https://doi.org/10.17221/9/2019-PPS

Controlling the abundance of the rose tortrix moth [*Archips rosana* (L.)] by parasitoids in apple orchards in Wielkopolska, Poland

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Citation: Piekarska-Boniecka H., Rzanska-Wieczorek M., Siatkowski I., Zyprych-Walczak J. (2019): Controlling the abundance of the rose tortrix moth [*Archips rosana* (L.)] by parasitoids in apple orchards in Wielkopolska, Poland. Plant Protect. Sci., 55: 266–273.

Abstract: The rose tortrix moth [*Archips rosana* (Linnaeus)] is a dominant species among leafroller moths in Poland's apple orchards. The study found high levels of parasitisation of the tortrix (15.5–40.1%), with the average level of parasitisation of 24.6%, by parasitoids of the families Ichneumonidae, Chalcididae and Tachinidae. The most effective were the Ichneumonidae, which decreased the tortrix abundance by 17.2%. The rose tortrix moth was parasitised by 7 Ichneumonidae species, namely: *Trichomma enecator* (Rossi), *Phaeogenes semivulpinu* (Gravenhorsts), *Exochus mitratus* (Gravenhorsts), *Apechthis quadridentata* (Thomson), *Apechthis rufata* (Gmelin in Linnaeus), *Itoplectis maculator* (Fabricius) and *Pimpla turionellae* (Linnaeus). The tortrix abundance was mainly reduced by *I. maculator*, which parasitised 5.1–32.2% of the pupae (15% on average).

Keywords: Ichneumonidae; Chalcididae; Tachinidae; parasitisation

The rose tortrix moth [*Archips rosana* (Linnaeus)] belongs to the leafroller family of moths (Lepidoptera: Tortricidae), which are found in large numbers ever year in Poland's apple orchards and have to be controlled chemically (Płuciennik & Olszak 2010). For many years, the rose tortrix moth has been one of the most dominant species among the phytophages found in western and south-eastern Poland (Płuciennik & Tworkowska 2004; Kot & Jaśkiewicz 2007; Piekarska-Boniecka *et al*. 2008). Their larvae feed on the leaves, flower buds and fruit buds, thus, damaging the crops (Jaśkiewicz & Kot 2003). The rose tortrix moth is also considered an economically significant orchard pest in Germany (Mey 1987), Bulgaria (Velcheva 2009) and Turkey (Aydoğdu & Güner 2012; Ercan *et al*. 2015). It is a polyphagous species, frequently occurring on decorative trees and shrubs in urban greenery (Polat & Tozlu 2010).

Entomophagous parasitoids are one of the biotic factors which control the abundance of the rose tortrix moth. They can attack the eggs, the larvae and the pupae of the moth (Miczulski & Koślińska 1976; Dronka 1981; Mey 1987; Balazs 1997; Kot 2007; Płuciennik & Olszak 2010; Polat & Tozlu 2010; Piekarska-Boniecka & Trzciński 2013; Aydoğdu 2014) and limit the moth population.

https://doi.org/10.17221/9/2019-PPS

The aim of the study was to define the degree of parasitisation of the rose tortrix moth in its pupae stage, and determine the effectiveness of the parasitoid species of the family Ichneumonidae (Hymenoptera: Apocrita) in reducing its numbers.

MATERIAL AND METHODS

Locality. The study was conducted in 2011–2013 in apple orchards in the Wielkopolska region, Poland. In 2011 and 2012, the orchard in Pamiątkowo was the subject area (52º33'N 16º41'E), and in 2013 – the orchard was in Jarogniewice (52º09'14.9''N 16º41'08.7"E). No studies could be conducted in 2013 in Pamiątkowo, as the chemicals used there destroyed rose tortrix larvae.

The orchard in Pamiątkowo is 9 ha in size, while that in Jarogniewice is 20 ha. Both orchards bordered on crops; in both orchards, the research was conducted in plots of 1 ha in size. An experimental plot in the Jarogniewice orchard was adjacent to a shrubbery belt (300 m long and 7–8 m wide), mainly consisting of the blackthorn plum tree (*Prunus spinosa* Linnaeus.), the common pear tree (*Pirus communis* Linnaeus), the common elm (*Ulmus campestris* Linnaeus), the European spindle tree (*Evonymus europaea* Linnaeus) the hawthorn (*Crataegus monogyna* Jacquin), the whitethorn (*C. oxyacantha* Linnaeus), the elder (*Sambucus nigra* Linnaeus), the dewberry (*Rubus caesius* Linnaeus), the blackberry (Rubus *suberectus* Anders.), the briar rose (*Rosa canina* Linnaeus), the common carrot (*Daucus carota* Linnaeus), the common yarrow (*Achillea millefolium* Linnaeus), the common nettle (*Urtica dioica* Linnaeus) and couch-grass (*Agropyron repens* Linnaeus).

The experimental plot in the Pamiątkowo orchard contained eight- or nine-year-old apple trees of the Jonagold and Topaz cultivars, while that in Jarogniewice was made up of fifteen-year-old Idared and Jonagold apple trees. In both orchards, the rows of trees were divided by strips of grass and, in the rows, there was an herbicide fallow land. The apple trees were protected from pests and diseases by an integrated system in both orchards. In the orchard in Pamiątkowo, only one anti-pest treatment was carried out during each year of the study – the substance applied was Mospilan 20 SP (Nippon, JPN). In Jarogniewice, four anti-pest treatments were applied: Karate Zeon 50 CS (Syngeta, GB), Steward 30 WG (DuPont, CH) and Pirimor 500 WG (Syngeta, GB).

Method. From May to June of each year, the feeding spots of tortrix larvae were identified in the studied area of the orchard and the pupae were located in the rolled leaves. The pupae were collected from the orchard twice a week throughout the study period. All the pupae were collected from randomly selected trees. We tried to collect 1 000 pupae per orchard each year. The pupae were placed individually in glass tubes and capped with cotton wool. They were then transferred to wooden boxes and reared in the orchard under a roof. They were checked daily and the moths and parasitoids which appeared were recorded. The pupae which did not develop into insects were observed under a microscope in order to define their parasitoids.

The parasitoid families of the order Hymenoptera were classified according to Goulet and Huber (Goulet & Huber 1993), while the Ichneumonidae species – according to Kasparyan (Kasparyan 1981).

The weather conditions in the study years were very similar. 2011 was warm and dry, with a particularly warm spring and early summer. The years 2012–2013 were also warm and dry, although a large amount of rainfall was recorded in June and July.

Data analysis. The correlation between the abundance of the parasitoids and the years was analysed using the χ^2test. The χ^2test evaluates whether there is a significant association between the categories of two variables, in this case, the years and the parasitoid families. The data was a contingency table containing 3 parasitoid families: the Ichneumonidae, Chalcididae and Tachinidae in rows, while the columns are the different years and the values are the abundances of the parasitoids for a particular year. Furthermore, their similarity was studied by cluster analysis based on the Bray-Curtis index (Bray & Curtis 1957) and the results were presented on a dendrogram (Everitt 1974; Mardia *et al*. 1979). Thanks to this method we assigned the observations, i.e., the parasitoid occurrence in the tortrix pupae in individual ten-day periods in the years of study to clusters so that observations within each group are similar to one another. For this purpose we used the nearest neighbour hierarchical clustering.

Finally, the Generalised Linear Models (GLM) with Poisson error distribution were used to show the variability of the percentage share of parasitisation in the individual ten-day periods in the months in the research years.

The statistical calculations were performed using R software (version 3.2.1) by R Core Team(2016).

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RESULTS

In 2011–2013, the apple orchards in Wielkopolska produced 2 954 pupae of the rose tortrix moth (Table 1), of which 24.6% (726) of the pupae were parasitised. The pupae were parasitised by 3 families of parasitoids, namely Chalcididae and Ichneumonidae of the order Hymenoptera and Tachinidae of the order Diptera. The most effective entomophages turned out to be the parasitoids of the Ichneumonidae family, as they reduced the abundance of the tortrix to the greatest extent (17.2% – 508 pupae). The other parasitoid families parasitised the tortrix to a lesser extent (3–4.4%).

In the years 2011–2012, a similar decrease in the tortrix abundance due to the parasitoids was reported from the orchard in Pamiątkowo. In 2011, it was 17.8%, while in 2012, it decreased to 15.5%. In 2011, the parasitoids of the family Ichneumonidae parasitised the tortrix to the greatest extent (8.9%). The parasitoids of the family Chalcididae affected its abundance to a slightly lesser extent, parasitising only 6.5% of the tortrix. The lowest level of parasitisation was reported for the Tachinidae, which attacked the tortrix at a rate of 2.4%. In 2012, the most effective parasitoids were the Tachinidae and Ichneumonidae, which accounted for 7.5–6.4% of the parasitised pupae. The Chalcididae were the least effective in reducing the abundance of the rose tortrix (1.6%).

In 2013, the tortrix in the orchard in Jarogniewice was found to be highly parasitised, as its abundance decreased by 40.1%. The Ichneumonidae were the most important parasites, accounting for 35.9% of the cases. The other parasitoid families reduced the abundance of the tortrix to a lesser extent – the Tachinidae by 4.4% and the Chalcididae by 1.1%.

The correlation between the abundance of the parasitoids developing in rose tortrix pupae and the years was analysed using the χ^2 test. The χ^2 test of independence was significant, which means that the parasitoid abundance is not independent from the year and the parasitoid families: the Ichneumonidae, Chalcididae and Tachinidae (χ^2 test = 267.45; df = 4; *P*-value < 0.001). This implies that they are significantly associated.

In the years 2011–2012, in the Pamiątkowo apple orchards, parasitisation of the rose tortrix moth pupae started at an analogous time, i.e., the first ten-day period of June, whereas, in 2013, in Jarogniewice, it was later, in the second ten-day period of that month (Figures 1–3). Generally, the parasitisation ended in the first ten-day period of July. Only in Pamiątkowo, it lasted until the second ten-day period of that month.

In each year of the study in June, the population of that leafroller species was reduced by all the parasitoid families, with the parasitoids from the family Ichneumonidae having the markedly highest share. The parasitisation of the tortrix pupae reached a peak in the third ten-day period of June, except for 2011 in Pamiątkowo, when it was observed earlier, in the second ten-day period of that month. In July, the tortrix pupae were mainly parasitised by parasitoids from the family Chalcididae, followed by the Tachinidae. In July, the parasitisation of the tortrix moths was generally very limited. Only in 2011, in Pamiątkowo, in the first ten-day period of July, the parasitisation level was also high.

The values of the parasitisation in the individual ten-day periods of the successive years of the study were analysed using GLM with Poisson's error distribution (Table 2). It was found that the parasitisation values in the first ten-day period of June and in the first ten-day period of July did not differ significantly, while in the other ten-day periods, significant differences were recorded.

The dynamics of the parasitoid emergence from the tortrix pupae in the individual ten-day periods in the successive years of the study were analysed using

Table 1. The parasitisation of the *Archips rosana* pupae in the Poznań area orchards, 2011–2013

	Pamiątkowo (2011)		Pamiątkowo (2012)		Jarogniewice (2013)		Total (2011–2013)	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Total pupae	953		1 000		1 001		2 945	
Parasitised by Chalcididae	62	6.5	16	1.6	11	1.1	89	3
Parasitised by Ichneumonidae	85	8.9	64	6.4	359	35.9	508	17.2
Parasitised by Tachinidae	23	2.4	75	7.5	31	3.1	129	4.4
Total parasitisation	170	17.8	155	15.5	401	40.1	726	24.6

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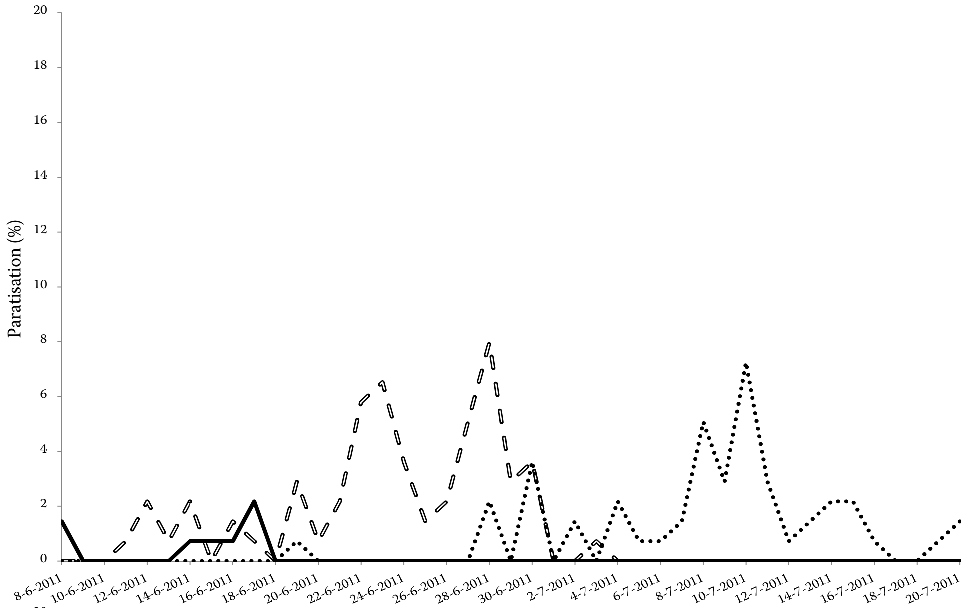

Figure 1. The percentage of parasitisation of the *Archips rosana* pupae in Pamiątkowo (2011)

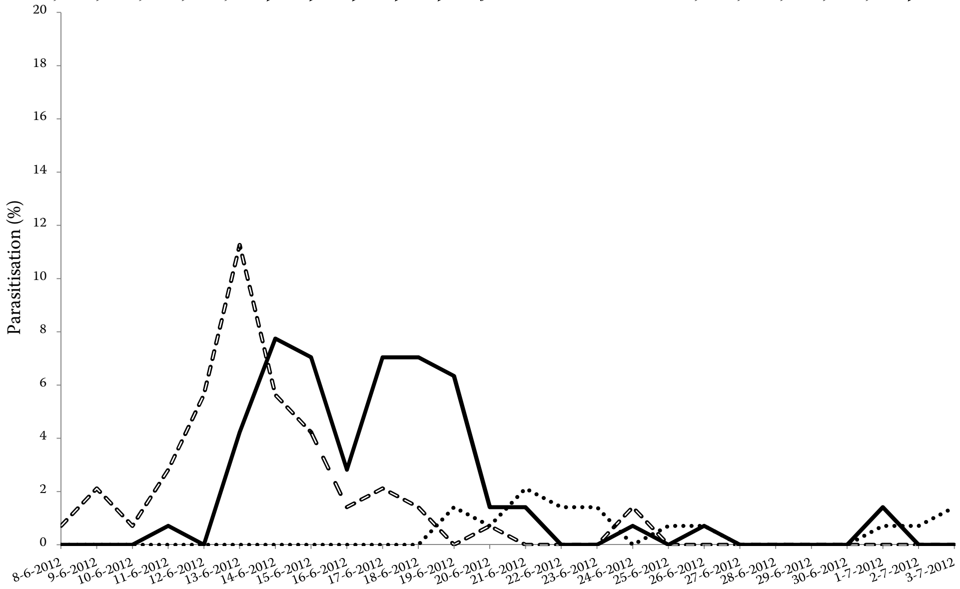

Figure 2. The percentage of parasitisation of the *Archips rosana* pupae in Pamiątkowo (2012)

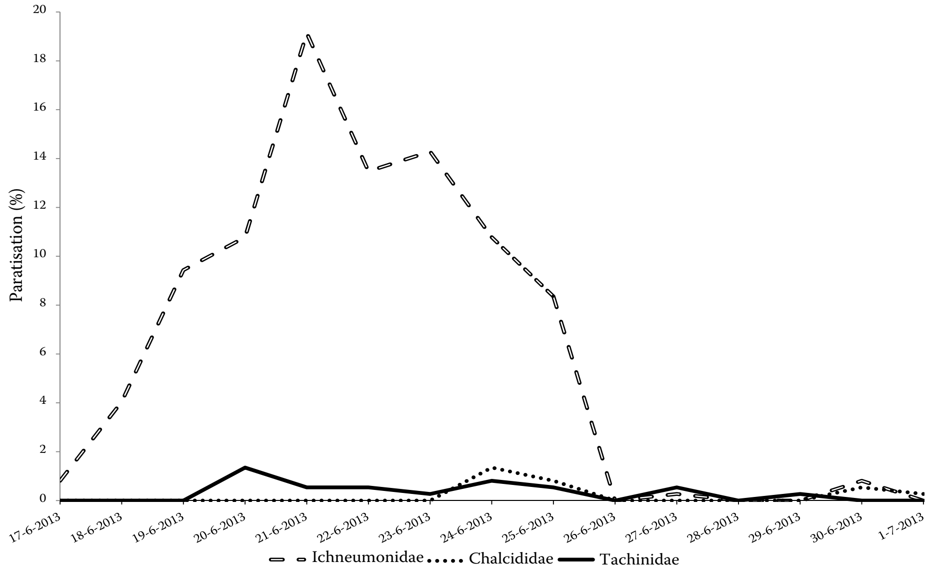

Figure 3. The percentage of parasitisation of the *Archips rosana* pupae in Jarogniewice (2013)

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Table 2. The parasitisation of the Archips rosana pupae by the Ichneumonidae in the Poznań area orchards (Pamiątkowo and Jarogniewice), 2011–2013

Species	Pamiątkowo (2011)		Pamiątkowo (2012)		Jarogniewice (2013)		Total (2011–2013)	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
Anomaloninae								
T. enecator (Rossi)	1	0.1	1	0.1			2	0.1
Ichneumoninae								
P. semivulpinus(Gravenhorst)			5	0.5	11	1.1	16	0.5
Metopiinae								
E. mitratus (Gravenhorst)	3	0.3					3	0.1
Pimplinae								
A. quadridentata (Thomson)					6	0.6	6	0.2
A. rufata (Gmelin)					7	0.7	7	0.2
I. maculator (Fabricius)	70	7.3	51	5.1	322	32.2	443	15
P. turionellae (Linnaeus)					2	0.2	2	0.1
Larvae of Ichneumonidae	11	1.2	7	0.7	11	1.1	29	1
Total parasitisation	85	8.5	64	6.4	359	35.9	508	17.2

hierarchical clustering with the nearest neighbour method (Figure 4). The dynamics of the parasitoid emergence showed the greatest similarity in the second and third ten-day periods of June in the individual years and in the individual orchards, as well as the first and second ten-day periods of July in the same year in one orchard.

In both orchards, in the successive years of the study, the species composition of the parasitoids from the family Ichneumonidae was comparable (Table 3). In each year of the study, the population of the investigated leafroller species was reduced most effectively by *I. maculator* (Fabricius), with the highest reduction rate recorded in the Jarogniewice orchard amounting to 32.2%. The shares of the other 6 species in the regulation of the tortrix population were slight.

T. enecator (Rossi), *P. semivulpinus* (Gravenhorst) and *E. mitratus* (Gravenhorst) are species of larval-pupal endoparasitoids. In turn, species from the family Pimplinae are pupal endoparasitoids.

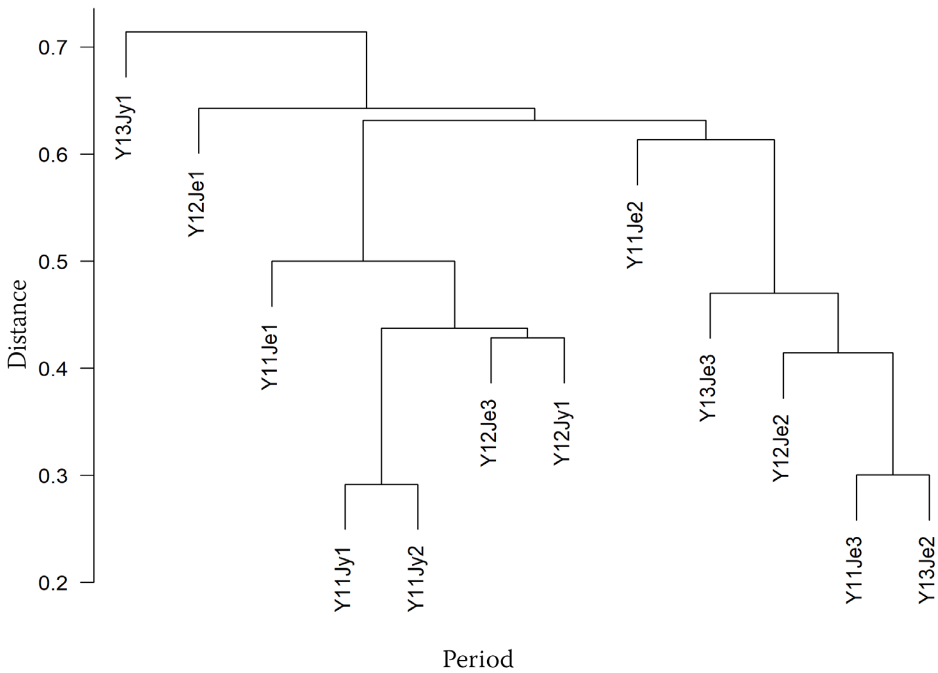

Figure 4. The dendrogram of similarity of the ten-day periods based on the parasitoid insects single-linkage Bray–Curtis

Y11Je1 – period I of June 2011; Y11Je2 – period II of June 2011; Y11Je3 – period III of June 2011; Y11Jy1 – period I of July 2011; Y11Jy2 – period II of July 2011; Y12Je1 – period I of June 2012; Y12Je2 – period II of June 2012; Y12Je3 – period III of –June 2012; Y12Jy1 – period I of July 2012; Y13Je2 – period II of June 2013; Y13Je3 – period III of June 2013; Y13Jy1 – period I of July 2013

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Table 3. The GLM representing the percentage share of the parasitisation in the individual ten-day periods of June and July in the study years

Source (10-day period)	Estimate	Std. error	Z-score	Pr (>|z|)	Signif. level
I of June 2011 (Intercept)	– 0.4055	0.7071	–0.573	0.5664	
II of June 2011	2.4423	0.7372	3.313	0.0009	***
III of June 2011	3.4812	0.7179	4.849	< 0.0001	***
I of July 2011	2.7408	0.7296	3.757	0.0002	***
II of July 2011	2.1401	0.7475	2.863	0.0042	**
I of June 2012	0.9163	0.8367	1.095	0.2734	
II of June 2012	4.0604	0.7132	5.693	< 0.0001	***
III of June 2012	2.0149	0.7528	2.677	0.0074	**
I of July 2012	1.0986	0.8165	1.346	0.1785	
II of June 2013	3.8918	0.7143	5.449	< 0.0001	***

*** 0; ** 0.001; * 0.01

DISCUSSION

The studies conducted in the apple orchards in the Wielkopolska region on the reduction of the pupal rose tortrix population have shown its high parasitisation rate. The parasitoids may have reduced its population by as much as 40.1%. The tortrix was most parasitised (40.1%) in the Jarogniewice orchard, which can be explained by the abundant shrubbery adjacent to the orchard. The shrubberies acted as refugia for the parasitoids, which were then able to transfer to the orchard. A higher level of species diversity of the entomophages on the borders of the orchard and the positive impact of blooming plants on the orchard edges on the entomophages were presented by Miliczky and Horton (2005), Debras *et al.* (2006) and Olszak *et al.* (2009). Literature data from studies conducted in apple orchards located in various regions of Poland (Piekarska-Boniecka 2004; Kot 2007; Piekarska-Boniecka *et al.* 2008; Płuciennk & Olszak 2010; Piekarska-Boniecka & Trzciński 2013), in eastern Germany (Mey 1987), in Hungary (Balazs 1997) and Bulgaria (Velcheva & Atanossow 2016) as well as cherry orchards in Turkey (Aydoğdu 2014) indicate that the abundance of the leafroller larvae and pupae, also including the rose tortrix, was reduced by parasitoids to 33.3%. Most frequently, the parasitoids reduced the populations of these phytophages by approx. 25% to 28%.

The study established that the abundance of the rose tortrix moth at its pupae stage was controlled by the parasitoids of the families Ichneumonidae, Chalcididae (Hymenoptera) and Tachinidae (Diptera). The same parasitoid families were found by Piekarska-Boniecka and Trzciński (2013) and Aydoğdu (2014) in similar studies.

The study found the Ichneumonidae parasitoids to be most effective in controlling the abundance of the rose tortrix. The high effectiveness of these entomophages was presented in the papers by Piekarska-Boniecka *et al.* (2008), Piekarska-Boniecka and Trzciński (2013) and Aydoğdu (2014). Also, Płuciennik and Olszak (2010) found the Ichneumonidae to be the most numerous among the parasitoids of that moth. Kot (2007) proved that the parasitoids of the family Ichneumonidae are dominant among the tortrix entomophages. Polat and Tozlu (2010) also established that the Ichneumonidae have the highest contribution to the parasitisation of the tortrix occurring on decorative trees and shrubs in Turkey. While conducting studies on the parasitoids of leafroller moths in orchard habitats in Azerbaijan, Maharramova (2010) showed that the Ichneumonidae were one of the main parasitoid families controlling the abundance of the tortrix moths.

Research has established the high effectiveness of the species *I. maculator* in controlling the natural abundance of the rose tortrix moth. Earlier studies by Mey (1987) conducted in Germany, by Kot (2007), Piekarska-Boniecka *et al.* (2008), Piekarska-Boniecka and Trzciński (2013) in Poland as well as Polat and Tozlu (2010), Aydoğdu and Güner (2012) and Aydoğdu (2014) in Turkey indicated that this species is the main entomophage of this leafroller. Moreover, Miczulski and Koślińska (1976) established the significant contribution of this species in the group of leafroller moth parasitoids in apple orchards in southern Poland. Also Zaemdzhikova (2017), while researching a community

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of leafroller parasitoids infesting oak forests in the Sofia region of Bulgaria, established the definite dominance of the *I. maculator* (Fabricius) among those entomophages. She also found a large proportion of the *A. quadridentata* (Thomson) and *A. rufata* (Gmelin in Linnaeus) among the parasitoids of the leafrollers, which was not recorded in this research.

The study showed that, in general, the highest level of parasitisation of the rose tortrix moth was observed in the second ten-day period of June. Generally, the Ichneumonidae made the largest contribution to controlling the abundance of the tortrix in the first half of this parasitisation period, while later, the parasitoids of the families Chalcididae and Tachinidae took over this role.

The study established that the rates of tortrix parasitisation at its pupae stage in the first ten-day periods of June and July in both orchards did not differ significantly.

The study indicated very similar dynamics of parasitoid emergence from the tortrix pupae in the first and second ten-day periods of July in the Pamiątkowo orchard in the first study year, in the third ten-day period of June in the Pamiątkowo orchard in the first study year and in the second ten-day period of June in the Jarogniewice orchard

Summing up, the abundance of the rose tortrix moth [*Archips rosana* (Linnaeus)], a dominant species in the community of tortrix infesting apple orchards in Wielkopolska, can be controlled by parasitoids of the families Ichneumonidae, Chalcididae and Tachinidae. This is why the ecological structure of orchard biocoenosis should be created in such a way so as to provide favourable conditions for protection and development of these entomophages in their natural habitat.

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Received: January 15, 2019
Accepted: June 1, 2019
Published online: September 5, 2019