ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 101, No. 2 (2014), p. 205–214
DOI 10.13080/z-a.2014.101.027

Variety-specific population density and infestation levels of apple sawfly (*Hoplocampa testudinea* Klug) in two differently managed apple orchards in Lithuania

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Abstract

An investigation of apple sawfly (*Hoplocampa testudinea* Klug 1816) (Hymenoptera: Symphyta: Tenthredinidae) populations was conducted in conventionally and organically managed apple orchards of Institute of Horticulture of Lithuanian Research Centre for Agriculture and Forestry in 2010–2013. The aim of this investigation was to examine population density of apple sawfly in conventionally and organically managed apple orchards by means of white sticky traps Rebell®Bianco, determine relationship between population density and infestation levels of fruits, and evaluate susceptibility of various apple cultivars to this pest. Density of apple sawfly populations varied considerably between years, management systems and apple cultivars. Strong or moderate dependence of infestation on trap catches was determined in six out of seven cultivars studied in organic orchard. In conventional orchard cultivars 'Noris', 'Auksis' and 'Lobo' suffered significantly higher damage and cultivars 'Lodel', 'Ligol' and 'Spartan' could be attributed to a moderately susceptible group of cultivars. Reliable damage levels could not be determined for conventional orchard. In organic orchard, cultivars 'Aldas', 'Rubinola', 'Rajka', were classified as highly susceptible, 'Lodel' and 'Vitos' – as moderately susceptible and 1 cultivar – 'Enterprise' as of low susceptibility. Control thresholds for six cultivars was defined at 5% infestation level: 'Aldas' – 13 sawfly trap^{-1}, 'Rubinola' – 11 sawfly trap^{-1}, 'Vitos' – 23 sawfly trap^{-1}, 'Lodel' – 21 sawfly trap^{-1}, 'Rajka' – 11 sawfly trap^{-1} and 'Enterprise' – 34 sawfly trap^{-1}. No reliable damage threshold for hybrid No. 18501 was determined.

Key words: apple pests, *Hoplocampa testudinea*, Hymenoptera, Tenthredinidae, white sticky traps.

Introduction

The apple sawfly (*Hoplocampa testudinea* Klug, 1816) is a widespread and destructive pest, occasionally causing severe damage in commercial apple (*Malus domestica* Borkh.) orchards in most apple-growing areas worldwide (Vincent, Bélair, 1992; Alford, 2007). In years or locations with high sawfly activity or low fruit setting, yield losses due to apple sawfly often exceed the damage done by the codling moth *Cydia pomonella* (Linnaeus, 1758) which is considered to be the major pest of apple (Graf et al., 1996 a). Problems related to high apple sawfly infestation have been repeatedly reported from the United Kingdom, Central, Southern and Eastern Europe (Ciglar, Barić, 2002; Roller, Haris, 2008; Walczak et al., 2009).

The biology of apple sawfly was investigated in detail in a number of studies (Nagy, 1960; Chaboussou, 1961; Gottwald, 1982). It is a monovoltine species which spends most of its life cycle below the soil surface as a hibernating mature larva in a cocoon. Adult sawflies usually emerge during the flowering period of early and moderately early apple cultivars. Flight period of imagoes is highly concentrated and usually lasts approximately a month, depending on environmental conditions. Adult sawfly females emerge with fully matured eggs and can start mating and egg-laying immediately as soon as there are blossoms fit for oviposition. Eggs are inserted into receptacles of blossoms by the female sawflies with the help of saw-like ovipositor. Only blossoms of certain growth stages are acceptable for oviposition. Opening blossoms of growth stages 62–64 (Meier, 1997) are most prone to sawfly attack (Chaboussou, 1961).

Several studies indicated highly variable damage levels in the same orchards and to different apple cultivars (Graf et al., 1996 b; Ciglar, Barić, 2002). Several factors determining level of fruit damage could be involved. Population density of apple sawfly, heterogeneity of sawfly spatial distribution, weather conditions during egg-laying period, apple cultivars, flowering intensity of certain cultivars all are considered to be crucial factors contributing to the extent of sawfly damage (Chaboussou, 1961; Graf et al., 1996 a). When the fruit setting is low even moderate apple sawfly infestation may result in severe fruit loss and reduced yields. Several authors indicated that some apple cultivars were more susceptible to apple sawfly attack than others (Graf et al., 1996 b). Such variation between cultivars is explained by temporal differences between flowering stages of different cultivars (Kuenen, van de Vrie, 1951). However, no detailed studies on variety-dependent infestation levels were performed and no cultivars prone to high sawfly risk were indicated.

Although potential of biological control of apple sawfly using hymenopteran parasitoids *Aptesis nigrocincta* (Gravenhorst, 1815) and *Lathrolestes ensator* (Brauns, 1898) (Hymenoptera: Ichneumonidae) has been examined (Babendreier, 1998; Zijp, Blommers, 2002), control is mostly based on synthetic or biological pesticides. In commercial integrated protection orchards sawfly control strategies rely mostly on non-selective insecticide treatments. In organic orchards biological products such as quassia extracts and “NeemAzal” or entomogenous nematodes are used to control sawfly populations, but efficacy of these products is low (Vincent, Bélair, 1992). These control measures are mainly aimed at first instar larvae during process of hatching before penetrating into the fruits, thus heavily dependent on timing of applications in order to reach high efficacy of treatments. In Lithuania, apple sawfly control strategies are based mainly on pesticide treatments – mostly synthetic pyrethroids with a contact mode of action. Treatments are usually applied before and immediately after flowering period, combining them with other insecticides against other common apple pests (Raudonis et al., 2007). So far, no specific integrated pest management (IPM) tactics has been applied to control apple sawfly in Lithuania.

Past studies on infestation levels of the apple sawfly in Lithuanian conditions indicated that damage caused by apple sawfly was equal or higher than caused by the codling moth when the weather was favourable for the insects. Furthermore, several apple cultivars were found to suffer considerably higher sawfly damage. However, at that time setup and the set of apple genotypes cultivated were completely different from conventional orchard management techniques and cultivars at present time. Therefore, the growing diversity of cultivated apple genotypes leaves gaps in knowledge as to how apple sawfly will affect some of the newer cultivars. In Lithuania no data on susceptibility of economically important apple cultivars to apple sawfly damage in commercial orchards are available. Shift towards integrated pest management and development of organic apple farming poses new challenges to apple growers and plant protection specialists (Grieshop et al., 1988; MacHardy, 2000). According to requirements of these management strategies, use of synthetic pesticides must be reduced or not allowed at all. Several reports from countries where use of synthetic insecticides was significantly reduced or suspended indicated gradual recovery of apple sawfly populations and, subsequently, regular mass outbreaks and massive crop losses (Walczak et al., 2009; Доля и др., 2004). Therefore, in the wake of implementation of sustainable pesticide use actions and expansion of organic apple growing, the apple sawfly is likely to become a dangerous pest in conventional and organic apple management systems under Lithuanian conditions on a regular basis. For this reason, a set of field surveys was designed to investigate life history, population density and variety-specific infestation levels of apple sawfly in conventionally and organically managed apple orchards and to develop an integrated control tactics for this pest by means of modern monitoring techniques and damage thresholds adjusted for local conditions.

The aim of this investigation was to examine population density of apple sawfly in conventionally and organically managed apple orchards by means of visual traps, determine relationship between population density and infestation levels of fruits, and evaluate susceptibility of various apple cultivars to this pest.

Materials and methods

Field studies. The study was performed at experimental apple orchards of Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry in Central Lithuania (55°4′ E, 23°48′ N) for three consecutive apple seasons from 2010 to 2013. Apple sawfly populations and fruit damage levels were investigated in two differently managed apple orchards – conventional and organic located approximately 0.7 km from each other. Both orchards were separated by a valley and natural hedgerows of multi-species vegetation. Both were productive orchards, aged 6 (organic) and 8 (conventional) years in 2010. Rows were oriented in a south-north direction and planting distances were 4 × 2 m (density 1250 trees ha^{-1}), except cvs ‘Noris’ and ‘Ligol’ grafted on rootstock P22 with planting distances 4 × 1 m (density 2500 trees ha^{-1}). Average height of trees in both orchards was ca. 2.5 m and trees were shaped as a spindle canopy. Conventionally managed orchard occupied an area of 13 ha and was comprised of different apple cultivars planted in two to four row blocks throughout the orchard. In the inter-rows of the orchard the mixture of couch grass was sown and grass in the alleys was regularly mown during the season. Herbicide treatments were applied below the trees several times during the season and herbicide fallow was 1 m wide. Fungicide treatments were applied regularly according to recommendations for plant pest and disease management in conventional orchards (Raudonis et al., 2007). The following pre-bloom insecticide treatments relevant to apple sawfly control were applied – in 2010 Decis Mega (a.i. deltamethrin) on 27 April, 2011 – Decis Mega (a.i. deltamethrin) on 29 April, 2012 – Bulldock (a.i. β-cyfluthrin) on 26 April and 2013 – Bulldock (a.i. β-cyfluthrin) on 4 May. Organic orchard occupied an area of 0.5 ha, where different apple cultivars were arranged in random order throughout the orchard in four repetitions per cultivar, each repetition plot consisting of four trees. Organic orchard was pesticide and artificial fertilizer-free since the moment it had been planted. Inter-rows were arranged in changing order where inter-row covered with grass was followed by shallow cultivated one. Grass in the alleys was repeatedly mown as well as alleys without grass were cultivated regularly. Apple genotypes (15 cultivars and 1 breeding kit) of regional economic importance for commercial and organic horticulture were selected for the survey (Table 1). All cultivars were moderately-late to late blooming except breeding kit No. 18501. The latter was moderately-early blooming.

Table 1. The experimental design of the study

No.	Cultivar	Root-stock	Number of traps			
			2010	2011	2012	2013
Conventional orchard						
1	'Noris'	M26	1	4	4	4
2	'Lodel'	M26	1	4	4	4
3	'Ligol'	P2	2	4	4	4
4	'Auksis'	M26	3	4	4	4
5	'Delikates'	MM106	2	4	4	4
6	'Alva'	M26	3	4	4	4
7	'Spartan'	M26	1	4	4	4
8	'Lobo'	M26	2	4	4	4
9	'Connell Red'	M26	1	4	4	4
	No. of fruits sampled (number of traps)		4500 (17)	9000 (36)	9000 (36)	9000 (36)
Organic orchard						
1	'Rubinola'	B396	1	4	4	4
2	'Aldas'	B396	1	4	4	4
3	Breeding kit No. 18051	B396	1	4	4	4
4	'Vitos'	B396	1	4	4	4
5	'Enterprise'	B396	–	4	4	4
6	'Lodel'	B396	–	4	4	4
7	'Rajka'	B396	–	4	4	4
	No. of fruits sampled (number of traps)		1349 (4)	6900 (28)	6041 (28)	5037 (28)

Note. Cultivars surveyed, rootstock, cultivars sampled, number of traps deployed and number of fruitlets sampled during the study period are presented.

White sticky traps Rebell®bianco ("Andermatt Biocontrol", Switzerland) were used to monitor apple sawfly flight activity and population density. Trap distribution and infestation sampling details in different cultivars are shown in Table 1. In conventional orchard, study plots consisted of two neighbouring rows per each cultivar equipped with 4 equally distributed traps – two being placed closer towards the end and two towards the centre of the rows at 30–50 m distances. In organic orchard, traps were installed on each of four repetition plots per cultivar studied and distances between traps varied between 5–10 m. Traps were hung on branches or supporting wires at the height of 1.6–1.7 m on the external south part of the tree canopy. The positions of traps remained unchanged during each year of the study. Sawfly population density was expressed as a relative measure based on mean number of sawflies captured per trap during certain time interval.

Every year of the survey, white sticky traps were introduced into the orchards two weeks before beginning of May. In order to determine the beginning of adult sawfly flight period traps were inspected every 1–2 days. After the first adult sawflies had been recorded, trap catch assessments were carried out weekly in 2010 and at 1–3 days intervals in 2011 and daily in 2012. Traps remained effective for entire flight period of adult sawflies. In the cases when traps where heavily filled with other insects, they were replaced by the new ones. Around middle of June before the affected fruit drop on-tree fruit injury surveys were performed by visual examination of 50 (in 2010) or 100 fruits per tree selected at random from lower, central and upper parts of the tree canopy from 10 random trees per cultivar (Coli et al., 1985; Graf et al., 1996 b). In cultivars where fruit setting was too low and number of trees was limited all fruits from every tree were inspected. Numbers of fruits sampled per orchard and per cultivar are presented in Table 1. Infestation levels were expressed as percentage and calculated using formula – $A / B \times 100$, where A – infested fruit on certain cultivar, B – overall fruit sampled on certain cultivar.

Environmental conditions during larval development, flight and egg-laying periods. Environmental conditions were monitored by means of weather station iMetos® ("Pessl Instruments", Austria), located at the experimental apple orchard of Institute of Horticulture, Lithuanian Research Centre of Agriculture and Forestry, approximately 1.5 km from the experimental sites. Key environmental parameters determining apple sawfly life cycles during post-diapause development, flight and egg-laying periods, embryonic and larval development periods are presented in Table 2. Environmental conditions during the flight period may play significant role on success of oviposition of females as well as numbers of sawflies caught on traps. Flight of imagoes usually takes place on calm sunny days. During cold, rainy and windy spells of weather sawflies mostly tend to remain inactive on the leaves or blossoms. In 2011 such conditions occurred approximately a week after emergence of first adults and continued for several days. It resulted in reduced trap catches as new adults kept emerging from the soil, but remained inactive. Adverse environmental conditions might also influence the mortality of larvae and, consequently, reduced numbers of imagoes in the subsequent season. High temperature fluctuations during winter, thaws with complete melting of snow cover and subsequent rapid freezing when soil temperature remain below zero for prolonged periods of time may increase larval mortality or induce physiological processes triggering diapause prolongation. For example, in 2011 season population density was very low after successful 2010 season in terms of reproduction and feeding and it could be consequence of a thaw in end of February – beginning of March 2011, when a complete melting of snow cover occurred followed by a rapid frost and, consequently, soil temperatures dropped as low as −1.5°C. In 2012, population density and infestation levels were slightly higher than in 2011, but did not reach the level of 2010 season and it could also be explained by same situation in February 2012 when soil temperatures dropped as low as −0.7°C for more than a week. On the contrary, in 2009 snow cover was present during all the winter and soil temperatures had never dropped below zero, strongly suggesting that constant snow cover, ensuring optimal temperature conditions under soil surface during sawfly hibernation period, is a crucial factor determining numbers of adults for the upcoming season.

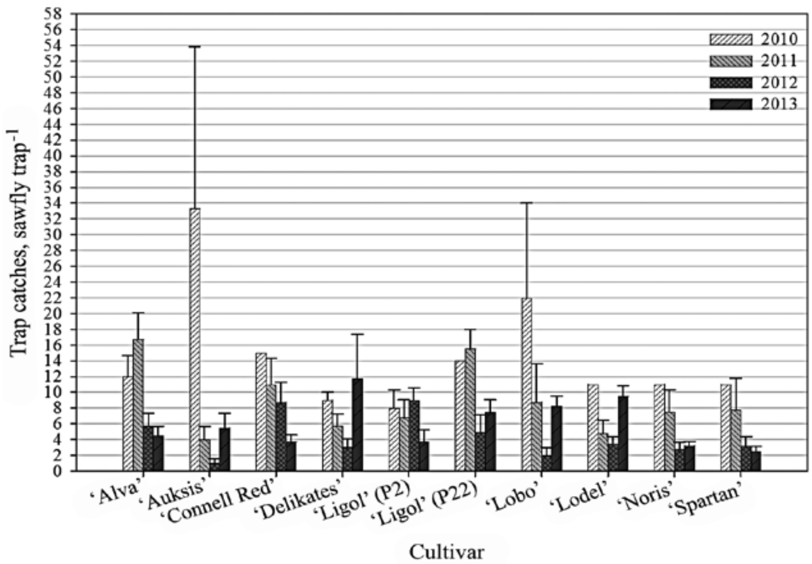
Table 2. Key environmental factors influencing development of apple sawfly at different life stages during the periods of post larval development, emergence, flight, egg-laying of imagoes, embryonic and larval development

Month	Air temperature °C				Soil temperature °C at 10 cm depth				Precipitation mm			
	2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
March	1.5	0.5	2.1	−3.9	0.7	0.2	1.4	0.2	25.6	9.5	19.6	5.8
April	9.5	8.0	7.8	5.6	7.0	7.2	6.7	3.3	58.6	15.6	56.2	50.2
May	13.5	14.1	13.7	16.2	14.1	13.2	14.3	14.6	71.4	50.2	60.2	112.4
June	14.6	18.5	15.5	19.0	–	–	–	–	72.6	45.8	108.4	39.0

Statistical analysis. Adult sawfly trap catch data were not distributed normally. Since variances of trap catches were higher than the means, assumption that trap catch data could be fitted to negative binomial distribution was made. Goodness-of-fit to negative binomial was tested by means of Kolmogorov-Smirnov test (Zar, 2010). Normality of data was tested by means of Shapiro-Wilk test. Homogeneity of variation for *ANOVA* was tested using Bartlett's test. In the cases where trap catch data were not normally distributed variety-dependent densities were compared using non-parametric Kruskal-Wallis test and specific differences between means were compared using Dunn`s (in the case of different sample size) or Student-Newman-Keuls methods. Variety-dependent differences between the infestation levels were compared using one-way *ANOVA* method and specific differences between means were compared by means of Holm-Sidak method. Non-normally distributed infestation data were transformed using square root transformation. The relationships between trap catches (population density) and infestation levels were calculated by means of Pearson correlation and linear regression analysis. For both management systems correlations were calculated separately for each year of the study and also correlation coefficients for pooled data in both orchards were computed. For regression analysis of data obtained from conventional orchard, only data from 2010 were used, as in 2011–2013 infestation levels were negligible. Additionally, only trap catch data from cultivars with at least 2 traps per cultivar were used for correlation and regression analysis. For organic orchard correlation and linear regression analyses between trap catches and fruit damage were performed using data obtained in 2011–2013. Pooled data were used for regression analysis of data observed in organic orchard. All statistical routines were performed with the help of statistical softwares *SYSTAT* and *SIGMAPLOT*.

Results and discussion

Sawfly density and infestation levels in conventional orchard. Trap catches (population density) varied between cultivars during the period of the study. The highest trap catches were observed in 2010 on cvs 'Auksis' and 'Lobo' – 33.3 ± 20.5 and 22.0 ± 12.0 sawfly trap^{-1} (Fig. 1). Extremely high standard errors of mean sawfly trap catches in these two cultivars indicated a strong tendency of sawfly populations to aggregate in particular portions of the orchard. On the rest of the cultivars numbers of imagoes caught on traps were distributed quite evenly and ranged from 7.7 ± 2.0 sawfly trap^{-1} on cv. 'Lodel' to 15.0 sawfly trap^{-1} on cv. 'Connell Red'. Only data where at least two traps were installed were used in comparison of trap catches between cultivars and years of the study. In 2011, trap catch data distribution pattern was different

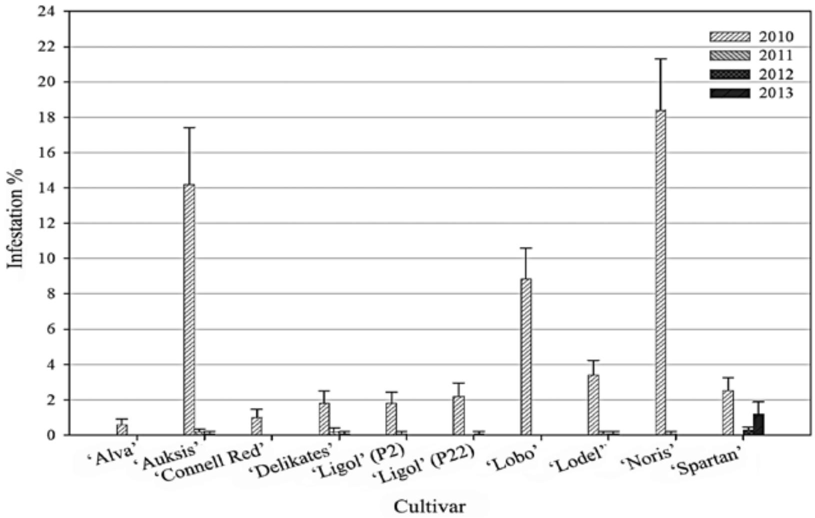


Note. Arithmetic means and their standard errors are listed.

Figure 1. Annual mean trap catches of apple sawfly in different apple cultivars over the study period (2010–2013) in conventional orchard

– the highest sawfly density was recorded on cvs ‘Alva’ (16.8 ± 3.3 sawfly trap^{-1}), ‘Ligol’ (15.5 ± 2.5 sawfly trap^{-1}) and ‘Connell Red’ (11.0 ± 3.3 sawfly trap^{-1}). Opposite to 2010, in 2011 the lowest sawfly density was observed on cv. ‘Auksis’ and reached only 4.0 ± 1.7 sawfly trap^{-1}. On the rest of the cultivars the numbers varied from 5.8 ± 3.3 on ‘Delikates’ to 8.8 ± 4.9 sawfly trap^{-1} on ‘Lobo’. In 2012, overall sawfly density was the lowest during all study period. The highest numbers of sawflies captured were recorded on cvs ‘Connell Red’ and ‘Lodel’ – 8.8 ± 2.5 and 9.0 ± 1.6 sawfly trap^{-1}. On the rest of the cultivars overall density was equally low ranging from 2.0 ± 3.2 to 5.0 ± 2.1 sawfly trap^{-1}. The lowest numbers of sawflies were observed again on cv. ‘Auksis’ – 1.0 ± 0.6 sawfly trap^{-1}. In 2013, the highest trap catches were observed on cvs ‘Alva’, ‘Delikates’ and ‘Connell Red’ – 11.8 ± 5.7, 9.5 ± 1.3 and 8.3 ± 1.3 sawfly trap^{-1}. On the rest of the surveyed cultivars trap catches varied from 2.5 ± 0.7 (cv. ‘Spartan’) to 5.5 ± 1.9 (cv. ‘Auksis’) sawfly trap^{-1}. Despite seemingly higher trap catches on cvs ‘Auksis’ and ‘Lobo’ in 2010, no statistically significant differences were detected in sawfly trap catches between apple cultivars in any year of the survey and for pooled data as well (Kruskal-Wallis test, $p > 0.05$).

In conventionally managed orchard, high sawfly infestation was observed only in the first year of the study. In 2011–2013, numbers of fruitlets infested by apple sawfly were unusually low and reached a negligible level of 0.1 ± 0.03% despite the fact that relative density suggested infestation levels supposedly to be higher. It indicates population density to be not necessarily a primary factor determining damage to the fruit. In 2010, overall infestation in conventional orchard reached 15.6 ± 2.2%; however, in certain cultivars it was relatively high and, on the other hand, in some varieties it was negligible (Fig. 2). Cultivars that suffered heaviest infestation were ‘Noris’ – 18.5 ± 2.9%, ‘Auksis’ – 14.2 ± 3.2% and ‘Lobo’ – 8.9 ± 1.7% of damaged fruits. Infestation in these three cultivars was significantly higher than in the rest of the genotypes surveyed (Student-Newman-Keuls test, $p < 0.05$). On cvs ‘Connell Red’, ‘Alva’ and ‘Ligol’, no damaged fruitlets were recorded at all. In 2013, no insecticide treatment on cv. ‘Spartan’ was applied and, consequently significantly higher sawfly infestation was observed than on the rest of the cultivars and percentage of damaged fruits reached 1.2 ± 0.7%, indicating an increased risk of sawfly attack as insecticide treatments are absent.

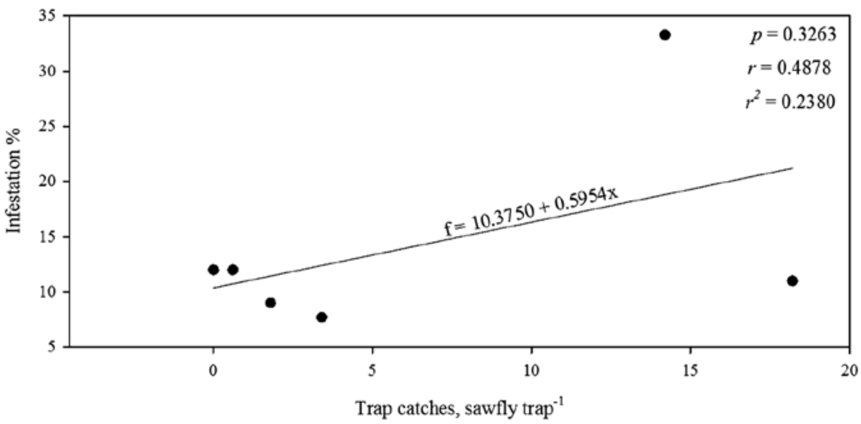


Note. Arithmetic means, percentage of infested fruits and their standard errors are listed.

Figure 2. Infestation levels of apple sawfly in different apple cultivars over the study period (2010–2013) in conventional orchard

An attempt was also made to detect relationships between trap catches and infestation levels in both orchards. In conventional orchard, significant negative strong correlation was detected only in 2011 (Fig. 3), but due to extremely low infestation level, the reliability of this relationship is unlikely. Nonlinear regression analysis was performed in order to determine the influence of sawfly population density on fruit damage levels. For conventionally managed orchard only data from 2010 were used in regression, since data from 2011 and 2013 were considered not appropriate for analysis. Results of analysis demonstrated weak influence of sawfly density on infestation (Fig. 3). Coefficient of determination r^2 = 0.238 indicated that only approximately 24% of the change in the number of damaged fruit was influenced by the change in sawfly population; however, regression was not reliable.

In summary, trap catches in our study represented relatively high density in the first year of the study (this as well might be influenced by drawbacks in experimental design, as fewer traps were installed) and this resulted in considerably higher infestation and two years when density was low, which in turn resulted in lower overall infestation. Compared to several other field studies conducted using visual traps (Coli et al., 1985; Zijp, Blommers, 1997; Ciglar, Barić, 2002), sawfly trap catches were relatively low, reaching at most 33 sawflies trap^{-1} in 2010 in orchard with no pre-bloom insecticide applications. However, damage threshold of 30–40 apple sawflies per trap was determined by Wildbolz and Staub (1984) and yet in another study damage threshold of 30–40 sawfly trap^{-1} for apple cv. ‘Idared’ was specified and it corresponded to 4.5% primary sawfly damage, but only 2% for cv. ‘Golden Delicious’ (Graf et al., 1996 b).

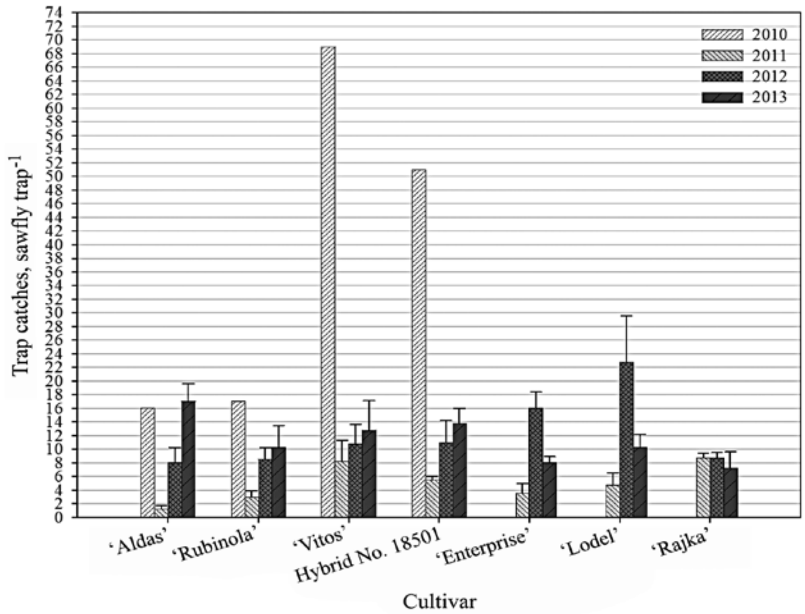


Notes. For conventional orchard only data from 2010 were used in analysis. Regression equations, coefficients of correlation and determination and significance level of regression are also presented.

Figure 3. Results of linear regression analysis to determine influence of apple sawfly density on infestation level in conventional orchard

This strongly suggested that varietal differences in the risk assessment of the apple sawfly should have been taken into account. This was well illustrated in our study, when high infestation levels were reached even with trap catches lower than the established threshold. Results of correlation and regression analysis between trap catches and infestation levels indicated that strong relation between population density and infestation existed only in organic orchard. However, direct relationship between density and damage as was shown by the means of nonlinear regression analysis constituted only about a half of variation. This indicates that yet another major factor influencing infestation levels is apple cultivar itself. Three apple cultivars – 'Noris', 'Auksis' and 'Lobo', demonstrated significantly increased susceptibility to apple sawfly attack than the rest of the cultivars investigated in the conventional orchard. However, these cultivars were affected by the pest only in 2010, when the circumstances were highly favourable for the pest. It also must be mentioned that some cultivars 'Alva', 'Connell Red', 'Ligol' and 'Delikates' suffered very little or no damage at all, indicating these cultivars being of reduced susceptibility to apple sawfly attack. 'Lodel', 'Ligol' and 'Spartan' could be attributed to a moderate susceptibility group of cultivars.

Sawfly density and infestation levels in organic orchard. Trap catches of adult sawflies also varied a great deal on different cultivars in both orchards. In organic orchard in 2010, the highest number of sawflies was captured on 'Vitos' and hybrid No. 18501 – 69 and 51 sawfly trap^{-1}, respectively (Fig. 4). In 2011, due to overall low population density, the numbers of sawflies on all cultivars surveyed were distributed uniformly most sawflies also being captured on 'Vitos' and hybrid No. 18501 – 8.3 ± 3.1 and 5.5 ± 1.6 sawfly trap^{-1}, respectively. Statistically significant difference in trap catches between

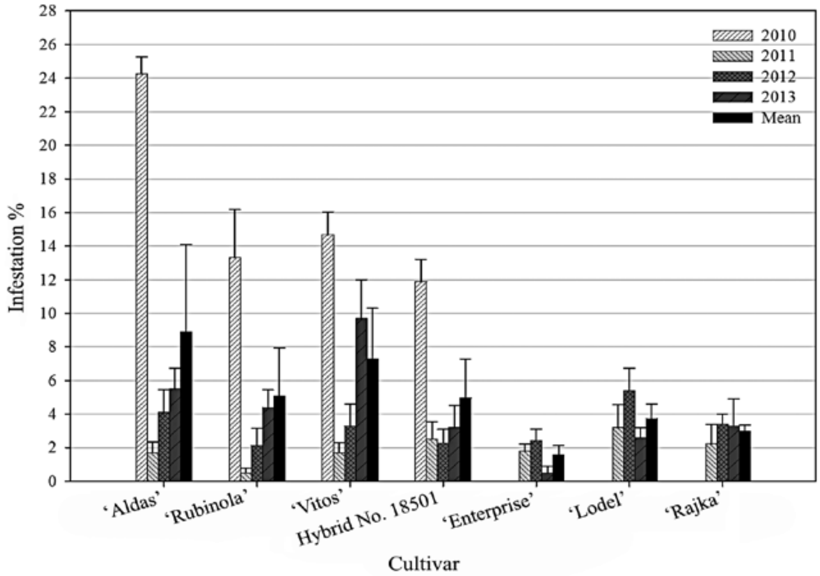


Note. Arithmetic means and their standard errors are listed.

Figure 4. Annual mean trap catches of apple sawfly in different apple cultivars over the study period (2010–2013) in organic orchard

'Vitos' and 'Aldas' was detected (Mann-Whitney, $p < 0.05$). In 2012, the highest trap catches were recorded on cvs 'Lodel', 'Enterprise', 'Vitos' and hybrid No. 18501; however, no significant differences were obtained between cultivars (Kruskal-Wallis test, $p > 0.05$). The lowest apple sawfly numbers were observed on cv. 'Aldas' in all years of the survey. In 2013, the highest trap catches were observed on cv. 'Aldas' – 17.0 ± 2.6 sawfly trap^{-1}. On other cultivars rather similar trap catches were observed – 'Vitos' and hybrid No. 18501 – 12.8 ± 4.4 and 13.8 ± 2.3 sawfly trap^{-1}, 'Lodel' and 'Rubinola' – 10.3 ± 1.9 and 10.3 ± 3.2 sawfly trap^{-1}, 'Enterprise' and 'Rajka' – 8.0 ± 0.9 and 7.3 ± 2.4 sawfly trap^{-1}. Trap catch differences between 2010 and the rest of the years of the study must be interpreted carefully, as trap density was different and it may have significantly influenced the amount of imagoes caught. However, the results from conventional orchard and significantly higher infestation levels in organic orchard in 2010 strongly suggest that actual density of sawfly populations was significantly higher than in 2011–2013.

Certain cultivars suffered higher damage than the rest. In 2010, significantly higher (Holm-Sidak test, $p < 0.05$) infestation in cv. 'Aldas' – 24.3 ± 2.9% damaged fruit was recorded (Fig. 5). The rest of the cultivars had twice as less damaged fruits and no statistical differences were detected between them (Holm-Sidak test, $p > 0.05$). In 2011 and 2013, the amount of damage between cultivars varied at lesser extent and ranged from 0.5 ± 0.3 to 3.2 ± 1.4% in 2011 and from 2.1 ± 1.0 to 5.4 ± 1.3% in 2012.

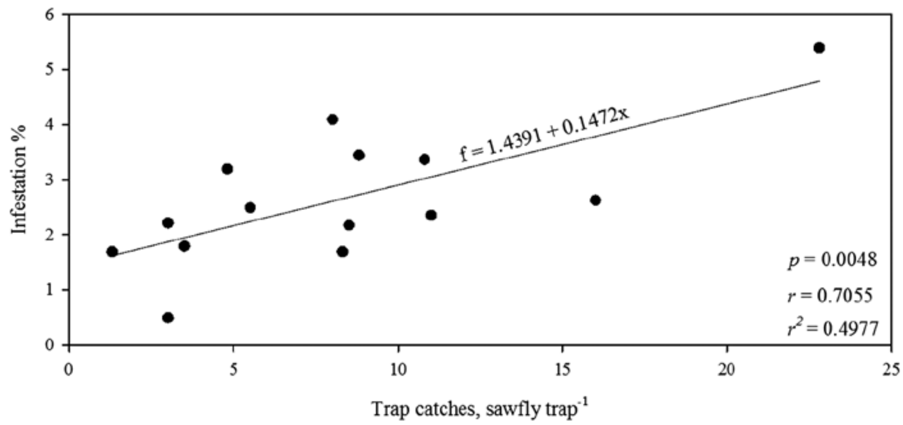


Note. Arithmetic means, percentage of infested fruits and their standard errors are listed.

Figure 5. Infestation levels of apple sawfly in different apple cultivars over the study period (2010–2013) in organic orchard

No significant differences were detected respectively (Kruskal-Wallis test, $p > 0.05$). In 2013, considerable variation between cultivars was observed with 'Aldas' and 'Vitos' having suffered the highest damage – 5.5 ± 1.2% and 9.7 ± 2.3%, meanwhile on 'Enterprise' only 0.5 ± 0.4% infestation was recorded. Significant differences were detected between 'Vitos' and 'Enterprise' (Holm-Sidak test, $p < 0.001$), 'Vitos' and 'Rajka' (Holm-Sidak test, $p < 0.05$), and 'Aldas' and 'Enterprise' (Holm-Sidak test, $p < 0.05$). In all 4 years of the survey, cvs 'Aldas' and 'Vitos' suffered the highest infestation – 8.9 ± 5.2 and 7.3 ± 3.0% of damaged fruits. On the rest of the cultivars infestation levels varied from 1.6 ± 0.6% on 'Enterprise' and 3.0 ± 0.4% on 'Rajka' to 5.1 ± 2.9%, 5.0 ± 2.3% and 3.7 ± 0.9% on 'Rubinola', hybrid 18501 and 'Lodel' respectively. The lowest infestation levels were on cvs 'Enterprise' and 'Rajka', although the data only from 2011 and 2013 are available. No statistically significant differences were observed between any of the cultivars (Kruskal-Wallis test, $p > 0.05$). Analysis was performed in order to determine a relationship between numbers of sawflies caught on traps and extent of damaged fruits in different cultivars. No significant correlation between trap catches and infestation levels was obtained in different years of the study in organic orchard. However, when pooled trap catch and infestation data were compared, the relationship was found to be significant indicating relatively strong dependence of infestation levels on sawfly density ($r = 0.706$, $p < 0.001$). Therefore, it could be stated that sawfly density in different cultivars clearly influences extent of damaged fruit; however, for one season cumulative trap catches are not a reliable estimate to predict possible extent of damage. Linear regression analysis was performed in order to determine the influence of sawfly population density on fruit damage levels as well. Coefficient of determination displayed ca. 50% dependence between the two variables, strongly suggesting other factor or several factors to be involved in determining the extent of infested fruit (Fig. 6).

Also, linear regression analysis was performed to determine functional relationship between variety-specific trap catches and infestation levels. Strong significant correlation and functional relationship ($p < 0.05$) between two variables was determined in six cultivars – 'Aldas', 'Rubinola', 'Vitos', 'Lodel', 'Rajka'



Notes. For organic orchard pooled data from 2011–2013 were used in analysis. Regression equations, coefficients of correlation and determination and significance level of regression are also presented.

Figure 6. Results of linear regression analysis to determine influence of apple sawfly density on infestation level in organic orchard

and 'Enterprise' (Table 3). In hybrid No. 18501 no relation was detected between quantity of sawflies caught on traps and resulting fruit damage.

Table 3. Results of linear regression analysis to determine a relationship between trap catches and infestation levels of apple sawfly in individual apple cultivars

Cultivar	r	r^2	p	Regression equation
'Aldas'	**0.795**	**0.595**	**0.0020**	**f = 0.848 + 0.305x**
'Rubinola'	**0.913**	**0.817**	**<0.0001**	**f = −0.838 + 0.388x**
'Vitos'	**0.833**	**0.643**	**0.0102**	**f = 0.665 + 0.181x**
Hybrid No. 18501	0.370	−0.007	0.3673	f = 0.914 + 0.153x
'Enterprise'	**0.604**	**0.301**	**0.0375**	**f = 0.495 + 0.132x**
'Lodel'	**0.853**	**0.700**	**0.0004**	**f = 1.108 + 0.189x**
'Rajka'	**0.771**	**0.553**	**0.0033**	**f = 0.103 + 0.465x**

Note. Lines denoted in bold represent statistically significant relationship ($p < 0.05$) between trap catches (sawfly trap^{-1}) and infestation (%).

It must be stated that these estimates are only true for management systems where no pre-bloom or during-bloom sawfly control measures are applied. According to our data, maximum mean cumulative trap catches of 22 sawflies per trap were reached and at this relative density infestation level of 8% could be predicted for apple cv. 'Aldas' (Table 4). Of course, infestation prediction will only be true if performed in the range of 0 to 22 sawfly trap^{-1}.

For cv. 'Rubinola' a maximum threshold of 18 sawfly trap^{-1} corresponding to 8% of damaged fruit in the range from 1 to 18 sawfly trap^{-1} was set. For cv. 'Vitos' a damage threshold of 23 sawfly trap^{-1} corresponding to 5% of damaged fruit in the range from 4 to 23 sawfly trap^{-1} was specified. For cv. 'Lodel' a damage threshold of 40 sawfly trap^{-1} corresponding to 6% of damaged fruit in the range from 2 to 40 sawfly trap^{-1} was set. For cv. 'Enterprise' a damage threshold of 21 sawfly trap^{-1} corresponding to 3% of damaged fruit in the range from 0 to 21 sawfly trap^{-1} was set. Finally, for cv. 'Rajka' a damage threshold of 14 sawfly trap^{-1} corresponding to 7% of damaged fruit in the range from 1 to 14 sawfly trap^{-1} was set. Trap catches were recalculated using regression equations and adjusted to specified infestation level of 5%, which was considered to be a damage threshold for the apple sawfly (Тарасова, 2007). Results indicated that in different cultivars the same infestation level was reached at different population densities. The least number of sawflies that resulted in 5% of damaged fruit was observed in cultivars 'Aldas', 'Rubinola' and 'Rajka' – where economic threshold was reached at 11–13 sawflies trap^{-1}. In cultivars 'Vitos' and 'Lodel' the threshold was reached at relative density of 23 and 21 sawflies trap^{-1}, respectively. The highest number of sawflies – 34 sawfly trap^{-1} corresponding to 5% of damaged fruit was determined for apple cultivar 'Enterprise'. Results on trap catch and infestation data strongly suggest the idea that every cultivar exhibits different vulnerability to apple sawfly and the same amount of damage could be expected at different population densities depending on cultivar. In current study from this point of view cultivars 'Aldas', 'Rubinola' and 'Rajka' tended to be most susceptible to sawfly attack, as the least numbers of

Table 4. Damage thresholds based on trap catches of apple sawfly adults and susceptibility of different cultivars based on density-dependent damage thresholds

Cultivar	Range, sawfly trap^{-1}	Damage threshold, sawfly trap^{-1}	Corres-ponding damage, %	$EDT_{5\%}$	Suscepti-bility category
'Aldas'	0–22	22	8	13	high
'Rubinola'	1–18	18	8	11	high
'Vitos'	4–23	23	5	23	moderate
'Lodel'	2–40	40	6	21	moderate
'Enterprise'	0–21	21	3	34	low
'Rajka'	1–14	14	7	11	high

Note. For damage thresholds maximal possible value of trap catches observed during whole study period is used to predict corresponding damage; $EDT_{5\%}$ – economic damage threshold when 5% of damaged fruit can be expected.

sawflies caused the damage equal to economic threshold. As was stated before, a general damage threshold of 30–40 apple sawfly per trap was determined by Wildbolz and Staub (1984) and in another study damage threshold of 30–40 sawfly trap^{-1} for apple cultivar 'Idared' was specified and it corresponded to 4.5% primary sawfly damage and only 2% for cultivar 'Golden Delicious' at trap catches of 15 sawfly trap^{-1} (Graf et al., 1996 b). This strongly suggested that varietal differences in the risk assessment of the apple sawfly should have been taken into account. However, in the study of Graf et al. (1996 b) only primary sawfly damage was taken into account, meanwhile in current study total amount of fruits infested by sawfly larvae was assessed. As higher primary sawfly damage level inevitably means higher secondary damage it could be deducted that total amount of damaged fruit observed by Graf et al. (1996 b) should have been much higher than damage levels observed in our investigation. This enables us to conclude that thresholds specified in our study are adequate estimates in order to predict total amount of damaged fruits for six cultivars surveyed in organic orchard in certain range of trap catches.

Conclusions

1. Considerable variation in trap catches and infestation levels were observed between different apple cultivars. No apparent pattern of population density fluctuations was detected in any of cultivars in both management systems. In conventional orchard where pre-bloom insecticide treatments were applied, cultivars 'Alva', 'Connell Red', 'Delikates', 'Spartan', 'Lodel'and 'Ligol' suffered significantly lower damage in comparison to the rest of the cultivars surveyed. In organic orchard, no significant difference in infestation levels was observed between cultivars; however, cultivars 'Vitos', 'Lodel' and 'Enterprise' were identified as more resistant to sawfly attack.

2. In conventional orchard no functional relationship between trap catches and infestation of apple sawfly was determined. In organic orchard significant but relatively weak relationship between two variables was detected ($r = 0.5548$, $r^2 = 0.2714$, $p < 0.01$). It indicates population density to be important factor influencing infestation in apple orchards; however, there are some other driving factors involved.

3. Strong or moderate dependence of infestation on trap catches of apple sawfly was determined in six out of seven cultivars studied in organic orchard. Strong significant relationship between trap catches and infestation was determined for cultivars 'Rubinola' ($r = 0.913$, $r^2 = 0.817$, $p < 0.001$) and 'Lodel' ($r = 0.853$, $r^2 = 0.700$, $p < 0.001$). Moderate relationship was determined for cultivars 'Aldas' ($r = 0.795$, $r^2 = 0.595$, $p < 0.01$), 'Vitos' ($r = 0.833$, $r^2 = 0.643$, $p < 0.05$) and 'Rajka' ($r = 0.771$, $r^2 = 0.553$, $p < 0.01$). Significant weak relationship was determined for cultivar 'Enterprise' ($r = 0.604$, $r^2 = 0.301$, $p < 0.05$) and no relation between the two variables was determined for breeding kit No. 18501 ($r = 0.370$, $r^2 = -0.007$, $p > 0.05$).

4. Individual cultivars exhibited different susceptibility to apple sawfly at the same population density levels in organic orchard. Based on results of regression analysis, variety-specific damage thresholds and corresponding susceptibility categories for six out of seven surveyed cultivars were specified. Three cultivars 'Aldas', 'Rubinola', 'Vitos' were classified as highly susceptible, two cultivars 'Lodel' and 'Rajka' – as moderately susceptible and one cultivar 'Enterprise' – as of low susceptibility.

5. Damage thresholds based on trap catches required to reach specified economic threshold of 5% were determined as follows: 'Aldas' – 13 sawfly trap^{-1}, 'Rubinola' – 11 sawfly trap^{-1}, 'Vitos' – 23 sawfly trap^{-1}, 'Lodel' – 21 sawfly trap^{-1}, 'Rajka' – 11 sawfly trap^{-1} and 'Enterprise' – 34 sawfly trap^{-1}. No reliable damage threshold for hybrid No. 18501 was determined.

Acknowledgments

The paper presents research findings, obtained through the long-term research programme "Harmful organisms in agro and forest ecosystems (KOMAS)" implemented by Lithuanian Research Centre for Agriculture and Forestry.

Received 14 08 2013
Accepted 26 01 2014

References

Alford D. V. 2007. Pests of fruit crops: a colour handbook
Babendreier D. 1998. Ecology of parasitoid *Lathrolestes ensator* and *Aptesis nigrocincta* (Hym. Ichneumonidae) and their influence on populations of their host apple sawfly (*Hoplocampa testudinea*) (Hym. Tenthredinidae): Ph. D. thesis, Christian Albrechts University. Kiel, Germany
Chaboussou F. 1961. Research on apple sawfly (*Hoplocampa testudinea* Klug). Method of chemical control. Annales des Epiphyties, 12: 293–315
Ciglar I., Barić B. 2002. Monitoring the appearance and possibility for prevention of the apple sawfly in Croatia. Journal of Pest Science, 75: 41–45 http://dx.doi.org/10.1046/j.1439-0280.2002.02013.x
Coli W. M., Green T. A., Hosmer T. A., Prokopy R. J. 1985. Use of visual traps for monitoring insect pests in the Massachusetts apple IPM program. Agriculture, Systems and Environment, 14: 251–265
Gottwald R. 1982. Research on biology, dispersion and control of apple sawfly (*Hoplocampa testudinea* Klug) in Havelland orchards. Nachrichten Blatt der Pflanzenschutz, 36: 57–63 (in German)
Graf B., Höhn H., Höpli H. U. 1996 (a). The apple sawfly, *Hoplocampa testudinea*: a temperature driven model for spring emergence of adults. Entomologia Experimentalis et Applicata, 78: 301–307 http://dx.doi.org/10.1111/j.1570-7458.1996.tb00794.x
Graf B., Höhn H., Höpli H. U. 1996 (b). Optimizing the risk assessment for the apple sawfly *Hoplocampa testudinea* Klug (Hymenoptera, Tenthredinidae). IOBC/WPRS Bulletin, 19: 113–117
Grieshop J. I., Zalom F. G., Miyao G. 1988. Adoption and diffusion of integrated pest management innovations in agriculture. Bulletin of the Entomological Society of America, 34: 72–8
Kuenen D. J., van de Vrie M. 1951. Observations on the biology and control of the apple sawfly (*Hoplocampa testudinea* Klug, Hymenopt., Tenthredinidae). Tijdschrift over Plantenziekten, 57: 135–157 (in Dutch)
MacHardy W. E. 2000. Current status of IPM in apple orchards. Crop Protection, 19: 801–806 http://dx.doi.org/10.1016/S0261-2194(00)00107-1

Meier U. H. 1997. Growth stages of mono- and dicotyledonous plants: BBCH monograph. Berlin, Germany

Nagy B. 1960. Fruit sawflies (*Hoplocampa* spp.) (in Hungarian)

Raudonis L., Survilienė E., Valiuškaitė A. 2007. Sodo ir daržo augalų apsaugos technologijos 2007–2008 m. Lithuanian Institute of Horticulture

Roller L., Haris A. 2008. Sawflies of the Carpathian basin history and current research. Natura Somogyiensis, 11: 1–264

Vincent C., Bélair G. 1992. Biocontrol of the apple sawfly, *Hoplocampa testudinea*, with entomogenous nematodes. Entomophaga, 37 (4): 575–582 http://dx.doi.org/10.1007/BF02372327

Walczak F., Gałęzewski M., Jakubowska M., Rosiak K., Tratwal A., Złotkowski J., Heryng I., Gajewski M. 2009. Harmfulness of certain cultural crops in Poland in year 2008. Progress in Plant Protection, 49 (2): 508–528 (in Polish)

Wildbolz T., Staub A. 1984. Supervision of sawflies by checking the egg laying, the infestation and with the use of white traps. Schweizerische Zeitschrift für Obst- und Weinbau, 120: 228–232 (in German)

Zar J. H. 2010. Biostatistical analysis (5th ed.)

Zijp J. P., Blommers L. H. M. 1997. Prediction of flight of apple sawfly, *Hoplocampa testudinea*, using temperature sums. Entomologia Experimentalis et Applicata, 84: 71–75 http://dx.doi.org/10.1046/j.1570-7458.1997.00199.x

Zijp J. P., Blommers L. H. M. 2002. Impact of the parasitoid *Lathrolestes ensator* (Hym., Ichneumonidae, Ctenopelmatinae) as antagonist of apple sawfly *Hoplocampa testudinea* (Hym., Tenthredinidae). Journal of Applied Entomology, 126: 366–377 http://dx.doi.org/10.1046/j.1439-0418.2002.00666.x

Доля Н. Н., Бондарева Л. М., Доля Л. И. 2004. К агроэкологическому обоснованию защиты яблони от плодового пилильщика (*Hoplocampa testudinea* Klug.) в Лесостепи Украины. Інтегрирована захист рослин на початку XXI століття: материалы международной научно-практической конференции. Киев, с. 289–294 (in Russian)

Тарасова Ю. С. 2007. Основные вредители яблони на северо-западе России и оценка их комплексной вредоносности. Автореферат диссертации на соискание ученой степени кандидата биологических наук. Великие Луки (in Russian)

ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 101, No. 2 (2014), p. 205–214
DOI 10.13080/z-a.2014.101.027

Obuolinio pjūklelio (*Hoplocampa testudinea* Klug) populiacijos tankis ir žalingumas soduose Lietuvoje, įvairių veislių obelis auginant pagal dvi ūkininkavimo sistemas

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Santrauka

Obuolinio pjūklelio (*Hoplocampa testudinea* Klug, 1916) populiacijų tyrimai atlikti LAMMC Sodininkystės ir daržininkystės instituto intensyviajame ir ekologiniame obelų soduose 2010–2013 m. Tirtas pjūklelio populiacijų tankis abiejuose soduose panaudojus baltos spalvos lipniąsias gaudykles, taip pat populiacijų tankis bei žalingumas įvairių veislių obelims, ir siekta nustatyti priklausomybę tarp gaudyklėmis sugautų pjūklelių gausumo ir pažeistų vaisių kiekio. Obuolinio pjūklelio populiacijų gausumas gerokai įvairavo skirtingais metais, tarpusavyje lyginant abiejų ūkininkavimo sistemų sodus ir skirtingas obelų veisles. Stiprus ir vidutiniškas ryšis tarp populiacijos tankio (gaudyklėmis sugautų pjūklelių gausumo) ir pažeistų vaisių užuomazgų kiekio buvo nustatytas 6 iš 7 tirtų veislių ekologiniame sode. Intensyviajame sode nė vienos veislės obelims tokios priklausomybės nustatyti nepavyko. Intensyviajame sode nuo obuolinio pjūklelio labiausiai nukentėjo veislių 'Noris', 'Auksis' bei 'Lobo' obelys, o pjūklelio žalingumas šių veislių vaismedžiams buvo esmingai didesnis. 'Lodel', 'Ligol' ir 'Spartan' priskirtinos obuoliniam pjūkleliui vidutiniškai jautrių veislių grupei. Ekologiniame sode 'Aldas', 'Rubinola' ir 'Rajka' priskirtinos obuoliniam pjūkleliui jautrių, 'Lodel' ir 'Vitos' – vidutiniškai jautrių, o 'Enterprise' – mažai jautrių veislių grupei. Šešioms veislėms nustatytos vienai gaudyklei tenkančio pjūklelių skaičiaus vidutinės vertės, kai pasiekiama 5 % pažeistų užuomazgų riba: 'Aldas' – 13 vnt. gaudyklė$^{-1}$, 'Rubinola' – 11 vnt. gaudyklė$^{-1}$, 'Vitos' – 23 vnt. gaudyklė$^{-1}$, 'Lodel' – 21 vnt. gaudyklė$^{-1}$, 'Rajka' – 11 vnt. gaudyklė$^{-1}$ ir 'Enterprise' – 34 vnt. gaudyklė$^{-1}$. Selekcinio Nr. 18501 obelims esminės vertės nustatyti nepavyko.

Reikšminiai žodžiai: baltos lipniosios gaudyklės, Hymenoptera, *Hoplocampa testudinea*, obelų kenkėjai, Tenthredinidae.