Biological and chemical protection of melon crops against *Myiopardalis pardalina* Bigot

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Abstract

The aim of this project was to explore the cycle of the pest's development and to evaluate the efficacy of insecticides from the pyrethroid, organophosphate and neonicotinoids groups in controlling *Myiopardalis pardalina* Bigot in melon plantations under the conditions of Southeast Asia. Three kinds of traps were tested (pheromone, stick and feeding) for monitoring quarantine flies. The application of thiamethoxam/cyhalothrin (A) and chlorpyrifos/cypermethrin (B) in variant A, B, A in dose 0,2; 0,5; 0,2 l/ha was more effective than threefold applications of chlorpyrifos/cypermethrin in variant B, B, B in dose 0,7; 0,7; 0,7 l/ha during the growing season. Among all traps used, the lowest degree of melon damage (8.8%) was noted only for the variant with 10 pheromone traps per hectare, where the crop yield of melon was slightly higher than in the case of the other traps (16.63 t/ha). The combination A, B, A improved the quality of fruit, decreased melon infestation with ovipositor marks and significantly reduced fly population up to 14 days. Only chlorpyrifos residues were determined in melon after harvesting at an acceptable level.

Keywords *Myiopardalis pardalina* Bigot · *Cucurbitaceae* · Melon crops · Chemical control · Southeast Asia

Introduction

Melon is a very important fruit in the human diet. It is usually consumed fresh or used in juice, desserts, fruit salads, or custards. It contains a high amount of vitamins (niacin, vitamin A, B6, C), minerals (potassium) and antioxidants. The fruit has many medical qualities and is used as a tonic, laxative and diuretic. The term “melon” encompasses many diverse plants belonging to the *Cucurbitaceae* family.

In Kazakhstan, *Cucurbitaceae* are the leading crops grown on an area of over 80 thousand ha with (70%) concentrated in the south parts of Kazakhstan. Most melons are exported to Europe and Russia. Due to the *Cucurbitaceae* economic importance and sensitivity to diseases and pests, scientists are trying to create new varieties of melon which are resistant to diseases and pests under the conditions in south Kazakhstan.

The melon belongs to crops susceptible to attacks of pests. However, the number of insecticides registered for protection of melon grown under irrigated conditions is limited in this area; therefore, the effective protection against insects is a challenge (Karimi and Darsouei 2014). Furthermore, the increasing area of melon farms based on simplified agricultural techniques (e.g., monocultures, systems without plowing, etc.) and climate change cause this crop to be exposed to harmful organisms (Stonehouse 2003).

The Baluchistan melon fly *Myiopardalis pardalina* Bigot, also called the Russian melon fly (Diptera: Tephritidae), is relatively new organism occurring in *Cucurbitaceae* crops in Kazakhstan. This pest is widely distributed in temperate, tropical and sub-tropical regions of the world including southeast Asia, India, China, Japan and Nepal, the Middle

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East, Africa and several Pacific islands (Dhillon et al. 2005). This pest can attack flowers as well as fruit and will additionally attack even its stem and root. Heavy attacks may occur even before the fruit has set, with eggs laid into unopened male and female flowers, and larvae may even develop in the stems and leaf stalks (Stonehouse 2003). The melon fly colonizes fruit plantations throughout the whole growing season, increasing melon sensitivity to the invasion of pathogens.

In Kazakhstan, the first melon fly centers were found in the Kyzylorda region in 2004. Now, *M. pardalina* Bigot has infested almost 50% of the farms in Kazalinsk, Karmakshy, Zhalagash, Syrdarya, Shieli, Zhanakorgan. In the Kyzylorda region, due to the melon fly infestations, crop losses range from 10 to 25%, sometimes up to 100%.

Over the last 4 years, the situation with the spread of melon flies has become more dangerous, and the problem with this pest is more significant than ever before. A quarantine system has been introduced in some farms. Despite this measure, the area of damaged melons is increasing annually (Pašková 2007). Due to the growing number of melon fly infestations and huge production losses, finding an effective method of protection is a priority. Attention is being paid to monitoring and using the chemical method, as an element of integrated pest management strategy, because there are no reports on the successful use of bio-control agents against the melon fruit fly (Nishida 1955), and there are limited reports concerning new insecticides (Singh et al. 2000; Waseem et al. 2009; Matyjaszczyk 2018).

This article presents the first comprehensive research on the occurrence of *M. pardalina* Bigot in Kazakhstan. The aim of this project was to explore the cycle of the pest's development and evaluate the efficacy of combinations of insecticides from the pyrethroid/organophosphate and pyrethroid/neonicotinoid groups in controlling *M. pardalina* Bigot in melon plantations under the conditions of Southeast Asia. An additional aim was to estimate the effectiveness of traps for the melon fly monitoring and study the residue problems associated with the chemical protection.

Materials and methods

Field experiment

During 2015–2016, in a field located in the Kyzylorda region, Kazakhstan (53°10'N, 63°35'E), trials were carried out under natural conditions. The experiment was set in four replicates by randomized blocks. Certified seed (Guliabin, local sort) was sown (May 4th 2015 and May 17th 2016) on separated (by 1 m buffer zone) plots with an area of 50 m² (5 × 10 m) for each combination, and the control plot was separated. Harvest was conducted at the stage of full maturity: in September 5th 2015 and September 30th 2016.

Chemical treatments

Chemical protection was applied using an air-assisted sprayer employing a petrol engine to drive the pump and centrifugal fan with four nozzles at a liquid flow of 300 l/ha. Two commercial mixture insecticides were thiamethoxam/cyhalothrin—A and chlorpyrifos/cypermethrin—B at doses 0.25, 0.5 and 0.7 l/ha.

The first chemical application (A1, A2, B1, B2) at the flowering stage of melon (BBCH 55–56) was performed on July 10th 2015 and July 15th 2016, (Table 1). The second application was done at an interval of 2 weeks (BBCH 71–79) using chlorpyrifos/cypermethrin (B1, B2) only for experimental plots, where A2 and B2 were applied early. The third treatment (A2, B2) was performed at peak population of the second fly generation (BBCH 82–87). The full combined chemical program was for the first combination: A2, B1, A2 and B2, B2, B2 for second (Table 2).

Climate condition

The climate in Kyzylorda is called a desert climate. There is virtually no rainfall during the year in Kyzylorda. The average temperature is 10.2 °C, and about 151 mm of precipitation falls annually (Fig. 1).

Table 1 Effectiveness of two mixture insecticides applied in two doses (A1, A2, B1, B2) in controlling *Myiopardalis pardalina* Bigot melon fly (mean from 2015 to 2016, BBCH 54–58)

Variant	Active substance	Dose (l/ha)	Effectiveness (%) Day after application			
			1st	3rd	7th	14en
A1	Thiamethoxam/cyhalothrin	0.20	75.0	87.9	95.5	83.5
A2	Thiamethoxam/cyhalothrin	0.25	83.3	93.9	95.5	89.0
B1	Chlorpyrifos/cypermethrin	0.5	66.7	81.8	86.4	78.0
B2	Chlorpyrifos/cypermethrin	0.7	70.8	83.7	88.7	81.9

Means in columns indicated by the same letter do not differ at $p < 0.05$ level of significance in Tukey's test

Table 2 Characteristic of chemical treatments (A1, B1, A1 and B2, B2, B2) against *Myiopardalis pardalina* Bigot melon fly

Time of application	BBCH		Active substance concentration (g/l)	Dose (l/ha)		Active substance	Dose (l/ha)
End of flowering phase	54–58	A1	Thiamethoxam (141)	0.25	B2	Chlorpyrifos (500)	0.70
			Lambda-cyhalothrin (106)			Cypermethrin (50)	
Start of fruiting phase	71–79	B1	Chlorpyrifos (500)	0.50	B2	Chlorpyrifos (500)	0.70
			Cypermethrin (50)			Cypermethrin (50)	
At max. appearance of 2nd genrat. fly	82–87	A1	Thiamethoxam (141)	0.25	B2	Chlorpyrifos (500)	0.70
			Lambda-cyhalothrin (106)			Cypermethrin (50)

Fig. 1 *Myiopardalis pardalina* Bigot fly dynamics in melon plantations and climate conditions in Kyzylorda, south Kazakhstan (2015–2016)

Characteristic of soil

The soil of the experimental plots was classified as loamy sand with pH in the range 7.7–8.4, soil density 1.1–1.2 g/ml, with high carbonate content (10–24%) and a relatively low value of absorption capacity. The soil is rich in K_2O (350–420 mg/kg) and P_2O_5 (18–25 mg/kg) and poor in NO_3^- (14–17 mg/kg), with low humus content (0.5–3.4%). Irrigation was carried out depending on climate conditions 4–6 times in the amount of 500–600 m³/ha. N, P, K fertilizer was applied at 180:90:90 kg/ha 1 week before seedling germination, and 90 kg/ha N fertilizer was applied 2 weeks later.

The biological efficacy of insecticides

Directly before chemical treatments, the number of melon flies was counted. The biological effectiveness of each mixture insecticides (A1, A2, B1 and B2 on the 1st, 3rd, 7th and 14th days) (Fig. 2) and full chemical program (A2, B1, A2 and B2, B2, B2 from appearance first generation of fly to harvest) (5 plants from experimental plot) were calculated according to Abbott (1925). The fruits in the selected area were carefully examined for ovipositor marks per fruit and compared with control (Table 4).

Monitoring of melon fly

The occurrence of the melon fly and climate conditions were monitored from May (1–2 leaves of melon) to October in South Kazakhstan (Fig. 1). The 0.5 ha plots were separated, and every 5 days, 10 plants from five sites were inspected for the presence of the melon fly. Three kinds of traps: pheromone stick, yellow stick and feeding (melon juice and sugar, 1 ml/1 g) in two combinations (2 or 10 per hectare), were placed in the fields (5 ha) at a distance of 20–30 m (Table 3).

Analytical method of determination of pesticide residues in melon

A validated QUick, Easy, CHEap, Effective, Rugged and Safe (QuEChERS) technique based on LC–MS/MS was applied for the simultaneous determination of thiamethoxam, lambda-cyhalothrin, chlorpyrifos and cypermethrin residues in melon (Łozowicka et al. 2016).

Statistical analysis

Data were analyzed using general linear models (GLM) multivariate analysis of variance (MANOVA) with Statistica version 10 software. Tukey's least significant difference post

Fig. 2 Influence of two mixtures applied in two doses (A1, A2, B1, B2) on the number of *Myiopardalis pardalina* Bigot fly in melon

Table 3 Efficiency of pheromone, sticky and feeding traps against the *Myiopardalis pardalina* Bigot melon fly (2015–2016, South Kazakhstan)

Variant of traps	Number of traps per ha	Mean number of flies*	Damage of melon (%)	Yield (t/ha)
Pheromone traps	2	25.0	13.8	15.2
	10	58.3	8.8	16.6
Yellow sticky traps	2	9.8	15.8	15.7
	10	15.5	17.5	15.9
Feeding traps	2	9.5	15.5	16.3
	10	22.3	16.3	16.3

*Means in columns do not differ at $p < 0.05$ level of significance

hoc analysis was performed to determine where significance was obtained. Means were considered significantly different when the probability of error was 0.05 or less in statistical tendencies.

Results

The meteorological data at the field trial site in south of Kazakhstan from January 2015 to December 2016 are given in Fig. 1. During the growing period of the melon in May–June, the minimum and maximum temperatures ranged from 17 to 36 °C (2015) and from 11 to 34 °C (2016). The average relative humidity for the vegetation months ranged from 30.3 to 35%. Based on the conducted monitoring and numerical indicators of fly appearance, the degree of its propagation and the time of the pest's active flight were determined and extrapolated according to the melon vegetation period (Fig. 2). During the monitoring, it was observed that the pest developed full three generations in 1 year. A 2-year observation of the dynamics of the *M. pardalina* Bigot on melon showed that their population peak

occurred in various periods in particular years of study. In 2015, the maximum appearance of fly was noted on the last/first decade of May and June, and in 2016, in the first/second decade of June (the flowering stage of melon). The maximum fly population in the 2nd generation occurred in the second decade of July in 2015 and 2016. The 3rd generation was noted in the second/third decade of August in 2015 and 2016, respectively. The maximum number of eggs and larvae of the 1st the melon fly generation usually occurs in the third decade of June–early July (depending on the weather conditions). The maximum number of eggs and larvae of the next generation appears on about 20th of July, and for the third generation, the maximum of eggs and larvae occurred in the third decade of August or in early September.

Table 3 presents the efficiency of pheromone, sticky and feeding traps against the melon fly in South Kazakhstan in 2015–2016. Additionally, the percentage of damage to melon plants and yield was included. Among all traps used in this experiment, the lowest degree of melon damage (8.8%) was noted only for the variant with 10 pheromone traps per hectare, where the crop yield of melon was slightly higher than in the case of the other traps (16.63 t/ha).

Based on the conducted monitoring of appearance of melon fly, optimal time for the performance of chemical pest control was determined. On the control and treated experimental plots, before application, an average population density of 11.5 fly/plant was noted. The control plot and treated plots were characterized by varied fly population density on successive days of observation, with 11–22 flies per plant on the 7th and 14th days after the treatment (Fig. 2).

After comparing the obtained results from the control plots and the number of flies before the pesticide application, it was determined that using insecticides (A1, A2 and B1, B2) had a significant impact on reducing the average number of flies. We observed that the number of flies after the insecticides application compared with the number of flies before the application decreased on average: in case

Table 4 Effectiveness of full chemical program mixtures (A1, B1, A1 and B2, B2, B2) applied in three BBCH melon-growing phase in controlling *Myiopardalis pardalina* Bigot melon fly (mean from 2015 to 2016)

Combination dose (l/ha)	Number of fruits with ovipositor marks Effectiveness (%)				Yield (t/ha)	
	2015		2016		2015	2016
	I first generation of fly	Before harvest	I first generation of fly	Before harvest		
A2, B1, A2 (0,2; 0,5; 0,2)	2.4 ^c	2.6 ^c	1.8 ^c	2.2 ^c	13.2 ^b	14.9 ^b
	92.9	95.7	94.7	96.5		
B2, B2, B2 (0,7; 0,7; 0,7)	5.4 ^c	6.8 ^c	5.2 ^c	6.6 ^c	12.9 ^b	13.8 ^b
	83.9	88.8	84.7	89.4		
Control	33.6 ^b	60.8 ^a	34.0 ^b	62.4 ^a	5.2 ^a	4.9 ^a

Means in columns indicated by the same letter do not differ at $p < 0.05$ level of significance in Tukey's test. A—thiamethoxam/lambda-cyhalothrin and B—chlorpyrifos/cypermethrin

of variant A1 from 12.1 to 2.3, for A2 from 10.9 to 1.5, for B1 from 11.5 to 3.5 and for B2 from 11.7 to 3. The lowest number of flies was observed after thiamethoxam/lambda-cyhalothrin had been applied at a dose of 0.25 l/ha (A2) (Fig. 2). In all cases, the greatest efficacy was observed on the seventh day after the application. At that time, the efficacy of treatment calculated using Abbott's formula was in the range of 86.4–95.5%. High activity was also noted after the passage of 2 weeks from the treatment. It was in the range of 78.0–89.0% for all the applications of insecticides (Table 1; Fig. 2).

Significant differences were observed on control combinations, where a higher number of flies were noted before the harvest than in the 1st fly generation. The applied pesticide combinations (A2, B1, A2 and B2, B2, B2) significantly reduced the number of fruits with ovipositor marks in comparison with the control plots. The lowest mean number of fruits with ovipositor marks was obtained for A2, B1, A2 in the 1st generation of fly—1.8 in 2016, and the highest for B2, B2, B2 before the harvest—6.8 in 2015 (Table 4). No significant differences were observed between the time before harvest and the 1st generation of fly for individual applications. Performed treatments caused a significant increase in yield in 2 years in comparison with the control plots (Table 4). The biological activity of the first combination during the period of appearance of the first generation amounted to 92.9% and 94.7%, and before the harvest 95.7% and 96.5%, while in the second variant 83.9% and 84.7% as well as before the harvest 88.8% and 89.4%, in 2015 and 2016, respectively. In addition, thiamethoxam/lambda-cyhalothrin and chlorpyrifos/cypermethrin increase the quality of harvested cucumber fruits in terms of infestation of fruits with ovipositor marks and the crop yield was higher (Table 4).

In this study, we analyzed all the variants with chemical protection at the end of vegetation in 2015 and 2016 for residues. In any case, in melon fruits were not found pesticides above the maximum residue levels (MRLs) set by the European Union.

Discussion

The conducted monitoring showed the occurrence of melon flies in south Kazakhstan, which allowed us to determine the optimum time for chemical application. The first pest appeared in May and the last in September, which means that insects occurred in the plants almost throughout the whole growing period. To assess flight dynamics, we used pheromone sticky traps, yellow sticky traps and feeding traps with bait in the form of melon juice syrup and sugar. Fly catching was more effective with pheromone traps in comparison with sticky and feeding traps,

as confirmed by other authors (Gillani et al. 2002; Islam et al. 2013). However, regardless of their efficacy, the traps did not have a significant effect on the degree of damage to melons inflicted by the pest or on crop yield. It can be concluded that pheromone traps contribute to the effectiveness of population reduction. Moreover, they are noninvasive. However, they cannot serve as a method of protection against the quarantine pest on their own; they can be used only as part of an integrated system.

The chemical plant protection research conducted on the melon plantation in south Kazakhstan showed the high effectiveness of insecticides in controlling *M. pardalina* Bigot in melon. In the literature, insecticides such as malathion, dichlorvos, phosphamidon and endosulfan are moderately effective against the melon fly (Agarwal et al. 1987). The application of fenthion, formathion, carbofuran or carbaryl at 50% appearance of male flowers and again at 3 days after fertilization is helpful in reducing the melon fly damage (Srinivasan 1991). In this study, the mix of thiamethoxam/lambda-cyhalothrin proved to be effective when the insecticides were applied at doses of 0.2 and 0.25 l/ha during the melon vegetation period. As reported by Nath et al. (2007), Waseem et al. (2009) and Oke and Sinon (2013), ecofriendly insecticides, like malathion with molasses and cypermethrin, applied one after another as per schedule resulted in minimum fruit damage by the fruit fly.

Our studies are the first reports in the literature describing the effectiveness of the neonicotinoid/pyrethroid combination against the melon fly. Lambda-cyhalothrin was successfully used to control other insects in various crops (Bereś et al. 2017). Oke (2008) carried out an experiment to test the effectiveness of lambda-cyhalothrin and deltamethrin separately in controlling melon fruit fly in cucumber. The results obtained show that lambda-cyhalothrin was found to be better as its spray reduced the number of flies on melon fruit to a greater extent, but the other insecticide was also effective. Thiamethoxam is a contact, stomach and systemic second-generation neonicotinoid, and lambda-cyhalothrin is a non-systemic pyrethroid with contact and stomach action. Thiamethoxam interferes with a specific receptor site in the insect's nervous system, and lambda-cyhalothrin disrupts the normal functioning of the nervous system in an organism.

The second combination of chlorpyrifos/cypermethrin was applied at a dose of 0.5 and 0.7 l/ha. The applied dose of 0.7 l/ha was slightly more effective than the dose of 0.5 l/ha. Chlorpyrifos is one of the most widely used chlorinated organophosphate insecticides which act as cholinesterase inhibitors, and it is non-systemic with contact, stomach and respiratory action. Cypermethrin is a systemic pyrethroid, killing insects that eat it or come into contact with it, and works by quickly affecting the insect's central nervous system. The effects of cypermethrin on melon fruit fly were studied by Rana et al. (2015).

As suggested by Khan et al. (2015), the frequent application of the same insecticide in one vegetative season or over a longer period of time causes the pest to develop a resistance to the given pesticide and accumulation of residues. The studies of residues problems associated with the application of chemicals from combined program (A2, B1, A2 and B2, B2, B2) in melon were performed using the QuEChERS/LC/MS/MS method described earlier (Łozowicka et al. 2016). It may be expected that the values of pesticide residues after harvesting time from three-fold spraying of the same active substances—chlorpyrifos/cypermethrin (B2, B2, B2, total dose 2.1 l/ha), may be higher than those of pesticide residues from the sprayed mixed pesticides (A2, B1, A2, total dose 1.0 l/ha). Thus, the obtained results from the sprayed melon field were compliant with the current EU MRLs, showing melons to be safe and legally marketable. The melon samples from fields sprayed A2, B1, A2 and B2, B2, B2 were analyzed, and the mean concentration of chlorpyrifos ranged from 0.001 to 0.008 mg/kg in the second variant. New findings (Zhao et al. 2005) regarding the toxicity of chlorpyrifos resulted in lowering the allowed values of chlorpyrifos residues in plant. Because of the high-risk toxicological parameters of chlorpyrifos, plant protection products containing these active substances must be applied especially carefully.

Conclusion

The use of chemical plant protection products can cause serious ecological changes related to the resistance of agrophages to the active substances as well as dangerous environmental pollution with residues from plant protection products. Such a state of affairs can quickly influence the quality and quantity of yield and affect human health. Therefore, it is very important to use relatively new insecticides characterized by low biological and economic efficacy against agrophages. This is why the objective of the future studies will be to evaluate a comprehensive application system of insecticides from varied chemical classes and with differing mechanisms of biological action. The results showed that the combination of the four insecticides: thiamethoxam/lambda-cyhalothrin and chlorpyrifos/cypermethrin, was more effective in controlling the melon fruit fly in melon than threefold applications of only chlorpyrifos/cypermethrin during the growing season.

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Compliance with ethical standards

Conflict of interest No potential conflict of interest was reported by the authors.

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