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ORIGINAL ARTICLE

Integrated control of Lecanium scale (*Parthenolecanium* sp.) on highbush blueberry in open field and protected crops

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Abstract

The increased cultivation of highbush blueberry in Poland has been paralleled with enhanced damage to this crop by different pests and diseases, including soft scales. We have carried out trials to assess methods for controlling soft scales of the genus *Parthenolecanium* in highbush blueberry grown in open fields or under a plastic tunnel, with an approach based on integrated pest management (IPM) principles. The reduction of Lecanium scale population using alternative products, with mechanical mechanisms of action, was similar to that achieved with treatments of different formulations of neonicotinyl-based pesticides; sometimes they were even more effective on protected crops. Control programs on plantations with a large population of Lecanium scales based on the application of these alternative products in spring and at harvest time and chemical compounds in autumn resulted in a very high efficacy and are considered the most suitable strategies to assure yields without residues and a reduced impact on the environment.

Keywords: integrated pest control, mechanical action, *Parthenolecanium* spp.

Introduction

Species of the genus *Parthenolecanium* belonging to the family Coccidae can feed on many crops and are among the most serious pest species around the world (García Morales *et al.* 2016). Several species are present, at varying degrees, in Poland (Łagowska *et al.* 2015), but the most widespread and present on several fruit plants is *P. corni* (Bouché) (Łabanowska and Gajek 2013). Besides direct damage to the plants, the production of honeydew by these species, which supports the growth of several saprophytic fungi (e.g. *Capnodium* spp.), reduces the commercial value of fruits. The control of such pests has been traditionally based on chemical treatments (Wardlow and Ludlam 1975; Hahn *et al.* 2011). However, the recent discovery of parasitoids in different crops and countries has opened new avenues for biological control methods (Arnaoudov *et al.* 2006; Bolu and Hayat 2008; Rakimov *et al.* 2015). The difficulties in rearing parasitoids and applying them in open fields, together with the need of reducing the use of synthetic pesticides, have prompted the search for alternative products characterized by lower toxicity for humans and the environment. Among the possible alternatives, essential and paraffinic oils as well as other natural substances (i.e. chitosan) or modified mineral substances (e.g. silicon) have been found to have insecticidal properties through mechanical action, with limited impact on the environment (Rabea *et al.* 2005; Badawy and El-Aswad 2012; Sarwar and Salman 2015).

The increased cultivation of highbush blueberry in Poland in recent years (Smolarz and Pluta 2012) has been paralleled with enhanced damage to this crop by different pests and diseases, including Lecanium scales. The aim of this paper is to present the results of an integrated approach in controlling the population of *Parthenolecanium* sp. on highbush blueberry using products containing compounds characterized by mechanical action, alone or in combination with some synthetic chemical products.

Materials and Methods

The trials were conducted in 2013 and 2015 on highbush blueberry plantations cv. Bluecrop in four locations of the Mazowiecki Voivodship (central Poland). Control treatments were carried out during three different periods of the growing season: a) spring, when overwintering larvae begin feeding, b) summer, after the hatching of new larvae from eggs, b) autumn – just before larvae enter the overwintering stage (see Results). The experimental design was with four replications arranged in randomized blocks. Each plot (replication) covered 52.55 m^2 (3 rows 15 m long each, with a total of 45 plants). Tested and reference products having different mechanisms of action (Table 1) were applied with a motorized knapsack sprayer "Stihl SR 420", with a spray volume of 750 $l \cdot ha^{-1}$.

The Lecanium scale population density was estimated just before the treatment and approximately 2–3 weeks after spraying. The number of live Lecanium scale larvae was counted under a stereoscopic microscope, on either 10 leaves or three stems taken randomly from each plot/replication on each counting date. The results were statistically analyzed by ANOVA performed on values transformed by $\log^{(x+1)}$. The significance of differences between means was assessed using Tukey multiple range test at $p \leq 0.05$ with Statistica v.6.1. The value of actual mortality was calculated according to Abbott's formula.

Results

In 2013, all the products used reduced the average number of live larvae per leaf, irrespective of location and time of treatment (Table 2). After the summer treatment, the highest efficacy was noted with tiachlopryd, but also effective (70–85% average level of control) were the highest doses of cameline oil and of the product based on silicon polymers. The product based on polysaccharides showed the lowest efficacy. In autumn, the two fields tested showed a very different initial larval density per leaf, with the bushes in the Machnatka field having about a four-fold higher number of larvae than in the Piskórka location (Table 2). This condition affected the efficacy of all products on highly colonized shrubs (efficacy always <60%, limited control). However, on both plantations the effectiveness of products with mechanical action showed a higher efficacy (about two-fold) than the synthetic ones.

In 2015, the initial (springtime) average number of larvae on shoots in open or protected plantations was similar for the Piskórka locations (59.3 and 56.0 larvae/shoot in field and tunnel, respectively), while in the Prażmów field it was 79.0 larvae/shoot. This pattern was maintained in the control plants after the treatments (Table 3). In all fields, the products with mechanical action performed similarly, or even

Table 1. Active substances and relative product used for the trials and their main features

Active ingredient (a.i.)	Product [content of a.i.]	Classification according to IRAC Mechanism of Action (MoA)	Activity on the pest
Natural polysaccharides	Afik	unclassified	mechanical blocking the action of pest, suffocation
Silicon polymers	Siltac EC	unclassified	mechanical action on pest, suffocation
Camelina oil	Emulpar 940 EC	unclassified	mechanical action on pest, suffocation
Paraffin oil	Treol 770 EC (770 g)	unclassified	mechanical action on pest, suffocation
Tiachlopryd	Calypso 480 SC (480 g)	nicotinic acetylcholine receptor (nAChR) competitive modulators (A – Neonicotinoids)	contact and stomach poisoning
Acetamipryd	Mospilan 20 SP (20%) Stonkat 20 SP (20%)	nicotinic acetylcholine receptor (nAChR) competitive modulators (A – Neonicotinoids)	contact and stomach poisoning
Spirotetramat	Movento 100 SC (100 g)	inhibitors of acetyl CoA carboxylase (tetronic and tetramic acid derivatives)	inhibition of lipid biosynthesis

IRAC – Insecticide Resistance Action Committee

Table 2. Average number of larvae per leaf and efficacy of scale control on highbush blueberry after treatments in two different growing periods, on two plantations, 2013

Treatment	Concentration or dose	Average number of alive larvae/leaf			Efficacy according to Abbott's formula [%]		
		Machnatka (summer[#])	Machnatka (autumn)	Piskórka (autumn)	Machnatka (summer)	Machnatka (autumn)	Piskórka (autumn)
Control	–	37.6 d*	207.7 c	50.0 c	–	–	–
Polysaccharides	0.3%	18.7 cd	–	–	50.3	–	–
Silicon polymers	0.1%	10.9 bc	86.2 ab	7.2 a	71.0	58.5	85.6
Silicon polymers	0.2%	6.8 b	82.0 ab	6.0 a	81.9	60.5	88.0
Camelina oil	0.9%	10.3 bc	78.0 a	35.7 bc	72.6	62.4	28.6
Camelina oil	1.2%	5.8 b	159.2 abc	15.0 abc	84.6	23.4	70.0
Tiachlopryd	$0.2\ l \cdot ha^{-1}$	1.8 a	171.5 bc	13.5 ab	95.2	17.4	73.0

*means followed by the same letter (in columns) do not differ significantly according to Tukey multiple range test ($p \leq 0.05$)
[#]treatment dates: summer (July), autumn (September)

Table 3. Average number of larvae per shoot and efficacy of scale control on highbush blueberry grown in open field or under tunnel; treatments performed in spring (April), 2015

Treatment	Concentration or dose	Average number of alive larvae/shoot			Efficacy according to Abbott's formula [%]		
		Piskórka (field)	Piskórka (tunnel)	Prażmów (field)	Piskórka (field)	Piskórka (tunnel)	Prażmów (field)
Control	–	109.4 c*	104.2 d	341.4 d	–	–	–
Polysaccharides	0.3%	31.4 bc	13.7 ab	72.7 c	71.3	86.9	78.7
Silicon polymers	0.2%	15.8 b	9.0 ab	23.1 ab	85.6	91.4	93.2
Camelina oil	0.9%	41.7 bc	83.4 cd	54.3 bc	61.9	20.0	84.1
Camelina oil	1.2%	43.3 bc	30.5 bc	8.3 a	60.4	70.7	97.6
Paraffin oil	1.5%	2.7 a	10.9 ab	81.5 c	97.5	89.5	76.1
Acetamipryd	$0.2\ kg \cdot ha^{-1}$	57.2 bc	8.3 a	99.7 c	47.7	92.0	70.8

*means followed by the same letter (in columns) do not differ significantly according to Tukey multiple range test ($p \leq 0.05$)

better, than the chemical products (50–90% efficacy, from limited to good control) with the exception of the cameline oil applied under plastic tunnel conditions at a reduced dose. This product was in general the least effective among those having mechanical action. On the other hand, the products based on polysaccharides and silicon polymers were more effective when used on plants grown under protected conditions (plastic tunnel) than on open field grown plants (efficacy increased more than 10%). The growing method also affected the two products based on the same synthetic active substance, with both of them showing a lower efficacy on plants growing in open fields than those grown under a plastic tunnel (Table 3).

The effect of an autumn treatment with the alternative compounds was assessed in two trials having a quite different initial number of larvae per leaf: it ranged from 63.5 to 128.0 in Rokotów and from 12.4 to 94.5 in Prażmów (Table 4). In both locations, the product based on polysaccharides was the most effective (>80% efficacy, good control). The other products were effective only in the field characterized by a low initial infestation (Rokotów).

The efficacy of Lecanium scale larvae control with a complex program consisting of three to four treatments during the season, was assessed in three trials: one of them was on a protected crop, combining products with mechanical action and chemical products. At the beginning of the season (before starting the treatment applications) the average population size of scales in all three trials ranged from 16.7 to 23.7 larvae per leaf (Table 5). It increased in control plots during the growing season when observations were made (Table 5). The different control programs tested resulted in a final efficacy ranging from about 20% up to about 95%. The association of one summer treatment with

Table 4. Average number of larvae per leaf and efficacy of control on highbush blueberry grown under open field conditions; treatments performed in autumn (September), 2015

Treatment	Concentration [%]	Average number of alive larvae/leaf		Efficacy according to Abbott's formula [%]	
		Rokotów (field)	Prażmów (field)	Rokotów (field)	Prażmów (field)
Control	–	5.1 c*	27.6 b	–	–
Polysaccharides	0.3	0.8 a	2.9 a	84.3	89.5
Silicon polymers	0.2	1.5 ab	26.2 b	70.6	5.1
Camelina oil	0.9	2.0 b	15.1 b	60.8	45.3
Camelina oil	1.2	–	16.4 b	–	40.6

*means followed by the same letter (in columns) do not differ significantly according to Tukey multiple range test ($p \leq 0.05$)

acetamipryd and two treatments, one in spring and one in autumn, of the alternative products was effective particularly when using camelina oil at the highest dose (about 90% efficacy, good control). The programs combining only compounds having mechanical action gave from about 40% to about 70% efficacy. The program using only the product based on silicon polymers was the most effective. Combining three applications of alternative products and one with spirotetramat in autumn resulted in an efficacy from about 80% up to almost 95% on crops grown under tunnel (Table 5).

Discussion

The results obtained from applying different products based on alternative active substances controlling Lecanium scales mainly through mechanical action suggest that these products can be useful to control or limit the population of soft scales on highbush blueberry plants. However, the efficacy of the different products differed depending mainly on the period of application. The product based on silicon polymers and that based on camelina oil were more effective when applied during spring and summer than in autumn. The initial number of Lecanium scale larvae also affected the overall efficacy of the treatments, but this was not critical when a complex program of treatments based mainly on the alternative compounds was designed to cover the whole growing season.

The silicon-based product is a combination of silicone polymeric compounds which, when applied to plants, quickly spreads on the treated surface creating a three-dimensional polymeric grid structure with sticky properties blocking the insect's physical functions (Somasundaran *et al.* 2006). Its efficacy can thus be dependent on the application method and on the environmental conditions, as was also seen in our trials. The compound has no similarities with other available substances for plant protection. Further studies are planned to better understand the compound activity on plants and plant pests at a microscopic level.

The oil extracted from camelina (*Camelina sativa* (L.) Crantz) is normally characterized by a high content of alpha-linolenic acid and saturated fatty acids, with omega3 R-linolenic acid [C(18 : 3 n3)] being the most abundant (about 30–40%) (Hrastar *et al.* 2009). The unsaturated fractions of vegetal oils are chemically reactive and, similar to petroleum-based oils, can cause lesions on the leaf surface with variations in damage intensity depending on dosage and environmental conditions (Regnault-Roger 1997). However, we did not observe any phytotoxic effects on the plants treated with this product, either in the open field or under protected conditions (data not shown). Even though essential oils can have toxic actions, they cause insects to die from asphyxiation (Sarwar and Salman 2015). Therefore, this kind of products is unlikely to induce resistance in insect populations (Bakkali *et al.* 2008). Products based on paraffinic oils, such as that used in our trials, e.g. vegetable oils, are characterized by the prevention of gaseous exchange and toxic interference with cell membrane functions (Agnello 2002). Their use in the program for Lecanium scale control on highbush blueberry can thus be alternated with vegetable oils, to reduce the overall environmental impact, and as shown in our trials, to improve the overall efficacy of the control strategy.

The preparation based on polysaccharides showed a satisfactory level of efficacy irrespective of the period of application. A component of the product is chitosan, a compound that has been found to possess insecticidal activity on Hemiptera pests (Rabea *et al.* 2005; Badawy and El-Aswad 2012). Chitosans are also known for their effects on plant nutrition and plant growth stimulation, as well as the induction of plant defence mechanisms against pathogens (Sharp 2013). These properties were

Table 5. Average number of larvae per leaf at the end of the growing season and overall efficacy of scale control on highbush blueberry grown in open field or under protected conditions with different control programs, 2015

Control Programs	Concentration or dose	Application period#	Average number of alive larvae/leaf	Efficacy according to Abbott's formula [%]
		Prażmów (field)		
Before the first treatment	–	–	23.7	–
Control	–	–	27.6 c*	–
Polysaccharides Acetamipryd Polisaccharides	0.3% 0.2 kg · ha^{-1} 0.3%	spring summer autumn	21.9 c	20.8
Silicon polymers Acetamipryd Silicon polymers	0.2% 0.2 kg · ha^{-1} 0.2%	spring summer autumn	14.2 bc	48.5
Camelina oil Acetamipryd Camelina oil	0.9% 0.2 kg · ha^{-1} 0.9%	spring summer autumn	8.8 b	68.3
Camelina oil Acetamipryd Camelina oil	1.2% 0.2 kg · ha^{-1} 1.2%	spring summer autumn	3.0 a	89.2
		Piskórka (field)		
Before the first treatment	–	–	17.7	–
Control	–	–	65.4 b	–
Polysaccharides Silicon polymers Polysaccharides	0.3% 0.2% 0.3%	spring summer autumn	41.2 ab	37.0
Silicon polymers Silicon polymers Silicon polymers	0.2% 0.2% 0.2%	spring summer autumn	18.8 a	71.3
Camelina oil Silicon polymers Camelina oil	0.9% 0.2% 0.9%	spring summer autumn	28.6 a	54.7
Camelina oil Silicon polymers Camelina oil	1.2% 0.2% 1.2%	spring summer autumn	32.0 ab	51.0
		Piskórka (tunnel)		
Before the first treatment	–	–	16.7	–
Control	–	–	57.3 c	–
Polysaccharides Silicon polymers Polysaccharides Spirotetramat	0.3% 0.2% 0.3% 0.75 l · ha^{-1}	spring summer summer autumn	6.5 ab	88.7
Silicon polymers Silicon polymers Silicon polymers Spirotetramat	0.2% 0.2% 0.2% 0.75 l · ha^{-1}	spring summer summer autumn	3.2 a	94.4
Camelina oil Silicon polymers Camelina oil Spirotetramat	0.9% 0.2% 0.9% 0.75 l · ha^{-1}	spring summer summer autumn	12.1 b	78.9
Camelina oil Silicon polymers Camelina oil Spirotetramat	1.2% 0.2% 1.2% 0.75 l · ha^{-1}	spring summer summer autumn	7.6 ab	86.7
Paraffin oil Silicon polymers Camelina oil Spirotetramat	1.5% 0.2% 1.2% 0.75 l · ha^{-1}	spring summer summer autumn	4.8 a	91.6

*means followed by the same letter (in columns) within a single trial do not differ significantly according to Tukey multiple range test ($p \leq 0.05$)
#treatment dates: spring (April), summer (July), autumn (September)

not assessed in the present study, but if present could support a multifunctional use for the product in view of an integrated crop management system.

The application of products based on active substances of the neonicotinyl group was used as a standard method of control, particularly of young larvae. The results obtained with spirotetramat, an inhibitor of acetyl CoA carboxylase, confirmed the possibility of using this product against Lecanium scales. It had an efficacy similar to that of pests of different orders (Łabanowska *et al.* 2013, 2015; Tartanus *et al.* 2015).

With the alternative products a level of control was obtained that was in several trials comparable to that resulting from application of the chemical synthetic compounds, even with a quite high level of initial scale infestation, as in the case of the silicon polymers-based product. These products, when singly applied, were found to be more effective on protected crops than in the open field. On the other hand, the addition of the neonicotinyl products to the control program increased the overall efficacy of the treatments. The effectiveness of the tested substances was in line with similar trials performed to assess their effect on other pests of small fruits (Łabanowska *et al.* 2014; Tartanus *et al.* 2015).

A competitive advantage of applying the alternative products in summer (after the hatching of young larvae) derives from the lack of residues on fruits and thus of a withdrawal period, which is key for a crop having a long harvesting period such as highbush blueberry. However, it should be mentioned that the product based on polysaccharides used prior to harvest (in summer) was reported to alter the taste of the fruits and, if applied at concentrations higher than those recommended and used in this study, appeared to induce some phytotoxic responses (Łabanowska unpublished data).

The integrated approach developed with the tested control programs, i.e. combining the application of alternative compounds during the period of growth and harvest with that of chemical compounds at the end of the season, is also expected to reduce the risk of induction of resistance toward the neonicotinyl pesticides in the pest population and to limit the possible damage to pollinators.

Conclusions

Control programs on plantations with large Lecanium scale populations based on the application of alternative products, having mechanical control, in spring and at harvest combined with the application of chemical compounds in autumn resulted in a very high efficacy. This strategy is considered to be the most suitable to control Lecanium scales in highbush blueberry crops, assuring harvested fruits without residues and a reduced impact on the environment.

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