

EFFICACY OF SPINOSAD AND *Bacillus thuringiensis* var. *kurstaki* IN BIOLOGICAL CONTROL OF THE EUROPEAN CORN BORER ON SWEET CORN

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Abstract. The European corn borer (*Ostrinia nubilalis* Hbn.) is one of the most dangerous pests of sweet corn in Poland. As indicated in the guidelines for integrated pest management (IPM), harmful organisms on plants should at first be controlled by non-chemical methods and, if these are ineffective, the use of chemical methods is allowed. The aim of this study was to assess the effectiveness of biopesticides containing spinosad and *Bacillus thuringiensis* var. *kurstaki* to reduce the population and harmfulness of *O. nubilalis* caterpillars. The study was carried out in 2013–2015 in southeastern Poland, on ‘Candle’ sweet corn. Corn plants were sprayed either once or twice in July, when *O. nubilalis* larvae hatched on a mass scale. The pest was controlled with Spintor 240 SC (spinosad A + spinosad D) at doses of 0.2 and 0.4 l·ha⁻¹, Dipel WG (*B. thuringiensis* var. *kurstaki*) at doses of 1.0 and 2.0 kg·ha⁻¹, Karate Zeon 050 CS (lambda-cyhalothrin) at a dose of 0.2 l·ha⁻¹, and Proteus 110 OD (thiacloprid + deltamethrin) at a dose of 0.5 l·ha⁻¹. All products reduced the number and harmfulness of larvae, especially on cobs which are a commercial crop. The best effects were achieved after two treatments with biopesticides at higher doses. This reduced nearly by half the number of cobs damaged by the pest. Spinosad was more effective than *B. thuringiensis*. The effectiveness of biopesticides depended on weather conditions. Chemical pest control was found most effective.

Key words: *Zea mays* var. *saccharata*, *Ostrinia nubilalis*, biopesticides, effectiveness

INTRODUCTION

Sweet corn (*Zea mays* L. var. *saccharata*) is a popular vegetable grown in many countries worldwide. Cobs are harvested when the kernels are at the milk or milk-wax

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stage of ripening, and processed to produce canned or frozen corn, or used for consumption without processing [Waligóra 1992, Borowiak 2015].

The leading producers of sweet corn are the United States, with an acreage of about 200.000 ha⁻¹, and China, with an acreage of over 100.000 ha⁻¹. In Europe, sweet corn is grown mostly in Hungary and France, and the acreage in these countries is about 30.000–35.000 ha⁻¹ [Borowiak 2015]. In Poland sweet corn is grown on a small scale on about 8.000 ha⁻¹ [Warzecha and Malinowski 2015].

The successful cultivation of sweet corn is reflected in a high yield of cobs free of any damage caused by harmful organisms, especially pests [Hazzard et al. 2003]. In many countries one of the major hazards for the volume and quality of sweet corn yield is posed by the feeding European corn borer (ECB, *Ostrinia nubilalis* Hbn.), whose larvae damage cobs and stems [Capinera 2001, Velasco et al. 2004, Changying 2011, Bunn 2014]. In Poland ECB also poses a serious threat to sweet corn yield, and its harmfulness continues to increase, because since 2009 this pest has been reported from all regions of the country [Kunicki 2003, Waligóra et al. 2008, Bereś 2012 a, Bereś and Konefał 2015].

Because of its great harmfulness to sweet corn ECB has to be controlled directly on an increasingly larger number of fields. In Poland, the current recommendations regarding pest management on sweet corn list insecticides approved for the control of ECB containing lambda-cyhalothrin, indoxacarb, and a mixture of thiacloprid and deltamethrin [Zalacenia 2016]. However, due to consumer concerns about pesticide residues in food, researchers are looking for nonchemical methods to control ECB [Ben-Yakir et al. 1998].

Large-scale studies are being conducted worldwide on the suitability of natural enemies in limiting populations of *O. nubilalis*. In addition, GMO corn varieties and traditional corn varieties more resistant to the pest are grown, and a variety of biopesticides containing, e.g. spinosad, *Bacillus thuringiensis* and *Beauveria bassiana* are used [Schnepf et al. 1998, Burkness et al. 2001, Bourguet et al. 2002, Hazzard et al. 2003, Musser and Shelton 2003, Musser et al. 2006, Abd El-Mageed and Elgohary 2007, Moghanlou et al. 2014].

Studies carried out on corn fields in Poland to investigate the biological control of the European corn borer used only foliar biopesticides containing *Bacillus thuringiensis* var. *kurstaki* and insecticidal fungi *Isaria fumosorosea* [Mazurek et al. 2005, Nawrocka et al. 2011, Kuźniar et al. 2012].

In recent years, much hope in the biological protection of plants against pests, especially on organic farms, is placed in the use of spinosad obtained from *Saccharopolyspora spinosa* [Kowalska and Drożdżyński 2009]. Biopesticides containing spinosad have a relatively broad spectrum of insecticidal activity, especially on Lepidoptera and Coleoptera, and are relatively safe for useful entomofauna [Kowalska 2008 a].

The aim of the study was to assess the effectiveness of biopesticides containing spinosad and *B. thuringiensis* var. *kurstaki* in the biological control of *O. nubilalis* on sweet corn grown in southeastern Poland.

MATERIALS AND METHODS

The study was carried out in 2013–2015 in Nienadówka (50°11'N; 22°06'E), south-eastern Poland, on a 1 ha⁻¹ field of 'Candle' variety sweet corn. From the beginning of the study corn was grown in a 3-year monoculture. The effects of the biological control of *O. nubilalis* were tested in a field experiment on 4-row plots in the randomized block system in 4 replicates. The size of each plot was about 50 m⁻² (3.0 m × 16.5 m; width × length). Sweet corn was sown in the last ten days of April.

ECB larvae were controlled with two biopesticides: Spintor 240 SC (spinosad A + spinosad D) at doses of 0.2 and 0.4 l·ha⁻¹, and Dipel WG (*Bacillus thuringiensis* var. *kurstaki*) at doses of 1.0 and 2.0 kg·ha⁻¹. For comparative purposes, we also used the standard chemical control of larvae with Karate Zeon 050 CS (lambda-cyhalothrin) at a dose of 0.2 l·ha⁻¹, and Proteus 110 OD (thiacloprid + deltamethrin) at a dose of 0.5 l·ha⁻¹.

The optimum date for the control of *O. nubilalis* larvae hatching on a mass scale was established based on observation of moth flight using light traps, and direct observations of plants for the presence of eggs and young larvae. Plants were sprayed once or twice with either biopesticides or chemical insecticides on two dates:

I – on 8 July (2013), 9 July (2014) and 11 July (2015), when corn plants were at stage BBCH 51 (beginning of tassel development – beginning of larvae hatching on a mass scale),

II – on 18 July (2013), 19 July (2014) and 17 July (2015), when plants were at stage BBCH 63 (beginning of pollen shedding – peak of larvae hatching on a mass scale).

Both foliar biopesticides were used once or twice, while chemical insecticides were rotated with respect to the active substance, i.e. Karate Zeon 050 CS was used for the first treatment (date I) and Proteus 110 OD for the second treatment (date II). The reason for this was that Proteus 110 OD is labelled only for a single use during the corn growing season.

Corn was sprayed using an experimental backpack sprayer, model AP 1/p, with a compressed air tank of constant working pressure. In the experiment we used a 3 m-wide boom with three nozzles spaced every 50 cm, positioned above the plant tops. Medium-droplet spraying was applied using Tee Jet 11002 nozzles. 300 litres of water were used per hectare.

The effectiveness of treatments against ECB was assessed in mid-August, when kernels were at the milk-wax stage of ripening (BBCH 75–83). On each plot randomly selected plants in two central rows, 100 plants per plot, were inspected, and the percentage of damaged plants and cobs was calculated, as well as the percentage of stems broken above and below the cob. In addition, 25 randomly selected plants from each plot were cut lengthwise to calculate the mean number of larvae feeding inside the corn stems and cobs, the mean number of holes in plants, and the mean length of feeding tunnels in plants.

Weather data were acquired from a weather station of the Institute of Meteorology and Water Management – National Research Institute (IMGW – PIB), located in Jasionka, near Rzeszów, 10 km from the experimental field in Nienadówka.

Results were statistically analysed using Statistica 10.0 PL software from StatSoft. One-way analysis of variance in a random block design was used. The significance of differences between means was verified with the Student-Newman-Keuls test at a significance level of $p = 0.05$. The analysis of results from study years was based on a mixed variance analysis design which assumed a constant effect for an experimental plot and a random effect for study year. The significance of interaction between the experimental plot and study year was also calculated, and it was interpreted as a significant effect of weather conditions during the growth season on the effect of the experimental factor.

RESULTS

Changes in the most important weather parameters in the study years during the occurrence and control of European corn borer are presented in table 1. In the analysed 3-year period weather conditions were favourable for the growth of corn plants and the feeding of *O. nubilalis* larvae on them. In 2013 and 2015 a low amount of rainfall between July and August, and also high temperatures (including strong insolation) caused a periodic loss of turgor in plant tissues, manifested by wilting leaves. Strong insolation combined with high temperature had a potential influence on the effects of the biological control of the pest.

Table 1. Weather conditions in Nienadówka in 2013–2015

Month	Ten-day period	Mean daily air temperature (°C)			Mean daily rainfall (mm)			Mean daily air humidity (%)		
		2013	2014	2015	2013	2014	2015	2013	2014	2015
June	I	16.8	17.6	19.5	78.6	3.3	0.0	80.8	70.2	53.5
	II	20.1	16.1	17.9	25.3	12.5	8.0	73.7	64.3	60.5
	III	18.6	16.0	16.4	39.5	32.3	1.1	79.6	66.1	64.4
	monthly mean/sum	18.5	16.5	17.9	143.4	48.1	9.1	78.0	66.8	59.4
July	I	19.6	19.3	21.1	0.1	36.8	13.1	63.9	69.2	50.4
	II	17.5	20.2	19.9	19.1	43.4	25.7	77.1	73.2	62.8
	III	20.8	21.6	20.6	0.0	48.4	26.5	63.5	72.4	62.0
	monthly mean/sum	19.3	20.3	20.5	19.2	128.6	65.3	68.1	71.6	58.4
August	I	23.2	21.7	23.5	0.0	12.2	7.2	59.5	76.6	57.5
	II	19.4	18.3	22.8	3.0	20.5	6.1	61.8	76.9	49.4
	III	15.8	14.7	20.7	8.0	31.8	8.8	75.9	79.5	55.0
	monthly mean/sum	19.4	18.2	22.3	11.0	64.5	22.1	65.7	77.6	53.9

Results of the biological and chemical control of *O. nubilalis* are presented separately for each year in tables 2–4. Table 5 shows a summary for the 3-year study.

In 2013–2015 the European corn borer posed a very serious threat to sweet corn, which can also be attributed to the fact that the crop was grown in a monoculture. In the

analysed period, ECB damaged 81.0 to 91.7% of plants and 54.5 to 70.2% of cobs on the untreated plot. On average, 3.5 to 4.3 larvae were feeding on a single cob, and 1.5 to 2.2 larvae inside the stem. The pest gnawed on average 2.1 to 3.1 holes in a single plant, and the mean length of a feeding tunnel was 12.1 to 17.3 cm. Broken stems as a result of tissue damage were noted. On the untreated plot 17.5 to 36.2% of plants had stems broken above the cob; and 9.2 to 14.7% of plants below the cob (tab. 2–4).

Spinosad used for the control of ECB larvae hatching on a mass scale significantly reduced the population and harmfulness of *O. nubilalis* in all study years compared to the untreated plot. On the plots treated once or twice with spinosad larvae during the study years damaged 39.0 (2014) to 67.2% of plants (2015). The number of damaged cobs was also lower, and their protection against damage is a priority in pest management on corn, as cobs are a commercial crop. On the plots treated with spinosad the pest damaged 27.7 (2013) to 60.5% (2015) of cobs. The harmfulness of ECB to cobs was lower as fewer larvae fed on them compared to the untreated plot, which was particularly clear in 2013–2014. Regardless of the product dose and number of treatments, on average 2.0 to 3.2 larvae fed on cobs protected with spinosad (tab. 2–4).

No significant reduction in the population and harmfulness of *O. nubilalis* was obtained with respect to the number of larvae inside stems, the number of holes gnawed by them, and the length of feeding tunnels and broken stems in individual years on any plot treated with spinosad compared to the untreated plot. The best effects of the biological control of ECB were achieved with spinosad at a dose of $0.4 \text{ l}\cdot\text{ha}^{-1}$, especially when plants were sprayed twice. The weakest insecticidal effects were found after a single treatment of plants with spinosad at a dose of $0.2 \text{ l}\cdot\text{ha}^{-1}$ (tab. 2–4).

Slightly weaker insecticidal effects compared to spinosad were obtained on plots protected with a biopesticide containing *Bacillus thuringiensis*. On plots treated with this bacterial product larvae damaged 47.5 (2014) to 71.2% of plants (2013). *B. thuringiensis*, slightly less than spinosad, also reduced the percentage of damaged cobs, which in 2013–2015 was in the range of 33.2 (2013) to 62.0 (2015). However, another bioinsecticide, Dipel WG, significantly reduced the number of damaged plants and cobs compared to the untreated plot. The percentage of damaged cobs on plots treated once with crystal Cry protein did not differ significantly from the untreated plot only in 2015.

The analysis demonstrated that on the cobs of plants treated with Dipel WG 2.1 (2013) to 3.7 (2014) larvae fed on average during the study years. The number of the pest in 2013–2014 was significantly lower compared to the untreated plot, and in 2015 a significant difference was found only for the plot treated twice with Dipel WG at a dose of $2.0 \text{ kg}\cdot\text{ha}^{-1}$.

Treatments with *B. thuringiensis* did not effectively protect plants against stems breaking below cobs, but in some years (especially in 2013–2014) significantly reduced the number of stems broken above the cob compared to the untreated plot. The use of this biopesticide did not significantly reduce the number of larvae inside the stem, the number of holes gnawed by them (except for 2013), or the length of feeding tunnels (except for 2013) compared to the untreated plot (tab. 2–4).

Similar to experiments with spinosad, *B. thuringiensis* produced the best insecticidal effects when plants were treated twice with the higher dose of the product.

Table 2. Results of biological and chemical control of *Ostrinia nubilalis* in 2013

Experimental plot	Dose (l, kg·ha ⁻¹)	Treatment date		Damaged (%)				Stems broken (%)				Mean number of larvae (n)			Mean number of holes per plant (n)	Mean length of feeding tunnel per plant (cm)			
		I	II	plants	cobs	above the cob	below the cob	on the cob	inside stem										
Untreated plot	–	–	–	81.2	a	54.5	a	17.5	a	9.2	a	3.7	a	1.7	a	2.3	a	13.7	a
Spintor 240 SC	0.2	–	+	63.7	bc	41.5	b	15.5	a	8.0	ab	2.7	b	1.5	ab	1.5	b	8.7	b
Spintor 240 SC	0.2	+	+	54.2	c	39.5	b	10.7	b	7.2	ab	2.2	b	1.3	ab	1.5	b	6.5	cd
Spintor 240 SC	0.4	–	+	56.2	c	35.2	bc	10.2	b	5.7	ab	2.5	b	1.2	ab	1.4	b	6.2	cd
Spintor 240 SC	0.4	+	+	41.2	d	27.7	c	8.5	b	4.5	b	2.4	b	1.0	b	1.2	b	5.5	d
Dipel WG	1.0	–	+	71.2	b	40.5	b	15.2	a	8.5	ab	2.9	b	1.5	ab	1.7	b	7.8	bc
Dipel WG	1.0	+	+	61.7	bc	38.0	b	10.2	b	6.2	ab	2.7	b	1.4	ab	1.5	b	7.2	bcd
Dipel WG	2.0	–	+	62.5	bc	39.7	b	9.2	b	5.5	ab	2.5	b	1.3	ab	1.6	b	6.9	bcd
Dipel WG	2.0	+	+	54.2	c	33.2	bc	7.7	b	5.2	ab	2.1	b	1.1	ab	1.3	b	6.2	cd
Proteus 110 OD	0.5	–	+	10.2	e	6.5	d	2.2	c	1.0	c	0.5	c	0.2	c	0.5	c	1.5	e
Karate Zeon 050 CS + Proteus 110 OD	0.2 + 0.5	+	+	6.5	e	4.7	d	0.7	c	0.2	c	0.2	c	0.0	c	0.2	c	1.2	e

Treatment date: I – 08 July, II – 18 July

Means in columns followed by the same letter do not differ at 5% level of significance in the Student-Newman-Keuls test

Table 3. Results of biological and chemical control of *Ostrinia nubilalis* in 2014

Experimental plot	Dose (l, kg·ha ⁻¹)	Treatment date		Damaged (%)				Stems broken (%)		Mean number of larvae (n)			Mean number of holes per plant (n)	Mean length of feeding tunnel per plant (cm)					
		I	II	plants	cobs	above the cob	below the cob	on the cob	inside stem										
Untreated plot	–	–	–	91.7	a	63.5	a	36.2	a	14.7	a	4.3	a	2.2	a	3.1	a	17.3	a
Spintor 240 SC	0.2	–	+	59.7	c	58.0	ab	24.5	bcd	11.7	a	3.2	b	1.5	ab	2.5	a	13.7	ab
Spintor 240 SC	0.2	+	+	54.2	cd	52.7	bc	15.7	cde	8.7	a	2.7	b	1.2	ab	2.1	a	10.5	bc
Spintor 240 SC	0.4	–	+	44.2	e	43.7	de	21.5	bcd	8.2	a	2.9	b	1.4	ab	2.2	a	10.2	bc
Spintor 240 SC	0.4	+	+	39.0	e	30.5	f	13.7	de	8.5	a	2.5	b	1.1	ab	1.9	a	6.5	cd
Dipel WG	1.0	–	+	70.5	b	47.2	cd	28.2	b	13.5	a	3.7	ab	1.7	a	2.7	a	15.1	ab
Dipel WG	1.0	+	+	56.2	cd	39.5	de	25.7	bc	10.5	a	3.1	b	1.3	ab	2.5	a	11.7	abc
Dipel WG	2.0	–	+	69.7	b	42.5	de	23.5	bcd	11.7	a	3.3	b	1.5	ab	2.4	a	12.2	abc
Dipel WG	2.0	+	+	47.5	de	36.7	ef	15.2	cde	9.2	a	2.7	b	1.3	ab	2.3	a	10.7	bc
Proteus 110 OD	0.5	–	+	17.2	f	13.7	g	7.2	ef	1.2	b	0.7	c	0.5	bc	1.0	b	2.2	d
Karate Zeon 050 CS + Proteus 110 OD	0.2 + 0.5	+	+	8.5	g	8.2	g	2.5	f	0.2	b	0.5	c	0.2	c	0.5	b	1.7	d

Treatment date: I – 09 July, II – 19 July

Means in columns followed by the same letter do not differ at 5% level of significance in the Student-Newman-Keuls test

Table 4. Results of biological and chemical control of *Ostrinia nubilalis* in 2015

Experimental plot	Dose (l, kg·ha ⁻¹)	Treatment date		Damaged (%)				Stems broken (%)				Mean number of larvae (n)		Mean number of holes per plant (n)	Mean length of feeding tunnel per plant (cm)				
		I	II	plants	cobs	above the cob	below the cob	on the cob	inside stem										
Untreated plot	–	–	–	81.0	a	70.2	a	20.7	a	11.2	a	3.5	a	1.5	a	2.1	a	12.1	a
Spintor 240 SC	0.2	–	+	67.2	b	60.5	ab	16.2	abc	10.5	a	3.1	ab	1.3	a	1.9	a	10.6	ab
Spintor 240 SC	0.2	+	+	58.7	bc	51.2	bc	12.7	bc	8.7	a	2.8	abc	1.2	a	1.7	a	10.2	ab
Spintor 240 SC	0.4	–	+	52.7	cd	50.2	bc	13.0	bc	7.5	a	2.4	bc	1.1	a	1.6	a	8.5	ab
Spintor 240 SC	0.4	+	+	40.5	e	38.7	c	10.5	c	6.2	a	2.0	c	0.9	a	1.4	a	6.2	b
Dipel WG	1.0	–	+	65.2	b	62.0	ab	18.5	ab	9.7	a	3.2	ab	1.3	a	1.7	a	11.2	ab
Dipel WG	1.0	+	+	51.7	cd	49.2	bc	14.2	abc	8.2	a	2.6	abc	1.1	a	1.5	a	9.5	ab
Dipel WG	2.0	–	+	63.5	b	61.7	ab	12.7	bc	8.7	a	2.9	abc	1.2	a	1.6	a	8.3	ab
Dipel WG	2.0	+	+	48.2	d	45.0	c	9.5	c	7.2	a	2.3	bc	1.1	a	1.5	a	7.1	ab
Proteus 110 OD	0.5	–	+	10.5	f	9.7	d	1.2	d	0.7	b	1.2	d	0.2	b	0.7	b	1.6	c
Karate Zeon 050 CS + Proteus 110 OD	0.2 + 0.5	+	+	7.7	f	6.5	d	1.2	d	0.5	b	0.7	d	0.2	b	0.5	b	0.7	c

Treatment date: I – 11 July, II – 17 July

Means in columns followed by the same letter do not differ at 5% level of significance in the Student-Newman-Keuls test

The standard chemical control used for comparison was most effective in limiting the population and harmfulness of ECB compared to the untreated plot, as well as to both tested biopesticides. The effects of spinosad and *B. thuringiensis* on limiting the population and harmfulness of *O. nubilalis* were significantly weaker with compared to chemical pest control.

The summary of results from individual study years demonstrated that biopesticides, especially at higher doses and used twice during the corn growth season, significantly reduced the population and harmfulness of ECB. Nevertheless, spinosad and *B. thuringiensis* did not reduce the hazard posed by *O. nubilalis* to the level offered by chemical pest control (tab. 5).

The analysis focused on the interaction between the experimental factor and study year revealed significant differences with respect to the analysed three parameters, i.e. percentage of damaged plants and cobs, and percentage of stems broken above the cob. Weather conditions in the study years had a significant impact on the effectiveness of the tested pesticides.

DISCUSSION

The study revealed the great harmfulness of the European corn borer to sweet corn grown in the climate and soil conditions in southeastern Poland. Of all the analysed types of damage caused by feeding ECB, damage to cobs is of most concern to farmers growing this plant, because it makes the crop unsuitable for sale on the fresh produce market, and for processing, which generates a loss for farmers [Borowiak 2015].

In the study years ECB damaged 54.5 to 70.2% of cobs on the untreated plot. As demonstrated by our previous research, ECB, having access to fodder corn, sweet corn and sorghum, causes most severe damage to sweet corn, which is most likely associated with the high sugar content in the tissues of this plant [Bereś 2012a]. Studies carried out by other authors in Poland also reported the great harmfulness of *O. nubilalis* to sweet corn cobs, and it often fluctuated year-to-year. In 2003–2006 Waligóra et al. [2008] investigated the susceptibility of various sweet corn cultivars to ECB, and reported that the pest damaged from a few to 69.8% of cobs in central Poland. This great harmfulness of ECB is comparable to that noted in our study, and justifies the need for pest control. Lower harmfulness of ECB in central Poland, but varying depending on the date of corn sowing, was reported by Kruczek [2011]. On the other hand Mazurek et al. [2005], who carried out research in 1998–2001 in southwestern Poland, demonstrated that ECB larvae damaged up to 45.3% of cobs on plots not treated with pesticides.

Spinosad (Spintor 240 SC), used in our study during the abundant pest occurrence, significantly reduced the population and harmfulness of ECB compared to the untreated plot. Although the effectiveness of spinosad in the control of *O. nubilalis* was much lower compared to chemical insecticides, it still allowed for a reduction in the number of damaged cobs. The best effects of control (a nearly 50% reduction in the number of damaged cobs) were achieved after two treatments of plants with spinosad at a dose of 0.4 l·ha⁻¹.

The high suitability of spinosad in the control of *O. nubilalis* on corn was also found in the USA by Tembo and Pavuk [2011]. The researchers indicated spinosad as a useful product for integrated pest management, also on organic farms. Similar conclusions were reached by Bažok et al. [2009], who tested spinosad on sweet corn in Croatia, and found it very useful for the control of *O. nubilalis*. Experiments carried out by Bailey et al. [2005] in Canada on sweet corn demonstrated that the effectiveness of spinosad in the control of ECB was comparable to carbofuran and lambda-cyhalothrin.

Apart from ECB, spinosad has also been tested on other Lepidoptera pests. Studies carried out in Mexico by Méndez et al. [2002] demonstrated the suitability of spinosad in the control of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on corn. The insecticidal effect of spinosad on Lepidoptera pests was also confirmed in laboratory studies carried out by Pineda et al. [2004], who used this substance for the control of *Spodoptera littoralis*. Spinosad also successfully controlled this species on cotton in a study by Abouelghar et al. [2013]. The broad insecticidal spectrum of spinosad, as well as the low risk of developing resistance to it and its safety for useful entomofauna, were reported by Downard [2001].

The second biopesticide (Dipel WG) containing crystal Cry protein extracted from *Bacillus thuringiensis* var. *kurstaki* provided weaker insecticidal effects than spinosad, but in the majority of experimental combinations it still significantly reduced the number of cobs damaged by larvae compared to the untreated plot. As with spinosad, better results in limiting the number of cobs damaged by larvae were obtained after a double treatment of plants with Dipel WG at a dose of 2.0 kg-ha⁻¹. Such treatment reduced the number of damaged cobs by nearly 50% compared to the untreated plot.

Foliar biopesticides formulated using *B. thuringiensis* for the control of pests in many crops have been used for several decades. These biopesticides have become the cornerstone for the development of green biotechnology associated with growing GMO plants, including sweet corn synthesizing Cry1Ab protein, a hybrid resistant to the European corn borer [Betz et al. 2000, Burkness et al. 2001]. In Poland, genetically-modified sweet corn has never been grown, and in 2013 a ban on the cultivation of GMO plants was instituted [Dz. U. z 2013 r. poz. 39 ze zm.]. Facing such circumstances, crystal Cry protein can only be used for the control of pests in the form of foliar biopesticides formulated with *B. thuringiensis*.

Studies on the protection of sweet corn against *O. nubilalis* using foliar biopesticides containing *B. thuringiensis* var. *kurstaki* have already been carried out in Poland. For example, a one-year comparative study investigating the effects of Biobit 3,2 WP and chemical products containing, e.g. lambda-cyhalothrin was carried out in 1998 by Mazurek and Hurej [1999] in southwestern Poland. The researchers reported that larvae damaged on average 23.7% of cobs on the untreated plot, and only slightly less, 19.2% of cobs, on a plot sprayed once in July with Biobit 3,2 WP. The best insecticidal effects (5.5% of damaged cobs) were produced by lambda-cyhalothrin.

In another study carried out in 1998–2000 Mazurek et al. [2005] tested two biopesticides: Biobit 3,2 WP and Lepinox WDG for the control of *O. nubilalis*. They reported that on the control plot ECB damaged 13.3 to 27.3% of cobs, which is nearly 50% less than in our study. Mazurek et al. [2005] found that in one year (2000) the tested biopesticides protected up to 95% of cobs against the pest feeding, and in two other years

(1998–1999) their effectiveness was lower, 19.0–35.0%. The researchers attributed the differences in the insecticidal effect of *B. thuringiensis* to the impact of unfavourable weather conditions.

The insecticidal effect of Dipel WG in the protection of sweet corn against *O. nubilalis* was also investigated in 2010–2011 by Nawrocka et al. [2011]. Experimental plots were located near Warsaw. The plants were sprayed twice between 30 July and 24 August, and then the effectiveness of biopesticide was assessed twice: two and four weeks after the treatment. The study by Nawrocka et al. revealed considerable differences in the effectiveness of *B. thuringiensis* in the control of *O. nubilalis* depending on observation date. The number of larvae recorded on the first date on plants sprayed with biopesticide and on the untreated plot was comparable. However, on the second date of observation the number of larvae on the plot treated with Dipel WG was significantly lower compared to the untreated plot. A similar relationship was reported for the number of damaged cobs. Despite the considerable differences in the effectiveness of Dipel WG, the researchers indicated its suitability for the protection of sweet corn against ECB.

It should be pointed out, however, that Nawrocka et al. [2011] applied insecticidal treatments against ECB a few weeks later than in our study, and established that date using pheromone traps. This date is questionable, considering the fact that the biology of *O. nubilalis* is well-investigated and clearly shows that the pest hatches on a mass scale in July [Mazurek and Hurej 1999, Mazurek et al. 2003, Lisowicz and Tekielna 2004], while pheromone traps for capturing ECB males are very imprecise and should not be used for establishing dates of pest control [Furlan and Girolami 2001, Bereś 2012b].

Studies carried out outside Poland demonstrated differences in the effectiveness of biopesticides containing *B. thuringiensis* for the control of ECB. For example, in the USA, Hudon [1962] reported the low effectiveness of biopesticides, and emphasized the need to use high doses of *B. thuringiensis*. In a study by Tembo and Pavuk [2011] *B. thuringiensis* was also less effective than spinosad or other products.

Bažok et al. [2009] investigated the effects of *B. thuringiensis* var. *kurstaki* at doses of 0.75 and 1.0 kg·ha⁻¹ on the control of *O. nubilalis* on sweet corn in Croatia in 2002–2003. Depending on the treatment date and location of the experimental plot, *B. thuringiensis* reduced the number of cobs damaged by the pest by 27.2–71.3%. In their analysis of this wide range of effectiveness of the biopesticide the researchers emphasized the need for establishing a precise date of its application. In their study, high insecticidal effectiveness was achieved when plants were sprayed just before the hatching of larvae on a mass scale.

The insecticidal effectiveness of biopesticides containing *B. thuringiensis* is influenced by many factors. The most important of them are: precise dispersal of prepared fluid on leaves, droplet sedimentation, deposition of bioinsecticide on the leaves, intake of lethal dose by insects, effectiveness of the biopesticide inside insects, and weather conditions [Sierpińska 2000]. The most important weather conditions are temperature, UV radiation, air humidity and rainfall [Raun et al. 1966, Morris 1982, Salama and Zaki 1985, Sundaram and Sundaram 1991]. For example, some researchers point out the fact

that the degradation of spinosad is enhanced by exposure to natural light [Kowalska and Drożdżyński 2009].

In our study the insecticidal effect of spinosad and *B. thuringiensis* was also potentially influenced by weather conditions, particularly temperature and strong insolation accelerating the degradation of biopesticides on corn leaves. Studies conducted by other authors have indicated the diverse reaction of pests controlled using spinosad depending on changes in temperature and humidity and the applied dose. Laboratory tests carried out by Musser and Shelton [2005] on the control of the European corn borer showed that the insecticidal effect of spinosad and two pyrethroids (lambda-cyhalothrin and bifenthrin) was reduced at temperatures of 24 to 35°C, and the reduction for spinosad was significantly lower than for pyrethroids. Studies on the control of Coleoptera pests, e.g. *Leptinotarsa decemlineata*, *Tribolium confusum* and *Tribolium castaneum*, also demonstrated great differences in the insecticidal effect of spinosad for different doses and temperatures [Yousefnezhad-Irani and Pourmirza 2007, Kowalska 2008b, Thompson and Reddy 2016].

Weather conditions also had an impact on the effectiveness of the biopesticide Dipel WG. The insecticidal effect of biopesticides containing *B. thuringiensis* sprayed on plants is strongly influenced by UV radiation, temperature and rainfall [Griego and Spence 1978, Moxtarnejad et al. 2014]. For example, a study by Sleem Rasha et al. [2012] demonstrated that longer exposure to high temperatures and natural light reduced the effectiveness of Dipel 2X WP containing *B. thuringiensis* used for the control of *Spodoptera littoralis* larvae. Exposure to UV light without photo protective materials also limited the effective control of *Pieris brassicae* larvae.

Conventional chemical treatments used for the control of ECB larvae on sweet corn were highly effective and comparable with rates reported by other authors [Mazurek and Hurej 1999, Mazurek et al. 2005, Bereś 2010].

CONCLUSIONS

1. The study demonstrated the great harmfulness of *Ostrinia nubilalis* to sweet corn grown in southeastern Poland and justified the need for direct control of this pest.

2. Spinosad (Spintor 240 SC) reduced the population and harmfulness of the European corn borer compared to the untreated plot, especially on cobs. Two treatments of plants with spinosad at a dose of 0.4 l·ha⁻¹ provided the best results.

3. Dipel WG, containing *Bacillus thuringiensis* var. *kurstaki*, reduced the population and harmfulness of *O. nubilalis* compared to the untreated plot. *B. thuringiensis* was slightly less effective in limiting the number of damaged cobs compared to spinosad. The best insecticidal effects were achieved after two treatments using a dose of 2.0 kg·ha⁻¹.

4. The significantly lower insecticidal effectiveness of spinosad and *B. thuringiensis* compared to conventional chemical products can be attributed to weather conditions during the study years, which accelerated the degradation of biopesticides on corn leaves.

5. The tested biopesticides are suitable for the biological protection of sweet corn against the European corn borer, especially when used twice and at higher doses.
6. Standard chemical control of *O. nubilalis* was highly effective.

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PRZYDATNOŚĆ SPINOSADU I *Bacillus thuringiensis* var. *kurstaki* W BIOLOGICZNEJ OCHRONIE KUKURYDZY CUKROWEJ PRZED OMACNICĄ PROSOWIANKĄ

Streszczenie. Omacnica prosowianka (*Ostrinia nubilalis* Hbn.) zaliczana jest do najgroźniejszych szkodników kukurydzy cukrowej w Polsce. W zaleceniach integrowanej ochrony roślin (IPM) przed organizmami szkodliwymi preferuje się stosowanie wpiery metod niechemicznych, a dopiero w ostateczności zastosowanie chemicznej ochrony. Celem wykonanych badań była ocena przydatności biopreparatów zawierających spinosad oraz *Bacillus thuringiensis* var. *kurstaki* do ograniczania liczebności i szkodliwości gąsienic *O. nubilalis*. Badania wykonano w latach 2013–2015 w południowo-wschodniej Polsce na kukurydzy cukrowej odmiany Candle. Jedno- oraz dwukrotne opryskiwanie roślin kukurydzy wykonano w lipcu, w okresie licznego wylęgu gąsienic *Ostrinia nubilalis* (Hbn.). Do zwalczania szkodnika wykorzystano preparaty: Spintor 240 SC (spinozyn A + spinozyn D) w dawce 0,2 i 0,4 l·ha⁻¹, Dipel WG (*Bacillus thuringiensis* var. *kurstaki*) w dawce 1,0 i 2,0 kg·ha⁻¹; Karate Zeon 050 CS (lambda-cyhalotryna) w dawce 0,2 l·ha⁻¹ oraz Proteus 110 OD (tiachlopyryd + deltametryna) w dawce 0,5 l·ha⁻¹. Wszystkie zastosowane preparaty pozwoliły obniżyć liczebność oraz szkodliwość gąsienic, zwłaszcza w odniesieniu do kolb, które są plonem handlowym. Przy stosowaniu biopreparatów najlepsze efekty uzyskano, stosując dwa zabiegi opryskiwania roślin z zastosowaniem maksymalnych dawek. Pozwoliły one niemal o połowę obniżyć liczbę kolb uszkodzonych przez szkodnika. Lepszą skutecznością odznaczał się spinosad w porównaniu z *B. thuringiensis*. Na skuteczność biopreparatów wpływ miały warunki meteorologiczne. Najskuteczniejsza była ochrona chemiczna.

Słowa kluczowe: *Zea mays* var. *saccharata*, *Ostrinia nubilalis*, biopreparaty, skuteczność

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