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Efficacy of agrochemicals against *Phyllobius oblongus*

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Abstract: The contact, residual, and ingestion efficacy of two conventional insecticides was compared with that of another five environmentally friendly agrochemicals in a laboratory for the control of the European snout beetle. Very good efficacy was observed for the conventional product Reldan 22® after all types of exposures. The conventional Mospilan® 20 SP showed good efficacy after ingestion. SpinTor® was very effective 72 h after ingestion and contact, and Siltac® EC showed comparable efficacy with conventional insecticides 72 h after ingestion and residual contact. SpinTor® and Siltac® conform to the principles of organic farming and integrated pest management (IPM) and are able to replace both the tested conventional products in young fruit plantations and nurseries. Pyrethrum PNC – 17, FerrumOil, and Boundary SW did not sufficiently control the beetle.

Keywords: weevil; orchards; plant protection products; contact efficacy; residual efficacy; ingestion efficacy

The European snout beetle [*Phyllobius oblongus* (Linnaeus, 1758)] is a pest of broadleaf trees. It was even included to the international important species in relation to damaging poplar trees (Tillese et al. 2006). In central Europe and Great Britain, *P. oblongus* is also found in fruit plantations (Morris 1997; Balan et al. 2001; Bayley et al. 2010; Markó et al. 2017), where adult beetles can cause serious damage to young fruit trees during spring. They feed on leaves, buds, and flowers (Savic 1963; Witter & Fields 1977; Billiald et al. 2010). Targeted controls do not exist in orchards and we do not have sufficient knowledge of the efficiency of agrochemicals in the event of an outbreak of this pest. Only broad-spectrum insecticides containing chlorpyrifos-methyl (Reldan 22®) have been widely used against the pest (Gall 2015). Although the efficacy of chlorpyrifos-methyl against various pests is high, it is also detrimental to beneficial arthropods, with prolonged use (Suma et al. 2009; Mansour et al. 2011; Lozowicka 2015). In addition, evidence exists for negative consequences on the human population (Trasande 2017; PAN Europe 2018). For this reason, use of chlorpyrifos-methyl to protect orchards has been withdrawn in a number of countries in the EU.

Consequently, there is a need for alternative agrochemicals for the control of the European snout beetle for early spring orchard protection.

Neonicotinoids are effective in lower doses compared to other conventional insecticides. The neonicotinoid product Mospilan® (20 SP, Mospilan, Czech Republic) (acetamiprid) is approved for foliar application on a range of pests of fruit and vegetable crops (Kundoo et al. 2018)

SpinTor® (SpinTor, spinosad, Czech Republic) is a metabolic product of the actinomycete *Saccharopolyspora spinose* (Bacci et al. 2016). Spinosyns are expected to have great potential because these agrochemicals show a greater selectivity toward target insects while being relatively harmless to most beneficial arthropods and mammals (Cleveland et al. 2001) and have a proven efficacy for controlling a wide range of pests in agriculture (Kerns 1996; Linduska et al. 1998; Gazit et al. 2013).

Pyrethrum PNC – 17 (pyrethrins) is a product class extracted from chrysanthemum plants and

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generally short of persistence (Sarwar & Salman 2015), and have broad usage in organic agriculture (Maina et al. 2016). They exhibit an excellent knockdown effect against flying insects, but weevils have been known to be resistant to pyrethrins for a very long time (Lloyd & Parkin 1963; Kikuta et al. 2012).

The vast majority of insecticides are biologically active on the nervous or metabolic pathways in the target insects, but it also is possible to find agrochemicals that act purely physically. For example, Siltac® EC (ICB Pharma, Poland) is a silicone-based product, which immobilises the insects that feed on the plants (ICB Pharma 2019).

Some fertilisers claim to protect against diseases and pests (Reuveni & Reuveni 1998; Nour-Eldin & Sholla 2015). For example, Boundary® SW (ICAS, Italy) claims to have insecticidal side effects and is sold as a fertiliser. It contains extracts from seaweed and succulent plants (ICAS 2018). Another fertiliser, FerrumOil® (Bioka, Slovakia), contains natural fatty acids and terpenes (Bioka 2019). Some terpenes and natural acids are known to have insecticidal properties (Perumalsamy et al. 2015; Dambolena et al. 2016).

Using laboratory tests to test for the residual, contact and ingestion efficacy, the aim of this study was to find an effective insecticidal treatment that would prevent damage to young trees from *P. oblongus*. The agrochemicals used in the study were selected on the basis of their current (recently approved) and potential (probably approved in the future) use in orchards. We also focused on agrochemicals (SpinTor®, Pyrethrum PNC – 17, Siltac® EC, Boundary® SW, and FerrumOil®) that would fit into an Integrated Pest Management (IPM) Programme and be compliant with organic crops (Rigby & Cáceres 2001; Barzman).

MATERIAL AND METHODS

The experiments were conducted under laboratory conditions in 2017 and 2018 with adult *P. oblongus* collected by hand into plastic tubes within agrochemically untreated apple, pear, and cherry nurseries of the Research and Breeding Institute of Pomology Holovousy, Hořice, Czech Republic (50°22'24.9"N, 15°34'53.2"E). The beetles were housed together in laboratory conditions (22 ± 1 °C, 75 ± 5% relative humidity, 16 : 8 light/dark photoperiod) in plastic catches (12 × 12 × 6 cm) two weeks prior to the laboratory experiment. They were fed *ad libitum* with untreated cherry tree leaves and water was provided on a moistened piece of tissue.

Application of agrochemicals. In three experiments, the residual, contact, and ingestion efficacy of seven agrochemicals were investigated. Distilled water was used as a control. For each experiment, 160 adult individuals (80 adult individuals in each year) were used (total $N = 480$). Five beetles in four replications (altogether 20 beetles) were used each year for each agrochemical treatment, again with distilled water as a control. Each beetle was tested once. All agrochemicals (Table 1) were tested at the concentrations and field doses recommended for orchards, according

Table 1. The specifications of the agrochemicals studied for the possible effects on *P. oblongus*

Trade name and formulation	Type	Distributor	Active ingredient	Specification	Dose/ha
Mospilan® 20 SP	C	Nisso Chemical Europe GmbH	Acetamiprid	Insecticide	0.25 kg
Siltac® EC	EF	ICB Pharma	3D-IPNS – polymers Silicones+siloxanes	physically based plant protection product	1.5 L
Boundary® SW	EF	ICAS SRL	fermented seaweed extract and succulent extract	auxiliary plant protection product	2.5–4.0 L
FerrumOil®	EF	Bioka s.r.o.	Fe,Mg, N+ terpenes, limonene, geraniol	fertilizer	2.0–6.0 L
SpinTor®	EF	Dow AgroSciences s.r.o.	Spinosad	insecticide	0.6 L
Reldan 22®	C	Dow AgroSciences s.r.o.	Chlorpyrifos-methyl	broad-spectrum insecticide	2.7 L
Pyrethrum PNC – 17	EF	In registration process	Pyrethrum	insecticide	0.47 L

C – conventional; EF – enviromental friendly

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to the product labels, and while following the instructions provided by the Central Institute for Supervising and Testing in Agriculture (2018), which provides the exact rules on how to use plant protection products (a very important group of agrochemicals).

For the residual efficacy tests, each treatment was sprayed using a Potter precision laboratory spray tower (Burkard Scientific, UK) into the bottom of a Petri dish (5.5 cm in diameter) and also into the inner part of the lid. The standard application was between 1.5 and 2 mg/cm^2, which is equivalent to wet deposit of a pesticide for a volume of 400 L/ha in orchards. Each Petri dish and its lid were then allowed to dry under a laboratory hood. One beetle was placed into each treated Petri dish along with an untreated leaf as food and a piece of moistened tissue to provide water. Each Petri dish was marked with an exclusive code consisting of an abbreviation for the treatment and number of the repetition.

For the contact efficacy test, each beetle was sprayed using the Potter tower. The amount of material applied was the same as for the residual efficacy methodology. Immediately after spraying, the beetles were placed into clean Petri dishes (5.5 cm in diameter) and water and food were provided as in the residual efficacy test.

For the ingestion effect test, cherry leaf disks (25 mm in diameter) were submerged (dipped) into the agrochemical treatment for 3 seconds. Each leaf disk was dried, then placed in the Petri dish with one beetle.

Efficacy assessment. The mortality of each individual was recorded 24, 48, and 72 h after the direct treatments (spraying), the first contact with the treatment residues on the Petri dish or the first contact with the treated cherry leaf disk.

Statistical analysis. Abbott's method (1925) was used for testing the agrochemical efficacy (e.g., Rodríques-Gonzáles et al. 2017). The data were transformed using an arcsine transformation. The untransformed means and standard errors are reported in the figures. The differences in the mortality of P. oblongus among the tested insecticides were analysed using a repeated-measures ANOVA with the exposure time as the repeated factor. The group means were compared using Tukey's HSD test (α = 0.05). All the analyses were performed with STATISTICA 10 (version 10). All the laboratory experiments were conducted twice and, because the results from the two experimental runs were similar (variance between the two runs ≤ 0.05), the data were combined for analysis.

RESULTS

For each insecticidal mode of action, the insecticide treatment, exposure time, and their interactions significantly affected the mortality of *P. oblongus* (Table 2).

Residual effect of the tested agrochemicals. The efficacy was dependent upon exposure time (Table 2) for the *P. oblongus* exposure to the product residuals. The effectiveness of the insecticides generally increased over time, except Pyrethrum, which had the same efficacy at all exposure times (a mortality of only 5%). Reldan 22® was the most effective insecticide; the mortality was 100% at all the exposure times. Siltac® EC was also effective (a mortality of 65% at 72 h), with Mospilan® 20 SP, FerrumOil®, Boundary® SW, SpinTor®, and Pyrethrum PNC – 17 causing the lowest mortality in the *P. oblongus* at all the exposure times (Figure 1).

Contact effect of the tested agrochemicals. Reldan 22® had the highest efficacy when *P. oblongus* was sprayed directly with the products. The efficacy was 70% at 24 and 48 h, and 85% at 72 hours (Figure 1). Similarly, the efficacy from direct application of SpinTor® was 50% at 48 h and 85% at 72 hours. The lowest efficacy was observed for Boundary® SW, FerrumOil®, and no mortality was recorded after the Pyrethrum PNC – 17 application. The efficacy of the insecticides was significantly affected by the exposure time (Table 2).

Ingestion effect of the tested agrochemicals. The most effective insecticide in the dipped leaf

Table 2. The analysis of variance results from the laboratory testing for the efficacy of the agrochemicals according to the treatment, time, and their interaction on the mortality of *P. oblongus*

Insecticidal mode of action	Factor	*df*	*F*	*P*
Residual	TR	6	48.04	< 0.0001
	T	2	29.99	< 0.0001
	TR × T	12	4.01	0.0004
Contact	TR	6	8.18	< 0.0001
	T	2	28.53	< 0.0001
	TR × T	12	3.89	0.0005
Ingestion	TR	6	16.53	< 0.0001
	T	2	45.82	< 0.0001
	TR × T	12	5.10	< 0.0004

The data for the analysis of variance were combined from the two experimental runs; *df* – degree of freedom; *F* – *F* value, *P* – significance level; TR – treatment; T – time

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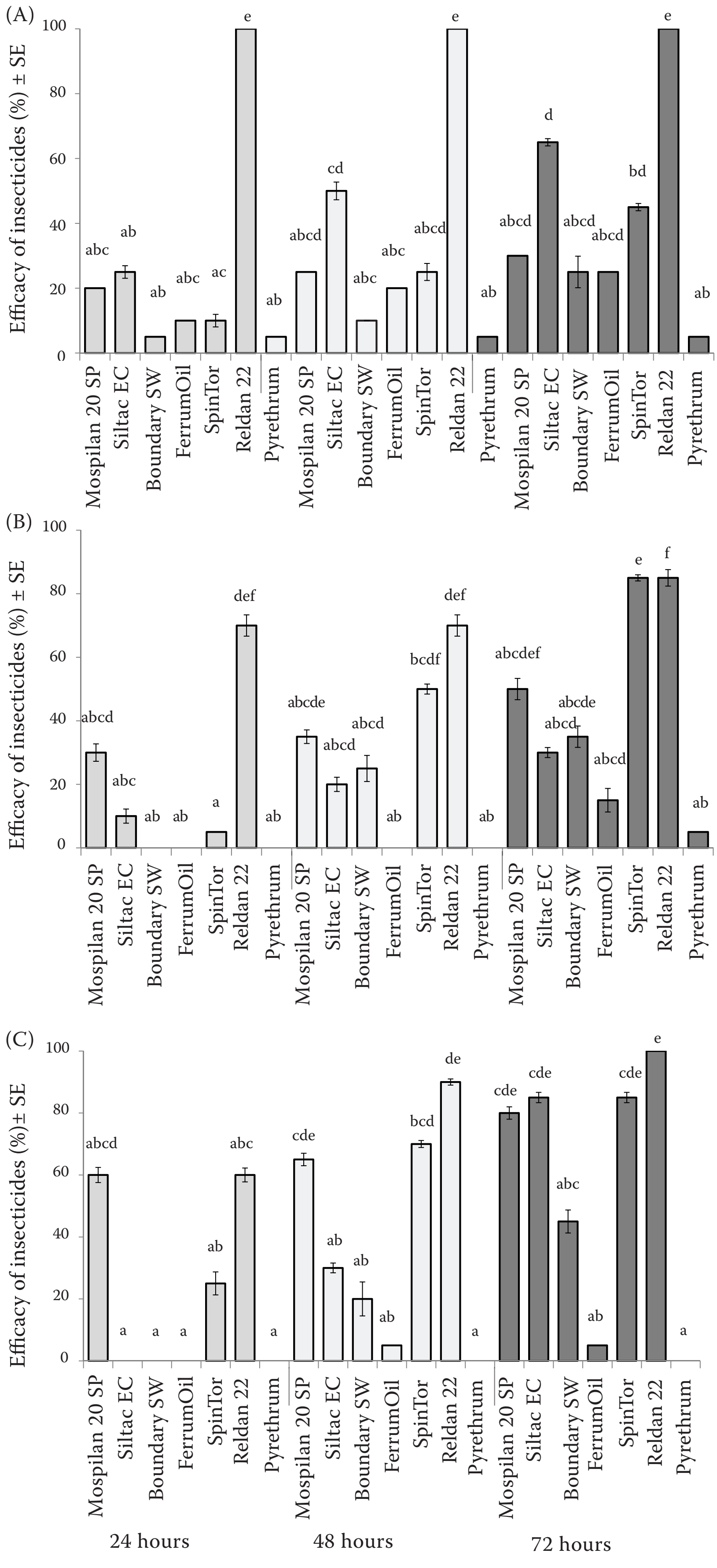

Figure 1. (A) The residual, (B) contact and (C) ingestion (product applied directly to a petri dish) effect of the agrochemicals on the mortality of *P. oblongus*

The results are presented as a mean percentage effect ± SE of the agrochemicals on the mortality of *P. oblongus*; the bars with the same letter do not differ significantly at $P < 0.05$; the different colours of the bars represent the exposure time (24, 48 and 72 h)

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ingestion tests was Reldan 22®, and its efficacy was dependent upon the exposure time (60, 90 and 100% at 24, 48, and 72 h, respectively). It was followed next by Mospilan® 20 SP (the efficacy was 60, 65 and 80% at 24, 48, and 72 h, respectively) and SpinTor® (an efficacy of 70% at 48 h and 85% at 72 hours). A high efficacy was also observed for Siltac® EC (30% at 48 h and 85% at 72 hours). Pyrethrum PNC – 17 had zero efficacy, and a very low efficacy was recorded for FerrumOil®, and Boundary® SW (Figure 1C).

DISCUSSION

Seven agrochemical products were evaluated under laboratory conditions for the control of *P. oblongus* adults with the aim of identifying the products suitable to replace the broad-spectrum insecticide chlorpyrifos-methyl.

Spinosad (SpinTor®) had poor efficacy upon contact with the dried residue (10% after 24 h), the highest efficacy occurred 72 h after direct contact (85 %), and after ingestion (85%). Bažok et al. (2016) achieved the highest effectivity of a spinosad by ingestion (36.36%) and ingestion combined with direct contact (45.45%) on the sugar beet weevil, *Bothynoderes punctiventris* (Germar, 1824) (Coleoptera: Curculionidae) and 100% mortality after 24 h (direct spraying) was observed via contact with SpinTor® residues on *Phyllobius oblongus* (Skalský et al. 2015).

Mospilan® 20 SP had low efficacy after residual contact on *P. oblongus* adults, and its highest effectivity was achieved by ingestion (80% after 72 hours). This product has, however, been effective against the strawberry blossom weevil, *Anthonomus rubi* (Herbst, 1795) (Coleoptera: Curculionidae) (Łabanowska et al. 2000). Thiamethoxam, a second-generation neonicotinoid, has been proven effective 72 h after ingestion of treated leaves against the eucalyptus snout beetle adults, *Gonipterus scutellatus* (Gyllenhal in Schönherr, 1833) (Coleoptera: Curculionidae), but the efficacy was insufficient 72 h after direct contact (Echeverri-Molina & Santolamazza-Cardone 2010).

Pyrethrin was relatively ineffective in our study on *P. oblongus* by all three methods of exposure. However, the efficacy of pyrethrum can be improved in formulation with other insecticides, such as piperonylbutoxide, gamma-cyclodextrin, or botanical oils (Watts & Berlin 1950; Biebel et al. 2003). Wanyika et al. (2009) found pyrethrins are effective against maize weevils [*Sitophilus zeamais* (Motschulsky, 1855)] (Coleoptera: Curculiondiae) when applied with oils extracted from *Azadirachta indica* A. de Jussieu (neem tree), *Thevetia peruviana* (Pers.) K. Schum, and *Gossypium hirsutum* Linnaeus. Natural pyrethrum extracts are very quickly degradable by UV (ultraviolet) light and lose their insecticidal activity. Therefore, it is necessary to make them photostable in pesticide formulations (Maina et al. 2016). Based on the references cited above, it is possible that the efficacy of Pyrethrum PNC – 17 could be improved by the addition of oils to the tank mixes, or when this active ingredient will be formulated into the final product. However, further investigation is warranted, due to the high probability of resistance.

According to the manufacturer, the mode of action of Siltac® EC is to physically create a thin, sticky film on the body of the insect that immobilises and rapidly eliminates them. The product is recommended for use on fruit trees and berries to control aphids, spider mites, rust mites, psyllids, and scale larvae (ICB Pharma 2019). However, our experiments indicate that this product may have other modes of action.

Both fertiliser products, Boundary® SW and FerrumOil®, were low in the lethality of *P. oblongus*. In a previous study, however, Boundary® SW was 100% effective against the leaf-rolling beetles, *Anthonomus pomorum* (Linnaeus, 1758) and *Tatianaerhynchites aequatus* (Linnaeus, 1767) 24 h after being sprayed irectly using a hand sprayer (Skalský 2017). To our knowledge, FerrumOil® has never been tested for its effect on pests. This product did not show any potential for acting against *P. oblongus*.

Our study offers an initial screening of agrochemicals, which require further investigation and field testing in commercial crops for the control of *P. oblongus*. Our laboratory tests showed a huge potential for SpinTor® and Siltac® EC, both of which could be incorporated into organic and IPM crops to reduce foliar and flower damage to fruit trees by *P. oblongus*. However, further field testing is required to support this.

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