Biological Efficacy of Some Biorational and Conventional Insecticides in the Control of Different Stages of the Colorado Potato Beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae)

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Abstract

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The biological efficacy of some biorational and conventional insecticides against different stages of Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae) was evaluated under laboratory and semi-field conditions. Seven different commercial products were tested, including the biorational insecticides: Spinosad, Mectin, Fitoverm, Match, Neemix in addition to two conventional insecticides: Actara and Actellic. Data indicated that all tested insecticides showed low toxic effects to *L. decemlineata* eggs, but most hatching neonates died shortly after hatching. All tested insecticides at their field rates showed high toxicity to larvae of *L. decemlineata.* The highest mortality was obtained in earlier instars, as compared to older ones, and mortality increased with the time of exposure. Moreover, the lower concentrations (up to 25% of the field rate) of Actara, Mectin, Spinosad, and Fitoverm showed high efficacy against *L. decemlineata* third instar larvae. Also, Actara caused the highest mortality in *L. decemlineata* adults, followed by Spinosad, Mectin, and Fitoverm as compared to Actellic, Match, and Neemix. In pupal bioassay, Fitoverm caused the greatest reduction in *L. decemlineata* adult emergence followed by Mectin, Actara, Actellic and Spinosad. In translocation bioassays, Actara caused the highest mortality in *L. decemlineata* 3^{rd} instar larvae or adults followed by Spinosad and Mectin. The residual activity of tested insecticides against third instar larvae was also evaluated. Actara, Spinosad, and Mectin were more persistent under field conditions, consequently the mortality rates after 30 days of application were 46.67%, 44.44%, and 35.56%, respectively.

Keywords: *Leptinotarsa decemlineata*; biorational and conventional insecticides; survival; mortality; translocation, residual effect

Potato, *Solanum tuberosum* L., is the world's most widely grown tuber crop, and the fourth largest food crop in terms of fresh production after rice, wheat, and maize (Rutz & Janssen 2007), with an estimated cultivated area of 19.33 million hectares. It accounts for more than 2.85 million hectares of Russian farmland (FAOSTAT 2008), producing about 36 784 200 tons. This crop is subjected to severe attacks with scores of insect and pathogen pests which affect its production. The actual average worldwide losses in potato yields due to agricultural pests were estimated at 39% (Oerke & Dehne 2004). In Russia, for instance, as much as 4 million tons of potatoes are lost annually because of the infestation with Colorado beetle, late blight and plant viruses (Potato World 2008).

The Colorado potato beetle (CPB), *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae), is the main limiting factor for the production of potatoes. It is a major insect pest attacking potato in many potato-producing regions worldwide (Hare 1990). It is widely accepted that potato is the preferred host plant of the CPB. In addition to potato, it devastates, by its voracious feeding, other solanaceous crops such as eggplant, tomato, pepper, and tobacco (Radcliffe 1982; Hare 1990; Metcalf & Metcalf 1993; Phyllis 2004). *L. decemlineata* can completely defoliate plants prior to tuber formation if not adequately controlled (Koopmanschap *et al.* 1989; Zehnder & Evanylo 1989; Nault & Kennedy 1998; Karimzadeh *et al.* 2007), and may reduce tuber yields by as much as 50% (Hare 1980). Moreover, this pest is widely considered as a quarantine pest in most countries of the world including Egypt (EPPO 2006).

Until recently, there has been no efficient biocontrol agent for the CPB. The control of this pest has relied over the last 50 years on the use of most major classes of insecticides (Lipa 2008). Shortly after insecticide application, the CPB acquires resistance to such used insecticides (Dickens 2002). Biological control would be the concerted use as a major component of integrated pest management for the control of CPB. Natural enemies of CPB include a variety of predatory insects, parasitoids and microbial control agents (Lacey *et al.* 1999).

Fortunately, biological control using biorational insecticides has become the most efficient means in potato pest management programs because their use reduce pollution and delay the development of resistance to other classical insecticides (Barčić *et al.* 2006). Several biopesticide products based on the bacterium *Bacillus thuringiensis* (Bt) and on the fungal agent *Beauveria bassiana* have received considerable attention as a potential biological control agent over the last three decades against CPB (Lacey *et al.* 1999). Nevertheless, Bt-based bioinsecticides are generally efficient if applications are timed to coincide with peak egg hatch or when early larval instars of CPB predominate. Humidity, temperature and solar radiation affect the activity of microbial agents (Kalushkov & Batchvarova 2005). Moreover, foliar applications of *Beauvaria bassiana* have not provided the commercially acceptable control of *Leptinotarsa decemlineata* (Wraight & Ramos 2002).

Currently, the group of new biorational insecticides suitable for the CPB control in IPM programmes is represented by different active ingredients: Spinosad is a biopesticide that is produced through the fermentation of the soil actinomycete *Saccharopolyspora spinosa* Mertz and Yao (Thompson & Hutchins 1999), its active ingredient consists of a mixture of spinosyn A and spinosyn D (Salgado 1998). This product is benign towards biological control agents, humans and environment. It can be used in IPM programmes particularly in situations, such as in many edible crops. Mectin is widely used against the CPB. It is a mixture of avermectins, containing 80% avermectin B1a and 20% avermectin B1b, and Fitoverm, the product containing the active ingredient avermectin C. Mectin and Fitoverm are natural fermentative products of the soil microorganism *Streptomyces avermitilis*. Its novel chemistry, unique mechanism of toxicity, and broad spectrum of insecticidal activity make abamectin a suitable choice for this purpose (Clark *et al.* 1995). Also, Match is an insect growth regulator (IGR) that has the active ingredient lufenuron with proven wide activity against many pests including CPB and that showed satisfactory residual action, good leaf protection and high yields (Igrc *et al.* 1999). Other biorational compounds as Neem (Azadirachtin), a plant derived preparation from the neem tree (*Azadirichta indica* A. Juss.) that has low or moderate efficacy against CPB larvae (Barčić *et al.* 2006). Azadirachtin, a complex tetranortriterpenoid limonoid from the neem seeds, is the main component responsible for the toxic effects in insects. Neem insecticides are efficient mainly in a variety of different ways: as an antifeedant, insect growth regulator and sterilant (Mordue & Nisbet 2000).

Actara is an insecticide containing the active ingredient thiamethoxam. Thiamethoxam is a second-generation neonicotinoid insecticide and acts through contact and ingestion. The primary mode of action for thiamethoxam involves interference with or binding to nicotinic acetylcholine receptors (Maienfisch *et al.* 2001). This mode of action makes them highly desirable for controlling insects that develop resistance to conventional organophosphate, carbamate, and pyrethroid insecticides (Maienfisch *et al.* 1999). Thiamethoxam also has minimal effects on beneficial insects, low toxicity toward mammals, and does not produce any teratogenic or mutagenic effects (Lawson *et al.* 1999) whereas Actellic (Pirimiphos-methyl) is an organophosphorus insecticide which is widely used to protect field grown vegetables from the infestation by several insect pests (Radwan *et al.* 2004). Widespread resistance was recorded in a local population of the CPB to organophosphorus insecticides in Russia (Leontieva *et al.* 2006).

Bearing all these facts in mind, the aim of this study is to evaluate the efficacy of some biorational insecticides for the control of *L. decemlineata* as compared to conventional insecticides as an attempt to introduce such safer insecticides in the IPM protocol of controlling several insect pests in vegetable crops.

MATERIALS AND METHODS

All experiments were conducted in a laboratory of the Plant Protection Department, Russian State Agricultural University, Moscow, Russian Federation, during the period from May to August, 2007. During this period, the weather conditions were mainly hot, which provided unusual two generations of *L. decemlineata* (Gritsenko & Osman unpublished data). The grown variety of potato in these experiments was Magician, which is the common variety in most potato-production regions in Russia.

***Maintenance of** L. decemlineata*. Egg masses and different larval instars of *L. decemlineata* were periodically collected from the CPB infested potato fields. Larvae were reared on potato branches (30 cm long). The lower parts of these potato branches were inserted in glass vials 2 × 10 cm containing fresh water to keep these branches fresh as long as possible (Gelman *et al.* 2001). These vials were placed in a cage of 60 × 60 × 60 cm under laboratory conditions of 25 ± 2°C; 60 ± 10% RH and photoperiod of 16:8 h (L:D). Upon emergence, adults of CPB were collected, fed and reared as previously mentioned in the larval stage.

Insecticides used and soil characteristics. The formulated insecticides used in this study were: Spinosad 12% SL (spinosyns A and D, *Saccharopolyspora spinosa*,), Mectin 1.8% EC (*Streptomyces avermitilis*, 80% avermectin B1a and 20% avermectin B1b), Fitoverm 0.2% EC (*Streptomyces avermitilis*, aversectin C), Match 50% EC (lufenuron), Neemix 4.5% EC (azadirachtin), Actara 25% WG (thiamethoxam) and Actellic 50% EC (pirimiphos-methyl). Solutions of all tested compounds were prepared in distilled water at the field rate concentrations (Spinosad 0.5 ml/l, Mectin 0.4 ml/l, Fitoverm 1.2 ml/l, Match 0.4 ml/l, Neemix 1.25 ml/l, Actara 0.16 g/l, and Actellic 1.5 ml/l). The tested concentrations of all tested compounds in the present study were 100% field rate (FR), 50% FR, 25% FR, 12.5% FR, 6.25% FR, and 3.12% FR using fresh concentrations prepared one hour prior to experiments.

The soil used was clay (10.1% coarse sand, 5.3% fine sand, 25.7% silt and 58.9% clay; pH = 6.1; organic matter 3.7%), the soil type prevails in potato production regions near Moscow.

Experimental bioassays

Bioassay of L. decemlineata eggs. The experiment was conducted using CPB egg masses (< 1-day old eggs) on potato leaves. The egg masses were treated in 9 replications (20 eggs in each) with one of the tested solutions of the tested insecticides through direct spray using a hand sprayer. Treated eggs were then removed, kept on clean Petri dishes (10 cm in diameter) and observed till egg hatching. Moreover, the rate of mortality in surviving first instar larvae was recorded 24 h post hatching.

Bioassay of L. decemlineata larvae. In this experiment, the effect of the field rate (FR) of the tested insecticides was studied against *L. decemlineata* 1^{st}, 2^{nd}, 3^{rd} and 4^{th} instar larvae in the middle age of each instar depending on the size of the abdomen and arched back of theses instars. Moreover, the effect of 50% FR, 25% FR, 12.5% FR, 6.25% RF, and 3.12% FR against *L. decemlineata* third instar larvae was also investigated. Each treatment was replicated 9 times with 10 larvae each. The treatments were performed by dipping small potato leaves in the tested solution for 15 s with gentle agitation. The treated potato leaves were then placed on a paper towel for at least 2 h or until they dried out before being used in the experiments. The tested larvae of *L. decemlineata* were starved for at least 4 h prior to the experiment. Larvae were removed gently with a fine camel-hair brush and placed into Petri dish having a small treated potato leaf. Petri dishes were closed and kept in the laboratory under the abovementioned laboratory conditions. Control treatments were also conducted with the same protocol using distilled water. One day after treatment, the surviving larvae were fed on untreated leaves for the rest of the experimental period. To record mortality, Petri dishes were daily observed till the larvae developed into pupae. Rates of mortality in *L. decemlineata* larvae were recorded 3 days and 7 days post feeding on the treated leaves. Larvae were considered dead if they gave no response to stimulation by touch with the hair-camel brush.

Bioassay of L. decemlineata pupae. To study the effect of the field rate of the tested insecticides on the pupae of *L. decemlineata*, each 500 g of soil were mixed thoroughly with 100 ml of each insecticide solution. These treated soils were left to dry completely before being packed into small plastic pots (1 l). Ten full grown larvae of *L. decemlineata* were placed on the treated soil. These pots were covered with muslin sheets and fixed in place with rubber bands. Fifteen days later, pots were checked to record the rates of adult emergence. Each treatment was replicated 9 times with 10 pupae each. Control treatment was performed using the same protocol and number of replications but with distilled water only.

Bioassay of L. decemlineata adults. In this experiment, three concentrations (FR, 50% FR and 25% FR) of each insecticide were tested. Potato leaves were treated as previously mentioned in larval bioassay. Each treatment was replicated 9 times. The tested adults were starved for at least 4 h prior to the experiment. Ten *L. decemlineata* adults were confined in clean Petri dish with treated potato leaves. Petri dishes were then closed and kept under the aforementioned laboratory conditions. One day later, adults were checked and fed on untreated potato leaves until the end of experimental period. Control treatments were also conducted using the same protocol with distilled water. Treatments were checked at daily basis and the rate of adult mortality was recorded 3 days and 7 days post feeding on the treated leaves.

Persistence of insecticides on foliage-treated potato plants. To study the persistence/residual activity of the tested insecticides against *L. decemlineata* larvae under field conditions, 3 plants (5 weeks-old) were carefully sprayed with the FR of each of the tested insecticides. Another 3 potato plants were also sprayed with water as untreated control. Exactly zero, 5, 10, 20, 30, and 40 days after application, the leaves of treated and untreated plants were picked up and transported to the laboratory. The bioassay was conducted only for starving third instar larvae of *L. decemlineata*. Nine replications with 10 third-instar larvae of *L. decemlineata* were used for each treatment. Larvae were gently moved into the Petri dish and allowed to feed on the treated leaves for 24 h, only then they were fed on untreated leaves till the end of the experiment. *L. decemlineata* larvae were daily observed and the mortality percentages

Table 1. Mortality percentages (± SE) of *L. decemlineata* 1st, 2nd, 3rd, and 4th instar larvae fed on potato leaves treated with the recommended dose of tested insecticides three and seven days post treatment

Treatment	1st instar		2nd instar		3rd instar		4th instar	
	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days
Control	4.44 ± 2.94^{b}	8.89 ± 3.51^{b}	6.67 ± 3.33^{c}	8.89 ± 3.51^{c}	2.22 ± 2.22^{e}	8.89 ± 3.51^{c}	0.0^{d}	6.67 ± 3.33^{c}
Actara	88.89 ± 5.88^{a}	100.00^{a}	84.44 ± 6.48^{a}	100.00^{a}	82.22 ± 7.78^{a}	100.00^{a}	75.56 ± 7.29^{a}	100.00^{a}
Spinosad	86.67 ± 5.77^{a}	100.00^{a}	84.44 ± 6.48^{a}	100.00^{a}	73.33 ± 8.82^{ab}	100.00^{a}	57.78 ± 9.69^{ab}	95.56 ± 4.44^{a}
Mectin	88.89 ± 6.76^{a}	100.00^{a}	73.33 ± 4.71^{a}	100.00^{a}	71.11 ± 5.88^{ab}	100.00^{a}	48.89 ± 5.88^{b}	100.00 ^{a}
Match	60.00 ± 10.54^{a}	100.00^{a}	42.22 ± 9.10^{b}	97.78 ± 2.22^{a}	37.78 ± 10.24^{cd}	82.22 ± 10.24^{ab}	0.0^{d}	46.67 ± 9.43^{b}
Fitoverm	77.78 ± 5.21^{a}	100.00^{a}	75.56 ± 6.48^{a}	100.00^{a}	64.44 ± 4.44^{abc}	95.56 ± 4.44^{a}	46.67 ± 3.33^{bc}	66.67 ± 3.33^{b}
Actellic	80.00 ± 6.67^{a}	93.33 ± 3.33^{a}	66.67 ± 6.67^{ab}	86.67 ± 3.33^{a}	46.67 ± 8.82^{bcd}	66.67 ± 8.82^{b}	24.44 ± 5.56^{c}	53.33 ± 3.33^{b}
Neemix	15.56 ± 7.29^{b}	88.89 ± 5.88^{a}	11.11 ± 3.51^{c}	71.11 ± 6.76^{b}	15.56 ± 4.44^{de}	24.44 ± 5.56^{c}	0.0^{d}	6.67 ± 4.71^{c}
F-value	25.844	137.617	26.975	108.333	16.746	43.187	31.659	72.507
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Means followed with the same letters (column wise) are not significantly different (Tukey' HSD; $P > 0.05$)

were recorded 3 days and 7 days post feeding on treated leaves.

Translocation of the tested insecticides into plants. This study was carried out to record the translocation activity of the tested insecticides through potato plants and its residual activity against *L. decemlineata* larvae and adults. Potato was planted into untreated soil in plastic pots. Pots were irrigated for the first time with the tested solution of insecticides at a field rate (500 ml/pot), and then with fresh water when needed. After 25 days of planting, each pot was covered thoroughly with transparent muslin and provided with ten third instar larvae or adults of *L. decemlineata*. Nine replications were used for each treatment including the control. Insects were observed at 3-day intervals after exposure and the rates of mortality in *L. decemlineata* larvae or adults were recorded.

Statistical analysis. Data on mortality in *L. decemlineata* eggs, larvae, pupae, adults were analyzed using one-way ANOVA (SAS Institute 2003). In the case of significant *F*-values, means were separated by Tukey's HSD test at a 0.05 significance level.

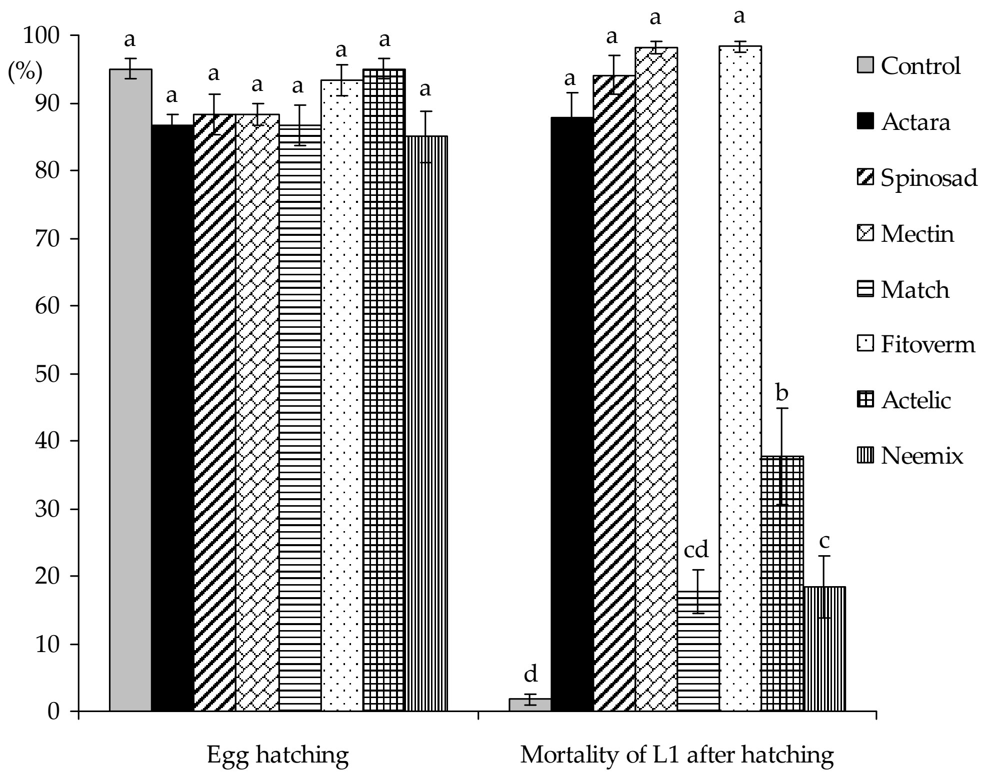
RESULTS

Bioassay of *L. decemlineata* eggs

Data in Figure 1 show that the tested insecticides were harmless to *L. decemlineata* eggs and no significant difference was observed in hatching ability. However, significant differences existed among the tested insecticides in rates of mortality in surviving first instar larvae one day after hatching. Mortality rates could be arranged as Fitoverm > Mectin > Spinosad > Actara > Actellic > Neemix > Match.

Bioassay of *L. decemlineata* larvae

All tested insecticides at their field rates showed high toxicity to larvae of *L. decemlineata* (Table 1). Mortality rates decreased as *L. decemlineata* larvae aged, but increased with the time post treatment. There were significant differences among the tested insecticides in their mortality rates in first instar cohorts 3 days and 7 days post treatment; and in second instar cohorts 3 days and 7 days post treatment (Table 1). The same trend of significance was



Bars with the same letters are not significantly different (Tukey's HSD test; $P > 0.05$)

Figure 1. Effect of tested insecticides on the percentages of egg hatching and mortality of first instar larvae after hatching

observed in third instar larvae for 3 days and 7 days post treatment and in fourth instar bioassays for 3 days and 7 days post treatment. Generally, Actra and Mectin caused the highest mortality in all tested larval instars, being 100% after 7 days of treatment, whereas Neemix was the least efficient insecticide (Table 1).

As for *L. decemlineata* third instar larvae bioassays, data indicated that the mortality rate increased significantly with the increase in insecticide concentration (Table 2). While Mectin was the most toxic insecticide to *L. decemlineata* 3rd instar larvae, Neemix was the least efficient one. Significant differences were found 3 days and 7 days post treatment in all tested concentrations (Table 2).

Bioassay of *L. decemlineata* pupae

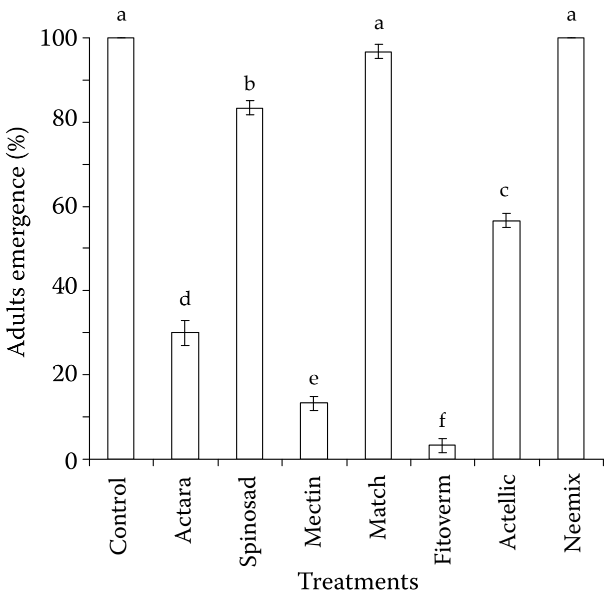
As shown in Figure 2, Fitoverm caused the greatest reduction in *L. decemlineata* adult emergence at 96.67%, followed by Mectin (86.67%), Actara (70.00%), Actellic (43.33%) and Spinosad (16.67%). Significant differences among the insecticides were found out, but emergence rates in Match and Neemix did not differ significantly from that of the control.

Bioassay of *L. decemlineata* adults

As shown in Table 3, Actara caused the highest mortality in *L. decemlineata* adults, followed by Spinosad, Mectin and Fitoverm, either 3 days or 5 days post treatment. Significant differences in mortality rates were recorded at 100% RF, 50% FR and 25% FR after 3 days and 7 days since treatment.

Persistence of insecticides on foliage-treated potato plants

The obtained results (Table 4) indicated that the mortality rate of *L. decemlineata* third instar larvae decreased gradually over time in all treatments and significant differences were found 3 days post treatment for zero time, 5 days, 10 days, 20 days, 30 days, and 40 days. The same trend of significance was observed when mortality was recorded 7 days post feeding on treated leaves for all investigated intervals (Table 4).



Bars with the same letters are not significantly different (Tukey's HSD test; $P > 0.05$)

Figure 2. Rate of adult emergence (± SE) of *L. decemlineata* placed as full grown larvae on treated soil with the recommended dose of tested insecticides

Translocation of the tested insecticides into plants

In this experiment, *L. decemlineata* third instar larvae and adults were allowed to feed on potato leaves taken from plants grown in treated soil after 25 days since planting and insecticide application. Actara, Spinosad, Mectin and Actellic showed the high ability of persistence and translocation through potato plants, causing the death of *L. decemlineata* larvae and adults (Figure 3). The tested insecticides differed significantly in causing mortality in *L. decemlineata* larvae and adults. Meanwhile, no significant difference was observed among Neemix, Match, and Fitoverm compared to the control (Figure 3).

DISCUSSION

L. decemlineata is a very destructive pest to the potato crop worldwide. The increasing incidence of resistance to the majority of available insecticides may lead to serious control problems in most potato-growing areas (Casagrande 1987). One way to obviate resistance development is to use the insecticides belonging to the new classes as indicated in this study (Koopmanschap *et al.*

Table 2. Effect of different concentrations of tested insecticides on the mortality of *L. decemlineata* third instar larvae 3 days and 7 days post treatment

Treatment	FR*		50% FR		25% FR		12.5% FR		6.25% FR		3.125% FR	
	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days
Control	2.22 ± 2.22^{e}	8.89 ± 3.51^{c}	2.22 ± 2.22^{c}	8.89 ± 3.514^{c}	2.22 ± 2.22^{d}	8.89 ± 3.51^{c}	2.22 ± 2.22^{d}	8.89 ± 3.51^{d}	2.22 ± 2.22^{d}	8.89 ± 3.51^{c}	2.22 ± 2.22^{c}	8.89 ± 3.51^{d}
Actara	82.22 ± 7.78^{a}	100.00^{a}	82.22 ± 6.19^{a}	100.00^{a}	77.78 ± 7.78^{a}	100.00^{a}	53.33 ± 9.43^{ab}	95.56 ± 2.94^{a}	22.22 ± 5.21^{bcd}	64.44 ± 7.29^{b}	22.22 ± 7.78^{bc}	40.00 ± 5.77^{c}
Spinosad	73.33 ± 8.82^{ab}	100.00^{a}	71.11 ± 6.76^{ab}	100.00^{a}	62.22 ± 5.21^{ab}	97.78 ± 2.22^{a}	64.44 ± 9.87^{a}	97.78 ± 2.22^{a}	46.67 ± 10.54^{ab}	88.89 ± 4.84^{a}	24.44 ± 4.44^{bc}	44.44 ± 2.94^{c}
Mectin	71.11 ± 5.88^{ab}	100.00^{a}	68.89 ± 5.88^{ab}	100.00^{a}	68.89 ± 7.54^{a}	100.00^{a}	62.22 ± 5.21^{a}	100.00^{a}	62.22 ± 4.01^{a}	97.78 ± 2.22^{a}	55.56 ± 4.44^{a}	91.11 ± 3.51^{a}
Match	37.78 ± 10.24^{cd}	82.22 ± 10.24^{ab}	57.78 ± 7.02^{ab}	88.89 ± 5.88^{a}	37.78 ± 11.76^{bc}	71.11 ± 8.24^{b}	26.67 ± 4.71^{bcd}	60.00 ± 4.71^{b}	20.00 ± 8.17^{bcd}	57.78 ± 10.24^{b}	20.00 ± 6.67^{bc}	37.78 ± 5.21^{c}
Fitoverm	64.44 ± 4.44^{abc}	95.56 ± 4.44^{a}	60.00 ± 3.33^{ab}	93.33 ± 3.33^{a}	53.33 ± 4.71^{ab}	93.33 ± 4.71^{a}	44.44 ± 4.44^{abc}	86.67 ± 5.774^{a}	35.56 ± 8.68^{abc}	77.78 ± 5.21^{ab}	35.56 ± 6.48^{ab}	68.89 ± 7.54^{b}
Actellic	46.67 ± 8.82^{bcd}	66.67 ± 8.82^{b}	46.67 ± 9.43^{b}	60.00 ± 11.55^{b}	17.78 ± 6.19^{cd}	26.67 ± 3.33^{c}	22.22 ± 5.21^{cd}	33.33 ± 3.33^{c}	13.33 ± 4.71^{cd}	22.22 ± 2.22^{c}	20.00 ± 5.77^{bc}	35.56 ± 4.44^{c}
Neemix	15.56 ± 4.44^{de}	24.44 ± 5.56^{c}	11.11 ± 4.84^{c}	17.78 ± 4.01^{c}	6.67 ± 3.33^{d}	15.56 ± 5.56^{c}	4.44 ± 2.94^{d}	13.33 ± 4.71^{d}	2.22 ± 2.22^{d}	11.11 ± 3.51^{c}	2.22 ± 2.22^{c}	11.11 ± 3.51^{d}
F. value	16.746	43.187	22.400	55.946	18.975	87.381	16.486	104.252	11.033	40.908	10.468	32.865
P. value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*field rate; Means followed with the same letters (column wise) are not significantly different (Tukey' HSD; $P > 0.05$)

Table 4. Residual effect of the recommended dose of tested insecticides on the mortality of *L. decemlineata* 3rd instar larvae fed on treated field potato plants at different intervals of application

Treatment	Zero time*		5 days*		10 days*		20 days*		30 days*		40 days*	
	3 days**	7 days**	3 days**	7 days**	3 days**	7 days**	3 days**	7 days**	3 days**	7 days**	3 days**	7 days**
Control	0.0^{c}	0.0^{e}	0.0^{c}	0.0^{d}	0.0^{c}	0.0^{d}	0.0^{c}	2.22 ± 2.22^{c}	0.0^{c}	2.22 ± 2.22^{d}	0.0^{b}	2.22 ± 2.22^{d}
Actara	93.33 ± 3.33^{a}	100^{a}	57.78 ± 5.21^{a}	95.56 ± 2.94^{a}	42.22 ± 7.03^{a}	82.22 ± 5.21^{a}	33.33 ± 3.33^{a}	64.44 ± 6.48^{a}	24.44 ± 4.44^{a}	46.67 ± 4.71^{a}	17.78 ± 4.01^{a}	35.56 ± 4.44^{a}
Spinosad	91.11 ± 4.84^{a}	100^{a}	55.56 ± 5.56^{a}	93.33 ± 3.33^{a}	35.56 ± 4.44^{ab}	66.67 ± 4.71^{a}	26.67 ± 3.33^{ab}	55.56 ± 4.44^{a}	20 ± 5.77^{ab}	44.44 ± 4.44^{a}	15.56 ± 5.56^{ab}	33.33 ± 4.71^{ab}
Mectin	93.33 ± 3.33^{a}	100^{a}	64.44 ± 2.94^{a}	95.56 ± 2.94^{a}	46.67 ± 8.16^{a}	84.44 ± 4.44^{a}	35.56 ± 5.56^{a}	68.89 ± 6.76^{a}	17.78 ± 4.01^{abc}	35.56 ± 2.94^{ab}	13.33 ± 5.77^{ab}	22.22 ± 4.01^{abc}
Match	20.17 ± 5.77^{c}	46.67 ± 4.71^{c}	13.33 ± 5.77^{bc}	28.89 ± 4.84^{c}	8.89 ± 4.84^{c}	22.22 ± 4.01^{bc}	8.89 ± 4.84^{c}	17.77 ± 6.19^{bc}	4.44 ± 2.94^{bc}	13.33 ± 3.33^{cd}	4.44 ± 2.94^{ab}	11.11 ± 3.51^{cd}
Fitoverm	77.77 ± 7.03^{a}	97.78 ± 2.22^{a}	24.44 ± 5.56^{b}	64.44 ± 6.48^{b}	15.56 ± 4.44^{bc}	40 ± 4.71^{b}	11.11 ± 3.51^{bc}	26.67 ± 3.33^{b}	6.67 ± 4.71^{abc}	22.22 ± 5.21^{bc}	6.67 ± 3.33^{ab}	17.78 ± 4.01^{bcd}
Actellic	46.67 ± 4.71^{b}	66.67 ± 3.33^{c}	6.67 ± 4.71^{bc}	42.22 ± 9.10^{c}	11.11 ± 5.88^{c}	22.22 ± 7.03^{bc}	8.89 ± 4.84^{c}	20 ± 5.77^{bc}	8.89 ± 5.88^{abc}	17.78 ± 6.19^{bcd}	2.22 ± 2.22^{ab}	13.33 ± 4.71^{cd}
Neemix	11.11 ± 4.84^{c}	28.89 ± 4.84^{d}	2.22 ± 2.22^{c}	6.67 ± 3.33^{d}	2.22 ± 2.22^{c}	11.11 ± 3.51^{cd}	0.0^{c}	6.67 ± 3.33^{bc}	2.22 ± 2.22^{bc}	6.67 ± 3.33^{cd}	2.22 ± 2.22^{ab}	6.67 ± 3.33^{cd}
F-value	72.231	195.646	36.924	67.188	12.471	50.853	14.568	26.977	4.672	15.916	3.390	9.233
P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0039	0.0000

Means followed with the same letters (column wise) are not significantly different (Tukey' HSD; $P > 0.05$)

*intervals after treatment of potato plants with the tested insecticides

**days of inspection post feeding

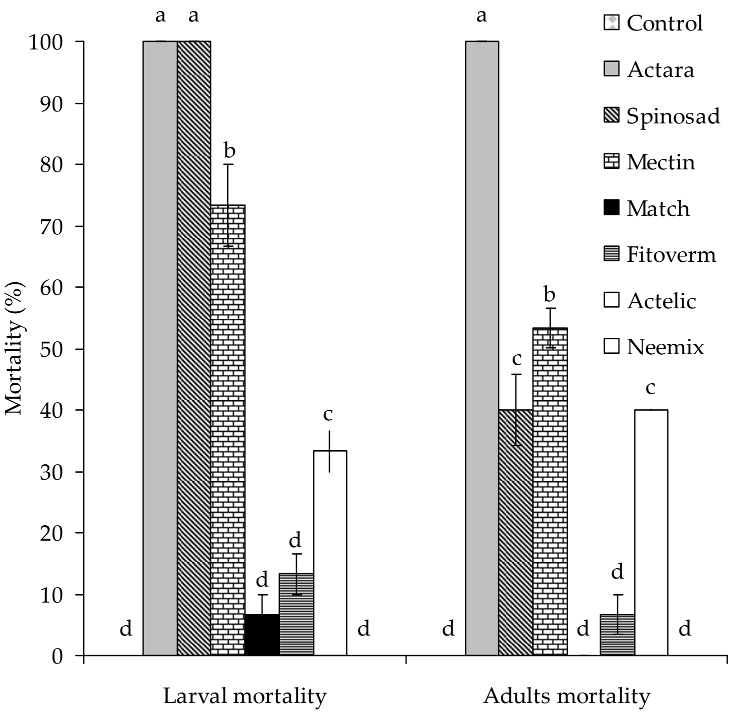


Figure 3. Mortality rates (± SE) of third instar larvae and adults of *L. decemlineata* fed on leaves of potato plants irrigated for the first time with insecticide solutions

Bars with the same letters are not significantly different (Tukey's HSD test; $P > 0.05$)

1989). The control of third and fourth instar larvae of *L. decemlineata* is especially important since these stages are usually responsible for approximately 90% of defoliation caused by this pest (Hare 1990).

Effects on different stages of ***L. decemlineata***

In the present study, the tested insecticides showed low toxicity to *L. decemlineata* eggs; however, most hatching neonates died shortly after hatching. These results are consistent with those reported by Koopmanschap *et al.* (1989), who found that the larvae of *L. decemlineata* failed to emerge from treated eggs with the juvenile hormone analogue S-71639 and emerging larvae died soon after hatching. However, the high toxicity of Spinosad and Match was observed in eggs of *Spodoptera littoralis* (Osman & Mahmoud 2008).

In foliar bioassays, the tested insecticides differed in their toxicity to *L. decemlineata* larval instars. High mortality was obtained in earlier instars as compared

Table 3. Effect of different concentrations of tested insecticides on the mortality of *L. decemlineata* adults nine and seven days post treatment

Treatment	FR*		50% RF		25% RF	
	post 3 days	post 7 days	post 3 days	post 7 days	post 3 days	post 7 days
Control	0.0 c	2.22 ± 2.22	0.0^{c}	2.22 ± 2.22^{d}	0.0^{c}	2.22 ± 2.22^{c}
Actara	91.11 ± 3.51^{a}	100.00^{a}	73.33 ± 3.33^{a}	93.33 ± 3.33^{a}	60.00 ± 4.71^{a}	86.67 ± 3.33^{a}
Spinosad	86.67 ± 6.67^{a}	93.33 ± 3.33^{a}	73.33 ± 5.77^{a}	86.67 ± 3.33^{a}	62.22 ± 5.21^{a}	77.78 ± 2.22^{a}
Mectin	71.11 ± 4.84^{ab}	95.56 ± 2.94^{a}	62.22 ± 5.21^{a}	82.22 ± 4.01^{a}	51.11 ± 4.84^{a}	75.56 ± 5.56^{a}
Match	2.22 ± 2.22^{c}	11.11 ± 3.51^{c}	0.0^{c}	6.67 ± 3.33^{d}	0.0^{c}	6.67 ± 3.33^{c}
Fitoverm	80.00 ± 5.77^{ab}	93.33 ± 3.33^{a}	60.00 ± 3.33^{a}	84.44 ± 4.44^{a}	51.11 ± 4.84^{a}	75.56 ± 4.44^{a}
Actellic	57.78 ± 11.28^{b}	86.67 ± 6.67^{a}	31.11 ± 7.54^{b}	62.22 ± 4.01^{b}	24.44 ± 8.01^{b}	48.89 ± 7.54^{b}
Neemix	24.44 ± 5.56^{c}	35.56 ± 6.48^{b}	15.56 ± 4.44^{bc}	26.67 ± 3.33^{c}	13.33 ± 3.33^{bc}	17.78 ± 2.22^{c}
F-value	40.724	101.447	50.162	113.505	32.477	68.142
P-value	0.000	0.000	0.000	0.000	0.000	0.000

*field rate; Means followed with the same letters (column wise) are not significantly different (Tukey' HSD; $P > 0.05$)

to older ones and mortality increased with the time after exposure. The most efficient insecticides were Actara, Mectin, and Spinosad. These findings are in agreement with those reported for Thiamethoxam (Actara), which is regularly used by potato growers in the USA as a systemic insecticide to control *L. decemlineata* and *Empoasca fabae* (Kuhar *et al.* 2007). Spinosad was previously reported to show high efficacy against the larvae of *Palpita unionalis*, being the highest against first and third instar larvae as compared to fifth instar larvae (Mandour *et al.* 2008). Fitoverm showed a broad-spectrum activity against insects belonging to Coleoptera, Homoptera, Diptera, Orthoptera, Isoptera, Hymenoptera, and Lepidoptera (Fisher & Mrozik 1984).

As shown in Table 2, the low concentration of the tested insecticides such as Actara, Mectin, Spinosad, and Fitoverm showed high efficacy when used up to 25% of the field rate. This, undoubtedly, has two advantages. First, it would reduce the amount of insecticides in the environment and encourage the natural enemies of *L. decemlineata*. Second, it would increase the profit through reducing the cost of the control. Fortunately, Spinosad, Mectin, and Fitoverm are recognized worldwide as benign compounds towards biocontrol agents and are widely used in IPM programs for different pests. However, the safety of Actara to beneficial arthropods, humans and environment is still controversial.

Fitoverm, Mectin, and Actara showed high efficacy in reducing the rates of emergence; however, the action of Spinosad was less pronounced. The lower mortality may be attributable to the rapid degradation of Spinosad in wet environments (Liu & Li 2004).

In the present study, Actara, Spinosad, Mectin, and Fitoverm were promising against *L. decemlineata* adults even at 25% FR. The results of Spinosad agree with those reported previously by Azimi *et al.* (2009), who found that Spinosad had high potentiality against CPB adults. Toxicity symptoms appeared only 4–5 h after treatment. The results indicated a direct positive relationship between the mortality of CPB adults and Spinosad exposure time.

Residual action

The application of the full dose of Actara, Spinosad and Mectin resulted in a very high mortality in third instar larvae of *L. decemlineata* at rates of 46.67%, 44.44%, and 35.56%, respectively, after 30 days since application. However, Fitoverm showed the shortest residual activity as compared to Actara, Spinosad, and Mectin. Similarly, Barčić *et al.* (2006) reported a high efficacy of Spinosad against *L. decemlineata* with a residual activity between 10 and 20 days after treatment. Mandour *et al.* (2008) reported a longer residual activity of Spinosad against *Palpita unionalis* larvae with a LT_{50} of 27.7 days. Spinosad caused significant reductions in *Thrips tabaci* up to 21 days post treatment (Mahmoud & Osman 2007).

Translocation activity

When applied with irrigation water, the tested insecticides differed markedly in their effect in controlling *L. decemlineata* larvae or adults. While Actara, Spinosad, and Mectin were the most efficient against CPB larvae, Actara was the most efficient against adults. This may be due to the fact that Actara has a translocation activity and is known to be translocated via the xylem (Senn *et al.* 1998), and this property has been confirmed by its prompt activity following the drench application. In addition, it also has a systemic property and can be transported to untreated areas of the plant (Lawson *et al.* 1999). Similarly, Mason *et al.* (2000) found that the translocation of thiamethoxam (Actara) following drench application appeared quite fast and caused high mortality up to 22 days in whiteflies, whereas the foliar treatment was very efficient but short-lasting.

It could be concluded that the application of Acatra, Spinosad, Mectin, and Fitoverm as foliar application at full dose or even at 50% FR would effectively control *L. decemlineata*. Also, the application of Actara, Spinosad, and Mectin, not Fitoverm, to the soil before planting or through the irrigation system could result in a significant reduction in *L. decemlineata* population for at least one month (with approximate 50% mortality). The applications of these three insecticides have minimal effects on beneficial insects, mammals and environment (Bret *et al.* 1997; Lawson *et al.* 1999; Mandour *et al.* 2008). Thus, introducing such safer biorational insecticides in IPM protocols during controlling insect pests in field grown vegetables may be useful tools for minimizing the most hazardous effects of conventional insecticides.

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