Efficacy of Selected Insecticides and Natural Preparations Against *Leptinotarsa decemlineata*

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Abstract

A field experiment was carried out to evaluate the effectiveness of synthetic and natural preparations in protecting potato against *Leptinotarsa decemlineata* (Colorado Potato Beetle). Seven substances and microorganisms with proved or potential toxic effect on the pest were used: Neem extract (*Azadirachta indica*), suspensions of *Beauveria bassiana* Balsamo (Vuillemin) (Hypocreales: Cordycipitaceae) and *Isaria fumosorosea* Wize (Hypocreales: Cordycipitaceae) entomopathogenic fungal spores, natural pyrethrin and three chemical insecticides (lambda-cyhalothrin, thiamethoxam and imidacloprid). Plots where no protection measures were applied served as control. Chemical insecticides were more effective in controlling *L. decemlineata* larvae than natural preparations. It was found that chemical insecticides protected potato yield more effectively than the preparations containing natural pyrethrin or spores of entomopathogenic fungi. Tuber yield from the plots protected with entomopathogenic fungi and Neem extract was significantly higher than that on unprotected plots but still lower than the yield obtained from the plots protected with a chemical preparation.

Keywords Colorado potato beetle · Entomopathogenic fungi · Insecticides · *Leptinotarsa decemlineata* · Pest control · Potato yield

Introduction

Colorado Potato Beetle (*Leptinotarsa decemlineata* Say) has been a major pest problem for potato cultivation for many years with serious infestations every few years (Sosnowska et al. 2009). Colorado Potato Beetle (CPB) may be controlled by various

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methods, starting from quarantine or mechanical methods. Currently, there are many synthetic preparations available for this pest control, such as phospho-organics, pyrethroids or neonicotinoids. Application of synthetic insecticides still remains the most efficient method of reducing the damage caused by this pest. An obvious drawback of this method is the fast development in pests of resistance to applied insecticides, as has happened in CPB to the widely applied neonicotinoids (Szendrei et al. 2012). Control options may affect not only tuber yield but also its quality (Kołodziejczyk et al. 2009). Chemical composition, as well as tuber flesh darkening, is a very important feature of tuber quality, with insecticides known to affect the latter (Sawicka et al. 2006; Zarzecka et al. 2011). Moreover, each application of synthetic insecticides poses a hazard to the environment. In 2013, the European Commission restricted the use of three neonicotinoids (clothianidin, imidacloprid and thiamethoxam) in plant protection products designed for seed dressing. The measure was taken to protect bees and other pollinators. Further restrictions on the uses of these neonicotinoids are under discussion (European Commission 2018). Implementing integrated pest management on a large scale led to growing interest in non-chemical methods. Also, organic agriculture lacks efficient methods for control of CPB. For this reason, research has been conducted on the use of natural enemies to combat this pest. Research on the possible use of entomopathogenic fungi for potato beetle control has been conducted in Poland for many years (Lipa et al. 1998). Results of many works evidence an average to good efficiency of *Beauveria bassiana* in potato protection against potato beetle (Fargues et al. 1980; Hajek et al. 1987; Poprawski et al. 1997; Kołodziejczyk et al. 2009). Despite some promising results, none of the preparations based on entomopathogenic fungi has been registered so far. Natural substances, most frequently plant compounds, which are products of plant metabolism are also gaining importance. These compounds include among others saponins, farnesol and NEEM extract (Waligóra-Rosada 2010; Szczepanik et al. 2011).

The objective of the study was to evaluate the efficacy of foliar application of entomopathogenic fungi and natural plant preparations against CPB larvae, and to compare their efficacy to synthetic insecticides.

Materials and Methods

Experimental Treatments

A field trial was conducted in each of the years 2007 and 2008 at the Experimental Station in Prusy (50° 07' N and 20° 05' E, 271 m asl) of the University of Agriculture in Krakow. Seven methods of potato beetle control were assessed against control without insecticide protection. (1) Neem extract (*Azadirachta indica*—NEEM EXTRACT H.G.—producer Provital S.A. P.I.) (concentration 4%), (2) and (3) suspensions of *Beauveria bassiana* (10^{12} ha⁻¹) and *Isaria fumosorosea* (10^{12} ha⁻¹) entomopathogenic fungal spores, (4) pyrethrin (Spruzit 04EC, 20 g a.i. ha⁻¹) and (5–7) chemical insecticides: lambda-cyhalothrin (Karate Zeon 050 CS, 7 g a.i. ha⁻¹), thiamethoxam (Actara 25 WG, 20 g a.i. ha⁻¹) and imidacloprid (315 g a.i. ha⁻¹) + penycycuron fungicide (337.5 g a.i. ha⁻¹) (Prestige 290 FS). The doses of registered plant protection products were applied in accordance with the information appearing on their labels. Field doses of entomopathogenic fungi were calculated on the basis of

preceding laboratory and field trials (unpublished data). The following strains of entomopathogenic fungi were used in the trials: *B. bassiana* (Bb 57) and *I. fumosoroseus* (12 AL). Prior to the field test, the fungi were cultured on artificial media (potato dextrose agar). The fungal formulation was prepared in a laboratory from conidia powder, which was prepared from sporulating mycelium. The viability of conidia (>94%) was determined under a microscope as follows. A suspension of conidia in Sabouraud Dextrose Broth was placed in hole of glass microscopic slide. After 24 h at 25 °C, the percentage of germinating spores was evaluated.

Imidacloprid (+ pencycyron) was applied only once as a wet tuber treatment during planting, whereas for the other treatments (1–6) and control, the tubers were treated with the fungicide pencycyron (Monceren 250 FS, 375 g a.i. ha⁻¹) to equalise the experimental conditions in all treatments. Other chemical and biological insecticides were used during the period of L₁ and L₂ larval stage appearance—the first treatment. Thiamethoxam was applied only once due to its long-lasting effect. The treatment with lambda-cyhalothrin, pyrethrin, Neem extract, *B. bassiana* and *I. fumosorosea* spore suspensions was repeated 7 days after the first application—the second treatment. All treatments were applied with backpack sprayer (Neptun Kwazar).

Field Experiment

The field experiment each year had a randomised block design with 4 replications. The plot area for harvesting was 18 m² (8 × 2.25 m). Potatoes, cv. Satina, were planted in the second week of April at row spacing 75 × 35 cm. The preceding crop was spring wheat. Mineral fertilisation was applied with 115 kg N ha⁻¹, 31.3 P ha⁻¹ and 233.3 kg K ha⁻¹. Mechanical hilling and chemical weed control was applied: linuron (Afalon Dyspersyjny 450 SC, 900 g a.i. ha⁻¹) and quizalofop-p-ethyl (Targa Super 05 EC, 75 g a.i. ha⁻¹). Fungicides metalaxyl-M and mancozeb (Ridomil Gold MZ 68 WG, 80 g a.i. and 1.24 kg a.i. ha⁻¹) and propamocarb and fluopicolide (Infito 687.5 SC 1.0 kg a.i. and 0.1 kg a.i. ha⁻¹) were applied to control late blight. Characteristics of pluvio-thermal conditions during the period of research and selected physical and physico-chemical properties of the soil's arable layer are presented in Tables 1 and 2.

Table 1 Climatic conditions

Year	Month					Mean/sum
	April	May	June	July	August	
Temperature (°C)						
2007	10.4	15.8	18.1	19.6	19.4	16.7
2008	8.6	14.1	18.5	19.1	18.2	15.7
Long-term period 1997–2007	8.1	13.7	16.5	18.2	17.9	14.9
Rainfall (mm)						
2007	15	57	59	72	125	328
2008	35	28	26	142	45	276
Long-term period 1997–2007	50	65	80	75	79	349

Table 2 Soil characteristics of Luwic Chernozems from trial location (0–25 cm layer)

Properties	pH _{KCl}	P	K (mg kg ⁻¹)	Mg	Organic C	Total N	Sand (g kg ⁻¹)	Silt	Clay
Value	6.1	65.3	140.4	67.5	10.2	1.14	120	540	340

The monitoring of potato beetle was carried out from the beginning of ground cover (BBCH-31). The number of CPB larvae was determined on 10 randomly chosen plants. The larval instars were identified in the field. At the plant flowering stage (BBCH-65), the foliar area was measured by using a LICOR 3100 area meter and values of leaf area index (LAI) were calculated. Prior to the harvest, tuber samples of about 10 kg were collected from each plot to determine the yields of the fractions with small (< 35 mm), medium-sized (35–50 mm) and large (> 50 mm) tubers. At harvest, during the first week of September, total tuber yield was determined. Tubers were assessed for dry matter content (gravimetric method), starch (on Reimann scales), total protein (Kjeldahl method, $N \times 6.25$) and flesh darkening 10 min, 1 and 4 h after cutting tuber in two (on 9-degree reversed Danish scale, where 9, no darkening and 1, the strongest darkening).

Statistical Analysis

Data were subjected to statistical analysis using ANOVA. The significance of differences (LSD, least significant difference) between means was verified by Tukey's test (yield, chemical composition of tubers) or Newman-Keuls test (number of *L. decemlineata* larvae) at significance level $P = 0.05$.

Results

The treatments had a significant effect on CPB larvae occurrence on potato plants (Table 3). Seed tuber dressing with thiamethoxam prior to planting resulted in almost total lack of plant colonisation by potato beetle larvae. For the other treatments, including the control, the mean number of *L. decemlineata* on the day of the first treatment was between 4.4 and 5.8 larvae per plant. On the control (no protection), the number of larvae on the successive dates of observations increased, and the maximum number was noted on the second date of observation (3 days after the first spraying). Three days after the first treatment, the smallest number of larvae was found on the plants protected with lambda-cyhalothrin. Also, the application of imidacloprid during planting caused a significant decrease in the plant colonisation by CPB larvae. Three days after the second treatment of lambda-cyhalothrin, the number of CPB larvae on plants protected by both insecticides was the same. A single spraying with *I. fumosorosea* did not lead to a decrease in larvae number on plants and only 3 days after the second spraying had the number of larvae on plants diminished. Application of *B. bassiana* fungus already caused a decline in the number of CPB larvae developing on potato plants 3 days after the first treatment. Three days after the second spraying, the number of CPB larvae had increased slightly. In case of spraying with pyrethrin, the

Table 3 Population of *L. decemlineata* larvae in plots receiving various protection treatments

Treatments	Number of <i>L. decemlineata</i> larvae (larvae per plant)			Change in number of <i>L. decemlineata</i> larvae (%)	
	Before application	3 days after 1st application	*10 days after 1st and 3 days after 2nd application	3 days after 1st application	10 days after 1st and 3 days after 2nd application
Protection treatments					
Control	5.1	8.6	7.5	+ 70.6	+ 47.4
Neem extract	4.4	3.3	5.0	− 24.1	+ 13.8
<i>B. bassiana</i>	5.8	4.1	4.3	− 29.8	− 26.2
<i>I. fumosorosea</i>	4.8	4.9	3.6	+ 1.5	− 24.7
Pyrethrin	5.1	5.9	6.8	+ 14.6	+ 32.0
Imidacloprid	5.6	1.6	0.6	− 70.8	− 89.0
Lambda-cyhalothrin	5.7	0.5	0.6	− 91.3	− 89.6
Thiamethoxam	0.0	0.0	0.0	–	–
LSD _{p = 0.05}	2.35	2.57	2.19	–	–
Years					
2007	4.9	3.1	4.3	− 36.7	− 12.2
2008	4.2	4.2	2.7	0.0	− 35.7
LSD _{p = 0.05}	n.s.	0.80	0.67	–	–
Mean	4.6	3.6	3.5	− 21.7	− 23.9
Interaction treatment x year significance at $p = 0.05$	n.s.	n.s.	Significant	–	–

*Second spraying was 7 days after the first, n.s. non significant differences

number of CPB larvae increased on the subsequent dates of observations but was still smaller than on the control.

The number of larvae was divided into younger (L₁–L₂) and older larval stages (L₃–L₄) (Table 4). On the date of the first treatment, a majority of CPB larvae (on average ca 96%) were at the L₁–L₂ stage. Three days after the first treatment, the proportion of older developmental stages increased on average by 42%. The highest share of older larvae was on plots controlled with lambda-cyhalothrin, because the younger larvae died after insecticide application. The older larvae seemed to be more resistant to applied insecticides. On control plots, the young larvae developed into older instars. Three days after the second treatment, the share of older larvae was the highest on the control plots (54.7%). The lowest number of older developmental stages of larvae was recorded on the plots protected with lambda-cyhalothrin and imidacloprid.

The investigations revealed a significant effect of insecticides on the LAI, the level of crop yield and on potato tuber yield components (Table 5). The lowest LAI was recorded in control (2.07) and on the plants protected with pyrethrin (2.18). Application of Neem extract, *B. bassiana* and *I. fumosorosea* biopreparations significantly increased LAI in comparison to control. The highest LAI was recorded on plots protected with chemical insecticides (2.91–3.17). The lowest total tuber yield, on average 38.9 t ha^{−1}, was harvested from the control (without insecticide protection) and from plots where pyrethrin was applied (39.1 t ha^{−1}). On plots protected with Neem extract,

Table 4 The age structure of *L. decemlineata* larvae in plots receiving various protection treatments

Treatments	Percentage of L ₃ -L ₄ larvae		
	Before application	3 days after 1st application	10 days after 1st and 3 days after 2nd application
Control	5.5	47.3	54.7
Neem extract	2.9	46.0	42.9
<i>B. bassiana</i>	4.9	40.2	40.1
<i>I. fumosorosea</i>	1.3	47.5	51.5
Pyrethrin	4.6	47.1	47.0
Imidacloprid	3.9	6.5	28.5
Lambda-cyhalothrin	5.2	61.7	21.5
Thiamethoxam	—	—	—
LSD _{p=0.05}	n.s.	33.31	n.s.
Years			
2007	7.1	50.2	48.0
2008	1.0	34.5	33.7
LSD _{p=0.05}	2.91	11.47	13.70
Mean	4.0	42.3	40.9
Interaction treatment x year significance at $p = 0.05$	n.s.	Significant	n.s.

n.s. non significant differences

Table 5 Leaf area index (LAI), yield and tuber size distribution

Treatments	LAI	Total yield of tubers (t ha ⁻¹)	Number of tubers per plant	Average weight of tuber (g)	Fraction of tubers (%)		
					< 35 mm	35–50 mm	> 50 mm
Control	2.07	38.9	8.9	127	2	36	62
Neem extract	2.47	44.0	8.6	137	2	33	65
<i>B. bassiana</i>	2.54	44.2	9.2	129	3	32	65
<i>I. fumosorosea</i>	2.42	44.0	8.7	137	1	35	64
Pyrethrin	2.18	39.1	8.3	135	2	33	65
Imidacloprid	3.17	46.1	8.9	140	2	32	67
Lambda-cyhalothrin	2.91	46.2	8.9	141	1	33	66
Thiamethoxam	2.94	46.1	8.7	142	3	32	65
LSD _{p=0.05}	0.23	3.8	n.s.	12	n.s.	n.s.	n.s.
Years							
2007	2.60	41.0	7.9	121	3	61	36
2008	2.57	46.2	9.7	151	1	5	94
LSD _{p=0.05}	n.s.	1.2	0.4	5	1	2	2
Mean	2.59	43.6	8.8	136	2	33	65
Interaction treatment x year significance at $p = 0.05$	Significant	n.s.	Significant	n.s.	n.s.	n.s.	n.s.

n.s. non significant differences

B. bassiana and *I. fumosorosea* biopreparations, the total tuber yield was on average 44.1 t ha⁻¹ compared with 46.1 t ha⁻¹ for the plants protected with chemical insecticides. There was little variation in tuber size distribution between treatments but a big difference between the 2 years. Total tuber yield, the number of set tubers and their average weight, as well as the share of large tubers, were greater in 2008, which was characterised by a lower amount of rainfall and lower average air temperature than in the same period in 2007.

The average dry matter content in potato tubers of cv. Satina was 21.4%, starch content was 13.9% and total protein content was 20.9 g kg⁻¹ (Table 6). Potato plants protected with *I. fumosorosea* fungus suspension accumulated the lowest amounts of dry matter in their tubers, on average 20.1%, whereas the plants protected with Neem extract preparation accumulated the largest amounts, on average 22.1%. The differences in starch content between treatments were not statistically significant. Total protein concentration fluctuated from 20.0 in the potato tubers protected with lambda-cyhalothrin to 22.0 g kg⁻¹ in those protected with *B. bassiana*. There were no significant differences between treatments on the tendency to raw tuber flesh darkening, although a tendency to stronger darkening of tuber flesh was observed after the application of thiamethoxam. There were just small differences between years with the weather conditions during potato growth in 2008 (smaller amount of rainfall and lower than average air temperature) favouring a slightly greater accumulation of starch and protein and slightly less tuber flesh darkening.

Table 6 Chemical composition of tubers and tuber flesh darkening of raw tubers

Treatments	Content			Darkening after:		
	Dry matter (%)	Starch (%)	Protein (g kg ⁻¹)	10 min	1 h 9° scale	4 h
Control	21.7	14.1	20.9	8.9	8.6	8.1
Neem extract	22.1	14.2	21.1	8.8	8.5	7.9
<i>B. bassiana</i>	21.9	14.0	22.0	8.8	8.5	8.1
<i>I. fumosorosea</i>	20.1	13.5	21.4	8.8	8.5	8.1
Pyrethrin	20.8	13.7	21.0	8.9	8.6	8.1
Imidacloprid	21.3	14.1	20.3	8.8	8.6	8.0
Lambda-cyhalothrin	21.1	13.8	20.0	8.9	8.5	8.0
Thiamethoxam	21.9	13.9	21.2	8.6	8.3	7.7
LSD _{p=0.05}	1.8	n.s.	1.1	n.s.	n.s.	n.s.
Years						
2007	21.1	13.6	20.1	8.7	8.4	8.0
2008	21.6	14.2	21.7	8.9	8.6	8.0
LSD _{p=0.05}	n.s.	0.2	0.3	0.1	0.1	n.s.
Mean	21.4	13.9	20.9	8.8	8.5	8.0
Interaction treatment x year significance at p = 0.05	n.s.	Significant	Significant	n.s.	n.s.	n.s.

n.s. non significant differences

Discussion

Entomopathogenic fungi are regarded as promising control agents of many important pests in Europe and worldwide (Rudeen et al. 2013; Reddy et al. 2014; Wanga and Feng 2014). However, the practical application of entomopathogenic fungi in plant protection is rather limited. Some authors report that entomopathogenic fungi like *B. bassiana* or *I. fomesoroseus* are effective in controlling pests not only occurring in soil but also damaging aboveground parts of plants (Hajek et al. 1987; Daniel and Wyss 2010). Results of our tests revealed that the effectiveness of natural preparations in controlling *L. decemlineata* larvae was significantly lower than chemical insecticides. Chemical insecticides were effective in protecting potatoes against *L. decemlineata* larvae. The reduction in pest larvae was around 90%, 10 days after one spray of imidacloprid or lambda-cyhalothrin. The most effective control was achieved by tuber dressing with thiamethoxam. No *L. decemlineata* larvae developed on potato plants protected with this insecticide. The lower efficiency of *B. bassiana* or *I. fomesoroseus* may be explained by their generally slower action than chemical insecticides. All insecticides were applied in the same weather conditions, but natural ones are more weather dependent than chemical insecticides. This may explain contrasting results in the literature. Foliar application of *B. bassiana* was ineffective or of low to moderate efficacy against *L. decemlineata* in trials done by Wraight and Ramos (2002). The timing of foliar application of entomopathogenic fungi is important. Research of Osman (2010) demonstrates a relative toxicity of some biopreparations and insecticides towards younger larval stages of potato beetle. Our first application was done when most of the *L. decemlineata* larvae were in early development stages (L₁–L₂). Application of entomopathogenic fungi on *L. decemlineata* could then be counterproductive according to Long et al. (1998). So, although the field tests were promising, further trials are needed to improve the strategies of *L. decemlineata* larvae control with entomopathogenic fungi.

The yield of potato tuber depended on the method of CPB control. The lowest total tuber yield was harvested from plots without any protection against CPB. Application of pyrethrin did not cause any increase in potato tuber yield. A marked increase in yield was recorded for the other treatments. The amount of saved tuber yield on the plants protected with Neem extract, *B. bassiana* and *I. fumosorosea* biopreparations was on average 5.2 t ha⁻¹ compared with 7.2 t ha⁻¹ for the plants protected with chemical insecticides. Also, Cutler et al. (2007) found a significant increase in tuber yield on the plants protected chemically in comparison with the unprotected ones. The authors' own studies did not reveal any marked differences either in potato tuber yield between the plants protected by chemical insecticides: lambda-cyhalothrin, imidacloprid and thiamethoxam. Although the level of potato yields on the plants protected by Neem extract, *B. bassiana* and *I. fumosorosea* biopreparations was lower than on the chemically protected plants, the differences were not statistically significant, which points to a considerable yield protective role of these preparations in potato cultivation. In contrast, a rather low yield protective efficiency of various combinations of bioinsecticides was demonstrated by Barčič et al. (2006).

Assimilation area is a decisive factor for plant productivity and its size depends among others on genetic traits of the species and variety, stage of plant development, plant healthiness and on the climatic conditions (Lepiarczyk et al. 2005, Kulig et al. 2010, Zarzyńska and Pietraszko 2015). Reduction of potato plant assimilation area due

to potato beetle larvae feeding leads to reduction of tuber yield. The extent of losses depends on the defoliation degree and leaf development stage at which the defoliation occurs. Cranshaw and Radcliffe (1980) demonstrated that a 33% reduction of leaf area at the initial period of potato development does not affect its yielding because the plants of a majority of potato cultivars may reconstruct their leaf area to a value of four. The influence of the date of the defoliation occurrence on the extent of losses in potato tuber yield was shown also by Zehnder and Evanylo (1989), Dripps and Smilowitz (1989), Senanayake et al. (1993) and Ewing et al. (1994). The largest losses in tuber yield occur when the defoliation occurs at the plant flowering phase (Boiteau 1988). However, as stated by Shields and Vlyman (1984), a 10% defoliation at the flowering phase does not cause a decrease in tuber yield. In the authors' own investigations, the biggest LAI at the plant flowering phase, on average 3.00, was observed on the plants protected chemically. The largest total tuber yield, on average 46.1 t ha⁻¹, was also registered on these plants. On the plants protected with Neem extract, *B. bassiana* and *I. fumosorosea* biopreparations, LAI was smaller on average by 17.6% and tuber yields by 4.5%. On the other hand, on the control and on the plants protected with pyrethrin, LAI at the flowering phase was lower in comparison with chemically protected plants by 29.3% and the tuber yield by 15.5%.

The harmfulness of potato beetle feeding results not only from a reduction in potential tuber yield but also from a worsening of tuber quality, e.g. a diminution or darkening of tubers. Laznik et al. (2010) revealed that both on chemically and biologically protected plants, large- and medium-sized tubers have the greatest share in the total yield, whereas on unprotected controls, it is medium-sized and small tubers. Although the authors' own research revealed a significant effect of potato protection on the formation of average tuber mass, this fact was not reflected in the proportional share of small-, medium- and large-sized tubers in the total yield. No effect of the protection against potato beetle was observed for the number of tubers set by the potato plants. Different results were obtained by Cutler et al. (2007), who demonstrated a significant effect of potato protection against CPB on the number of set tubers. The application of insecticides did not affect the raw potato tuber tendency for darkening. The results are consistent with the reports of Homouz et al. (2005) about a lack of pesticide effect on the concentration of phenol compounds, whose enzymatic oxidation leads to a reddish brown tinge of the tubers. However, other authors (Sawicka et al. 2006, Zarzecka et al. 2011) have found that chemical crop protection has an effect on darkening of tuber flesh.

Potato protection against CPB is also crucial for the chemical composition of tubers. The effect should be regarded in two ways. On the one hand, plant defoliation may affect the intensity of photosynthesis and accumulation of individual components of tuber dry mass, on the other hand, application of insecticides may have a phytotoxic influence on plants. Biological and chemical insecticides assessed in the present investigation did not have any influence on starch concentration in tubers but they affected protein content. The lowest content of this component was found in the plants protected by the chemical insecticides imidacloprid and lambda-cyhalothrin and the highest content after the application of Neem extract, *B. bassiana* and *I. fumosorosea* biopreparations.

Summarising, chemical insecticides protected potato plants against CPB more effectively than the preparations containing natural pyrethrin, whereas tuber yields from the plots protected with entomopathogenic fungi and Neem extract preparation may in some years be similar to the yields obtained from the plots protected with a chemical preparation.

Conclusions

1. Plant derivatives Neem extract and pyrethrin had low insecticidal activity in field conditions against *L. decemlineata* larvae.
2. *B. bassiana* and *I. fumosorosea* were more effective in controlling *L. decemlineata* larvae than other natural preparations but were significantly less effective than chemical insecticides.
3. *B. bassiana*, *I. fumosorosea* and Neem extract preparation protected potato tuber yield almost as effectively as chemical insecticides: imidacloprid, lambda-cyhalothrin and thiamethoxam.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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