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AKADÉMIAI KIADÓ

Efficacy of some chemical insecticides and plant extracts combined with *Bacillus thuringiensis* against *Phthorimaea operculella*

Fereshteh Khorrami* and Asmar Soleymanzade

Young Researchers and Elite Club, Urmia Branch, Islamic Azad University, Urmia, Iran

RESEARCH ARTICLE

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ABSTRACT

Phthorimaea operculella (Zeller, 1873) is one of the most damaging pests of potatoes in the world. Since the chemical pesticides play a key role in managing of potato tuber moth (PTM), the present study was conducted to assess the efficacy of Proteus®, Takumi®, Avaunt®, Dorsban®, Decis®, Consult® and Vertimec® against neonate larval penetration and one-day-old eggs of *P. operculella*. But adverse effects of chemical insecticides, actuated researchers to seek secure tools such as medicinal plants and biopesticides like *Bacillus thuringiensis* Berliner, 1715 for pest managements. Hence, we also examined toxicity of savory, ziziphora and cumin methanolic extracts against the pest under laboratory conditions. We also surveyed the synergistic/antagonistic interactions between the most effective insecticide and methanolic extract with *Bt* against PTM. Our results showed that both Vertimec® and savory synergized the performance of *Bt* against neonate larval penetration of *P. operculella*. Probit analysis of insecticides and methanolic extracts demonstrated that Vertimec® and Takumi® had high toxicities to the neonate larval penetration of PTM which exhibited LC_{50} values equivalent to 7.09 ppm and 0.008 g L^{-1}, respectively. Savory was the most effective extract against larval penetration and hatching rate of the pest (LC_{50} = 440.36 and 635.93 ppm, respectively). Oviposition preference demonstrated that Vertimec® and Decis® exhibited inhibitory ovipositional effects against *P. operculella*.

KEYWORDS

potato tuber moth, medicinal plant extract, chemical insecticide, biopesticide

* Corresponding author. E-mail: fkh.khorrami@gmail.com

INTRODUCTION

The potato tuber moth (PTM), *Phthorimaea operculella* (Zeller) is a noticeable pest of potatoes in many potato cultivation areas (Kroschel and Sporleder, 2006). The pest is difficult to control and many farmers have relied on broad spectrum chemical insecticides. Since PTM larvae penetrate into potato tubers, leaves and stems, making tunnels throughout the potato tubers and high reproductive potential (Khorrami et al., 2018a, b), it causes serious damage and crop losses. As high performance of chemical pesticides, farmers dependent on these compounds to control the pest. Because chemical pesticides are the best way to pest controls, there is a necessity to introduce new pesticides that are effective and low-risks (Kaya and Lacey, 2007). High cost and harm effects of chemical insecticides lead to search and apply safe sources like botanical sources particularly medicinal plants (Rafiee-Dastjerdi et al., 2013a; Sadeghi et al., 2020). Biopesticides based on *Bacillus thuringiensis* are effective. *Bt* appears to be a suitable PTM biological agent against potato tuber moth (Sharaby et al., 2019). There are several investigations to exhibit the role of some botanical extracts as control factors against storage pests but there is less knowledge about their impacts on PTM, for example, Rafiee-Dastjerdi et al. (2013a) reported that applying 5% methanolic extracts of lavender, oregano and licorice extracts on potato tubers caused 19.3%, 24.6% and 34% penetration to tubers, respectively. They estimated larval penetration according to larval tunnels. Some researchers investigated toxicities of some chemical insecticides to 1st instar larvae of PTM (Rafiee-Dastjerdi et al., 2013b; Vaneva-Gancheva and Dimitrov, 2013) but they did not assay their penetrations to tubers. Therefore, we investigated efficacy of some chemical insecticides (Proteus®, Takumi®, Avaunt®, Dorsban®, Decis®, Consult®), two bio-pesticides (*Bt* and Vertimec®) and methanolic extracts of *Satureja hortensis* Linnaeus, 1753, *Ziziphora tenuior* Linnaeus, 1753 and *Cuminum cyminum* Linnaeus, 1753 against neonate larval penetration and one-day-old eggs of the potato tuber moth under laboratory conditions (at 26 ± 1°C, 60 ± 5% RH and a photoperiod of 8L: 16D).

Proteus (Proteus®) exhibits both systemic and contact effects, allowing its active ingredients to protect new areas in the plant. The insecticide is a combination of thiacloprid and delta-methrin (Almasi et al., 2013). Deltamethrin (Decis®) is a synthetic pyrethroid pesticide that kills insects through contact and stomach action. It is applied for a range of commercial crops. It is based structurally on natural pyrethrins, which rapidly paralyze the insect's nervous system giving a quick knockdown effect (Haug and Hoffman, 1990). Flubendiamide (Takumi®) is an insecticide of new chemical class with a novel chemistry and new mode of action by targeting and disrupting the Ca^{2+} balance (Jaiswal et al., 2017). Indoxacarb (Avaunt®) is a novel oxa-diazine insecticide which has good activity against a number of lepidopteran pests, as well as certain homopteran and coleopteran pests. It can be metabolized by insect esterases or amidases to *N*-decarbomet hoxylated metabolite (DCJW), which is a more active sodium channel blocker than indoxacarb, resulting in paralysis and death of target pest species (Shi et al., 2019). Hex-aflumuron (Consult®) like other benzoylphenylureas altered cuticle composition, especially that of chitin, thereby affecting the firmness of the endocuticle (Grosscurt and Anderson, 1980). Abamectin demonstrates both insecticidal and acaricidal properties by acting as agonist to GABA receptors of arthropods nervous system (Kavallieratos et al., 2009). Chlorpyriphos (Dorsban®) inhibits the enzyme acetylcholinesterase (AChE) in synaptic junctions of the nervous system. As a result of this inhibition, acetylcholine accumulated in the synapse causes repeated and uncontrolled stimulation of the post-synaptic axon. Disruption of the nervous system that results is the secondary effect that causes death of the insect (Solomon et al., 2014). *B. thuringiensis* var kurstaki (*Bt*) is a biocontrol agent for defoliating pests worldwide, and individual strains are specific to a small group of insect targets without effects on animals and environment. *Bt* is a Gram-positive spore-forming bacterium. In the sporulation, *Bt* produces crystalline or "Cry" inclusions, called *δ*-endotoxins, biosynthesized during the second phase of the growth cycle. In this cycle, the Cry proteins are converted in active toxins upon insect ingestion (Plata-Rueda et al., 2020).

To obtain PTM same age eggs, 25 male-female pairs of the newly emerged moths were kept inside cylinder containers. The adults were fed using a piece of cotton imbued with a solution of 10% honey-water. The containers covered with fine mesh netting on the ends. Filter paper placed on the netting provided an oviposition site for the moths (Golizadeh and Zalucki, 2012). We also studied synergistic/antagonistic interactions between the most effective insecticide and methanolic extract with *Bt*. In present study efficacy of Vertimec® and Decis® were assessed on ovipositional preference activity of *P. operculella*.

MATERIAL AND METHODS

Insect rearing

The colony of the potato tuber moth was obtained from the University of Mohaghegh Ardabili, Ardabil, Iran and reared on potato cultivar Agria. Experiments were carried out under laboratory conditions (at 26 ± 1°C, 60 ± 5% RH and photoperiod of 8: 16 (L: D)) during 2019–2020.

Insecticides

The insecticides were Proteus® (110 OD, 100 g l^{-1} thiacloprid and 10 g l^{-1} deltamethrin, Bayer Crop Science, New Zealand), Flubendiamide (Takumi®, 20% WG, Nihon Nohgaku, Japan), Indoxacarb (Avanut®, 150 SC, DuPont, France), Hexaflumuron (Consult®, 10% EC, Dow Agrosciences Company), Abamectin (Vertimec®, 1.8 EC, Partonar, Iran), Chlorpyriphos (Dursban®, 40.8 EC, Ariashimi, Iran), Deltamethrin (Decis®, 2.5% EC, Partonar, Iran) and *B. thuringiensis* var *kurstaki* (Costar®, 90.4 MIU g^{-1} WG, Sungenta, Spain).

Methanolic extracts

S. hortensis, *Z. tenuior* and *C. cyminum* were purchased from local market of West Azarbaijan Province, Iran. Methanolic extracts were obtained from leaves of *S. hortensis*, *Z. tenuior* and seeds of *C. cyminum* by using a soxhlet extractor. The soxhlet was heated to the boiling point of the solvent and allowed to cycle for 9h. Excess methanol was evaporated in a rotary evaporator. The collected extracts were tested in the experiments.

Bioassays

Larval penetration

Potato-dipping. To survey larval penetration, each potato was dipped in solutions of Proteus®, Takumi®, Avaunt®, Dorsban®, Decis®, Consult®, *Bt* and Vertimec® determined by preliminary concentrations setting experiments. The concentration ranges for Proteus®, Takumi®, Avaunt®, Dorsban®, Decis®, Consult®, *Bt* and Vertimec® were (5–100 ppm), (0.007–0.01 g L^{-1}), (40–100 ppm), (10–25 ppm), (5–20 ppm), (18–40 ppm), (2–10 g L^{-1}) and (5–10 ppm), respectively. For controls the tubers were immersed in distilled water. When the water evaporated and tubers were dry, the potato tubers were transferred into plastic containers with ventilated lids kept at 26 ± 1°C, 60 ± 5% RH and a photoperiod of 8L: 16D. Then 20 newly hatched larvae (<5 h old) were placed on each tuber by a soft hairbrush. Criterion of larval penetration was the number of pupae and adult emergence in all experiments. Each trial was replicated three times. The experiments carried out for *S. hortensis*, *Z. tenuior* and *C. cyminum* as mentioned above but in control experiments, methanol was used instead of distilled water. The ranges for savory, cumin and ziziphora were (200–800), (500–1500) and (400–1100) ppm, respectively.

One-day-old egg-dipping. To investigate the toxicities of mentioned insecticides and methanolic extracts, one-day-old eggs of *P. operculella* were dipped in solutions of Proteus®, Takumi®, Avaunt®, Dorsban®, Decis®, Consult®, *Bt* and Vertimec® determined by preliminary dose setting experiments. The concentration ranges for Proteus®, Avaunt®, Decis®, Consult® and Vertimec® were (75–150), (110–160), (120–170), (75–110) and (50–100) ppm, respectively. Each filter paper contained 20 one-day old eggs. When the water had evaporated and filter papers were dry, they were transferred into plastic containers with ventilated lids which contained intact potato tubers to stimulate egg hatching. The plastic containers were kept at 26 ± 1°C, 60 ± 5% RH and a photoperiod of 8L: 16D. Egg hatchability was assayed using a light microscope after eight days. Each trial was replicated three times. The trials of methanolic extracts were performed as the same one while methanol was used instead of distilled water. The ranges for savory, cumin and ziziphora were (350–1000), (650–2000) and (700–1400) ppm, respectively.

Bt combined with Vertimec®/methanolic extract of savory. Sub-lethal concentration (LC_{25}) of *Bt* was combined with LC_{25} of Vertimec® (*Bt* + Vertimec®)/savory (LC_{25}) (*Bt* + savory) separately to examine whether there was a synergistic or antagonistic interactions between *Bt* with plant extract/Vertimec®.

Ovipositional preference activity of PTM. Trials were carried out following Rafiee-Dastjerdi et al. (2013a), so each potato was dipped in solutions of LC_{50} of Vertimec® and Decis®. Three tubers were dipped in 100 ml of each insecticide and the fourth one (control) was dipped in 100 ml distilled water. After water evaporating, these tubers were put in the four sides of the mesh cage (35 × 35 × 35 cm). Fifteen virgin pairs of one-day-old adults (15 males & 15 females) were transferred into each mesh cage and their ovipositional rates was recorded up death of all females, but since the most ovipositional rate of the pest is in the first three days, data analysis was conducted for the first three days. The experiment had three replicates in laboratory conditions at 26 ± 1°C, 60 ± 5% RH and photoperiod of 8: 16 (L: D). Experiments carried out for each insecticide separately.

Data analysis. In order to determine LC_{50} and LC_{25} values, the data were analyzed using the probit procedures with SPSS for Windows® release 16. To assign synergistic/antagonistic interactions, trials were carried out following Khorrami et al. (2018a). The relationship between data was assayed by analysis of variance (ANOVA). The means were separated by using the

Tukey's test. The expected efficacy of a mixture, expressed as percent control (%C_{exp}) can be predicted by the %C_{exp}=A+B–(AB/100) formula in which A and B are the control levels given by the single insecticides (Tallarida, 2000; Khorrami et al., 2018a, c).

RESULTS

According to Table 1, bioassays on neonate larval penetration of potato tuber moth into potatoes by applying Avaunt®, Consult®, Decis®, Proteus® and Vertimec® resulted in LC_{50} values equivalent to 70.55, 28.16, 9.54, 26.14 and 7.09 ppm, respectively. Hence, Vertimec® and Decis® had high preventive effect against neonate larvae of PTM.

Results presented in Table 1 demonstrate LC_{50} values of using *Bt* and Takumi® on PTM larval penetration (4.55 and 0.008 g L^{-1}, respectively). Results showed that Vertimec® and Takumi® exhibited the lowest LC_{50} values (7.09 ppm and 0.008 g L^{-1}, respectively) that reveal they had the highest preventive effects on PTM neonate larval stage. *Bt* demonstrated high toxicity to penetrate of neonate larvae of *P. operculella* into potato tubers (LC_{50} = 2.04 g L^{-1}) (Table 1).

The results given in Table (1) show that neonate larval stage of PTM that were exposed to potatoes dipped in *C. cyminum*, *S. hortensis* and *Z. tenuior* methanolic extracts, responded to these extracts with LC_{50} values equivalent to 961.07, 440.36 and 719.12 ppm, respectively. Therefore, *S. hortensis* methanolic extract indicated the most efficacies against neonate larval penetration of *P. operculella* into tubers.

One-day-old eggs of PTM apparently were sensitive to Vertimec® (LC_{50} = 71.15 ppm). Consult® and Proteus® were toxic against the pest (Table 2).

Savory methanolic extract presented high activity against one-day-old eggs of PTM (LC_{50}= 635.93 ppm) (Table 2).

Despite the highest efficacy of Takumi® against larval penetration of PTM into tubers, as it has no ovicidal activity, we assayed synergistic/antagonistic interaction between Vertimec® with *Bt* against the pest. Inclusion of Vertimec® with *Bt* lead to a synergistic interaction against neonate larval penetration of potato tuber moth. However, there was an antagonistic interaction in the inclusion of Vertimec® with *Bt* against 1-day-old eggs of the pest (Table 3).

Methanolic extract of savory synergized the performance of *Bt* against neonate larvae of PTM but the inclusion of them appear to lead to an antagonistic interaction against 1-day-old eggs of the pest (Table 4).

According to Table (5), Decis® and Vertimec® reduced the number of laid eggs of PTM females on treated tubers while the pest preferred to lay eggs on non-treated potato tubers ($F_{(2,24)}$ = 12.80; $P < 0.05$). Hence, potato tubers dipped in the mentioned insecticides decreased egg laying of *P. operculella* and there was a significant difference between treatments and control (Table 5).

DISCUSSION

In the present study, Takumi®, *Bt*, Decis® and Vertimec® displayed high insecticidal activities against neonate larval penetration of potato tuber moth into potato tubers and Takumi®, *Bt* and Vertimec® had the highest preventive effects on PTM larval stage. Rafiee-Dastjerdi et al. (2013b)

Table 1. Effect of some toxic tested materials to neonate larvae of *Phthorimaea operculella* into potato tubers under laboratory conditions

Tested materials	LC_{25} (ppm/(g/L))	LC_{50} (ppm/(g/L))	LC_{90} (ppm/(g/L))	Slope ± SE	χ^2
Avaunt®	44.26 (35.12–50.60)	70.55 (63.67–79.54)	171.07 (132.70–279.11)	4.92 ± 0.56	1.60
Consult®	18.70 (14.70–21.30)	28.16 (25.62–30.97)	61.29 (49.45–93.80)	4.68 ± 0.66	1.33
Decis®	4.97 (3.53–6.10)	9.54 (8.17–11.05)	32.89 (24.21–56.96)	5.47 ± 0.36	0.80
Proteus®	5.75 (2.66–9.01)	26.14 (18.64–37.76)	76.44 (88.39–109.01)	5.06 ± 0.16	1.61
Vertimec®	4.83 (3.81–5.48)	7.09 (6.48–7.75)	14.70 (12.03–22.05)	4.55 ± 0.72	0.83
Bt	2.04 (1.34–2.62)	4.55 (3.79–5.48)	20.79 (13.92–43.95)	5.13 ± 0.31	1.70
Takumi®	0.007 (0.006–0079)	0.008 (0.0087–0.009)	0.012 (0.11–0.14)	5.09 ± 1.37	1.33
ziziphora	445.04 (352.53–511.88)	719.12 (645.94–808.11)	1789.67 (1401.15–2803.56)	5.31 ± 0.51	2.19
savory	218.77 (154.82–268.00)	440.36 (377.13–524.24)	1663.73 (1149.82–3339.61)	5.08 ± 0.36	1.13
cumin	538.78 (397.56–639.24)	961.07 (845.71–1111.76)	2886.10 (2104.85–5364.64)	4.77 ± 0.46	2.40

95% fiducial limit (FL) is shown in parentheses.

Table 2. Probit analysis of toxicity of some insecticides and three methanolic extracts to 1-day-old egg of *Phthorimaea operculella*

Tested materials	LC_{25} (ppm)	LC_{50} (ppm)	LC_{90} (ppm)	Slope ± S.E	χ^2
Avaunt®	106.48 (92.53–114.44)	132.46 (125.85–139.32)	200.56 (178.25–256.49)	4.34 ± 1.33	1.66
Consult®	76.82 (70.04–81.16)	92.40 (88.63–96.55)	131.24 (119.59–155.65)	5.29 ± 1.33	0.67
Decis®	119.90 (106.79–127.55)	144.27 (137.94–150.38)	205.05 (186.64–247.14)	4.65 ± 1.48	1.26
Proteus®	78.26 (65.79–86.64)	109.70 (101.61–118.82)	208.39 (175.70–285.99)	5.19 ± 0.74	0.62
Vertimec®	51.97 (44.33–57.23)	71.15 (66.11–76.45)	129.23 (111.43–168.00)	5.59 ± 0.75	0.58
ziziphora	743.95 (627.27–822.32)	1047.92 (971.05–1140.26)	2009.21 (1679.27–2814.95)	5.10 ± 0.74	2.00
savory	359.48 (263–426.96)	635.93 (560.26–732.59)	1879.79 (1376.20–2500.19)	4.66 ± 0.48	1.47
cumin	673.64 (495.03–802.69)	1210.50 (1062.14–1396.82)	3686.35 (2701.69–6710.83)	4.90 ± 0.44	2.47

95% fiducial limit (FL) is shown in parentheses.

Table 3. The synergistic/antagonistic interaction between Vertimec® with *Bt* against neonate larval penetration and 1-day-old eggs of *Phthorimaea operculella*

Bt + Vertimec®	% Mortality ± S. E.		
stage	Expected	Observed	Interaction
Neonate larvae	59.00 ± 1.99	78.00 ± 2.64	synergism
One-day-old eggs	57.91 ± 2.75	40.22 ± 2.19	antagonism

Table 4. The synergistic/antagonistic interactions between savory methanolic extracts with *Bt* against neonate larval penetration and 1-day-old eggs of *Phthorimaea operculella*

Bt + ME of savory	% Mortality± S. E.		
stage	Expected	Observed	Interaction
Neonate larvae	56.00 ± 1.68	79.00 ± 2.93	synergism
One-day-old eggs	58.66 ± 1.98	36.66 ± 1.09	antagonism

ME: methanolic extract.

Table 5. The mean number of laid eggs of *Phthorimaea operculella* on treated and untreated tubers after 24, 48 and 72 h (ovipositional preference)

Tested insecticides		The mean number of eggs ± S. E.		
	Concentrations (ppm)	24 h	48 h	72 h
Decis®	10	0^{b}	0^{b}	0^{b}
Vertimec®	10	0^{b}	0^{b}	0^{b}
Control	0	$2.66^{a} \pm 1.01$	$3.33^{a} \pm 1.51$	$4.00^{a} \pm 1.73$

* Means in columns with the same letter are not significantly different ($P < 0.05$).

assayed lethal and sub-lethal effects of abamectin and deltamethrin on potato tuber moth. They dipped the potato leaves in the insecticide solutions then the larvae were transferred on leaves into Petri dishes. They reported that abamectin had the highest toxicity to the first instar larvae of the pest that consistent with our results. Corbitt et al. (1989) noted that abamectin exhibited the highest toxicity on 1st instar larvae of *Heliothis* sp. The most investigated and practically used for control of PTM are a granulovirus and the bacterium *Bt*. *Bt* has been successfully used against PTM infestations in both field crops and stored tubers (Kaya and Lacey, 2007). In this investigation, the main goal of applying *Bt* was to test the combination of it with insecticides and medicinal plant extracts.

Salama et al. (1995) evaluated effectiveness of various strains of *Bt* against PTM larvae. They found that fourteen out of 65 cultures caused more than 80% larval mortality of the first instar which three of the most active strains were H-type *kurstaki* which confirm our result. Based on our results, savory methanolic extract had the highest preventive effects against first instar larvae of PTM. Rafiee-Dastjerdi et al. (2013a) reported that *Lavandula angustifolia* Miller, *Origanum vulgare* Linnaeus and *Glycyrrhiza glabra* Linnaeus methanolic extracts demonstrated the lowest larval penetration of the pest, compared with 90.22% and 82% penetration for the control and *Fumaria officinalis* Linnaeus extract, respectively. Vertimec® showed the most ovicidal activity to 1-day-old eggs of PTM. Abamectin and deltamethrin had toxic and acceptable effect on eggs of *P. operculella* (LC_{50}= 0.92 and 0.095 mg AI/L), but deltamethrin had the highest toxicity to the egg (Rafiee-Dastjerdi et al., 2013b). Savory methanolic extract was the most effective extract against one-day-old eggs of *P. operculella*. There was no research about efficacy of methanolic extracts to hatching rate of PTM eggs.

According to Kroschel and Koch (1996) research, Fenvalerate, diflubenzuron and *Bt* prevented the development of the larvae once eggs had hatched. Fenoxycarb prevented the development to the adult, but 50% of the eggs developed as far as the larval and pupal stages and larvae caused damage to the tubers. They also noted that the effectiveness of the water extract of neem was 93.8% that elicited high efficacy of neem extract against the pest. The inclusion of *Bt* with Vertimec® against neonate larval penetration and hatching rate of 1-day-old eggs of PTM appear to lead to synergistic and antagonistic interactions, respectively. *Bt. k* mixed with fine sand dust containing quartz supplied impressive control in tuber storage in the Republic of Yemen (Kroschel and Koch, 1996). Concerning the neonate larvae and 1-day-old eggs of PTM exposed to mixture of *Bt* with methanolic extract of savory, the synergistic and antagonistic interactions was recorded, respectively. *Bt* formulations in storage could be improved by the addition of plant extracts containing insecticidal properties. According to the report, extracts of *Atropa belladonna* Linnaeus, *Hyoscyamus niger* Linnaeus and *S. nigrum* plants decreased the LC_{50} values of *Bt* against PTM from 82 $\mu g\ ml^{-1}$ to 43, 31 and 40 $\mu g\ ml^{-1}$, respectively (Sabbour and Ismail, 2002). Based on our findings, the number of laid eggs on tubers treated with LC_{50} values of Decis® and Vertimec® were significantly decreased. Therefore, the pest preferred to oviposit on non-treated tubers. Two used pesticides had high inhibitory effects against the pest. Oviposition preference of some medicinal plant extracts was investigated against *P. operculella* (Rafiee-Dastjerdi et al., 2013a). They reported that females of PTM preferred to oviposit their eggs on non-treated tubers and the number of laid eggs on treated tubers that dipped in oregano, lavender and licorice methanolic extracts were 0 but *F. officinalis* had rather low inhibitory effects.

Ajamhassani and Salehi (2004) surveyed the effect of leaf powder and 5% extract of *Sambucus ebulus* Linnaeus, *Artemisia annua* Linnaeus and *Pterocarya fraxinifolia* Spach on oviposition rate of potato tuber moth. They noted that either the leaf powder or extracts was deterrent but the extracts were more deterrent than their powders. Therefore, one of the imperfections of botanical pesticides is their quick degradation that this problem can be overcome through recent technological advances such as nanotechnology that will convenient future use of these compounds in commercial and conventional crop production systems (Khater, 2012). In the other hand, one of the most significant problems for introducing and using botanical sources in stores and fields, is lack awareness and knowledge of farmers about these safe compounds for pest management.

We hope that farmers could agree and apply these compounds for healthy diet because a sound mind is in a sound body. Unfortunately, nowadays pesticides are the best components to control the pests; thus application of sub-lethal doses of pesticides can be very effective in reducing their risks. Therefore, integration of sub-lethal doses of these dangerous compounds with sub-lethal doses of safe compounds such as botanical and biorational sources can be useful and efficient.

CONCLUSIONS

Generally, our results presented that these chemical, biorational and botanical compounds had larvicidal and ovicidal activities against the potato tuber moth and can be suitable candidates in integrated PTM management programmes. Nevertheless, Takumi®, *Bt*, Vertimec® and savory showed the highest activities against the pest. Since the number of laid eggs of the pest on treated tubers with Decis® and Vertimec® were significantly lower than non-treated tubers, potato dipping in these pesticide solutions is a good method prior to potato storage.

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