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Field and greenhouse evaluation of rapeseed spray oil against spider mites, green peach aphid and pear psylla in Serbia

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Abstract

Biological efficacy of rapeseed spray oil against twospotted spider mite (*Tetranychus urticae* Koch) on cucumber, against European red mite [*Panonychus ulmi* (Koch)] on apple, green peach aphid (*Myzus persicae* Sulzer) on pepper and pear psylla [*Cacopsylla pyri* (L.)] was evaluated in seven field and three greenhouse trials at eight localities in Serbia during 2005-2008. The efficacy of rapeseed spray oil in controlling these pests was compared to the following insecticides and/or acaricides: abamectin, acetamiprid, bifenthrin, clofentezine, diflubenzuron, dimethoate, fenazaquin, mineral oil, combination of mineral oil and methidathion, pymetrozine and spirodiclofen. In two greenhouse trials against a *T. urticae* population on cucumber, the efficacy of rapeseed oil was 84.1% and 94.6%, 11 days after treatment (DAT). Applied as a late dormant oil against winter eggs of *P. ulmi* in two apple orchards at the BBCH 09 growth stage, rapeseed spray oil achieved 89.3% and 98.9% efficacy, 24 DAT. In a treatment against the summer population of *P. ulmi,* rapeseed oil showed 97.4% (7 DAT), 80.5% (14 DAT), 68.6% (21 DAT) and 67.7% (38 DAT) efficacy. Three field trials against *M. persicae* on pepper revealed high (> 96%, 7-14 DAT) efficacy of rapeseed spray oil; in a greenhouse trial, the oil achieved 86.9% efficacy 8 DAT. Applied at the BBCH 09 pear growth stage against eggs laid by winterform females of *C. pyri*, rapeseed oil showed a total efficacy of > 90% in both assessments. Such high and persistant efficacy primarily results from the fact that the number of newly deposited, white eggs was reduced to null, while the effect on nymphs was weaker. The importance of these results for biorational pest control of spider mites, green peach aphid and pear psyllid in Serbia is discussed.

Key words: rapeseed spray oil, twospotted spider mite, European red mite, green peach aphid, pear psylla, pest control.

Introduction

Fruit and vegetable production in Serbia is generally threatened by a number of arthropod pests, including prominently the spider mites (Acari Tetranychidae) and aphids (Homoptera Aphididae). Two-spotted spider mite (*Tetranychus urticae* Koch), a highly polyphagous and cosmopolitan species, is a common pest of greenhouse crops, while European red mite [*Panonychus ulmi* (Koch)] occurs regularly in orchards heavily sprayed with pesticides (Stojnić and Petanović, 1997; Zhang, 2003). Green peach aphid (*Myzus persicae* Sulzer) is a cosmopolitan and polyphagous species, highly efficient as a virus vector (Blackman and Eastop, 2007). Its secondary (summer) hosts in Serbia include pepper, tobacco, tomato, cabbage and over 30 other plant species (Petrović, 2003). Pear psylla, *Cacopsylla pyri* (L.) (Hemiptera Psyllidae), is the most important pest in pear-growing regions of Europe. In Serbia, overwintering females begin to lay eggs as early as in mid-February and the first generation nymphs appear before flowering in the first half of April, causing feeding damage on young leaves and buds. Apart from the immediate damage, the pest is also a vector of pear decline phytoplasma. Successful early season control of this pest is necessary to forestall problems during the following growing season (Stamenković *et al*., 1993; Carraro, 1998; Horton, 1999; Duduk *et al*., 2008).

Several compounds commonly referred to as conventional insecticides (organo-phosphates, carbamates, pyrethroids), as well as a few acaricides, have been widely used to control these and other harmful insects and mites. However, as a result of heavy selection pressures, caused by their extended, frequent and unrational use, many arthropod pest populations, including spider mites, aphids and psyllids, have developed resistance worldwide (Pree *et al*., 1990; Buès *et al*., 1999; Schaub *et al*., 2001; Foster *et al*., 2007; Whalon *et al*., 2008). In Serbia, there have been reports of resistance incidence in some populations of these pests (Marčić, 1997; Vučetić *et al*., 2007; 2008), and of reduced field efficacy of pesticides in controlling the species at various sites (Marčić *et al*., 1998; 2007a; 2007b). Besides resistance evolution, most conventional pesticides are harmful to arthropod natural enemies and other non-target species. This situation has created a need to develop and introduce biorational pesticides i.e. synthetic and/or natural compounds with novel modes of action that are more selective and ecotoxicologically safer, and therefore suitable to be included in pest management programs based on integration of biological and chemical control measures (Horowitz and Ishaaya, 2004).

Besides neonicotinoids, insect growth regulators, compounds derived from soil microorganisms and other novel groups of insecticides and acaricides, horticultural spray oils (mineral and vegetable) may also be considered as biorational pesticides. Horticultural oils have a number of advantages over conventional insecticides: they are less disruptive to natural enemies and non-toxic to vertebrates, they break down easily in the environment and are generally much safer to use from an ecological and human health perspective (Davidson *et al*., 1991; Agnello *et al*., 1994; Nicetic *et al*., 2001; Martin-López *et al*., 2006). Environmental toxicity of vegetable oils is even lower than that of mineral oils and they are compatible with organic farming (Zehnder *et al*., 2007).

Moreover, phytotoxicity risks are lower with vegetable oils than they are with mineral oils. Among biorational pesticides, horticultural spray oils have another advantage: their mode of action on insects and mites is usually assumed to be suffocation, so that development of resistance is not likely to happen (Davidson *et al*., 1991; Agnello *et al*., 1994; Jaastad, 2007).

Mineral oils have been used against a wide spectrum of arthropod pests (Davidson *et al*., 1991; Lawson and Weires, 1991; Agnello *et al*., 1994; Nicetic *et al*., 2001; Agnello, 2002; Fernandez *et al*., 2005; Martin-López *et al*., 2006; Jaastad, 2007), while our current knowledge of the effects of vegetable oils as insecticides and/or acaricides is more limited. The aim of this study was to investigate field and greenhouse efficacy of rapeseed spray oil - an emulsifiable concentrate of refined oil derived from *Brassica napus* L. seeds - against spider mites, green peach aphid and pear psylla in Serbia. Its efficacy was compared to other (conventional and biorational) pesticides, in order to evaluate potentials of this botanical compound to be assumed as an optional solution in pest/resistance management strategies.

Materials and methods

All trials were carried out in commercial orchards, fields and greenhouses at eight localities in Serbia during 2005-2008 (table 1, figure 1). The trials were conducted in four replications (plots) using a completely randomized design. The pesticides used at these localities (table 2) were applied by a Stihl portable spraying device at their recommended applications rates.

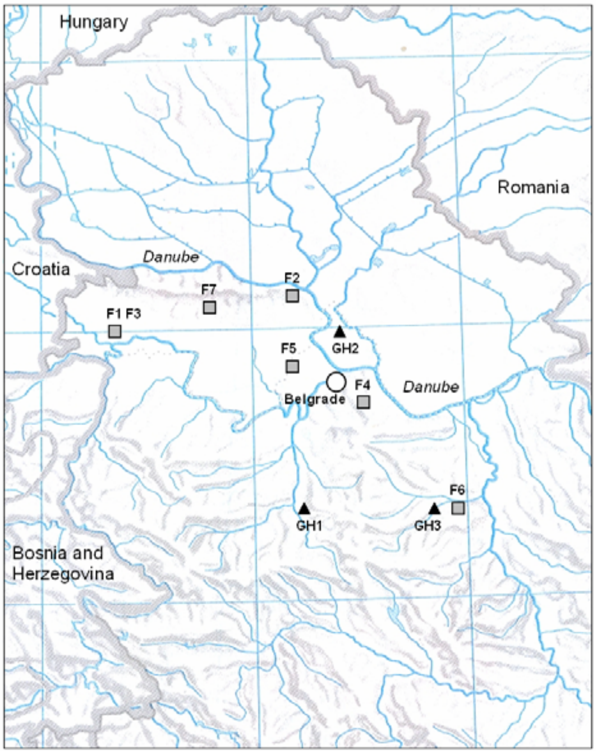

Figure 1. The localities in Serbia at which field (F) and greenhouse (GH) trials were carried out during 2005-2008.

Evaluation of efficacy against spider mites

Biological efficacy against *T. urticae* on cucumber was investigated in trials GH1 and GH2, the plot size being 10 plants and spray application volume 700 L ha^{-1}. Motile forms per leaf (one whole leaf per plant) were counted once before and twice after treatment, and the efficacy was calculated by Henderson-Tilton's formula (2).

The efficacy of rapeseed spray oil and other pesticides against overwintering eggs of *P. ulmi* on apple was evaluated in trials F1 and F2. The pesticides were applied at the BBCH 09 growth stage (green leaf tips about 5 mm above bud scales) to run-off on plots of five trees. Daily inspection of eggs on untreated plots showed that treatment was carried out five days before first larvae appeared. Motile forms per leaf (50 young leaves per plot) were counted 24 days after treatment and the efficacy was calculated by Abbott's formula (1).

The efficacy against *P. ulmi* summer population on apple was investigated in trial F3, with a plot size of five trees and spray application volume 1500 L ha^{-1}. Motile forms per leaf (25 leaves per plot) were counted before treatment and 7, 14, 21 and 38 days after treatment (DAT), and efficacy was calculated by Abbott's formula (1).

Evaluation of efficacy against green peach aphid

Biological efficacy of rapeseed spray oil and other pesticides against *M. persicae* on pepper was evaluated in a fall season treatment in three field (F4, F5 and F6) and one greenhouse (GH3) trials, with plot size 25 m^2

Table 1. Field (F) and greenhouse (GH) trials conducted during 2005-2008 in Serbia.

Pest and crop	Trial	Date	Locality	Cultivar
Tetranychus urticae - cucumber	GH1	2005, 9/19-9/30	Šopić	Marinda
	GH2	2008, 8/12-8/23	Padinska Skela	Caman
Panonychus ulmi - apple	F1	2006, 3/31-4/24	Morović	Red Chief
	F2	2006, 3/31-4/24	Stari Slankamen	Red Chief
	F3	2008, 6/27-8/4	Morović	Red Chief
Myzus persicae - pepper	F4	2005, 9/29-10/12	Veliko Selo	Campona
	F5	2005, 10/4-10/18	Dobanovci	Prima
	F6	2006, 10/2-10/9	Smederevska Palanka	Duga bela
	GH3	2008, 10/14-10/22	Smederevska Palanka	Virgina
Cacopsylla pyri - pear	F7	2007, 3/16-4/23	Borkovac	William's

Table 2. Pesticide products applied in the field and greenhouse trials.

Products	Formulations	Active ingredients	Manufacturers	Trials
Ogriol	Emulsifiable concentrate	Rapeseed oil (920 g L^{-1})	Pinus TKI, Slovenia	F1, F2, F3, F4, F5, F6, F7, GH1, GH2, GH3
Armada	Emulsifiable concentrate	Abamectin (18 g L^{-1})	Willowood Ltd.,Hong Kong	F7, GH1
Mospilan 20-SP	Water soluble powder	Acetamiprid (200 g kg^{-1})	Nippon Soda, Japan	F6
Talstar 10-EC	Emulsifiable concentrate	Bifenthrin (100 g L^{-1})	FMC International S.A., USA	F3
Fobos EW	Emulsion oil in water	Bifenthrin (100 g L^{-1})	Galenika-Fitofarmacija, Serbia	GH2
Apollo 50-SC	Suspension concentrate	Clofentezine (500 g L^{-1})	Makhteshim Chemical Works, Israel	F1, F2, F3, GH2
Perfekthion	Emulsifiable concentrate	Dimethoate (400 g L^{-1})	BASF AG, Germany	F4, F5, F6, GH3
Demitan 200-SC	Suspension concentrate	Fenazaquin (200 g L^{-1})	Margarita International, Portugal	GH1
Belo ulje	Emulsifiable concentrate	Mineral oil (900 g L^{-1})	Zorka-Zaštita bilja, Serbia	F1, F2
Galmin	Emulsifiable concentrate	Mineral oil (900 g L^{-1})	Galenika-Fitofarmacija, Serbia	F3, F7, GH2
Oleo-ultravet	Emulsifiable concentrate	Mineral oil (280 g L^{-1}) + methidathion (100 g L^{-1})	Vetzavod, Serbia	F1, F2
Chess 50-WG	Water dispersible granules	Pymetrozine (500 g kg^{-1})	Syngenta, Switzerland	F4, F5, F6, GH3
Envidor	Suspension concentrate	Spirodiclofen (240 g L^{-1})	Bayer CropScience, Germany	F3, F7, GH2

and spray application volume 400 L ha^{-1}. Living aphids per plant/shoot, on 20 marked plants/shoots per plot, were counted before treatment and twice after treatment, and efficacy was calculated by Abbott's formula (1) or Henderson-Tilton's formula (2).

Evaluation of efficacy against pear psylla

Biological efficacy of rapeseed spray oil and other pesticides against *C. pyri* was evaluated in one field trial (F7), with plot size of 5 trees and spray application until run-off. The pesticides were applied at the pear growth stage BBCH 09 (green leaf tips about 5 mm above bud scales) against eggs laid by winterform females just before the beginning of hatching; 18 DAT and 38 DAT, eggs and nymphs were counted per shoot on 10 marked shoots per plot. The eggs were counted as younger, 'white eggs' and older, 'yellow eggs' and the nymphs were counted as N_{1-3} nymphs (I-III instar) and N_{4-5} nymphs (IV-V instar). The efficacy was calculated by Abbott's formula (1).

Statistical analysis and efficacy calculation

The pests (motile forms of spider mites, green peach aphid larvae, eggs and nymphs of pear psyllids) were counted per plot, the numbers were compared using ANOVA and the means were separated by *t*-test. The data were transformed by $\sqrt{x} + 0.5$ before analysis; untransformed data are presented in this paper.

The efficacy of pesticides (Ef %) was calculated by Abbott's formula (1) or Henderson-Tilton's formula (2).

$$Ef\,\% = (1 - Nta/Nca) \times 100 \qquad (1)$$

N = the number of living pests per plot
t = treated plots
c = control plots
a = after treatment

$$Ef\,\% = [1 - (Nta/Nca)\,(Ncb/Ntb)] \times 100 \qquad (2)$$

N = the number of living pests per plot
t = treated plots
c = control plots
a = after treatment
b = before treatment

When infestation was uniform in plots before treatment (i.e. if there were no significant differences between the means in ANOVA), Abbott's formula was applied instead of Henderson-Tilton's formula (Dent, 2000).

Phytotoxicity assessment

In all trials, observations to assess possible symptoms of phytotoxicity (colour modifications, necrosis, deformations, etc.) on treated plants were performed.

Results and discussion

Spider mites

In two greenhouse trials (table 3), 2% emulsifiable concentrate of rapeseed oil showed good efficacy in

Table 3. The number of *T. urticae* on cucumber and efficacy of pesticides (Ef %) according to Henderson-Tilton formula (Trials GH1, GH2).

Trial GH1	Pesticides	Application rates	Mean number [1)] of *T. urticae*			Ef %	
			BT	7 DAT	11 DAT	7 DAT	11 DAT
	Rapeseed oil	2% v/v	28.4 *ab*	8.8 *a*	11.0 *a*	78.3	84.1
	Abamectin	9.45 g a.i. ha^{-1}	40.1 *ab*	5.5 *a*	7.6 *a*	90.4	92.2
	Fenazaquin	84 g a.i. ha^{-1}	69.2 *b*	11.4 *a*	13.8 *a*	88.5	91.8
	Untreated	-	23.1 *a*	33.0 *b*	56.2 *b*	-	-
Trial GH2	**Pesticides**	**Application rates**	**Mean number [1)] of *T. urticae***			**Ef %**	
			BT	6 DAT	10 DAT	6 DAT	10 DAT
	Rapeseed oil	2% v/v	22.8 *ab*	0.4 *a*	0.8 *a*	97.9	94.6
	Mineral oil	2.5% v/v	31.6 *b*	0.1 *a*	0.2 *a*	99.6	99.0
	Bifenthrin	35 g a.i. ha^{-1}	26.9 *ab*	0.8 *a*	0.2 *a*	96.5	98.8
	Clofentezine	210 g a.i. ha^{-1}	28.2 *ab*	1.1 *a*	1.2 *a*	95.4	93.4
	Spirodiclofen	67.2 g a.i. ha^{-1}	14.4 *a*	0.2 *a*	0.3 *a*	98.4	96.8
	Untreated	-	21.4 *ab*	18.1 *b*	13.8 *b*	-	-

1) motile forms per leaf (1 whole leaf per plant, 10 plants per plot).
BT = before treatment; DAT = days after treatment.
Within a column, means followed by the same letter are not significantly different (t-test, P < 0.05).

controlling the two-spotted spider mite population on cucumber, especially in the second trial (94.6%, 10 DAT), where the initial number of motile forms per leaf was lower. In the latter trial, the efficacy of rapeseed oil treatment was close to the efficacy achieved by 2.5% emulsifiable concentrate of mineral oil. Horticultural spray oils (narrow-range mineral oils and vegetable oils) could be effective acaricides in vegetables and ornamentals under greenhouse conditions. Nicetic *et al.* (2001) demonstrated that preventive treatment with 0.5% D-C-Tron Plus mineral oil applied forthightly maintained *T. urticae* population on greenhouse roses below economic threshold, while 0.2% Bionatrol soybean oil (nano-particle emulsion) achieved 88% efficacy against two-spotted spider mite on greenhouse grown cucumber (Lee *et al*., 2005). Apart from having direct effect, horticultural oils also have sublethal activity, reducing the number of eggs laid by *T. urticae* females on treated surface (Liu and Beattie, 2002). Possible sublethal effects of rapeseed oil on two-spotted spider mites and their characterization is a subject of further laboratory research.

Other insecticides (abamectin, a microbiological product, and bifenthrin, a pyrethroid compound) and acaricides (clofentezine, a growth inhibitor, and fenazaquin, an inhibitor of mitochondrial respiration) that have been used in practice for many years demonstrated high efficacy (> 90%), as well as spirodiclofen, which is a newly introduced compound. In baseline susceptibility bioassays, the latter acaricide demonstrated high acute toxicity to eggs and immatures of *T. urticae*, while its activity against females was slower: after direct treatment, it took most females several days to die, but fecundity and fertility of the treated individuals were significantly reduced (Wachendorff *et al*. 2002; Marčić, 2007).

Table 4. The number of *P. ulmi* motile forms and efficacy of pesticides (Ef %) according to Abbott formula 24 days after treatment at BBCH 09 against overwintering eggs (Trials F1, F2).

Trial F1	Pesticides	Application rates	Mean number [1)] of *P. ulmi* 24 DAT	EF %
	Rapeseed oil	4 % v/v	0.39 *a*	89.3
	Mineral oil	4 % v/v	0.12 *a*	96.7
	Mineral oil + methidathion	0.3 % v/v	1.33 *b*	63.5
	Clofentezine	0.025 % a.i. v/v	3.56 *c*	2.2
	Untreated	-	3.64 *c*	-
Trial F2	**Pesticides**	**Application rates**	**Mean number [1)] of *P. ulmi* 24 DAT**	**EF %**
	Rapeseed oil	4 % v/v	0.03 *a*	98.9
	Mineral oil	4 % v/v	0.04 *a*	98.5
	Mineral oil + methidathion	0.3 % v/v	1.42 *b*	45.8
	Clofentezine	0.025 % a.i. v/v	1.54 *b*	41.7
	Untreated	-	2.64 *b*	-

1) motile forms per leaf (50 leaf per plot).
DAT = days after treatment.
Within a column, means followed by the same letter are not significantly different (t-test, P<0.05).

Applied at the BBCH 09 growth stage in two orchards as a late dormant oil against winter eggs of *P. ulmi* on apple, 4% rapeseed spray oil achieved high efficacy 24 DAT (table 4), which was similar or slightly lower than the efficacy of 4% mineral oil treatment. Low efficacy of the combination mineral oil + methidathion, and clofentezine, was hardly unexpected as organophosphorus growth inhibiting insecticides and acaricides have been used in practice in those localities for a long time.

Dormant or delayed dormant application of horticultural mineral oils against overwintering eggs has been an effective management tool for European red mite on apple. Hill and Foster (1998) demonstrated that green tip or tight cluster application of 2% Dormant oil 435 significantly reduced cumulative mite-days, while Fernanadez *et al*. (2005) achieved similar effect after application of 1% Orchex 796 oil. Such mineral oil treatments enable simultaneous efficacy against other apple pests, such as rosy apple aphid, *Dysaphis plantaginea* Passerini (Lawson and Weires, 1991). Our results indicate that effective suppression of European red mite at the beginning of season could be achieved by one treatment of 4% rapeseed spray oil as well. Similarly, Jaastad (2007) demonstrated that 2% ProNature rapeseed oil applied at the late dormant stage against overwintering eggs of black cherry aphid, *Myzus cerasi* (F.), achieved 88% efficacy.

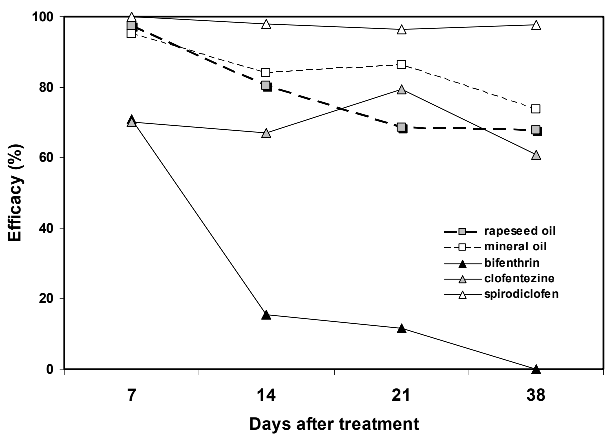

Figure 2. The efficacy of pesticides against motile forms of *P. ulmi* on apple (Trial F3).

In treatment against the summer population of *P. ulmi* (table 5, figure 2), 2% rapeseed oil achieved the efficacy of 97% (7 DAT), 77.9% (14 DAT), 64.4% (21 DAT) and 63.3% (38 DAT). This efficacy was similar to the efficacy of mineral oil treatment and may be considered satisfactory, having in mind that it is a single treatment. Agnello *et al*. (1994) demonstrated effective control of summer population of European red mite with three applications of 2% and 3% Sunspray Ultra Fine mineral oil, starting at the petal-fall stage and continuing on a 2-3 week intervals. Fernandez *et al*. (2005) showed that at least three applications of 1% Orchex 796 oil were needed in order to achieve effective suppression of tetranychid mites in apple orchards.

The unsatisfactory and low efficacy of bifenthrin and clofentezine is probably the result of a resistance developed under high selection pressure of these compounds in the Morović locality in preceding years. Applied at 144 g a.i. ha^{-1}, the new acaricide spirodiclofen showed high and long-lasting efficacy (97.7%, 38 DAT), which was expected with regard to its previous performance (Elbert *et al*., 2002; Marčić *et al*., 2007b).

Spider mite populations have an exceptional natural potential for rapid pesticide resistance evolution: among the top 10 resistant arthropod pests, *T. urticae* takes the leading position, while *P. ulmi* ranks ninth (Whalon *et al*., 2008). Because of its new mode of action – the inhibition of lipid synthesis – spirodiclofen is a solution for controlling mite populations resistant to other acaricides. On the other hand, in order to prevent/delay resistance development and save the product’s longevity, only one treatment per cropping cycle is recommended (Nauen *et al*., 2000; Elbert *et al*., 2002; Wachendorff *et al*., 2002). Considering that development of resistance to horticultural oils is not likely (Davidson *et al*., 1991; Agnello *et al*., 1994), treatment with rapeseed oil can be repeated and combined with spirodiclofen and/or some other acaricide with good efficacy within resistance management programs and in keeping with spider mite population dynamics.

Green peach aphid

Three field trials against green peach aphid on pepper (table 6) revealed high (>96%, 7-14 DAT) efficacy of rapeseed spray oil. In a greenhouse trial (table 7), rapeseed oil achieved 86.9% efficacy 8 DAT, a satisfactory

Table 5. The number of *P. ulmi* motile forms on apple before treatment (BT) and 7, 14, 21 and 38 days after treatment (DAT) (Trial F3).

Pesticides	Application rates	Mean number [1)] of *P. ulmi*				
		BT	7 DAT	14 DAT	21 DAT	38 DAT
Rapeseed oil	2% v/v	2.31 *a*	0.08 *a*	1.78 *b*	1.79 *a*	0.43 *a*
Mineral oil	2.5% v/v	1.70 *a*	0.15 *a*	1.47 *b*	0.78 *a*	0.35 *a*
Bifenthrin	30 g a.i. ha^{-1}	1.90 *a*	0.89 *a*	7.72 *c*	5.04 *b*	3.48 *b*
Clofentezine	450 g a.i. ha^{-1}	1.69 *a*	0.91 *a*	3.00 *bc*	1.17 *a*	0.52 *a*
Spirodiclofen	144 g a.i. ha^{-1}	2.10 *a*	0.00 *a*	0.19 *a*	0.20 *a*	0.03 *a*
Untreated	-	2.62 *a*	3.05 *b*	9.13 *c*	5.70 *b*	1.33 *b*

1) motile forms per leaf (25 leaf per plot).
Within a column, means followed by the same letter are not significantly different (t-test, $P < 0.05$).

Table 6. The number of *M. persicae* on pepper and efficacy of pesticides (Ef %) according to Henderson-Tilton formula (Trial F4) and Abbott formula (Trials F5, F6).

Trial F4	Pesticides	Application rates	Mean number [1)] of *M. persicae*			Ef %	
			BT	4 DAT	13 DAT	4 DAT	13 DAT
	Rapeseed oil	2% v/v	30.5 *a*	1.3 *a*	0.4 *a*	96.7	98.6
	Pymetrozine	80 g a.i. ha^{-1}	53.8 *b*	2.8 *a*	0.9 *a*	96.1	98.4
	Dimethoate	160 g a.i. ha^{-1}	34.2 *ab*	12.2 *b*	5.6 *b*	71.7	83.9
	Untreated	-	36.2 *ab*	48.0 *c*	38.7 *c*	-	-
Trial F5	**Pesticides**	**Application rates**	**Mean number [1)] of *M. persicae***			**Ef %**	
			BT	4 DAT	14 DAT	4 DAT	14 DAT
	Rapeseed oil	2% v/v	24.8 *a*	1.4 *a*	0.6 *a*	94.6	97.3
	Pymetrozine	80 g a.i. ha^{-1}	19.3 *a*	1.8 *a*	1.4 *a*	93.1	93.8
	Dimethoate	160 g a.i. ha^{-1}	24.4 *a*	1.2 *a*	0.6 *a*	95.4	97.3
	Untreated	-	22.8 *a*	26.1 *b*	22.5 *b*	-	-
Trial F6	**Pesticides**	**Application rates**	**Mean number [1)] of *M. persicae***			**Ef %**	
			BT	2 DAT	7 DAT	2 DAT	7 DAT
	Rapeseed oil	2% v/v	14.1 *a*	2.2 *a*	0.5 *a*	87.9	96.5
	Acetamiprid	40 g a.i. ha^{-1}	13.8 *a*	0.2 *a*	0.0 *a*	98.9	100.0
	Dimethoate	160 g a.i. ha^{-1}	15.2 *a*	1.4 *a*	1.0 *a*	92.3	93.1
	Untreated	-	17.0 *a*	18.2 *b*	14.4 *b*	-	-

1) aphids per plant (20 marked plants per plot).
BT = before treatment; DAT = days after treatment.
Within a column, means followed by the same letter are not significantly different (t-test, $P < 0.05$).

Table 7. The number of *M. persicae* on pepper and efficacy of pesticides (Ef %) according to Henderson-Tilton formula (Trial GH3).

Pesticides	Application rates	Mean number [1)] of *M. persicae*			Ef %	
		BT	3 DAT	8 DAT	3 DAT	8 DAT
Rapeseed oil	2% v/v	41.2 *c*	8.1 *b*	6.4 *c*	87.2	86.9
Pymetrozine	80 g a.i. ha^{-1}	27.5 *b*	3.2 *a*	0.9 *b*	92.4	97.2
Dimethoate	160 g a.i. ha^{-1}	34.2 *c*	13.1 *c*	13.0 *d*	75.0	68.0
Untreated	-	16.0 *a*	24.5 *d*	19.0 *e*	-	-

1) aphids per plant (20 marked plants per plot).
BT = before treatment; DAT = days after treatment.
Within a column, means followed by the same letter are not significantly different (t-test, $P < 0.05$).

level considering the relatively higher initial infestation, compared to field trials. Martin-López *et al*. (2003) reported 89.4% mortality of the apterous *M. persicae* 36 h after spraying of the infested pepper leaves with 1% rapeseed oil. In another test, the authors observed a degree of deterrence against aphid feeding. Besides these effects, rapeseed oil has also been reported to inhibit transmission of cucumber mosaic virus to pepper (Martin-López *et al*. 2004).

The efficacy of dimethoate, a conventional organophosphorus compound, was unsatisfactory (<84%) in the localities of Veliko Selo in 2005 (trial F4) and Smederevska Palanka in 2008 (trial GH3), while efficacy was >93% in another two trials. Interestingly, the 2006 trial at Smederevska Palanka (trial F6) showed high efficacy of dimethoate, while in a trial conducted two year later (trial GH3), the insecticide achieved only 68% efficacy. Such great differences in dimethoate efficacies are hardly a surprise as considerably low dimethoate efficacy against *M. persicae,* as well as resistance to organophosphorous compounds in populations of that pest in Serbia, have been confirmed previously (Marčić *et al*., 1998; 2007a; Vučetić *et al*., 2007; 2008). Pymetrozine, a newly introduced insecticide with a novel mode of action (irreversible feeding inhibition) was highly efficient against green peach aphid in all trials. As no cross-resistance is associated with this compound, pymetrozine is an excellent choice for effective control of *M. persicae* populations resistant to conventional insecticides (Foster *et al*., 2007). Acetamiprid, an insecticide introduced in Serbia several years ago, achieved high efficacy as well. This neonicotinoid compound is also a good solution for populations resistant to organophosphorous and pyrethroid insecticides.

Green peach aphid is a pest species with a high risk of resistance evolution, as suggested by its third place on the list of top 10 resistant arthropods (Whalon *et al*., 2008). Neonicotinoids are still a prominent class of insecticides for the control of *M. persicae*. However, neonicotinoids and other newly introduced insecticides are not immune to pest resistance, and appropriate guidelines for managing insect resistance have been developed. Besides other measures, Elbert *et al*. (2005) suggested that horticultural spray oils are good resistance management tools, which should be recommended for use in combination and/or rotation with neonicotinoid insecticides. On the other hand, the study conducted by Martin-López *et al*. (2006) indicates that efficient control of *M. persicae* could be achieved using 1% rapeseed oil mixed with imidacloprid at one-fifth of the dose recommended by the manufacturer for vegetables. Thus, the use of oils in combination with low doses of imidacloprid reduces selection pressure and slows down resistance evolution.

Pear psylla

Applied at the BBCH 09 pear growth stage against eggs laid by winterform females of *C. pyri*, 4% rapeseed spray oil showed total efficacy of > 90% in both assessments (table 8). Such high and extended efficacy is primarily due to the fact that the number of newly deposited white eggs was reduced to null, while the effect against nymphs was weaker. Compared to rapeseed oil, the efficacy of 2.5% mineral oil was slightly lower 18 DAT due to a lower effect on eggs. In the second evaluation, higher overall efficacy of mineral oil was achieved as a result of higher reduction in the number of N_{1-3} nymphs. The effect demonstrated by the oils was probably due to a combination of direct activity on eggs and oviposition deterrency. The results reported by Erler (2004) showed that 1% mineral oil had pronounced deterrent activity on pear psylla, preventing oviposition for approximately one month after application. This behavioral effect of oily substances on *C. pyri* was also reported by Zwick and Westigard (1978).

Abamectin achieved > 90% efficacy in both assessments, showing better activity against eggs than nymphs. After the withdrawal of amitraz and some other conventional insecticides from the market, abamectin has become one of the most common products used for pear psylla control. Resistance in *C. pyri* to this insecticide has not yet been reliably documented. Civolani *et al*. (2007) demonstrated that failures of abamectin treatments against pear psylla might be related to incorrect pest defense management and not to resistance development. The efficacy of spirodiclofen 18 DAT was significantly lower than that of the oils and abamectin, while better results were recorded in second evaluation. Besides its acaricidal action, spirodiclofen shows good insecticidal activity against pear psylla. Optimal application timing for spirodiclofen starts from mature eggs close to hatching and ends when numerous young nymphs are present (De Maeyer *et al*., 2002). The data acquired from our field trial with spirodiclofen are consistent with data reported by De Maeyer *et al*. (2002) after treatment with the same application rate when 30-50% of the eggs in first generation were close to hatching.

Pear psylla requires season-long management: in Serbia, the pest has 4-5 generations per year and multiple pesticide applications are needed. Abamectin and spirodiclofen, together with some other novel compounds (e.g. neonicotinoids) could be successfully used against succeeding generations of *C. pyri*. However, following general principles of resistance management, alternate products with different modes of action should be used, so that only one generation per season would be exposed to a class. On the other hand, psylla suppression by compatible combinations of insecticides and oils could be more effective than treatments with single insecticides (Erler and Cetin, 2005). Further research is needed to test rapeseed spray oil and its combinations with abamectin, spirodiclofen, neonicotinoids and other biorational products, against *C. pyri* throughout the season, with assessment of side-effects on Anthocoridae and other natural enemies of the pest.

Phytotoxicity

No signs of phytotoxicity on treated plants were observed during the trials.

Table 8. The number of *C. pyri* eggs and nymphs[1)] 18 days and 38 days after the treatment at BBCH 09 pear growth stage against 1st generation eggs and efficacy of pesticides (Ef %) according to Abbott formula (Trial F7).

Pesticides	Application rates	18 DAT				Ef %				
		Ew	Ey	N_{1-3}	N_{4-5}	Ew	Ey	N_{1-3}	N_{4-5}	Total
Rapeseed oil	4.0 % v/v	0.00 *a*	1.98 *a*	2.88 *a*	0.08 *a*	100.0	92.7	69.5	95.4	90.7
Mineral oil	2.5 % v/v	0.38 *a*	5.30 *b*	2.38 *a*	0.02 *a*	97.4	80.5	74.8	98.9	84.8
Abamectin	0.0135 % a.i. v/v	0.00 *a*	2.00 *a*	1.95 *a*	0.10 *a*	100.0	92.6	79.3	94.3	92.4
Spirodiclofen	0.0096 % a.i. v/v	2.50 *a*	7.15 *b*	5.15 *b*	0.00 *a*	83.1	73.7	45.4	100.0	72.1
Untreated	-	14.75 *b*	27.18 *c*	9.44 *b*	1.74 *b*	-	-	-	-	-
Pesticides	**Application rates**	**38 DAT**				**Ef %**				
		Ew	Ey	N_{1-3}	N_{4-5}	Ew	Ey	N_{1-3}	N_{4-5}	Total
Rapeseed oil	4.0 % v/v	0.00 *a*	0.00 *a*	0.00 *a*	6.20 *b*	100.0	100.0	100.0	63.7	90.2
Mineral oil	2.5 % v/v	0.00 *a*	0.00 *a*	0.12 *a*	1.30 *a*	100.0	100.0	99.2	92.4	97.7
Abamectin	0.0135 % a.i. v/v	0.00 *a*	0.00 *a*	0.05 *a*	5.85 *b*	100.0	100.0	99.7	65.8	90.6
Spirodiclofen	0.0096 % a.i. v/v	0.00 *a*	3.00 *a*	0.10 *a*	3.85 *ab*	100.0	82.6	99.3	77.5	89.0
Untreated	-	14.20 *b*	17.20 *b*	14.50 *b*	17.10 *c*	-	-	-	-	-

1) per shoot (10 shoots per plot).
DAT = days after treatment.
Ew = white eggs; Ey = yellow eggs; N1-3 = nymphs I-III instar; N4-5 = nymphs IV-V instar.
Within a column, means followed by the same letter are not significantly different (t-test, $P < 0.05$).

Conclusions

The data acquired from our field and greenhouse trials proved rapeseed spray oil to be an effective agent in control of European red mite on apple, two-spotted spider mite on cucumber, green peach aphid on pepper and the 1st generation of pear psylla, with no phytotoxicity observed on treated plants. Further investigation should be carried out to test rapeseed oil alone and combined with other biorational products against these pests throughout the growing season, with special emphasize on side-effects on natural enemies, in order to improve pest management strategies.

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