficiency than methoxyfenozide 24 SC, dinotefuran 20 SG and quinalphos 25 EC against yellow stem borer. The commercialization of flubendiamide prepared as a suitable insecticide for the control of SRSB and is effective against a range of insect pests of diverse. It had a low unwanted impact on natural enemies compared to broad-spectrum insecticides (Kato *et al*., 2009). Prasad *et al*. (2014) declared that flubendiamide could control rice yellow stem borer damages. Similar results were found for dinotefuran, which effectively controlled the moth and 3rd larval instar of *Tuta absoluta* (Meyrick) (Radwan and Taha, 2012).

More recently, the resistance of SRSB to chlorantraniliprole has been reported in eight field populations in China (Lu *et al*., 2017). However, chlorantraniliprole is a novel insecticide in Iran, and, to date, no resistance has been reported from field populations in Iran.

One of the most critical control methods in integrated pest management (IPM) programs is biological control by natural enemies such as predators and parasitoids. In contrast, most insecticides currently applied in crop protection indicate high toxicity to non-target organisms (Wu *et al*., 2007). Huang *et al*. (2011) proved that acute and stomach toxicity of chlorantraniliprole to *Cotesia chilonis* Munakata (Hymenoptera: Braconidae) (Major parasitoid of SRSB) was very low in comparison with fipronil (More than 2800 fold differences in LC_{50}). Also, chlorantraniliprole is harmless for birds, shellfish, mammals, and beneficial arthropods consisting of bees and spiders (Lahm *et al*., 2007; Lahm *et al*., 2009). Tohnishi *et al*. (2005) indicated that flubendiamide is safe for natural enemies and used in IPM programs. Ghosh *et al*. (2014) investigated that dinotefuran 20 SG would be safe for adult and nymph *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae).

The current study demonstrated that thiamethoxam 25 WG significantly reduced the rice striped stem borer damage compared to control. The previous studies showed that thiamethoxam had toxicity to *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) (Williams and Price, 2004) and *Trichogramma platneri* Nagarkatti (Brunner *et al*., 2001).

In conclusion, chlorantraniliprole 0.4 G, flubendiamide 20 WG, and dinotefuran 20 SG could be used as effective alternative insecticides in IPM programs in the rice field of

Iran. Moreover, our evaluated equation would help calculate the efficiency of rice fields. Further experimental investigations are needed to assess the efficiency of insecticides mentioned above on different rice varieties. Additional studies are required to determine sublethal effects on various stages of SRSB and their natural enemies.

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بررسی تعدادی حشره‌کش برای کنترل ساقه‌خوار نواری برنج *Chilo suppressalis* در شرایط مزرعه: ارزیابی کارایی براساس یک فرمول جدید

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چکیده: افزایش مقاومت حشرات به آفت‌کش‌ها و هم‌چنین سمّیت بالای آفت‌کش‌های ارگانوفسفره و سایر حشره‌کش‌های رایج، نشان‌دهنده اهمیت بالای توسعه و شناسایی آفت‌کش‌های جایگزین برای مدیریت موفقیت‌آمیز آفات ازجمله کرم ساقه‌خوار نواری برنج *Chilo suppressalis* (Walker) است. کرم ساقه‌خوار نواری برنج از مهم‌ترین آفات برنج در دنیا و آفت کلیدی برنج در بیشتر مناطق ایران به‌ویژه شمال کشور می‌باشد. در این پژوهش کارآیی آفت‌کش‌های دیازینون G 10% (بازودین) ۱۵ kg/ha، فیپرونیل G 0.2% (ریجنت) ۲۰ kg/ha، کلرانترانیلیپرول G 0.4% (فرترا) ۱۲/۵ kg/ha، تیامتوکسام WG 25% (آکتارا) ۰/۲ kg/ha، فلوبندیامید WG 20% (تاکومی) ۰/۹ kg/ha و دینوتفوران G 20% (استارکل) ۰/۷۵ kg/ha علیه ساقه‌خوار نواری برنج در شرایط مزرعه‌ای، در قالب طرح بلوک‌های کامل تصادفی با ۳ تکرار در مؤسسه تحقیقات برنج کشور (رشت) در سال‌های زراعی ۱۳۹۶-۱۳۹۷ و ۱۳۹۷-۱۳۹۸ مورد ارزیابی قرار گرفت. مؤثرترین تیمار، آفت‌کش کلرانترانیلیپرول و پس از آن آفت‌کش‌های فلوبندیامید و دینوتفوران بودند که پایین‌ترین درصد مرگ جوانه مرکزی و سفید شدن خوشه و بالاترین درصد کارآیی را داشتند و می‌توانند جایگزین خوبی برای حشره‌کش‌های دیازینون و فیپرونیل باشند. افزون بر این، فرمول جدیدی برای محاسبه کارایی حشره‌کش‌ها براساس درصد خسارت کرم ساقه‌خوار نواری برنج ارایه شده است.

واژگان کلیدی: کلرانترانیلیپرول، فلوبندیامید، دینوتفوران، کرم ساقه‌خوار برنج

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