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INSECTICIDE RESISTANCE MANAGEMENT FOR FALL ARMYWORM IN MAIZE FIELDS OF ISRAEL

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ABSTRACT

Fall Armyworm (*Spodoptera frugiperda*) (FAW) is endemic to tropical and subtropical regions of North and South America. FAW larvae, if not well managed can cause significant yield losses to various important crops, such as maize, rice and cotton. In Israel, populations of FAW have been found since 2018 damaging many maize fields. Management of FAW relies mainly on the use of insecticides; however, this pest has evolved high resistance levels to many insecticides, worldwide. To prevent or delay the development of insecticide resistance, resistance management strategy should be employed to decrease FAW exposure to insecticides. Our study is focusing on resistance management of FAW and field resistance monitoring to main control agents along with the use of biorational-selective insecticides and other non-chemical methods. The objective of the current study was to establish a baseline susceptibility of FAW larvae to insecticides such as diamides, IGRs and *Bt.* We rear a reference population, without exposure to any pesticide, on artificial diet under standard controlled room conditions. To date, we have assayed various recommended insecticides against third instars of FAW. During May 2022, we have collected larvae of FAW from maize fields, located in the eastern warm valley of Israel and they were tested for their susceptibility to various insecticides. We intend to assay late-season FAW populations as well. An outcome of this study is to form an IPM-IRM strategy that will have the ability to decrease FAW exposure to insecticides and to increase the use of other environmentally-friendly pest control practices.

Keywords: *Spodoptera frugiperda, Maize, Resistance management, Biorational-selective insecticides, IPM.*

INTRODUCTION

Fall Armyworm (*Spodoptera frugiperda*) (FAW) is endemic to tropical and subtropical regions of North and South America. However, recently it has rapidly invaded many regions worldwide due to its outstanding migration and dispersal ability (Johnson, 1987). In 2016, it was first appeared in Africa and then in India, Thailand, Australia and China; in addition, it is likely that this pest might migrate into southern Europe either from North Africa or Middle East, or via commercial trade. Currently, this pest is presented in many countries of the Old and New World (FAO, 2022). FAW is an economic pest that attacks maize and other important crops such as rice, sorghum, sugarcane, vegetable crops and cotton; and its host range includes more than 100 plant species (Pogue, 2002). In Israel, populations of FAW have been found since 2018 damaging many maize fields.

Management of FAW relies mainly on the use of insecticides; however, this pest has evolved high resistance levels to many insecticides (including the new diamide group), worldwide (Bolzan et al. 2019; Mota-Sanchez and Wise, 2021); and also, it has developed moderate resistance to *Bt*-maize (Omoto *et al*., 2016). To prevent or delay the development of insecticide resistance, resistance management strategy should be employed to decrease FAW exposure to insecticides (IRAC, 2021). Hence, it is important to evaluate the susceptibility of insecticides against this pest. In this study, we have assayed various new insecticides against a susceptible strain of FAW under standard controlled room conditions; at second step, we intend to monitor FAW resistance and insecticide susceptibility in maize fields of Israel in order to form a sustainable resistance-management strategy.

MATERIALS AND METHODS

Insects

A field strain of *S. frugiperda* was collected in June 2021 from maize fields near Negba (located in the northern Negev desert, near the city of Ashkelon) and was reared, without exposure to any pesticide, on mixture of maize leaves and premixed diet (Ward's Stonefly Heliothis Diet, USA) under standard room conditions of 27°C, 55% RH and 14 h photoperiod. Later on, we developed another diet that is based on polenta (boiled and ground cornmeal) plus some additives; this diet was comparable to the premix.

Table 1. Insecticides used for the bioassays against FAW

Brand name and formulation	**Active ingredients**	**type**	**Resistance group, IRAC**	**Producer**
Sparta Super 60 SC	Spinetoram	Contact and stomach	5	Dow AgroSciences
Uphold (Armada) 360SC	Spinetoram (60) + methoxyfenozide (300)	Contact and stomach	5+18	Dow AgroSciences
Coragen 200 SC	Chlorantraniliprole	Contact and stomach	28	FMC
Rimon 100 EC	Novaluron	Insect growth regulator	15	Adama
Avaunt 160	indoxacarb	Contact and	22	FMC

EC		stomach		
Dipel DF	*Bt* var kurstaki	Bio-insecticide	11	Valent BioSciences
Probit DF	*Bt* var. kurstaki and var. aizawai	Bio-insecticide	11	Certis

Bioassays

Leaves of maize were dipped in aqueous concentrations of tested compounds (Table 1) or in water, as control. After 15 seconds of dipping, the maize leaves were allowed to air dry for 2 h. Subsequently, *S. frugiperda* larvae (third instar, 8-10 mm), reared under controlled room conditions were put inside Petri dishes on the treated maize leaves; in addition, filter papers also placed into the dishes (to avoid excess moisture). The experiments were done with 10 larvae for each concentration and repeated at least three times, on separate days. Mortality of the larvae in comparison with the control was determined five days after exposure to the insecticides. To obtain a concentration- mortality line, at least four concentrations were used for most of the bioassays. LC values were estimated by probit analysis (POLO, 1987). Control mortality was corrected using Abbott's (1925) formula.

Maize field collections

To detect insecticide resistance, we have collected field populations of FAW in May-June 2022. Field populations of FAW larvae were collected from commercial maize fields located in the eastern valley of Israel, and they transferred on the same day to the lab location in SW Israel. One generation was reared under standard controlled room conditions and thereafter, similar bioassays were conducted as mentioned above. Resistance ratios (RR) were calculated by dividing the LC_{50}- and LC_{90}-values of the respective field populations by LCs of the reference strain.

RESULTS AND DISCUSSION

Table 2 and figure 1 present the effect of the various recommended insecticides on third instar *S. frugiperda*. Accordingly, the insecticides spinetoram, chlorantraniliprole, novaluron and uphold® exhibited quite similar effectiveness against susceptible larvae; indoxacarb was less effective. To control third instars of FAW with *Bt* formulations, we had to use higher concentrations compared with the other compounds, mentioned above. Other studies on susceptible populations reported similar results (Tay *et al*., 2022). Up to now, we did not detect significant insecticide resistance in the early-season field collections.

Bt-maize technology is an efficient control option for FAW; however, so far, Israel is GMO (Genetically Modified Organism)-Free. In addition, this technology would not carry sustainable options for long time; hence, *Bt*-maize should be combined with effective insecticide programs (IRAC, 2021).

Prior to developing an IRM (Insecticide Resistance Management) strategy of FAW, we have to establish baselines susceptibility of a reference ("susceptible") and field strains. After defining the laboratory baseline (Table 2, Fig. 1), we intend to collect maize-field populations in early- and late- growing seasons, in accordance with the Cotton IPM-IRM strategy that has been implemented in Israel, mainly, as countermeasures for delaying the evolution of resistance in the whitefly *Bemisia tabaci* (Horowitz and Ishaaya 1992; Horowitz *et al*., 2020).

Table 2. Comparative toxicity of various compounds on *Spodoptera frugiperda* (L3)

Compounds	n	**Slope ±SEM**	**LC_{50} mg a.i./liter (F.L.)**	**LC_{90} mg a.i./liter (F.L.)**
Spinetoram	160	1.44±0.11	0.05 (0.03-0.07) a*	0.35 (0.19-0.97) a
Chlorantraniliprole	180	0.86±0.07	0.03 (0.01-0.07) a	1.03 (0.37-6.28) abc
Novaluron	195	0.79±0.06	0.06 (0.03-0.12) ab	2.51 (0.80-20.7) abc
Uphold**	165	1.29±0.11	0.11 (0.09-0.14) b	1.08 (0.75-1.75) ab
Indoxacarb	160	1.19±0.09	0.38 (0.29-0.48) c	4.46 (3.00-7.46) bc
Bt- formulations***			in gr./0.1 liter (F.L.)	in gr./0.1 liter (F.L.)
Dipel DF	165	3.48±0.29	0.21 (0.14-0.30)	0.49 (0.33-1.29)
Probit DF	160	2.60±0.29	0.25 (0.21-0.29)	0.78 (0.65-1.01)

Mortality curves were constructed from 4-5 concentrations each and untreated control. Each concentration was conducted with 3-4 replicates. LC values were determined according to probit regression, using POLO-PC analysis procedure. * Failure of 95% FL (Fiducial Limits) to overlap at a particular lethal concentration indicated a significant difference. **Uphold (Armada) 360 SC is a mixture of Spinetoram (60g/L)+methoxyfenozide (300g/L);
*** Concentrations of *Bt*- formulations are in percentages.

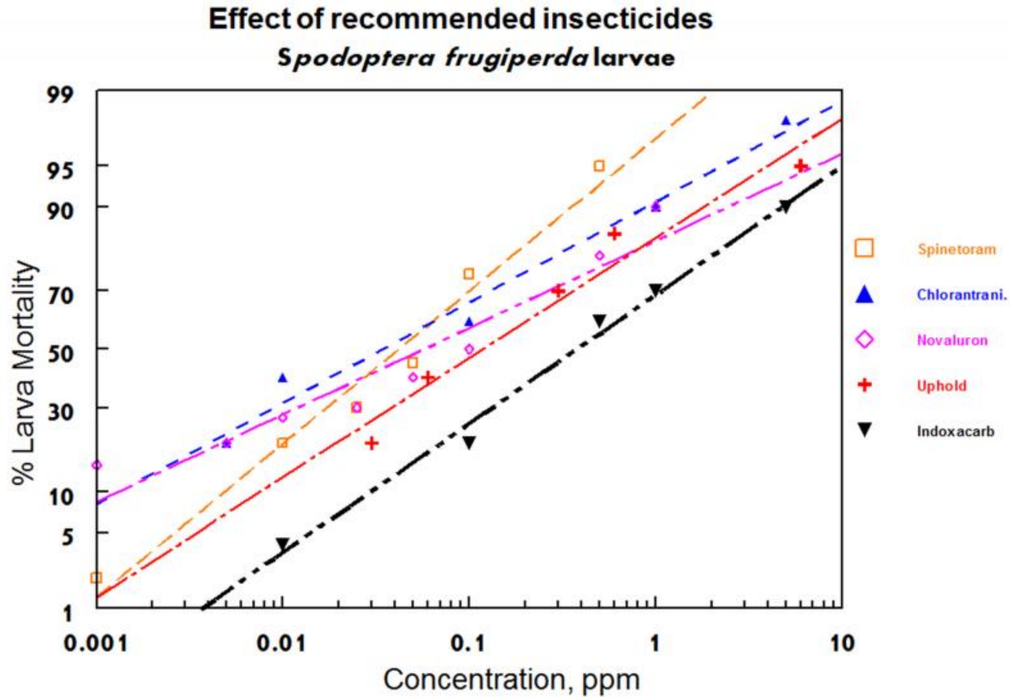

Figure 1. Log dose-response curve (on a probit scale) of the effect of various insecticides on *Spodoptera frugiperda* 3rd instars (reference strain)

IRM strategies are based on the assumption that the ratio between resistant and susceptible genotypes can be manipulated by various factors such as application frequencies, insecticide rotation with different modes of action and exposure of just one pest generation to the insecticide. These factors may help in diluting the resistant genotype by immigration of susceptible individuals from untreated fields, by reducing the fitness of the resistant strain in the absence of insecticides or both (Georghiou and Taylor 1986; Sawicki and Denholm 1987; Horowitz and Ishaaya 1992). Moreover, it is very important to enhance nonchemical control methods using IPM practices (e.g., biological control, crop plant resistance and pheromone mating- disruption techniques). The integration of these methods would contribute to improving the combat against FAW, and thus, helping to form sustainable managements in the future.

CONCLUSION

Our study is focusing on resistance management for FAW and field resistance monitoring to various recommended control agents along with the use of biorational-selective insecticides and other non-chemical methods. The integration of these methods would contribute to improving the combat against FAW, and thus, helping to form sustainable management in the future.

Prior to developing an IRM strategy for FAW, we ought to establish baselines susceptibility in a reference and field strains. After we have defined the laboratory susceptible baseline, we intend to collect maize-field populations in early- and late-growing seasons, in accordance with the cotton IPM-IRM strategy that has been implemented in Israel.

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